Hindawi
Journal of Food Quality
Volume 2018, Article ID 2637075, 19 pages
https://doi.org/10.1155/2018/2637075

Research Article

Quality Risk Evaluation of the Food Supply Chain Using a Fuzzy Comprehensive Evaluation Model and Failure Mode, Effects, and Criticality Analysis

Libiao Bai,[1] **Chunming Shi**,[2] **Yuntao Guo**,[3] **Qiang Du**,[1] **and Youdan Huang**[1]

[1]*School of Economics and Management, Chang'an University, Xi'an 710061, China*
[2]*Wilfrid Laurier University, Waterloo, ON, Canada N2L3C5*
[3]*School of Management, Northwestern Polytechnical University, Xi'an 710072, China*

Correspondence should be addressed to Chunming Shi; cshi@wlu.ca

Received 21 September 2017; Revised 5 January 2018; Accepted 14 January 2018; Published 4 March 2018

Academic Editor: Susana Fiszman

Evaluating the quality risk level in the food supply chain can reduce quality information asymmetry and food quality incidents and promote nationally integrated regulations for food quality. In order to evaluate it, a quality risk evaluation indicator system for the food supply chain is constructed based on an extensive literature review in this paper. Furthermore, a mathematical model based on the fuzzy comprehensive evaluation model (FCEM) and failure mode, effects, and criticality analysis (FMECA) for evaluating the quality risk level in the food supply chain is developed. A computational experiment aimed at verifying the effectiveness and feasibility of this proposed model is conducted on the basis of a questionnaire survey. The results suggest that this model can be used as a general guideline to assess the quality risk level in the food supply chain and achieve the most important objective of providing a reference for the public and private sectors when making decisions on food quality management.

1. Introduction

In 2016, the State Council of the People's Republic of China issued guidelines on food safety work. These provisions emphasized improving the quality of edible agricultural products, strengthening risk prevention and control measures, promoting quality management throughout the food supply chain, and accelerating nationally integrated regulations for food safety. These guidelines highlight China's attention to quality risk management in the food supply chain [1].

Food quality is defined as the access of all people to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life [2, 3]. Food quality covers a broad area that can be characterized by a set of different risk factors [4–6], such as the agricultural conditions [7], production process [8], use of antimicrobials [9], and consumer demand [10, 11]. These factors can be represented by various indicators such as environmental pollution, microbial contamination, logistics, warehousing, and transportation. The risk indicators are related to the food supply chain processes [12] and can be evaluated and documented on the basis of imprecise inputs. The data of these processes are imprecise and difficult to quantify since they pertain to both the resilience of the food supply chain and the consumer demand and supply channels such as retail outlets and restaurants. Therefore, it is difficult to use traditional data-based approaches to evaluate food quality. Addressing this challenge requires the managers to develop some precise methods for assessing the risk level of all factors in every link of the food supply chain [13] and calculating them as a whole [14]. Unfortunately, few related studies have been done.

The quality risk level of food is defined as the potential hazard which is caused by unsafe practices in the food supply chain. The uncertainty of the ability to acquire safe foods is also called food insecurity and can be measured by the risk level of food quality [15]. And the quality risk level of food security is an important problem related to the food supply chain environment. One effective solution to solve this problem is to build an evaluation indicator system based on the fuzzy sets theory [16]. Several studies have considered that building the indicator system is the first step in assessing the quality risk, and many research results have been made, such as in the case of Wang et al. who developed an index system to evaluate the transparency of the supervision of food safety in China as a prerequisite for an accurate evaluation of the food safety risk level. Jie et al. analyzed the supply chain performance of Australian cattle producers based on food supply chain performance indicators [17]. Turi et al. proposed aggregate indicators to assess the performance of the food supply chain by considering economic, social, and environmental development [18]. Nilsson et al. proposed total quality indicators for the food production chain [19]. Salvo et al. focused on the toxic inorganic pollutants in foods from agricultural producing to evaluate the risks for consumers [20]. In these studies, however, the evaluation objects were only a single link not the whole food supply chain. Moreover, the food quality risk supervision at the national level is missed in these studies. Therefore, the existing literature cannot provide an effective guidance for the quality risk evaluation throughout the whole food supply chain, which means that a comprehensive and systematic study on the area of quality risk evaluation in the food supply chain is still missing.

Many affecting factors of the quality risk evaluation in the food supply chain exhibit highly fuzzy uncertainty and cannot be analyzed quantitatively. Therefore, it is difficult to evaluate the level of quality risk by a single, defined management criterion [21]. To address this fuzzy uncertainty problem, in 1965, Zadeh proposed the concept of fuzzy sets, which laid the foundation for the application of the fuzzy comprehensive evaluation model (FCEM) in risk management [22]. The FCEM is a method to evaluate fuzzy mathematics, which can transform a qualitative evaluation into a quantitative evaluation [23–25]. Combined with other methods, the greatest feature of the FCEM is that it can integrate the intuition and fuzziness of human thinking, thus circumventing the unity of results required by traditional mathematical methods [26]. Therefore, the FCEM has become an effective multifactor decision-making tool for comprehensive evaluations [27] and real-word problem solving in areas such as international relations [28], aircraft flight safety [29], swine building environment [23], health, safety, and environmental management [30], regional water resources capacity [31], and teaching performance [32]. Therefore, in this paper, an FCEM for modeling these uncertainties and assessing food quality risk level is developed to determine the overall food quality risk by monitoring various independent risk factors and indictors in the food supply chain.

The rest of this paper is structured as follows. Section 2 describes the construction of a quality risk evaluation indicator system that covers the whole food supply chain based on an extensive literature review. Section 3 proposes an FCEM for the quality risk evaluation of the food supply chain based on FCEM and FMECA. Section 4 verifies the effectiveness and feasibility of the model using a computational experiment, and Section 5 presents the conclusions.

2. Quality Risk Evaluation Indicator System for the Food Supply Chain

To ensure the accuracy and effectiveness, a quality risk evaluation indicator system that covers the entirety of the food supply chain should be established before evaluating food quality risk. Existing research on this system has been very limited. There is no ready-made quality risk evaluation indicator system for the food supply chain [13]. Here, the effective approach to establishing the preliminary indicator framework is to analyze the existing literature and the laws and regulations of food safety regulatory [58]. On this basis, the quality risk evaluation indicator system for the food supply chain can be built by the method which is based on the fuzzy analytic hierarchy process (FAHP) proposed by Wang et al. [59], shown as Table 1.

According to Table 1, the evaluation objects for quality risk of the food supply chain can be generalized into five categories: raw material supply risk [33–37]; production and processing risk [34, 37–42]; logistics, warehousing, and transportation risk [40–46]; sales and consumption risk [42, 47–51]; and government regulatory risk [52–57]. Raw material supply; production and processing; logistics, warehousing, and transportation; sales and consumption are the four different links of the food supply chain, while government regulations could affect every link of the food supply chain. The connotations of each evaluation object could be described as follows.

(1) Raw Material Supply Risk. The risk of raw material supply involves the raw materials produced by human pollution, natural pollution, and other factors that lead to pesticide residues, pathogen pollution, and illegal additives during the process of planting or breeding, which results in long-term or short-term harm to human health [34]. Raw material supply risk is a source of food quality risk, including soil pollution, air pollution, water pollution, heavy metal pollution, illegal use of additives, residual inputs, microbial contamination, pathogenic bacteria pollution, and transgenic technology risk.

(2) Production and Processing Risk. This risk arises when the safety management and production environment during the processes of production and packaging are not compliant with regulations; this risk could lead to possible food contamination and illegal additives and produce potential safety hazards to human health. As this link involves the food quality and safety in the whole food industrial chain, its impact is relatively large. The main quality risk evaluation indicators included in this link are illegal use of additives, contamination with foreign matter, inability to wash a food product clean, presence of detergent residue, pathogen contamination, microbial contamination, uncertified processing equipment, nonstandardized processing personnel operation, insufficient processing environment, insufficient processing equipment, inappropriate packaging, insufficient packaging quality, uncertified packaging logo, insufficient assurance of

Table 1: Quality risk evaluation indicator system for the food supply chain.

