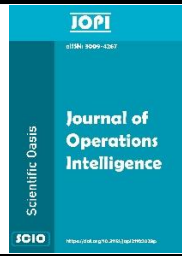




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A Fermatean Fuzzy ORESTE Method for Evaluating the Resilience of the Food Supply Chain

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ABSTRACT

To study the resilience and driving factors of key players in the food supply chain, this paper applies a decision model based on the Fermatean fuzzy set and improved ORESTE method. First, based on existing research on food supply chain resilience, the risk influencing factors affecting food supply chain resilience are established through a literature review. Second, Fermatean fuzzy sets are used to express and integrate uncertain information, calculate the membership and non-membership degrees of the factors affecting the resilience risk of the food supply chain, and then compute the score function to obtain the weight of the influencing factors and the risk weight of alternatives. Finally, the improved ORESTE method is used to rank key players, thereby identifying those in the food supply chain that affect resilience. The results show that transportation and logistics failures, government regulation, and diseases are the three most important risk factors with the highest weight coefficients, while water system failure is the least important risk factor. Among the key players, farmers and food processors are considered the most vulnerable in the food supply chain, while the most resilient are supermarkets and food wholesalers.

1. Introduction

Food security is the top priority of national development, and the No. 1 Central document in 2022 elevates “safeguarding national food security” to the height of the “bottom line”, and ensures food security is placed in a prominent position. Food security is inseparable from the stable operation of the food supply chain. Improving the resilience of the food supply chain is conducive to strengthening the stability of the food supply chain and improving the impact of emergencies. It also ensures the sustainable and effective operation of the food supply chain and achieves the national strategic goal of food security. According to the data of the General Administration of Customs, China will import 147 million tons of grain in 2022. Although it is 10.7% less than in 2021, imports still account for more

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than 20% of the total domestic grain production. Under the background of economic globalization, China's grain imports are large, its dependence on foreign countries is high, and it is more and more closely related to the global food security situation. However, the current international situation is complicated, especially because the impact of the epidemic and the Russia-Ukraine conflict have intensified the instability of international agricultural trade patterns and food prices. The vulnerability of the global food supply chain has become prominent, and China's food security is facing more challenges. Improving the resilience and stability of the domestic food supply chain has become the top priority to ensure food security.

The food supply chain has the characteristics of many participants, many links, and wide fields. So, it is easily affected by the complexity of the external environment, the instability of the implementation process, and the uncertainty of the internal links of the supply chain. In addition, in recent years, the traffic blockade and logistics disruption caused by the outbreak of COVID-19, as well as the combined impact of international instability and extreme weather, have had a huge impact on the food supply chain, disrupting the balance of food supply and demand, and making it more prone to the risk of food supply disruption. From the macro level, the food supply chain is faced with natural disasters, pests and diseases, changes in government policies and regulations, water system failures, and other risk factors. From the operational perspective, the food supply chain is affected by risk factors such as uncertain demand fluctuations, changes in consumer demand, food supply quality issues, transportation and logistics delays, skilled labor shortages, and insufficient backup suppliers. From the internal perspective, the food supply chain is faced with excessive inventory, system and IT risks, production and manufacturing disruptions, internal operational errors, and other risk factors, which means that the stability and resilience of the food supply chain are subject to many disturbances [1].

To guarantee the consistent functioning of the food supply chain and ensure food security, it is imperative to enhance the resilience of the food supply chain, bolster its capacity to manage risks and swiftly recover effectively, and continuously augment the stability, resilience, coordination, and security of the food supply chain, and enhance the ability to guarantee food provision and stable pricing. Therefore, it is of theoretical and practical significance to effectively identify the risk factors affecting the resilience of the food supply chain sort and analyze the resilience performance of key participants in the food supply chain. Thus, this paper proposes a Fermatean fuzzy ORESTE method to evaluate the final construction of the resilience of the food supply chain.

2. Literature review

2.1 The research status of food supply chain resilience

Food security concerns the national economy and people's livelihood. To ensure food security, it is necessary to improve the ability of the food supply chain to cope with emergencies, that is, to improve the resilience of the food supply chain. With the impact of international instability and the epidemic, the food supply chain has suffered unprecedented challenges and disruptions. In the face of emergencies, the food supply chain must have extremely high resilience to cope with disruptions and ensure the safety and stability of the food supply chain. Deng, et al. [2] pointed out that the food supply chain refers to the process of grain production and consumption, involving a series of related activities such as planting, processing, transportation, storage, retail, and wholesale, including production entities, processing enterprises, logistics service providers, collection and storage enterprises, distributors, retailers, and consumers. Most of the existing studies on the resilience of food supply chains are qualitative. For example, Hobbs [3] discussed the resilience of local supply chains based on the changes in agricultural supply chains in the United States and Canada since the epidemic one year ago and pointed out that economies of scale and scope have economic benefits

in normal times, while investment in adaptability and flexibility can improve the resilience of agricultural supply chains in abnormal times. Orengo Serra and Sanchez-Jauregui [4] consider the resilience model of the food supply chain in the case of critical infrastructure collapse and natural disasters and provide suggestions to enterprises on how to reduce vulnerability and improve resilience through a case survey of companies in Puerto Rico. Das, et al. [5] concluded through AHP that cost optimization is the most important factor in building supply chain resilience and affirmed the importance of government support through DEMATEL model analysis. Qualitative research has no quantitative index, is subjective and limited, and cannot fully adapt to the situation of the food supply chain in different situations. However, there is little literature considering the measurement of the resilience of the food supply chain. Yazdani, et al. [1] developed a decision model using the BWM method and fuzzy measurement of alternatives and used the fuzzy MARCOS method to rank key indicators to measure the difference in resilience performance of key players to different elasticity and risk factors in food supply chain management. Xu, et al. [6] proposed a conceptual hybrid multi-criteria decision-making (MCDM) technique, identifying three basic resilience criteria, namely "coordination and collaboration in the supply chain", "efficiency" and "strategic management", as well as the first five key sub-criteria. Such as "speed," "visibility," "continuity management," "connectivity," and "collaborative planning and complementing," and then prioritizing resiliency criteria based on understanding how they interrelate. The research on the measurement of the resilience of the food supply chain is cutting-edge and innovative to a certain extent. By measuring and identifying the risk factors that affect the resilience of the supply chain, the key influencing factors are identified, and the key participants are identified according to the resilience performance of the participants in the food supply chain in coping with the risk factors, to effectively improve the ability of the food supply chain to cope with and resist risks. It has theoretical and practical significance to the management and decision-making of enterprises.