Evaluation objects	Risk evaluation indicators		References
Raw material supply risk	Soil pollution Water pollution Illegal use of additives Microbial contamination, Transgenic technology risk	Air pollution Heavy metal pollution Residual inputs Pathogenic bacteria pollution	[33–37]
Production and processing risk	Illegal use of additives Inability to wash a food product clean Pathogen contamination Uncertified processing equipment Insufficient processing environment Inappropriate packaging Uncertified packaging logo Quality inspection risk	Contamination with foreign matter Presence of detergent residue Microbial contamination Nonstandardized processing personnel operation Insufficient processing equipment Insufficient packaging quality Insufficient assurance of personnel health Insufficient storage process	[34, 37–42]
Logistics, warehousing, and transportation risk	Inventory control technology Transport vehicle sanitation Third-party logistics level Product portfolio storage transport Logistics road infrastructure Vehicle scheduling and monitoring information feedback	Intelligent temperature-control facilities Cold chain hardware supporting facilities Partner technology platform convergence Cold chain logistics information transmission Illegal operation of Logistics transport personnel	[40–46]
Sales and consumption risk	Selling expired food False reporting of food ingredients Poor sanitation conditions Poor sanitation in cooking facilities Insufficient storage environment	Falsifying the date of production Poor sanitation in dining establishments Improper disposal of waste food Improper eating methods	[42, 47–52]
Government regulatory risk	Imperfect regulatory system Supervisor moral hazard Regulatory organization Regulatory process management Regulatory detection technology	Supervisory staff level Supervision channels Regulatory agency efficiency Regulatory results feedback Other risks	[53–57]

personnel health, quality inspection risk, and insufficient storage process.

(3) Logistics, Warehousing, and Transportation Risk. The logistics, warehousing, and transportation risk involves the raw food materials and finished products containing harmful substances or being subject to pollution or deterioration during the process of transport or storage, which results in the existence of potential safety hazards. In this paper, logistics, warehousing, and transportation includes both the process from the raw materials to production and the process from the finished product to consumption. The indicators of this evaluation objective include inventory control technology, intelligent temperature-control facilities, transport vehicle sanitation, cold chain hardware supporting facilities, third-party logistics level, partner technology platform convergence, product portfolio storage transport, cold chain logistics information transmission, logistics road infrastructure, illegal operation of logistics transport personnel, vehicle scheduling, and monitoring information feedback.

(4) Sales and Consumption Risk. The sales and consumption risk involves food contamination, deterioration, and contamination with harmful substances due to expired shelf life, food fraud, improper sales environments, or improper consumption of food, which poses a potential hazard to human health. The quality risk evaluation indicators in this link include selling expired food, falsifying the date of production, false reporting of food ingredients, poor sanitation in dining establishments, poor sanitation conditions, improper disposal of waste food, poor sanitation in cooking facilities, improper eating methods, and insufficient storage environment.

(5) Government Regulatory Risk. In the food industry, manufacturers may add chemical additives to augment the appearance or the taste of food. This process may increase food demand and sales profits but cause health problems among consumers [53]. The government can take punitive measures to regulate such risky behavior and benefit from the tax income generated by the increased revenues arising from such additives. An analysis of the current status of China's food quality regulations reveals that the quality risk evaluation indicators regarding government regulation include imperfect regulatory system, supervisory staff level, supervisor moral hazard, supervision channels, regulatory organization regulatory, agency efficiency, regulatory process management, regulatory results feedback, and regulatory detection technology.

3. Evaluation Model

3.1. Fuzzy Comprehensive Evaluation Method. FCEM is a method based on the membership degree theory in fuzzy mathematics, which transform the qualitative evaluation into quantitative evaluation [27, 60, 61]. It has now become an effective multifactor decision-making tool for comprehensive evaluation. Combined with experts grading method, FCEM can make a full reflection on the fuzziness of evaluation criteria and the influence factors and produce evaluation results closer to the actual situation [62]. The typical FCEM process could be shown in Figure 1.

Shown as Figure 1, the typical process of FCEM could be divided into five stages; the main task in the 1st stage is to establish a scientific set of indicators which is determined by the situation of evaluation objective; this indicators set will lay the foundation for the application of FCEM. In the 2nd stage, the assessment comment set of evaluation objective and the criterion used to reflect the standard of scoring should be established and proposed; this will provide the data foundation for quantifying the results of assessment comment. Each element in the set of indicators makes a different contribution to the realization of risk assessment; the weights of these factors are important and different; therefore, in the 3rd stage, the weight matrixes which are determined by the contribution of the evaluation objective should be built and measured. There are many ways to build the weight matrix, such as analytic hierarchy process (AHP), entropy, and FMECA; the criterion for the selection of these methods is whether the proposed method could satisfy the characteristics and requirements of the evaluation objectives. In the 4th stage, a fuzzy comprehensive assessment matrix which could reflect the risk level of assessment objective should be established on the basis of the construction results of weight matrixes. Combined with the assessment comment set, the fuzzy comprehensive assessment matrix, the value of the whole, and each evaluation objective should be calculated in 5th stage, which will provide a reference for managers to make risk management decisions.

3.2. Construction of the Food Quality Risk Evaluation Model Using FCEM. The process of food quality risk evaluation in the food supply chain is a typical FCEM process. According to Section 3.1, using FCEM to evaluate the level of food quality risk in the food supply chain could be divided into five stages: (1) construct the food quality risk evaluation indicator set, (2) establish the food quality risk assessment comment set, (3) determine the weight matrix, (4) establish the comprehensive assessment matrix, and (5) finalize the FCEM [63].

In the first stage, construct a food quality risk evaluation indicator set Q, which is composed of the evaluation objects Q_i and their corresponding evaluation indicators Q_{ij}, shown as follows:

$$Q = \{Q_1, Q_{\dots}, Q_i, Q_{\dots}, Q_n\},$$
$$Q_i = \{Q_{i1}, \dots, Q_{ij}, \dots, Q_{im}\} \quad (i = 1, 2, \dots, n;\ j = 1, 2, \dots, m), \tag{1}$$

where Q is the food quality risk evaluation indicator set, n is the number of evaluation objects, Q_i $(i \in [0, n])$ is the ith evaluation object, Q_{ij} is the jth food quality risk evaluation indicator of Q_i, and m is the number of food quality risk evaluation indicators in Q_i.

In the second stage, establish the food quality risk assessment comment set $\mathscr{L}$ to describe the fuzzy logic relationship among different indicators. Here, $\mathscr{L}$ is a collection

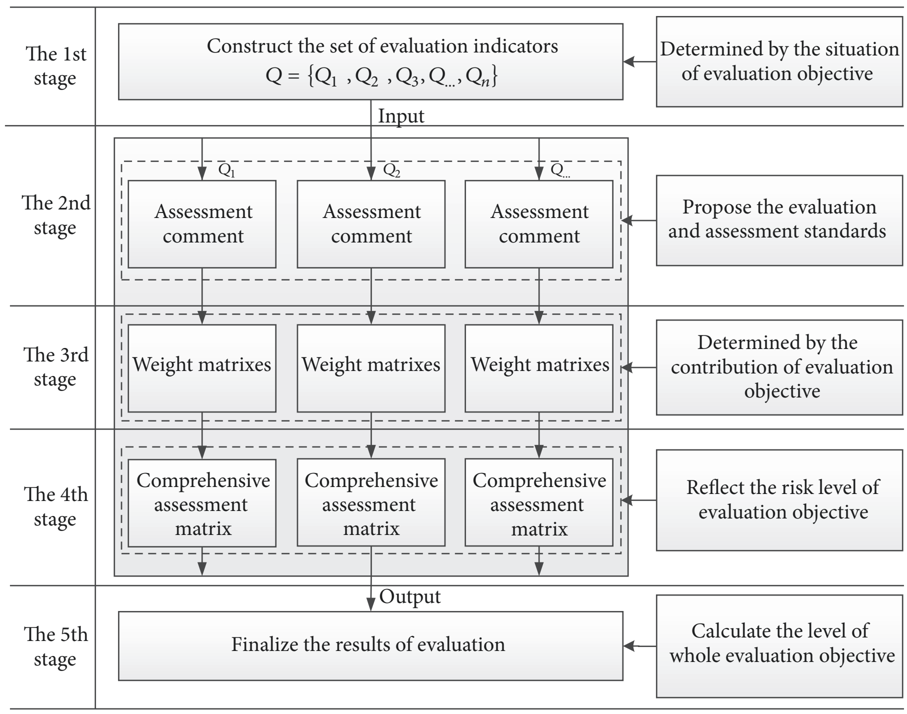

Figure 1: The application stage of FCEM.

of five comments used to evaluate the food quality risk level according to the criterion of the FCEM, shown as follows:

$$\mathscr{L} = \{\ell_1, \ell_2, \ell_3, \ell_4, \ell_5\}, \quad (2)$$

where $\mathscr{L}$ is the food quality risk assessment comment set and ℓ_1, ℓ_2, ℓ_3, ℓ_4, and ℓ_5 are the comments representing the food quality risk levels of "Terrible," "Unacceptable," "Fair," "Acceptable," and "Desirable." These levels are represented by scores of 1, 2, 3, 4, and 5. The risk assessment comment set $\mathscr{L}$ can be expressed as follows:

$$\mathscr{L} = \{1, 2, 3, 4, 5\}. \quad (3)$$

According to this criterion, the fuzzy comprehensive evaluation matrixes R and R_i $(i = 1, 2, \ldots, n)$ can be determined by

$$R_i = \begin{Bmatrix} r_{i11} & r_{i12} & r_{i13} & r_{i14} & r_{i15} \\ r_{i21} & r_{i22} & r_{i23} & r_{i24} & r_{i25} \\ r_{i31} & r_{i32} & r_{i33} & r_{i34} & r_{i35} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{im1} & r_{im2} & r_{im3} & r_{im4} & r_{im5} \end{Bmatrix}, \quad (4)$$

where $R = \{R_1, R, \ldots, R_i\}$ and R_i $(i = 1, 2, \ldots, n)$ are the fuzzy comprehensive evaluation matrixes of Q and Q_i. r_{imk} $(k = 1, 2, 3, 4, 5)$ is the comment level of Q_{im}.

In the third stage, determine the weight matrixes W and W_i'. Different elements in sets Q and Q_i provide different contributions to the level of food quality risk. Thus, the weights of these indicators are different. The assessment index weights vector can be determined by

$$\begin{gathered} W = \{W_1, W_2, \ldots, W_i, \ldots, W_n\} \quad (i = 1, 2, \ldots, n), \\ W_i' = \{W_{i1}', W_{i2}', \ldots, W_{ij}', \ldots, W_{im}'\} \quad (i = 1, 2, \ldots, n;\ 1 \le j \le m), \\ \sum_{i=1}^{n} W_i = 1, \\ \sum_{j=1}^{m} W_{ij}' = 1, \end{gathered} \quad (5)$$

where W and W_i' are the weight vectors of food quality risk evaluation objects and indicators. W_i and W_{im}' are the weights of Q_i and Q_{im}. The values of W_i and W_{im}' can be calculated by the method of FMECA.

In the fourth stage, establish the comprehensive assessment matrix V to reflect the food quality risk level of each evaluation objective by

$$V = \mathrm{W} \circ \mathrm{X}^T, \quad (6)$$

$$X = (X_1, X_2, \ldots, X_i), \quad (7)$$

$$X_i = W_i' \times R_i, \quad (8)$$

where V is the fuzzy comprehensive assessment matrix that can reflect the food quality risk level of the evaluation objective, X_i is the fuzzy comprehensive assessment matrix of Q_i, and X is the fuzzy comprehensive assessment matrix set.

Finally, finalize the FCEM. Recording the food quality risk level and each evaluation objective as Y and Y', combined with $\mathscr{L}$, V, and X_i, the values of Y and Y' can be calculated by

$$Y = \mathscr{L} \cdot V^T, \quad Y' = (Y_1, Y_2, \ldots, Y_i), \quad Y_i = \mathscr{L} \cdot X_i^T, \tag{9}$$

where Y and Y_i are the food quality risk levels of Q and Q_i. Y' is the set of Q_is' food quality risk levels. According to (9), the food quality risk levels of Q and Q_i can be obtained.

3.3. Determinants of the Weight Vectors Using FMECA. According to Section 3.2, when applying the FCEM to evaluate the food quality risk level, the weight of indicator is very important. Generally, the weights of indicators during the application of the FCEM are usually given based on the experience of various experts, which leads to the limitation of subjectivity. To reduce this subjectivity, this paper takes the FMECA as the method to determine the weight vectors of evaluation indicators.

FMECA is a safety and reliability analysis tool, which has been widely used for the identification of system/process potential failures, their causes, and consequences. This method focuses on "discussions before system failure" per the notion that "prevention is better than cure" [64]. FMECA provides an appropriate method to determine the weights of the elements depending on the occurrences of food quality risk parameters, their severity, the detection, and ability to control or compensate for the loss after a failure [64]. According to the FMECA, the weights of the indicators can be calculated by

$$W_i'' = \frac{O_i \times S_i \times D_i}{C_i}, \quad W_{ij}'' = \frac{O_{ij} \times S_{ij} \times D_{ij}}{C_{ij}}, \quad W_i = \frac{W_i''}{\sum_{i=1}^{n} W_i''}, \quad W_{ij} = \frac{W_{ij}''}{\sum_{j=1}^{m} W_{ij}''}, \tag{10}$$

where W_i'' is the cross-sectional area of the evaluation object Q_i and W_{ij}'' is the cross-sectional area of the evaluation indicator Q_{ij}. O_i is the occurrence probability of Q_i. S_i is the severity after the occurrence of Q_i. D_i is the likelihood of detection of Q_i, and C_i is the ability to control or compensate for the loss following the occurrence of Q_i. The values of O_i, S_i, D_i, and C_i can be obtained by the experts grading method (EGM), where $O_i \in [1,5]$, $S_i \in [1,5]$, $D_i \in [1,5]$, and $C_i \in [1,5]$. The principles of expert evaluation are shown as (11)–(14).

$$O_i = \begin{cases} 1 & \text{lowest probability} \\ 5 & \text{highest probability} \\ o_i & \text{otherwise,} \end{cases} \tag{11}$$

where $1 < o_i < 5$. The higher the value of o_i, the higher the probability of Q_i.

$$S_i = \begin{cases} 1 & \text{slightest severity} \\ 5 & \text{worst severity} \\ s_i & \text{otherwise,} \end{cases} \tag{12}$$

where $1 < s_i < 5$. The higher the value of s_i, the worse the severity after the occurrence of Q_i.

$$D_i = \begin{cases} 1 & \text{highest likelihood of detection} \\ 5 & \text{lowest likelihood of detection} \\ d_i & \text{otherwise,} \end{cases} \tag{13}$$

where $1 < d_i < 5$. The higher the value of d_i, the lower the likelihood of detection of Q_i.

$$C_i = \begin{cases} 1 & \text{most difficult to control or compensate for the loss} \\ 5 & \text{least difficult to control or compensate for the loss} \\ c_i & \text{otherwise,} \end{cases} \tag{14}$$

where $1 < c_i < 5$. The higher the value of h_i, the easier to control or compensate for the loss after the occurrence of Q_i.

According to (11)-(12), $W_i'' \in [0.2, 125]$and $W_{im}' \in [0.2, 125]$. Then, the weights of different elements W_i and W_{im} can be obtained after normalizing W_i'' and W_{im}' by (13)-(14).

4. Computational Experiment and Results

Henan is an important province of China, with a population of 107.22 million in 2017, accounting for 7.8% of China's total population. Thus, Henan plays an important role in China's food consumption. Food quality directly affects people's health and economic development; therefore, improving food quality and safety and making the food chain more ecofriendly are the development goals pursued by Henan Province. However, Henan is a large agricultural province; the food supply chain from farm to fork includes so many links such as raw material supply, production and processing, logistics, warehousing and transportation, and sales and consumption. In such a food supply chain, there are many risk factors that could affect the food quality level at each link. The probability of occurrences and the severity of each occurrence are uncertain; thus, identifying the risk factors and evaluating the risk level of each link in the food supply chain are the prerequisite for controlling the food quality.