2.2 Research status of ORESTE method

ORESTE method was first proposed by Roubens [7] and is an effective method to solve the MCDM problem. The method consists of two stages: Firstly, the global score function is used to calculate the utility value to determine the weak ranking of alternatives, and then conflict analysis is carried out to obtain the preference, indifference, and incomparability (PIR) relationship among alternatives, which is conducive to the selection of reliable alternatives. Unlike most MCDM methods, the ORESTE method does not require explicit attribute weight information. Although ORESTE method has some advantages, the classical ORESTE method also has some shortcomings: (1) the decision matrix processed only contains little information; (2) In the process of calculating the overall preference score and determining the weak preference and PIR, a large amount of calculation is required, which may lead to information loss; (3) In ORESTE method, preference conflict degree is given subjectively; (4) ORESTE method cannot process extended probabilistic language information. Therefore, many studies have refined the classical ORESTE method to obtain more accurate results. For example, Liao, et al. [8] established the hesitation-fuzzy language ORESTE method through the new global scoring and conflict testing framework and derived the indifference threshold, preference threshold, and incomparable threshold in PIR relationship analysis by defining the indifference threshold of hesitation-fuzzy language, reducing the subjectivity of traditional threshold determination. In addition, the advantages of this method are illustrated by comparison with ELECTRE, TOPSIS, and VIKOR sorting methods. Kaya, et al. [9] combined the ORESTE method with a mathematical model to improve the efficiency and reliability of the decision support system. Wang, et al. [10] proposed an MCDM method combining the two-level hesitation fuzzy language term set and ORESTE method, and applied it to the evaluation of intelligent transportation systems.

In addition, the mixed multi-attribute decision-making method has attracted wide attention in recent years. Compared with a single decision-making method, a mixed decision-making method can synthesize the advantages of various methods and make up for each other's shortcomings to obtain the ranking of alternatives more reasonably. Çoban and Onar [11] integrated the ORESTE-MULTIMOORA method to establish a multi-attribute decision-making method to solve the investment evaluation problem of solar power plants. Tian, et al. [12] improved the global score function of the ORESTE method based on the principle of the TOPSIS method. Therefore, this paper studies the multi-attribute group decision problem based on the ORESTE method in the hesitancy fuzzy language environment and further establishes an improved ORESTE method in the hesitancy fuzzy language environment to solve the ranking problem of factors affecting the resilience of the food supply chain.

Based on the literature analysis, the uncertainty of the internal environment and the complexity of the external environment of the food supply chain is significant, which makes the food supply chain vulnerable to the impact of emergencies and disruption, leading to food security panic and crisis. Therefore, in recent years, how to enhance the resilience of the food supply chain to cope with security emergencies has received extensive attention from scholars at home and abroad. In the study of the resilience of the food supply chain, Chinese scholars have made a lot of achievements, but there are few quantitative studies on the resilience of the food supply chain. Based on the perspective of the food supply chain, this paper will use the Fermatean fuzzy set method to quantitatively study the risk factors affecting supply chain resilience and identify the key influencing factors from it. The improved ORESTE method will be used to rank the toughness measurement of participants in the food supply chain under the influence of different risk factors and identify the key participants from it. Finally, relevant suggestions and suggestions are put forward to improve the stability and security of the food supply chain.

3. Identification of influencing factors of food supply chain resilience

This study aimed to measure the factors influencing resilience in agricultural operations to secure basic food supply through a decision analysis model. To do this, it is essential to identify and analyze risk-influencing factors and key players.

3.1 Perspective of risk factors

The food supply chain includes a series of processes from food production to consumption, with many participants, including food production enterprises, food processing enterprises, food collection and storage enterprises, food distributors, logistics enterprises, food retailers, and final consumers, including food production, processing, transportation, storage, distribution, consumption, and many other links. These characteristics make the food supply chain vulnerable to the complexity of the external environment, the instability of the implementation process, and the uncertainty of the internal links, resulting in disruption and abnormal operation, resulting in food security problems. Therefore, it is very important to accurately identify the risk factors affecting the resilience of the food supply chain, measure the weight of the influencing factors, and carry out early, accurate, and targeted intervention measures for the factors that have a greater impact on the resilience of the food supply chain, to improve the resilience and stability of the food supply chain. Table 1 provides a comprehensive list of the risk factors considered in most recent studies on food supply chain resilience and their corresponding definitions, which fall into three main categories: macro, operational, and internal risks. Each category consists of several subfactors. The primary goal of leveraging the above risk factors in supply chain resilience is to identify and address potential areas of failure during outages. Business managers can use the identified risk factors to come up with

strategies and recommendations to minimize the cost of an outage and maximize the recovery process after an outage.

Table 1

Factors affecting the resilience of the enterprise food supply chain [1]

Risk factor	Subfactor	Definition	Reference
Macro risk	Natural risk	Such as power loss and flooding	Ivanov [13]
	Illness	Such as bird flu	Liu, et al. [14]
	Government supervision	Food safety changes issued by the government, etc.	Li and Zobel [15]
Operational risk	Water system failure	Farm water system failure	Pettit, et al. [16]
	Unstable demand	Demand uncertainty and volatility	Gölgeci and
	Quality demand change	Risk of changes in required quality standards	Kuivalainen [17]
	Transport logistics fault	Delays, accidents, damage, and breakdowns in the transportation system	Goldbeck, et al. [18]
	Skilled labor shortage Alternate supplier	It is difficult to find suitable Labour An alternative when the current provider is not available	
Internal risk	Overstock	Due to improper planning, excessive inventory may lead to product aging and expiration	Elluru, et al. [19] Mzougui, et al. [20]
	System and IT risks	IT and infrastructure connectivity, network, ERP, and network failures	
	Manufacturing failure Internal operating risk	Failure quantity, probability, and intensity Internal asset outages and support for communications and infrastructure reliability	