This issue aligns with the problem addressed by the model proposed in this paper. Therefore, the food supply chain of the Henan Province (FSCHP) is taken as a computational experiment to introduce the process of food quality risk evaluation in order to verify the validity and effectiveness of the proposed model.

According to Table 1 and the process of risk evaluation described in Section 3.2, the risk evaluation indicator set of FSCHP Q can be constructed as shown in Table 2.

In Table 2, Q is the risk evaluation indicator set of FSCHP. n is the number of evaluation objects in Q, in which $n = 5$. Q_i ($i \in [1, n]$) is the ith evaluation object, Q_{ij} is the jth risk evaluation indicator of Q_i, and m is the number of risk evaluation indicators. As shown in Table 2, the number of FSCHP's risk evaluation indicators is

$$m = \begin{cases} 9, & i = 1 \\ 16, & i = 2 \\ 11, & i = 3 \\ 9, & i = 4 \\ 10, & i = 5. \end{cases} \quad (15)$$

According to the criterion of FCEM and (2), the risk assessment comment set of FSCHP $\mathscr{L}$ can be established, where $\mathscr{L} = \{\ell_1, \ell_2, \ell_3, \ell_4, \ell_5\} = \{1, 2, 3, 4, 5\}$. To aggregate the risk assessment comments of the FSCHP and establish the fuzzy comprehensive evaluation matrixes R and R_i ($i = 1, 2, \ldots, n$), a questionnaire survey was designed (shown as Appendix A). The objectives of this survey included five categories of respondents—farmers, food processing enterprises, logistics and warehousing enterprises, retailers and consumers, and government regulators—to ensure the accuracy of the survey results. A total of 1000 questionnaires were issued, and 898 were returned, which included 22 unfinished and 27 identical questionnaires; these 49 questionnaires were considered invalid according to the statistical principles. Thus, 849 questionnaires were considered valid and completed questionnaires. The recovery rate and the valid questionnaire rate were 89.8% and 84.9%. Therefore, the results of this survey are robust and effective and thus can be used for further analyses.

According to the results of the assessment comments of the risk evaluation indicators, the fuzzy comprehensive evaluation matrixes of evaluation objects Q can be constructed. Here, this paper takes the evaluation object Q_2 (Q_2 was selected because the number of risk evaluation indicators of Q_2 is the highest) as an example to introduce the calculation process of the fuzzy comprehensive evaluation matrix R_2.

By analyzing the results of the survey questionnaires, the assessment comment of evaluation objective Q_2 can be obtained, as shown in Table 3.

In Table 3, the level of comment of risk evaluation indicator Q_{im} can be calculated by $r_{imk} = \text{Frequency}(Q_{imp_\alpha}) / \sum_{\alpha=1}^{5} \text{Frequency}(Q_{imp_\alpha})$, where $\text{Frequency}(Q_{imp_\alpha})$ is the number of times that the objectives of this questionnaire survey scored Q_{im} as p_α (α = 1, 2, 3, 4 or 5). Then, the fuzzy comprehensive evaluation matrix R_2 can be established as follows:

$$R_2 = \begin{bmatrix} r_{211} & r_{212} & \cdots & r_{215} \\ r_{221} & r_{222} & \cdots & r_{225} \\ r_{231} & r_{232} & \cdots & r_{235} \\ \cdots & \cdots & \cdots & \cdots \\ r_{2m1} & r_{2m2} & \cdots & r_{2m5} \end{bmatrix}$$
$$= \begin{bmatrix} 0.065 & 0.225 & 0.337 & 0.273 & 0.100 \\ 0.094 & 0.243 & 0.360 & 0.235 & 0.069 \\ 0.096 & 0.283 & 0.382 & 0.168 & 0.071 \\ 0.085 & 0.232 & 0.342 & 0.255 & 0.087 \\ 0.047 & 0.200 & 0.306 & 0.284 & 0.163 \\ 0.045 & 0.236 & 0.335 & 0.266 & 0.118 \\ 0.065 & 0.232 & 0.349 & 0.268 & 0.087 \\ 0.071 & 0.245 & 0.357 & 0.259 & 0.067 \\ 0.067 & 0.236 & 0.333 & 0.277 & 0.087 \\ 0.087 & 0.272 & 0.362 & 0.233 & 0.047 \\ 0.243 & 0.312 & 0.275 & 0.126 & 0.045 \\ 0.249 & 0.298 & 0.268 & 0.135 & 0.049 \\ 0.174 & 0.229 & 0.340 & 0.168 & 0.089 \\ 0.176 & 0.285 & 0.284 & 0.182 & 0.073 \\ 0.185 & 0.236 & 0.280 & 0.199 & 0.100 \\ 0.214 & 0.241 & 0.355 & 0.108 & 0.082 \end{bmatrix}. \quad (16)$$

Similarly, the fuzzy comprehensive evaluation matrix of the other evaluation objects R_1, R_3, R_4, and R_5 can be established as follows:

$$R_1 = \begin{bmatrix} 0.056 & 0.225 & 0.346 & 0.224 & 0.149 \\ 0.232 & 0.310 & 0.275 & 0.088 & 0.096 \\ 0.122 & 0.283 & 0.384 & 0.090 & 0.120 \\ 0.241 & 0.310 & 0.277 & 0.079 & 0.094 \\ 0.220 & 0.289 & 0.317 & 0.077 & 0.098 \\ 0.065 & 0.236 & 0.344 & 0.215 & 0.140 \\ 0.118 & 0.274 & 0.386 & 0.095 & 0.127 \\ 0.038 & 0.238 & 0.360 & 0.217 & 0.147 \\ 0.053 & 0.205 & 0.271 & 0.277 & 0.194 \end{bmatrix},$$

Table 2: Risk evaluation indicator set of FSCHP Q.

Evaluation object Q_i	Risk evaluation indicators Q_{ij}	
Raw material supply risk Q_1	Soil pollution Q_{11}	Air pollution Q_{12}
	Water pollution Q_{13}	Heavy metal pollution Q_{14}
	Illegal use of additives Q_{15}	Residual inputs Q_{16}
	Microbial contamination Q_{17}	Pathogenic bacteria pollution Q_{18}
	Transgenic technology risk Q_{19}	
Production and processing risk Q_2	Illegal use of additives Q_{21}	Contamination with foreign matter Q_{22}
	Inability to wash a food product clean Q_{23}	Presence of detergent residue Q_{24}
	Pathogen contamination Q_{25}	Microbial contamination Q_{26}
	Uncertified processing equipment Q_{27}	Nonstandardized processing personnel operation Q_{28}
	Insufficient processing environment Q_{29}	Insufficient processing equipment Q_{210}
	Inappropriate packaging Q_{211}	Insufficient packaging quality Q_{212}
	Uncertified packaging logo Q_{213}	Insufficient assurance of personnel health Q_{214}
	Quality inspection risk Q_{215}	Insufficient storage process Q_{216}
Logistics, warehousing, and transportation risk Q_3	Inventory control technology Q_{31}	Intelligent temperature-control facilities Q_{32}
	Transport vehicle sanitation Q_{33}	Cold chain hardware supporting facilities Q_{34}
	Third-party logistics level Q_{35}	Partner technology platform convergence Q_{36}
	Product portfolio storage transport Q_{37}	Cold chain logistics information transmission Q_{38}
	Logistics road infrastructure Q_{39}	Illegal operation of logistics transport personnel Q_{310}
	Vehicle scheduling and monitoring information feedback Q_{311}	
Sales and consumption risk Q_4	Selling expired food Q_{41}	Falsifying the date of production Q_{42}
	False reporting of food ingredients Q_{43}	Poor sanitation in dining establishments Q_{44}
	Poor sanitation conditions Q_{45}	Improper disposal of waste food Q_{46}
	Poor sanitation in cooking facilities Q_{47}	Improper eating methods Q_{48}
	Insufficient storage environment Q_{49}	
Government regulatory risk Q_5	Imperfect regulatory system Q_{51}	Supervisory staff level Q_{52}
	Supervisor moral hazard Q_{53}	Supervision channels Q_{54}
	Regulatory organization Q_{55}	Regulatory agency efficiency Q_{56}
	Regulatory process management Q_{57}	Regulatory results feedback Q_{58}
	Regulatory detection technology Q_{59}	Other risks Q_{510}

Table 3: Assessment comment of evaluation objective Q_2.

Risk evaluation indicators	Frequency	Comment	P_1	P_2	P_3	P_4	P_5
Production and processing risk Q_2							
Illegal use of additives Q_{21}			58	202	303	245	90
Contamination with foreign matter Q_{22}			84	218	323	211	62
Inability to wash a food product clean Q_{23}			86	254	343	151	64
Presence of detergent residue Q_{24}			76	208	307	229	78
Pathogen contamination Q_{25}			42	180	275	255	146
Microbial contamination Q_{26}			40	212	301	239	106
Uncertified processing equipment Q_{27}			58	208	313	241	78
Nonstandardized processing personnel operation Q_{28}			64	220	321	233	60
Insufficient processing environment Q_{29}			60	212	299	249	78
Insufficient processing equipment Q_{210}			78	244	325	209	42
Inappropriate packaging Q_{211}			218	280	247	113	40
Insufficient packaging quality Q_{212}			224	268	241	121	44
Uncertified packaging logo Q_{213}			156	206	305	151	80
Insufficient assurance of personnel health Q_{214}			158	256	255	163	66
Quality inspection risk Q_{215}			166	212	251	179	90
Insufficient storage process Q_{216}			192	216	319	97	74

$$R_3 = \begin{bmatrix} 0.105 & 0.134 & 0.311 & 0.253 & 0.198 \\ 0.114 & 0.220 & 0.324 & 0.190 & 0.151 \\ 0.067 & 0.176 & 0.237 & 0.313 & 0.207 \\ 0.127 & 0.247 & 0.322 & 0.175 & 0.129 \\ 0.120 & 0.23 & 0.326 & 0.186 & 0.145 \\ 0.116 & 0.227 & 0.326 & 0.175 & 0.156 \\ 0.176 & 0.247 & 0.297 & 0.146 & 0.134 \\ 0.096 & 0.209 & 0.317 & 0.210 & 0.167 \\ 0.105 & 0.209 & 0.322 & 0.202 & 0.163 \\ 0.203 & 0.256 & 0.239 & 0.170 & 0.131 \\ 0.038 & 0.238 & 0.360 & 0.219 & 0.145 \end{bmatrix},$$

$$R_4 = \begin{bmatrix} 0.067 & 0.232 & 0.358 & 0.268 & 0.080 \\ 0.047 & 0.203 & 0.306 & 0.284 & 0.160 \\ 0.076 & 0.234 & 0.342 & 0.262 & 0.087 \\ 0.145 & 0.321 & 0.291 & 0.175 & 0.069 \\ 0.071 & 0.243 & 0.367 & 0.259 & 0.069 \\ 0.069 & 0.238 & 0.329 & 0.277 & 0.087 \\ 0.040 & 0.214 & 0.362 & 0.280 & 0.105 \\ 0.042 & 0.225 & 0.335 & 0.277 & 0.120 \\ 0.022 & 0.194 & 0.268 & 0.326 & 0.189 \end{bmatrix},$$

$$R_5 = \begin{bmatrix} 0.062 & 0.236 & 0.346 & 0.271 & 0.085 \\ 0.151 & 0.261 & 0.353 & 0.168 & 0.067 \\ 0.069 & 0.234 & 0.331 & 0.280 & 0.087 \\ 0.049 & 0.176 & 0.373 & 0.326 & 0.076 \\ 0.145 & 0.292 & 0.277 & 0.222 & 0.065 \\ 0.047 & 0.241 & 0.360 & 0.206 & 0.147 \\ 0.045 & 0.243 & 0.369 & 0.188 & 0.156 \\ 0.120 & 0.272 & 0.389 & 0.092 & 0.127 \\ 0.116 & 0.267 & 0.391 & 0.092 & 0.134 \\ 0.045 & 0.216 & 0.355 & 0.235 & 0.149 \end{bmatrix}. \quad (17)$$

Weight vectors are very important in determining the food quality risk level and can be calculated by FMECA according to Section 3.3. To calculate the weights of evaluation objects and risk indicators, five experts on food quality risk management were invited to score the values of O_i, S_i, D_i, and C_i with the principles of (11)–(14) (the scoring table is shown in Appendix B). The scoring results of the evaluation objects are shown in Table 4. Taking the average as the final score, the weights of evaluation objects W_i can be obtained according to (10):

$$W = [W_1, W_2, W_3, W_4, W_5] = [0.0925, 0.191, 0.243, 0.284, 0.190]. \quad (18)$$

Similarly, the weights of risk evaluation indicator W_i' can be calculated:

$$W_1' = \left[W_{11}', \ldots, W_{19}'\right] = [0.119, 0.143, 0.106, 0.104, 0.180, 0.060, 0.136, 0.092, 0.060],$$
$$W_2' = \begin{bmatrix} W_{21}', \ldots, W_{28}', \\ W_{29}', \ldots, W_{216}' \end{bmatrix} = \begin{bmatrix} 0.050, 0.133, 0.158, 0.033, 0.041, 0.027, 0.052, 0.055, \\ 0.031, 0.037, 0.075, 0.035, 0.065, 0.063, 0.042, 0.102 \end{bmatrix},$$
$$W_3' = \left[W_{31}', \ldots, W_{311}'\right] = [0.044, 0.089, 0.049, 0.086, 0.165, 0.186, 0.063, 0.177, 0.055, 0.025, 0.059], \quad (19)$$
$$W_4' = \left[W_{41}', \ldots, W_{412}'\right] = [0.152, 0.085, 0.055, 0.184, 0.162, 0.086, 0.054, 0.065, 0.156],$$
$$W_5' = \left[W_{51}', \ldots, W_{510}'\right] = [0.124, 0.149, 0.090, 0.078, 0.053, 0.123, 0.048, 0.148, 0.104, 0.083].$$

According to (8), the fuzzy comprehensive assessment matrix of evaluation objects can be calculated:

$$X_1 = [0.144, 0.271, 0.330, 0.133, 0.122],$$
$$X_2 = [0.128, 0.255, 0.338, 0.200, 0.079],$$
$$X_3 = [0.112, 0.219, 0.317, 0.197, 0.155], \quad (20)$$
$$X_4 = [0.071, 0.241, 0.322, 0.262, 0.105],$$
$$X_5 = [0.089, 0.246, 0.359, 0.198, 0.108].$$

According to (6)-(7), the fuzzy comprehensive assessment matrix V can be established:

$$V = W \circ X^T = W \circ \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \end{bmatrix}$$
$$= \begin{bmatrix} 0.0925 & 0.191 & 0.243 & 0.284 & 0.190 \end{bmatrix} \quad (21)$$
$$\circ \begin{bmatrix} 0.144 & 0.271 & 0.330 & 0.133 & 0.122 \\ 0.128 & 0.255 & 0.338 & 0.200 & 0.079 \\ 0.112 & 0.219 & 0.317 & 0.197 & 0.155 \\ 0.071 & 0.241 & 0.322 & 0.262 & 0.105 \\ 0.089 & 0.246 & 0.359 & 0.198 & 0.108 \end{bmatrix}$$
$$= \begin{bmatrix} 0.206 & 0.214 & 0.215 & 0.225 & 0.219 \end{bmatrix}.$$

According to (9), the level of FSCHP's food quality risk Y and the level of evaluation objects Y_i can be calculated:

$$Y = \mathscr{L} \cdot V^T = \begin{bmatrix} 1 & 2 & 3 & 4 & 5 \end{bmatrix} \cdot \begin{bmatrix} 0.206 \\ 0.214 \\ 0.215 \\ 0.225 \\ 0.219 \end{bmatrix} = 3.273,$$
$$Y_1 = \mathscr{L} \cdot {X_1}^T = \begin{bmatrix} 1 & 2 & 3 & 4 & 5 \end{bmatrix} \cdot \begin{bmatrix} 0.144 \\ 0.271 \\ 0.330 \\ 0.133 \\ 0.122 \end{bmatrix} = 2.819, \quad (22)$$
$$Y_2 = 2.847,$$
$$Y_3 = 3.065,$$
$$Y_4 = 3.089,$$
$$Y_5 = 2.990.$$

The food quality risk levels of evaluation objects are shown in Figure 2.