3.2 Perspective of key participants

The different choices identified as key factors are: (A1) Farmers, which include a wide range of actors, from large agricultural enterprises to small-scale farmers, from landowners to tenant farmers, as well as social enterprise operations in urban, peri-urban and rural areas; (A2) Food processors, including food manufacturers that combine farmer production with a range of chemical and nutritional additives to produce packaged foods; (A3) Grain dealers, who collect products from farmers and processors to store in warehouses and then transport them to wholesale buyers and retailers; (A4) Logistics platforms, including all activities related to the transport, logistics and distribution of goods, carried out by a variety of operators, including different types of participants, such as unimodal distribution centres, logistics regions and multimodal platforms; (A5) Grain wholesalers, who buy products in bulk from farmers, processors and distributors and then generate profits by exploiting economies of scale to sell to retailers or service providers. In addition, wholesalers also include wholesale markets, that is, wholesale markets that can accommodate many buyers and sellers in one place for the wholesale trade of agricultural products. (A6) Supermarkets, different from small retailers, directly facing consumers and with a certain level of distribution of multi-functional large merchants; (A7) Small retailers, covering a wide range of businesses, from large international multi-retailer supermarkets to small independent stores, from informal markets to street food traders, from home delivery to community bulk purchasing groups. The flow chart in the food supply chain is shown in Figure.1.

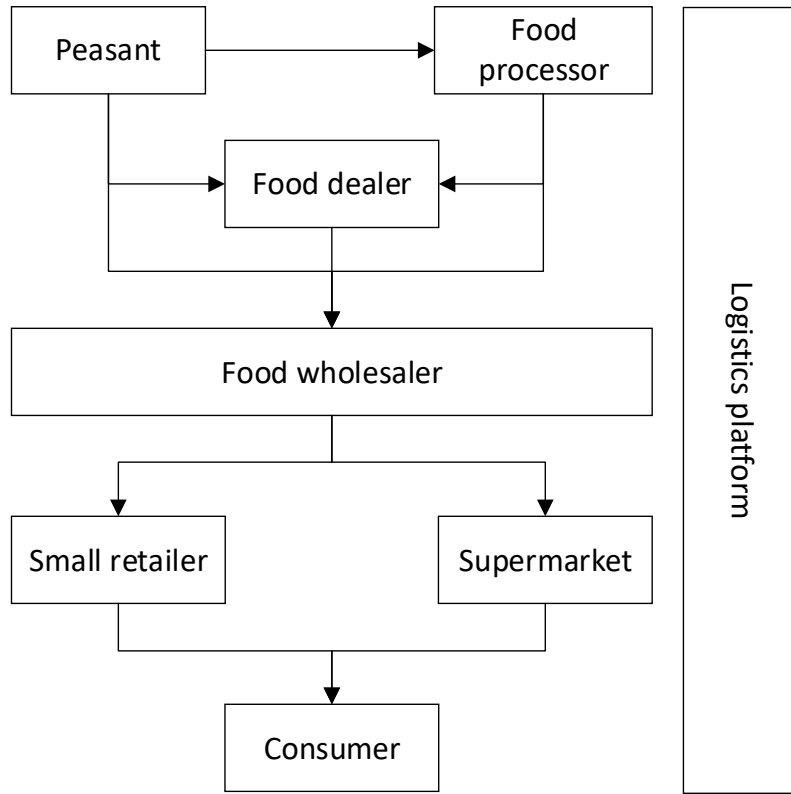


Fig. 1. Flowchart of key players in the food supply chain

4. Preliminaries

4.1 The basic concepts of FFNs

Definition 1[21]: Let X be a universal set, Fermatean fuzzy set (FFS) is defined as follows:

$$\tilde{F} = \{ \langle x, \mu_{\tilde{F}}(x), \nu_{\tilde{F}}(x) \rangle | x \in X \} \quad (1)$$

in which, $\mu_{\tilde{F}}(x): X \rightarrow [0,1]$ and $\nu_{\tilde{F}}(x): X \rightarrow [0,1]$ represent membership degree and non-membership degree, respectively.

$$0 \leq \mu_{\tilde{F}}(x)^3 + \nu_{\tilde{F}}(x)^3 \leq 1, x \in X \quad (2)$$

If:

$$\pi_{\tilde{F}}(x) = \sqrt[3]{1 - (\mu_{\tilde{F}}(x))^3 - (\nu_{\tilde{F}}(x))^3} \quad (3)$$

Then $\pi_{\tilde{F}}(x)$ is the degree of hesitation or uncertainty of $x \in X$ set \tilde{F} . For clarity and brevity, $\tilde{F} = (\mu_{\tilde{F}}(x), \nu_{\tilde{F}}(x))$ represents a Fermatean fuzzy number (FFN).

Definition 2[22]: Assume that any three are given as FFNs, $\tilde{F}_1 = (\mu_{\tilde{F}_1}, \nu_{\tilde{F}_1})$, $\tilde{F}_2 = (\mu_{\tilde{F}_2}, \nu_{\tilde{F}_2})$, $\tilde{F}_3 = (\mu_{\tilde{F}_3}, \nu_{\tilde{F}_3})$, Set aside $\eta > 0$, the operations are presented as:

$$\tilde{F}_1 \oplus \tilde{F}_2 = \left(\sqrt[3]{\mu_{\tilde{F}_1}^3 + \mu_{\tilde{F}_2}^3 - \mu_{\tilde{F}_1}^3 \mu_{\tilde{F}_2}^3}, \nu_{\tilde{F}_1} \nu_{\tilde{F}_2} \right) \quad (4)$$

$$\tilde{F}_1 \otimes \tilde{F}_2 = \left(\mu_{\tilde{F}_1} \mu_{\tilde{F}_2}, \sqrt[3]{\nu_{\tilde{F}_1}^3 + \nu_{\tilde{F}_2}^3 - \nu_{\tilde{F}_1}^3 \nu_{\tilde{F}_2}^3} \right) \quad (5)$$

$$\eta(\tilde{F}_3) = \left(\sqrt[3]{1 - (1 - \mu_{\tilde{F}_3}^3)^\eta}, \nu_{\tilde{F}_3}^\eta \right) \quad (6)$$

$$(\tilde{F}_3)^\eta = \left(\mu_{\tilde{F}_3}^\eta, \sqrt[3]{1 - (1 - \nu_{\tilde{F}_3}^3)^\eta} \right) \quad (7)$$

Definition 3[22] : Assume $\tilde{F}_1 = (\mu_{\tilde{F}_1}, \nu_{\tilde{F}_1})$ is a FFN. Satisfy the following scoring function $S(\tilde{F}_1)$ and accuracy functions $A(\tilde{F}_1)$:

$$S(\tilde{F}_1) = \mu_{\tilde{F}_1}^3 - \nu_{\tilde{F}_1}^3 \quad (8)$$

where, score function $S(\tilde{F}_1) \in [-1, 1]$.

$$A(\tilde{F}_1) = \mu_{\tilde{F}_1}^3 + \nu_{\tilde{F}_1}^3 \quad (9)$$

where, accuracy function $A(\tilde{F}_1) \in [0, 1]$.