According to the calculation results, the risk level of FSCHP's food quality Y is 3.273. This means that the risk level of FSCHP is much higher than the average level of risk comments of 2.5, more than 30.29%; it indicates that the risk level of FSCHP's food quality is relatively higher and requires scientific management in the process of supply chain management.

In Figure 2, the value of FSCHP's food quality risk assessment in descending order is sales and consumption risk Q_4; logistics, warehousing, and transportation risk Q_3; government regulatory risk Q_5; production and processing risk Q_2; raw material supply risk Q_1. Comparing the calculation results, the conclusion that the risk levels of sales and consumption risk Q_4 and logistics, warehousing and transportation risk Q_3, which are similar and equal to 3.09 and 3.06, are the highest two of the risk evaluation of FSCHP could be obtained. Meanwhile, the values of other indictors in FSCHP's quality risk Q_5, Q_2, and Q_1 which are equal to 2.99, 2.85, and 2.82 can be also obtained; these values are 3.25%,

Table 4: Values of O_i, S_i, D_i, and C_i scored by five experts.

Q		Scored by 1st expert					Scored by 2nd expert					Scored by 3rd expert					Scored by 4th expert					Scored by 5th expert					Average
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
	O				√				√						√				√					√			
	S			√						√					√					√				√			
Q_1	D	√					√							√				√					√				
	C				√					√					√						√			√			
	W_1''			3					3					12					2.4					6			5.28
	O			√							√				√				√				√				
	S					√			√						√					√						√	
Q_2	D		√					√						√				√						√			
	C				√			√							√				√					√			
	W_2''			7.5					15					12					10					10			10.90
	O				√					√		√							√						√		
	S			√						√					√					√				√			
Q_3	D		√								√					√		√					√				
	C				√				√					√			√						√				
	W_3''			6					26.67					6.67					6					24			13.87
	O		√						√							√			√					√			
	S				√					√				√							√				√		
Q_4	D					√					√		√							√					√		
	C				√				√				√						√					√			
	W_4''			10					20					15					20					16			16.20
	O		√							√		√								√				√			
	S				√						√				√			√								√	
Q_5	D					√			√							√					√		√				
	C				√				√					√						√					√		
	W_5''			10					20					6.67					10					7.5			10.83

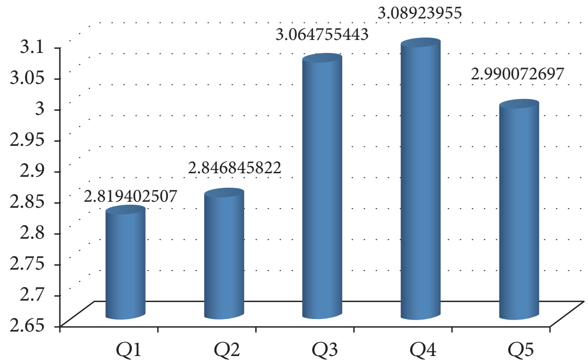

Figure 2: Food quality risk levels of evaluation objects.

7.77%, and 8.74% lower than the highest evaluation object Q_4. Analyzing this phenomenon, we can find that the reason why the risk levels of sales and consumption risk and the logistics, warehousing, and transportation risk are the highest is because there are too many uncontrollable factors such as cold chain hardware supporting facilities, cold chain logistics information transmission, poor sanitation in cooking facilities, and poor sanitation in dining establishments existing in these management processes, and the standard of them is missing or implemented poorly or supervised poorly. The results are consistent with the actual situation of the FSCHP. Therefore, if managers want to control the food quality risk of the FSCHP effectively, sales and consumption and the logistics, warehousing, and transportation are the key factors that should be addressed first. What is more, seen from Figure 2, we can find that the raw material supply risk Q_1 in FSCHP is the lowest, which is because Henan is one of the largest agricultural provinces in China, and in order to improve the food quality, the standardized food cultivation model has been promoted and accepted by all farmers, which makes a great contribution to achieving the goal of controlling the food quality from its source [65].

Through the statistical analysis of the existing literature, it can be found that a lot of studies have been carried out to explore food quality in the food supply chain, such as Fearne, Hornibrook, and Dedman who conducted two exploratory case studies of retailer-led quality assurance schemes (QAS) for beef in Germany and Italy and found that QAS have the potential to reduce perceived risk and increase consumer confidence in specific fresh beef products [66]; Ting et al. took the quality sustainability in the food supply chain as research object and proposed a supply chain quality sustainability decision support system to support managers in food manufacturing firms to define good logistics plans in order to maintain the quality and safety of food products [67]; Chen et al. presented a mutually supporting analytical model and exploratory case to study the managerial and policy issues related to quality control in food supply chain management with a focus on the Chinese dairy industry and discussed numbers of important managerial and policy insights and implications in managing the global food supply chain quality and risk [68]. These studies and findings have already provided a valid reference for controlling the food quality in the supply chain food; however, many of them are focused on the quality or risk control in a single link [66, 67] or some independent aspects [68] in the food supply chain, which could only provide a basis for the quality and risk management of the single or independent aspect not the whole food supply chain. Compared with these literatures, the evaluation model proposed in our paper based on the FCEM and FMECA can be used as a general guideline to assess the quality risk level of the food supply chain as a whole by the integration of all links in the food supply chain; what is more, it can achieve the most important objective by measuring and sorting the risk level of different links. These superiorities, which could be obtained by comparing with other methods, not only could reflect the potential in evaluating the quality and risk level in food supply chain but also could make up the gap between the traditional food risk evaluation from the aspect of single or independent link and the modern food risk evaluation from the aspect of the whole food supply chain and provide a reference for the public and private sectors when making decisions on food quality management.

5. Conclusion

The food industry in China is facing various challenges, including but not limited to reducing food waste, improving food quality and safety, and becoming more ecofriendly. To address these challenges and improve the food quality, it is critical to implement efficient and effective quality and operations management measures by identifying food quality risk factors and evaluating the risk levels of each link in the food supply chain. This study adopted a comprehensive approach to establish a fuzzy evaluation model for food quality risk evaluation. Through an extensive literature review, a quality risk indicator system for the food supply chain covering five evaluation objectives and 55 quality risk evaluation indicators was built to provide a basis for evaluating the food quality risk level. Then, the methods of FCEM and FMECA were applied based on surveys of experts to evaluate the food quality risk level. The results of a computational experiment suggest that this approach is reasonable for evaluating the food quality risk level.

The resulting quality risk evaluation model of the food supply chain can be used as a general guideline to highlight the most important objectives regarding the level of food quality risk evaluation according to the results of the computational experiment. Furthermore, the evaluation model provides a useful foundation for future case analyses. The government agencies responsible for food quality in supply chain management may adopt this model to assess the food quality risk level of each region. A food industry sector might also apply this model to review the strengths and weaknesses of its current food quality risk management so that better quality management plans could be developed for the food supply chain. In addition, compared with other provinces, it is clear that the food quality risk levels of the same objects, such as sales and consumption risk and logistics, warehousing, and transportation risk, are different due to the differences in cold chain logistics technology and eating habits. This finding

Table 5

Indicators	Assessment comments	Level of food quality risk indicators				
		1	2	3	4	5
Raw material supply risk Q_1						
Soil pollution Q_{11}						
Air pollution Q_{12}						
Water pollution Q_{13}						
Heavy metal pollution Q_{14}						
Illegal use of additives Q_{15}						
Residual inputs Q_{16}						
Microbial contamination Q_{17}						
Pathogenic bacteria pollution Q_{18}						
Transgenic technology risk Q_{19}						
Production and processing risk Q_2						
Illegal use of additives Q_{21}						
Contamination with foreign matter Q_{22}						
Inability to wash a food product clean Q_{23}						
Presence of detergent residue Q_{24}						
Pathogen contamination Q_{25}						
Microbial contamination Q_{26}						
Uncertified processing equipment Q_{27}						
Nonstandardized processing personnel operation Q_{28}						
Insufficient processing environment Q_{29}						
Insufficient processing equipment Q_{210}						
Inappropriate packaging Q_{211}						
Insufficient packaging quality Q_{212}						
Uncertified packaging logo Q_{213}						
Insufficient assurance of personnel health Q_{214}						
Quality inspection risk Q_{215}						
Insufficient storage process Q_{216}						
Logistics, warehousing, and transportation risk Q_3						
Inventory control technology Q_{31}						
Intelligent temperature-control facilities Q_{32}						
Transport vehicle sanitation Q_{33}						
Cold chain hardware supporting facilities Q_{34}						
Third-party logistics level Q_{35}						
Partner technology platform convergence Q_{36}						
Product portfolio storage transport Q_{37}						
Cold chain logistics information transmission Q_{38}						
Logistics road infrastructure Q_{39}						
Illegal operation of logistics transport personnel Q_{310}						
Vehicle scheduling and monitoring information feedback Q_{311}						
Sales and consumption risk Q_4						
Selling expired food Q_{41}						
Falsifying the date of production Q_{42}						
False reporting of food ingredients Q_{43}						
Poor sanitation in dining establishments Q_{44}						
Poor sanitation conditions Q_{45}						
Improper disposal of waste food Q_{46}						
Poor sanitation in cooking facilities Q_{47}						
Improper eating methods Q_{48}						
Insufficient storage environment Q_{49}						

Table 5: Continued.

Indicators	Assessment comments	Level of food quality risk indicators				
		1	2	3	4	5
Government regulatory risk Q_5						
Imperfect regulatory system Q_{51}						
Supervisory staff level Q_{52}						
Supervisor moral hazard Q_{53}						
Supervision channels Q_{54}						
Regulatory organization Q_{55}						
Regulatory agency efficiency Q_{56}						
Regulatory process management Q_{57}						
Regulatory results feedback Q_{58}						
Regulatory detection technology Q_{59}						
Other risks Q_{510}						
Imperfect regulatory system Q_{51}						
Supervisory staff level Q_{52}						

shows that the food quality risk level is relative, requiring managers to take the actual situation into account when making decisions on food quality risk management.

There may be two limitations in this study. First, systematic deficiencies of the risk evaluation indicator system may exist because the potential negative interactions among indicators were not taken into account, which might affect the validity of the evaluation results. Second, the effectiveness of this proposed model was verified by a computational experiment. However, the selected case to be implemented was consistent for only the problem of food quality risk evaluation. Thus, the results of the computational experiment may not be generalizable. Future research should address these limitations.

Appendix

A. A Sample of Survey Questionnaire

A.1. Basic Information

(1) Gender:

- □ male
- □ female

(2) Age:

- □ 20–29
- □ 30–39
- □ 40–49
- □ 50 or more

(3) Length of service:

- □ Within 1 year
- □ 1–5 years
- □ 6–10 years
- □ 11–20 years
- □ 20 years or more

(4) Your duties:

(5) Department:

(6) Nature of your department:

- □ Farmer
- □ Food processing enterprise
- □ Logistics warehousing enterprise
- □ Retailer and consumer
- □ Government regulator
- □ other

A.2. Assessment Comments of FSCHP's Food Quality Risk Indicators. See Table 5.

B. A Sample of Expert Scoring Table

See Table 6.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Acknowledgments

This study is sponsored by the National Natural Science Foundation of China (no. 51708039), Ministry of Education Humanities and Social Sciences Fund (nos. 17XJC630001 and 17YJCZH125), Soft Science Foundation of Shaanxi Province (no. 2017KRM123), and Social Science Planning Fund of

Table 6

Factors	Scoring																			
	Occurrence probability (H)					Severity after occurrence (S)					Likelihood of detection (D)					Ability to control and compensate (C)				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Raw material supply risk Q_1																				
Soil pollution Q_{11}																				
Air pollution Q_{12}																				
Water pollution Q_{13}																				
Heavy metal pollution Q_{14}																				
Illegal use of additives Q_{15}																				
Residual inputs Q_{16}																				
Microbial contamination Q_{17}																				
Pathogenic bacteria pollution Q_{18}																				
Transgenic technology risk Q_{19}																				
Production and processing risk Q_2																				
Illegal use of additives Q_{21}																				
Contamination with foreign matter Q_{22}																				
Inability to wash a food product clean Q_{23}																				
Presence of detergent residue Q_{24}																				
Pathogen contamination Q_{25}																				
Microbial contamination Q_{26}																				
Uncertified processing equipment Q_{27}																				
Nonstandardized processing personnel operation Q_{28}																				
Insufficient processing environment Q_{29}																				
Insufficient processing equipment Q_{210}																				
Inappropriate packaging Q_{211}																				
Insufficient packaging quality Q_{212}																				
Uncertified packaging logo Q_{213}																				
Insufficient assurance of personnel health Q_{214}																				
Quality inspection risk Q_{215}																				
Insufficient storage process Q_{216}																				

Table 6: Continued.

Factors	Scoring																			
	Occurrence probability (H)					Severity after occurrence (S)					Likelihood of detection (D)					Ability to control and compensate (C)				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Logistics, warehousing, and transportation risk Q_3																				
Inventory control technology Q_{31}																				
Intelligent temperature-control facilities Q_{32}																				
Transport vehicle sanitation Q_{33}																				
Cold chain hardware supporting facilities Q_{34}																				
Third-party logistics level Q_{35}																				
Partner technology platform convergence Q_{36}																				
Product portfolio storage transport Q_{37}																				
Cold chain logistics information transmission Q_{38}																				
Logistics road infrastructure Q_{39}																				
Illegal operation of logistics transport personnel Q_{310}																				
Vehicle scheduling and monitoring information feedback Q_{311}																				
Sales and consumption risk Q_4																				
Selling expired food Q_{41}																				
Falsifying the date of production Q_{42}																				
False reporting of food ingredients Q_{43}																				
Poor sanitation in dining establishments Q_{44}																				
Poor sanitation conditions Q_{45}																				
Improper disposal of waste food Q_{46}																				
Poor sanitation in cooking facilities Q_{47}																				
Improper eating methods Q_{48}																				
Insufficient storage environment Q_{49}																				
Government regulatory risk Q_5																				
Imperfect regulatory system Q_{51}																				
Supervisory staff level Q_{52}																				
Supervisor moral hazard Q_{53}																				
Supervision channels Q_{54}																				
Regulatory organization Q_{55}																				
Regulatory agency efficiency Q_{56}																				
Regulatory process management Q_{57}																				
Regulatory results feedback Q_{58}																				
Regulatory detection technology Q_{59}																				
Other risks Q_{510}																				

Shaanxi Province (nos. 2017S028 and 2016R026). The managers who participated in this study are also greatly appreciated for giving their time and sharing their experiences.

References

[1] T. Chen, L. Wang, and J. Wang, "Transparent assessment of the supervision information in china's food safety: a fuzzy-anp comprehensive evaluation method," *Journal of Food Quality*, vol. 2017, Article ID 4340869, 14 pages, 2017.

[2] P. Pinstrupandersen, "Food security: definition and measurement," *Food Security*, vol. 1, no. 1, pp. 5–7, 2009.

[3] Food security: Policy brief, FAO's Agriculture and Development Economics Division, Rome: Author, FAO, 2006.

[4] R. H. Abiyev, K. Uyar, U. Ilhan et al., "Assessment of food security risk level using type 2 fuzzy system," *Procedia Computer Science*, vol. 102, pp. 547–554, 2016.

[5] X. J. Chen, "An analytical framework and supervision system for chinese government to protect food quality and safety," *Journal of Nanjing Normal University*, vol. 1, pp. 29–36, 2011.

[6] L. J. Hubbard and C. Hubbard, "Food security in the United Kingdom: external supply risks," *Food Policy*, vol. 43, pp. 142–147, 2013.

[7] T. Gomiero, "Food quality assessment in organic vs. conventional agricultural produce: findings and issues," *Applied Soil Ecology*, 2017.

[8] L. Ludikhuyze, A. Van Loey, I. S. Denys, and M. Hendrickx, *Effects of High Pressure on Enzymes Related to Food Quality: From Kinetics to Process Engineering*, Kluwer Academic/plenum Publishers, New York, NY, USA, 2002.