According to the score function and the accuracy function, let's set two FFNs \tilde{F}_1 and \tilde{F}_2 , respectively. The comparison criteria are as follows:

1. If $S(\tilde{F}_1) > S(\tilde{F}_2)$, then $\tilde{F}_1 > \tilde{F}_2$;
2. If $S(\tilde{F}_1) < S(\tilde{F}_2)$, then $\tilde{F}_1 < \tilde{F}_2$;
3. If $S(\tilde{F}_1) = S(\tilde{F}_2)$, then
 - (1) If $A(\tilde{F}_1) > A(\tilde{F}_2)$, then $\tilde{F}_1 > \tilde{F}_2$;
 - (2) If $A(\tilde{F}_1) < A(\tilde{F}_2)$, then $\tilde{F}_1 < \tilde{F}_2$;
 - (3) If $A(\tilde{F}_1) = A(\tilde{F}_2)$, then $\tilde{F}_1 = \tilde{F}_2$.

Definition 4[22]: Assume $\tilde{F}_1 = (\mu_{\tilde{F}_1}(x_i), \nu_{\tilde{F}_1}(x_i))$, $\tilde{F}_2 = (\mu_{\tilde{F}_2}(x_i), \nu_{\tilde{F}_2}(x_i))$ is two FFNs, the distance between them is measured as follows:

$$d(\tilde{F}_1, \tilde{F}_2) = \sqrt{\frac{1}{2} \left[\sum_{i=1}^n (\mu_{\tilde{F}_1}^3(x_i) - \mu_{\tilde{F}_2}^3(x_i))^2 + (\nu_{\tilde{F}_1}^3(x_i) - \nu_{\tilde{F}_2}^3(x_i))^2 + (\pi_{\tilde{F}_1}^3(x_i) - \pi_{\tilde{F}_2}^3(x_i))^2 \right]} \quad (10)$$

in which, $0 \leq d(\tilde{F}_1, \tilde{F}_2) \leq \sqrt{2}$.

4.2 FF- ORESTE method

4.2.1 Information fusion

The expert weight calculation formula is shown as follows:

$$\delta_e = \frac{S(Q_e)}{\sum_{e=1}^k S(Q_e)}, e = 1, \dots, k \quad (11)$$

Where e is the number of experts, $S(Q_e)$ is the score function, the calculation formula is:

$$score(\tilde{F}) = \mu_{\tilde{F}}^3 - \nu_{\tilde{F}}^3 \quad (12)$$

FFS is used for information integration. After calculating expert weights, the aggregated fuzzy decision matrix is calculated. The information integration formula is shown as follows. The aggregated fuzzy decision matrix is shown in Table 4.

$$FFWA(\alpha_1, \alpha_2, \dots, \alpha_n) = \sum_{j=1}^n \delta_j \alpha_j \quad (13)$$

4.2.2 Indicator weight determine

Positive and negative risks are calculated according to Eq.(10), which is as follows:

$$d_j^+ = \sum_{i=1}^n d(\tilde{F}_{ij}, \tilde{F}_j^+) \quad (14)$$

$$d_j^- = \sum_{i=1}^n d|\tilde{F}_{ij}, \tilde{F}_j^-| \quad (15)$$

To calculate the risk weight, the formula is as follows:

$$\zeta_j = \frac{d_j^+}{(d_j^+ + d_j^-)} \quad (16)$$

$$\omega_j = \frac{\zeta_j}{\sum_{j=1}^n \zeta_j} \quad (17)$$

4.2.3 ORESTE method-based ranking framework

(1) The formula for calculating the global preference score $D(\tilde{F}_j)$ of the alternative A_i under the risk parameter C_i is as follows[23]:

$$D(\tilde{F}_j) = \sqrt{\zeta d(\tilde{F}_{ij}, \tilde{F}_j^+)^2 + (1-\zeta)d(w_{\tilde{F}_j}, w^+)^2} \quad (18)$$

where the parameter $\zeta \in [0,1]$ represents $d(\tilde{F}_1, \tilde{F}_2)$ and $d(w_{\tilde{F}_j}, w^+)$ relative importance of deviation measures. In this paper, the value of this parameter is $\zeta = 0.5$, indicates these two deviation measures are equally important in the global preference score.

(2) Based on Eq.(11), alternative A_j weak ordering can be scored by preference $D(\tilde{F}_i), i=1, \dots, n$. The formula is shown as follows:

$$D(\tilde{F}_i) = \sum_{j=1}^n D(\tilde{F}_{ij}) \quad (19)$$

The weak ordering of each alternative can be derived according to the following rules:

1. If $D(\tilde{F}_i) > D(\tilde{F}_{i^r})$, then $r(\tilde{F}_i) > r(\tilde{F}_{i^r})$, represent $\tilde{F}_i P \tilde{F}_{i^r} (i^r = 1, 2, \dots, n)$;
2. If $D(\tilde{F}_i) = D(\tilde{F}_{i^r})$, then $r(\tilde{F}_i) = r(\tilde{F}_{i^r})$, represent $\tilde{F}_i I \tilde{F}_{i^r} (i^r = 1, 2, \dots, n)$.

(3) Assume $D(\tilde{F}_j)$ and $D(\tilde{F}_{i^r j})$ is the alternative A_i and A_{i^r} the global preference score under the risk parameter C_j , then the average preference strength between $D(\tilde{F}_j)$ and $D(\tilde{F}_{i^r j})$ is shown as follows:

$$T(A_i, A_{i^r}) = \frac{\sum_{j=1}^m \max\{(D(\tilde{F}_{i^r j}) - D(\tilde{F}_j)), 0\}}{n} \quad (20)$$

The net preference strength between $D(\tilde{F}_j)$ and $D(\tilde{F}_{i^r j})$ is shown as follows:

$$\Delta T(A_i, A_{i^r}) = T(A_i, A_{i^r}) - T(A_{i^r}, A_i) \quad (21)$$

To construct the PIR relationship, thresholds should be determined. PIR relationship consists of three elements: preference (P) relationship, indifference (I) relationship, and incomparability (R) relationship. Therefore, this article uses three thresholds: preference threshold (σ), no difference threshold (ρ), and incomparability threshold (ε) to distinguish between these three relationships. The parameter σ is suitable for separating P. The parameter ρ is used to distinguish between I and R under each risk. The thresholds are determined as follows:

- ① The value range of the indifference threshold ρ is $\rho \in [0, 0.442]$;

② Based on the value of ρ , the preference threshold is defined by considering the minimum condition, so $\sigma = \frac{\rho}{n}$;

③ Based on knowing ρ and n , the incomparability threshold can be calculated. When ε is singular, $\varepsilon = \frac{(n+2)}{2n}\rho$; When n is a complex number, $\varepsilon = \frac{\rho}{2}$.

In this paper, $\rho = 0.03$. Based on the thresholds defined above, the specific PIR structure can be constructed as follows:

① When net preference strength $\Delta T(A_i, A_{i'})$ satisfies the condition $|\Delta T(A_i, A_{i'})| \geq \varepsilon$, then

$$\begin{cases} \Delta T(A_i, A_{i'}) > 0, A_i P A_{i'} \\ \Delta T(A_i, A_{i'}) < 0, A_{i'} P A_i \end{cases}$$

② When net preference strength $\Delta T(A_i, A_{i'})$ satisfies the condition $|\Delta T(A_i, A_{i'})| < \varepsilon$, then

$$\begin{cases} \Delta T(A_i, A_{i'}) > 0, A_i P A_{i'} \\ \Delta T(A_i, A_{i'}) < 0, A_{i'} P A_i \end{cases}$$

5. Application of the method

5.1 Initial data to identify risk influencing factors

Firstly, 13 risk factors affecting the resilience of the food supply chain and 7 key actors in the food supply chain process (A1, A2, A3, A4, A5, A6, A7) were identified based on literature research. Among them, the influencing factors of resilience risk mainly come from three aspects: macro-environmental risk, operational risk, and internal risk, including 13 sub-factors. Three senior experts from relevant backgrounds (E1, E2, E3) were selected in the group evaluation to score the impact value of supply chain resilience on key participants under the influence of different risk factors based on probabilistic hesitancy Fermatean fuzzy environment. Table 2 is the original evaluation data of experts, and Table 3 is the fuzzy interval scale that replaces expert evaluation. The decision matrix is constructed through data transformation, and the research results of experts are analyzed.

Table 2

Initial decision matrix from experts

		C11	C12	C13	C14	C21	C12	C23	C24	C25	C31	C32	C33	C34
E1	A1	VP	VG	M	VP	M	M	M	G	M	M	G	M	M
	A2	P	G	M	VP	M	G	M	VG	G	M	G	M	G
	A3	G	M	M	P	P	VG	P	M	VG	VG	VG	G	G
	A4	P	P	P	M	P	M	E	VG	M	M	VG	M	M
	A5	M	M	P	M	P	M	M	VG	VG	VG	M	M	VG
	A6	VG	E	M	M	VG	VG	M	VG	E	E	M	M	VG
	A7	M	P	P	P	P	P	P	M	P	P	M	P	VP
E2	A1	VP	VP	M	P	VP	M	VP	M	P	M	VG	M	M
	A2	M	P	M	M	VP	M	VP	M	M	M	VG	VP	M
	A3	VG	M	M	E	P	M	VP	M	VG	M	M	M	M
	A4	VG	VG	M	E	M	E	VP	P	VG	M	M	M	P
	A5	VG	VG	M	E	E	M	P	VG	E	P	P	VG	M
	A6	M	E	M	E	E	E	M	VG	E	P	P	VG	M
	A7	M	E	M	E	E	M	P	VG	E	P	P	VG	M

E3	A1	M	M	M	M	P	M	M	M	M	M	M	M	VG
	A2	M	VG	M	VG	M	M	M	M	M	M	M	M	M
	A3	M	VG	M	VG	M	M	M	M	M	M	M	M	VG
	A4	P	M	M	M	M	M	VG	M	M	M	VG	M	M
	A5	VG	M	VG	M	M	M	E	M	VG	M	M	M	VG
	A6	M	M	M	VG	M	M	M	M	M	M	E	M	M
	A7	M	M	M	M	M	M	M	VG	M	M	M	M	M

Table 3
 Fuzzy interval scale instead of evaluation

The fuzzy interval scale of the interval	Linguistic terms
(0.10,0.75)	Very poor (VP)
(0.25,0.60)	Poor (P)
(0.50,0.40)	Moderate (M)
(0.70,0.20)	Good (G)
(0.80,0.10)	Very good (VG)
(0.90,0.10)	Excellent (E)

5.2 Application of ORESTE method

First, according to Eq.(15)A total of three expert opinions are considered in this paper (E1, E2, E3). After calculation, the weight of the three experts in this paper (E1, E2, E3) is (0.306,0.368,0.326).

Table 4
 Aggregate fuzzy decision matrix

Alternatives	A1	A2	A3	A4	A5	A6	A7
C1	(0.6357, 0.6110)	(0.7571, 0.4528)	(0.8857, 0.1943)	(0.8138, 0.3103)	(0.9026, 0.1528)	(0.8537, 0.2617)	(0.7937, 0.4000)
C2	(0.8098, 0.4368)	(0.8580, 0.5362)	(0.8569, 0.5341)	(0.8415, 0.4639)	(0.8632, 0.4817)	(0.9402, 0.5422)	(0.8823, 0.4972)
C3	(0.7937, 0.3927)	(0.7937, 0.3927)	(0.7937, 0.3927)	(0.7571, 0.3927)	(0.8340, 0.1591)	(0.7937, 0.3927)	(0.7571, 0.3927)
C4	(0.6732, 0.4559)	(0.8223, 0.1591)	(0.9157, 0.0955)	(0.8977, 0.2358)	(0.8977, 0.2358)	(0.9263, 0.0955)	(0.8823, 0.2358)
C5	(0.6631, 0.6447)	(0.7238, 0.4950)	(0.6999, 0.4559)	(0.7571, 0.3927)	(0.8823, 0.2358)	(0.9249, 0.2358)	(0.8823, 0.2358)
C6	(0.7937, 0.3927)	(0.8303, 0.3927)	(0.8537, 0.3927)	(0.8977, 0.2358)	(0.7937, 0.3927)	(0.9249, 0.2358)	(0.7571, 0.3927)
C7	(0.7238, 0.4950)	(0.7238, 0.4950)	(0.6674, 0.4950)	(0.8957, 0.2005)	(0.8691, 0.1847)	(0.7937, 0.3927)	(0.6999, 0.4559)
C8	(0.8303, 0.3927)	(0.8537, 0.3927)	(0.7937, 0.3927)	(0.8250, 0.4559)	(0.9006, 0.2358)	(0.9006, 0.2358)	(0.9026, 0.0955)
C9	(0.7486, 0.4559)	(0.8303, 0.3927)	(0.9006, 0.2358)	(0.8632, 0.2358)	(0.9454, 0.0955)	(0.9402, 0.2358)	(0.8823, 0.2358)
C10	(0.7937, 0.3927)	(0.7937, 0.3927)	(0.8537, 0.3927)	(0.7937, 0.3927)	(0.8250, 0.4559)	(0.8641, 0.4559)	(0.6999, 0.4559)
C11	(0.8857, 0.2358)	(0.8857, 0.2358)	(0.8537, 0.3927)	(0.8962, 0.1591)	(0.7486, 0.4559)	(0.8691, 0.1847)	(0.7486, 0.4559)
C12	(0.7937, 0.3927)	(0.7238, 0.4950)	(0.8303, 0.3927)	(0.7937, 0.3927)	(0.8632, 0.2358)	(0.8632, 0.2358)	(0.8415, 0.2358)
C13	(0.8569, 0.1591)	(0.8303, 0.3927)	(0.8806, 0.1591)	(0.7486, 0.4559)	(0.8962, 0.1591)	(0.8537, 0.3927)	(0.7377, 0.3927)

Then, construct and normalize the score matrix. The score function is calculated according to Eq.(16), and the standardized score matrix and the ranking of risk factor weights are shown in Table 5.

Table 5
 Normalized score matrix

Crit.	A1	A2	A3	A4	A5	A6	A7	w_i	Ranking
C1	0.0288	0.3411	0.6874	0.5090	0.7317	0.6043	0.4360	0.0696	7
C2	0.4477	0.4776	0.4767	0.4962	0.5313	0.6716	0.5641	0.0974	3
C3	0.4394	0.4394	0.4394	0.3734	0.5761	0.4394	0.3734	0.0976	2
C4	0.2104	0.5520	0.7669	0.7104	0.7104	0.7940	0.6738	0.0506	13
C5	0.0235	0.2580	0.2481	0.3734	0.6738	0.7780	0.6738	0.0883	5
C6	0.4394	0.5118	0.5617	0.7104	0.4394	0.7780	0.3734	0.0924	4
C7	0.2580	0.2580	0.1760	0.7106	0.6502	0.4394	0.2481	0.0999	1
C8	0.5118	0.5617	0.4394	0.4667	0.7173	0.7173	0.7344	0.0684	8
C9	0.3248	0.5118	0.7173	0.6300	0.8442	0.8179	0.6738	0.0684	9
C10	0.4394	0.4394	0.5617	0.4394	0.4667	0.5505	0.2481	0.0634	11
C11	0.6816	0.6816	0.5617	0.7158	0.3248	0.6502	0.3248	0.0650	10
C12	0.4394	0.2580	0.5118	0.4394	0.6300	0.6300	0.5829	0.0615	12
C13	0.6251	0.5118	0.6788	0.3248	0.7158	0.5617	0.3409	0.0776	6

Calculated according to the weight of the score function, the ranking result of risk factor weight is $C7 > C3 > C2 > C6 > C5 > C13 > C1 > C8 > C9 > C11 > C10 > C12 > C4$. The top 3 risk factors affecting the resilience of the food supply chain are logistics and transportation failure, government regulation and disease, and production and manufacturing failure, and water system failure are the least influential risk factors.

Through the calculation of positive risks and negative risks using Eqs.(18)-(21), the weights of key players are finally calculated. The results are shown in Table 6.

Table 6
 Weights of alternatives

Alternatives	$d +$	$d -$	ζ_j	ω_j
A1	3.1738	0.9610	0.7676	0.2405
A2	2.4959	1.7319	0.5904	0.1850
A3	1.7899	2.4903	0.4182	0.1310
A4	1.9138	2.3341	0.4505	0.1412
A5	1.0496	3.0988	0.2530	0.0793
A6	0.5963	3.6425	0.1407	0.0441
A7	2.4122	1.8116	0.5711	0.1789

Next, the weights of key participants are calculated from the previous step, and then the global preference score $D(\tilde{F}_{ij})$ is calculated using the Eq.(11). The results are shown in Table 7.

Table 7
 Global preference scores

Crit.	A1	A2	A3	A4	A5	A6	A7
C1	0.2931	0.1903	0.0397	0.1333	0.0365	0.0851	0.1508
C2	0.2435	0.1438	0.1481	0.1927	0.1568	0.0395	0.1184
C3	0.0504	0.0531	0.0581	0.0942	0.0365	0.0641	0.0921
C4	0.3183	0.1686	0.0346	0.0539	0.0593	0.0395	0.0747
C5	0.3059	0.2620	0.2938	0.2390	0.0822	0.0395	0.0759

Crit.	A1	A2	A3	A4	A5	A6	A7
C6	0.1913	0.1419	0.1104	0.0548	0.1947	0.0395	0.2382
C7	0.2116	0.2123	0.2686	0.0268	0.0576	0.1453	0.2417
C8	0.1009	0.0712	0.1525	0.1099	0.0372	0.0402	0.0183
C9	0.2738	0.1763	0.0823	0.1412	0.0365	0.0406	0.1093
C10	0.0864	0.0880	0.0288	0.0905	0.0522	0.0530	0.1875
C11	0.0155	0.0228	0.0665	0.0268	0.1921	0.0591	0.1895
C12	0.0893	0.1633	0.0527	0.0932	0.0365	0.0395	0.0380
C13	0.0641	0.0926	0.0389	0.1905	0.0365	0.0718	0.2088

Based on the operation results in Table 7, Eq.(12) is used to calculate the preference score and weak ranking from the global preference score, and the results are shown in Table 8.

Table 8
 Preference scores and weak ranking

Alternatives	Preference score	Weak ranking
A1	2.2442	7
A2	1.7864	6
A3	1.3750	3
A4	1.4468	4
A5	1.0144	2
A6	0.7569	1
A7	1.7430	5

Eq.(13) is used to calculate the potential preference matrix among key participants, and the results are shown in Table 9.

Table 9
 Potential preference matrix

$T(H_i) - T(H'_i)$	A1	A2	A3	A4	A5	A6	A7
A1	0.0000	0.1148	0.1672	0.1983	0.1800	0.0650	0.5384
A2	0.5727	0.0000	0.2224	0.2329	0.2351	0.0473	0.5470
A3	1.0364	0.6337	0.0000	0.5063	0.2667	0.1135	0.7915
A4	0.9868	0.5724	0.4345	0.0000	0.3413	0.1507	0.7145
A5	1.4099	1.0071	0.6273	0.7738	0.0000	0.2104	0.7949
A6	1.5523	1.0768	0.7317	0.8407	0.4678	0.0000	1.0096
A7	1.0397	0.5904	0.4236	0.4183	0.0663	0.0235	0.0000

Eq.(14) is used to calculate the preference matrix, and the results are shown in Table 10.

Table 10
 Preference matrix

ΔH	A1	A2	A3	A4	A5	A6	A7
A1	0.0000	-0.4579	-0.8692	-0.7885	-1.2299	-1.4874	-0.5013
A2	0.4579	0.0000	-0.4113	-0.3395	-0.7720	-1.0295	-0.0434
A3	0.8692	0.4113	0.0000	0.0718	-0.3607	-0.6182	0.3679
A4	0.7885	0.3395	-0.0718	0.0000	-0.4325	-0.6900	0.2961
A5	1.2299	0.7720	0.3607	0.4325	0.0000	-0.2575	0.7286
A6	1.4874	1.0295	0.6182	0.6900	0.2575	0.0000	0.9861
A7	0.5013	0.0434	-0.3679	-0.2961	-0.7286	-0.9861	0.0000

Finally, the PIR relationship matrix is constructed according to the results obtained in Table 10 and the PIR relationship threshold, and the results are shown in Table 11.

Table 11

PIR relationship matrix

Alt.	A1	A2	A3	A4	A5	A6	A7
A1	-	<	<	<	<	<	<
A2	>	-	<	<	<	<	<
A3	>	>	-	>	<	<	>
A4	>	>	<	-	<	<	>
A5	>	>	>	>	-	<	>
A6	>	>	>	>	>	-	>
A7	>	>	<	<	<	<	-

According to the comparison results, the final order is A6>A5>A3>A4>A7>A2>A1. Supermarkets are the most resilient key players, followed by grain wholesalers. Farmers are the most vulnerable link in the food supply chain, followed by food processors.

6 Analysis result

The membership degree, non-membership degree, score function, and risk weight of key participants of 13 risk factors affecting the resilience of the food supply chain were calculated by improving the ORESTE method in the context of hesitation fuzzy language, and the key participants were ranked accordingly to analyze the influencing factors of the resilience of food supply chain. The risk factors affecting the resilience of the food supply chain mainly come from three aspects, namely macro risk factors, operational risk factors and internal risk factors, including 13 sub-factors, these are natural disasters (C1), disease (C2), government regulation (C3), water system failures (C4), unstable demand (C5), changes in quality needs (C6), transport logistics failures (C7), skilled labor shortages (C8), backup supplier issues (C9), excess inventory (C10), system and IT risks (C11), production and production Manufacturing failure (C12), internal operating risk (C13). Among all risk factors, transport logistics failure (C7), government regulation (C3), and disease (C2) are the three factors with the highest risk weights. Among all risk factors, the risk weight of C7 is 0.0999, ranking first. The risk weight of C3 is 0.0976, ranking second after C7. It is closely followed by C2 with a risk weight of 0.0974, ranking third.

Among the seven key players in the food supply chain are farmers (A1), grain processors (A2), grain distributors (A3), logistics platforms (A4), grain wholesalers (A5), supermarkets (A6) and small retailers (A7). The most vulnerable key players are farmers (A1), and supermarkets (A6), as the end of the food supply chain, are considered the most resilient key players.

This suggests that three factors - transport logistics failures, government regulation, and disease are considered to be critical risk factors for the resilience of food supply chains, as they all have a strong impact on key players in the food supply chain. Due to the easiness of transportation and logistics, the unpredictability of government supervision, the sudden difficulty of disease control, and the characteristics of food perishability, it is easy to lead to the failure of food transportation, resulting in the increase of inventory at each node, the decline of service level, the rise of food prices, and so on, leading to food panic and other problems. The biggest impact is that during the epidemic period, various countries and regions introduced restrictive measures, and the epidemic control seriously affected the transportation efficiency of grain, causing a serious impact on the food industry chain and supply chain. As the first end of the food supply chain, farmers are faced with the obstacles of lagging market information, low level of science and technology, and low adaptability, and are also

vulnerable to market impact, which damages farmers' interests. Farmers are the most vulnerable in food supply chain operations, and as an integral part of the food supply chain, they need long-term and integrated forecasting plans. Therefore, the central government has always attached great importance to the issue of "agriculture, rural areas". From breeding to farmland protection to the Food Security Law of the People's Republic of China, the CPC Central Committee always starts from the source, continuously strengthens food security, and firmly holds the rice bowl of the Chinese people in its own hands.

According to the above identification and analysis of risk factors and key players in the food supply chain, it can be seen that C7, C3, C2, and A1 are the key factors affecting the resilience of the food supply chain.

7. Managerial implications

7.1 Build a platform for exchanges on the grain supply chain

Actively integrate into the construction of the food industry chain, supply chain, and value chain, expand the food "circle of friends", the majority of food enterprises to establish closer upstream and downstream cooperation, through the construction of food supply chain information management platform and timely update processing, so that enterprises to each production link of the purchase, demand, logistics, and other enterprise operation information to achieve a more comprehensive understanding. The establishment of the food supply chain information management platform enables the main enterprises to quickly obtain the desired information, lays a solid foundation for the rapid operation of the food supply chain, and provides a basis for the formulation and implementation of risk control strategies.

The food supply chain exchange platform provides the following content:

(1) Demand information. Real consumer demand information can effectively reduce the vulnerability of the food supply chain caused by the "bullwhip effect", and reduce the impact of demand changes on nodal enterprises, especially upstream enterprises of the supply chain.

(2) Logistics information. Including food production, processing, transportation, storage, custody, etc., sharing logistics information enables key players in the food supply chain to know the real-time address and supply and demand of their products. If problems occur at any point in the food supply chain, the exchange of information can help relevant actors act quickly to respond to emergencies and improve the resilience of the food supply chain.

7.2 Increase policy support

(1) Promoting food support policies by variety. Diversified and refined promotion strategies can not only fully reflect different growth characteristics, consumption patterns, and changes in demand, but also reflect market changes, and help to improve the effectiveness of promotion policies, improve the importance of promotion, and reduce the pressure on resources and the environment.

(2) Promote food support policies by different means. On the premise of understanding government policies and regulations, we will propose targeted food support measures and explore various subsidy measures that can help improve the sustainable capacity of production.

(3) Improve grain import and export policies to prevent capital speculation. We will properly control grain exports to ensure a stable domestic grain supply, and at the same time control the proportion of important grain imports from abroad. Strengthen the monitoring and tracking of domestic and foreign agricultural funds, prevent domestic and foreign speculative capital from using emergencies to hype food security issues, and severely crack down on the manipulation of important domestic food markets and malicious bid-up food prices.

7.3 Strengthen disaster prevention and control

(1) Actively publicize and popularize the prevention and control measures of conventional diseases and pests, increase the technical training of agricultural technicians and farmers in a short period of time when specific diseases and pests occur, accurately guide the time, dosage and method of application, and improve the effect of pesticide use.

(2) Strengthen the monitoring and early warning of diseases and pests, increase the detection points of diseases and pests, and accurately predict the biological habits, reproductive characteristics, and possible migration direction of diseases and pests.

(3) Strengthen the monitoring, early warning, and forecast work in advance for the possible occurrence of rainstorms and super-large floods. Timely release of the rainstorm and flood meteorological early warning information, formulate spring and summer rainstorm and flood disaster response plans and increase the popularization and training of emergency rescue technology.

8. Conclusion and future work

First, based on the existing research, this paper consulted and analyzed the relevant literature at home and abroad to understand food security, supply chain resilience, and food supply chain resilience. The study found that China's food security is facing the challenge of high dependence on the international market, and food security is closely related to the stability of the food supply chain, so it is particularly important to improve the resilience and stability of the food supply chain.

Secondly, this paper analyzes the risk factors affecting the resilience of the food supply chain from three dimensions: macro risk, operational risk, and internal risk. By summarizing the findings, IT can be divided into natural disasters (C1), disease (C2), government regulation (C3), water system failures (C4), unstable demand (C5), changes in quality needs (C6), transport logistics failures (C7), skilled labor shortages (C8), backup supplier issues (C9), excess inventory (C10), system and IT risks (C11), and production and 13 sub-factors such as manufacturing failure (C12) and internal operating risk (C13). At the same time, the paper considers and evaluates a group of food supply chain players, from farmers to supermarkets and small retailers, to understand the production and distribution processes of food, and identifies seven key players, this includes farmers (A1), grain processors (A2), grain distributors (A3), logistics platforms (A4), grain wholesalers (A5), supermarkets (A6) and small retailers (A7). Three experts were then asked to rate the resilience of key players across 13 risk factors (Table 2).

Finally, using the improved ORESTE method in the context of hesitancy fuzzy language, the interaction relationship of influencing factors of food supply chain resilience was established and the influencing factors of key participants' resilience were identified. Three experts scored the resilience performance of seven key participants in the resilience of the food supply chain under the influence of 13 risk factors, constructed an initial fuzzy language matrix, and converted the initial matrix into an aggregated fuzzy decision matrix and a normalized score matrix through the Fermatean fuzzy language scale. Membership, non-membership, and score functions were calculated. The key risk factors affecting the resilience of the food supply chain were obtained according to the risk weights. Then, the ORESTE method is used to analyze the ranking of key participant weights. According to the results, transport and logistics failures, government regulation and disease are the three risk factors that have the greatest impact on food supply chain resilience, while water system failures and production and manufacturing disruptions are the least influential. Among key food supply chain participants, farmers are generally the most vulnerable, followed by food processors; According to experts, supermarkets tend to be more resilient as players at the end of the supply chain. Accordingly, targeted suggestions are put forward to improve the resilience of the food supply chain, such as

establishing a food supply chain information-sharing mechanism, increasing policy support, and strengthening disaster prevention and control.

Through the study of the internal and external influencing factors of the food supply chain, the key risk factors affecting its resilience are analyzed, which can be used as a reference to propose measures to improve resilience, enhance the production capacity of food, improve the food supply chain, and thus promote the development of the food industry. By strengthening the resilience of the food supply chain and improving the relevant policies of the food supply chain, information sharing can be realized among various subjects of the food supply chain, thus improving the stability and sustainability of the food supply chain. The analysis of the factors affecting the resilience of China's food supply chain from the perspective of the correlation of resilience factors can not only enrich the current resilience research methods but also provide a new perspective for the study of China's food supply chain resilience.

Nevertheless, this framework still has the following limitations. (1) The food supply chain is characterized by many participants, complex links, and a wide range of fields, and its influencing factors are numerous and interrelated. Based on the factor identification of existing methods, there may be some influencing factors that have not yet been discovered or considered, which require continuous attention in the future. (2) The original data matrix is based on expert scores to determine the scale of different influencing factors. The data in the matrix is based on the personal experience of experts, and the data specimens are limited, so the result analysis may have certain subjectivity and bias.

Based on the above shortcomings, the stability of the food supply chain is the guarantee of food security, to enhance the resilience and stability of the food supply chain, a wider range of influencing factors should be considered in the subsequent research. In quantitative research, increase the sample size, improve the accuracy of the results, find out the key influencing factors of toughness, and put forward effective suggestions.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The funders had worked on the writing of the manuscript.

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