[9] Z.-H. Ding, J.-T. Li, and B. Feng, "Radio frequency identification in food supervision," in *Proceedings of the 9th International Conference on Advanced Communication Technology, ICACT '07*, pp. 542–545, IEEE, Okamoto, Kobe, Japan, 2007.

[10] R. Wendyvan and F. Lynnj, "Consumer perceptions of food quality and safety and their relation to traceability," *British Food Journal*, vol. 110, no. 10, pp. 1034–1046, 2008.

[11] A. V. Cardello, "Food quality: relativity, context and consumer expectations," *Food Quality and Preference*, vol. 6, no. 3, pp. 163–170, 1995.

[12] M. K. A. Kadir, E. Hines, K. Qaddoum et al., "Food security risk level assessment: a fuzzy logic-based approach," *Applied Artificial Intelligence*, vol. 27, no. 1, pp. 50–61, 2013.

[13] S. Zhao and X. Yang, "Food safety risk assessment in whole food supply chain based on catastrophe model," *Advance Journal of Food Science and Technology*, vol. 5, no. 12, pp. 1557–1560, 2013.

[14] P. J. A. Chavez and C. Seow, "Managing food quality risk in global supply chain: a risk management framework," *International Journal of Engineering Business Management*, vol. 4, no. 1, 2012.

[15] X. J. Wang, D. Li, and X. L. Shi, "A fuzzy model for aggregative food safety risk assessment in food supply chains," *Production Planning and Control*, vol. 23, no. 5, pp. 377–395, 2012.

[16] J. Wang, T. Chen, and J. Wang, "Research on cooperation strategy of enterprises' quality and safety in food supply chain," *Discrete Dynamics in Nature and Society*, vol. 2015, Article ID 301245, 15 pages, 2015.

[17] F. Jie, K. Barton, and K. Wang, "Food quality as a supply chain performance indicator for Australian cattle producers," in *Proceedings of the 10th International Research Conference on Quality, Innovation and Knowledge (QIK)*, pp. 202–208, Monash University, Melbourne, Australia, 2011.

[18] A. Turi, G. Goncalves, and M. Mocan, "Challenges and competitiveness indicators for the sustainable development of the supply chain in food industry," *Procedia - Social and Behavioral Sciences*, vol. 124, pp. 133–141, 2014.

[19] H. Nilsson, H. J. Trienekens, and S. W. F. Omta, "Total quality indicators for the food production chain: is there a need for more labelling?" 2002.

[20] A. Salvo, G. T. La, V. Mangano et al., "Toxic inorganic pollutants in foods from agricultural producing areas of Southern Italy: level and risk assessment," *Ecotoxicology and Environmental Safety*, vol. 148, pp. 114–124, 2017.

[21] X. Wang, D. Li, and X. Shi, "A fuzzy model for aggregative food safety risk assessment in food supply chains," *Production Planning and Control*, vol. 23, no. 5, pp. 377–395, 2012.

[22] L. A. Zadeh, "Fuzzy sets," *Information and Control*, vol. 8, no. 3, pp. 338–353, 1965.

[23] Q. Xie, J.-Q. Ni, and Z. Su, "Fuzzy comprehensive evaluation of multiple environmental factors for swine building assessment and control," *Journal of Hazardous Materials*, vol. 340, pp. 463–471, 2017.

[24] J. Cheng and J.-P. Tao, "Fuzzy comprehensive evaluation of drought vulnerability based on the analytic hierarchy process—an empirical study from Xiaogan City in Hubei Province," *Agriculture and Agricultural Science Procedia*, vol. 1, pp. 126–135, 2010.

[25] Y. Y. Chen, *Fuzzy Mathematics*, Huazhong University of Science and Technology Press, Wuhan, China, 1984.

[26] R. Zhu, Q. Liang, and H. Zhan, "Analysis of aero-engine performance and selection based on fuzzy comprehensive evaluation," *Procedia Engineering*, vol. 174, pp. 1202–1207, 2017.

[27] A. Yazdani, S. Shariati, and A. Yazdani-Chamzini, "A risk assessment model based on fuzzy logic for electricity distribution system asset management," *Decision Science Letters*, vol. 3, no. 3, pp. 343–352, 2014.

[28] Z. X. He, *Fuzzy Mathematics and Its Application*, Tianjin Science and Technology Publishing House, Tianjin, China, 1983.

[29] W. Li, W. Liang, L. Zhang, and Q. Tang, "Performance assessment system of health, safety and environment based on experts' weights and fuzzy comprehensive evaluation," *Journal of Loss Prevention in the Process Industries*, vol. 35, pp. 95–103, 2015.

[30] J.-F. Chen, H.-N. Hsieh, and Q. H. Do, "Evaluating teaching performance based on fuzzy AHP and comprehensive evaluation approach," *Applied Soft Computing*, vol. 28, pp. 100–108, 2015.

[31] F. Deng, C. Wang, and X. Liang, "Fuzzy comprehensive evaluation model for flight safety evaluation research based on an empowerment combination," in *Proceedings of the 10th International Conference on Management Science and Engineering Management*, pp. 1479–1491, 2017.

[32] A. Afful-Dadzie, E. Afful-Dadzie, S. Nabareseh, and Z. K. Oplatková, "Tracking progress of African Peer Review Mechanism (APRM) using fuzzy comprehensive evaluation method," *Kybernetes*, vol. 43, no. 8, pp. 1193–1208, 2014.

[33] L. KrizOva, A. Vollmannova, E. Margitanova et al., "Can be blueberries the risk food and raw material?" *Journal of Microbiology Biotechnology and Food Sciences*, vol. 1, pp. 769–776, 2012.

[34] M.-H. Moncel, A.-M. Moigne, M. Arzarello, and C. Peretto, "Raw material supply areas and food supply areas: integrated approach of the behaviors," in *Proceedings of the XV World UISPP Congress*, 2007.

[35] A. Olsson and C. Skjoldebrand, "Risk management and quality assurance through the food Ssupply chain - case studies in the Swedish food industry," *The Open Food Science Journal*, vol. 2, no. 1, pp. 49–56, 2008.

[36] W. Huang and L. Chen, "Research on food safety and quality control process modeling and simulation based on the supply chain," *Journal of Convergence Information Technology*, vol. 8, no. 4, pp. 34–42, 2013.

[37] T. Matuszek, "Food production quality and risk assessment on machinery design," *Journal of Hygienic Engineering and Design*, 2012.

[38] H. Omura, K. Tanaka, and N. Sugimoto, "A hygienic hazard list for risk assessment of food processing machinery," *The journal of Reliability Engineering Association of Japan*, vol. 32, pp. 367–375, 2010.

[39] T. Matuszek, "Basic factors for food processing equipment hygienic design and its cleanabilities with minimal contamination risk," *Journal of Hygienic Engineering and Design*, pp. 38–45, 2014.

[40] X. U. Fucai and S. Meng, "Analysis on risk management of the food supply chain," in *Midwives, Research and Childbirth*, pp. 465–475, Springer, New York, NY, USA, 1989.

[41] L. I. U. Yongsheng and W. E. I. Xuan, "Food supply chain risk management situation evaluation model based on factor analysis," *International Business and Management*, vol. 12, no. 2, pp. 40–46, 2016.

[42] A. Marucheck, N. Greis, C. Mena, and L. Cai, "Product safety and security in the global supply chain: issues, challenges and research opportunities," *Journal of Operations Management*, vol. 29, no. 7-8, pp. 707–720, 2011.

[43] I. Vlachos and E. Dimitropoulos, "Supply chain management, 3rd party logistics and food quality and safety: evidence from Greece," in *Proceedings of the nternational Conference on Management in Agrifood Chains and Networks*, 2006.

[44] L. Xu, Q. Dong, and K. Xiao, "Research on early-warning model for food supply chain risk based on logistic regression," in *Proceedings of the 2010 International Conference on Logistics Engineering and Intelligent Transportation Systems, LEITS2010*, pp. 1–4, IEEE, Wuhan, China, 2010.

[45] L. Leger and D. Berkin, "Method for simulating and modeling the presence and growth of microbes, including pathogens and spoilage organisms, through a food supply chain," 2004.

[46] B. H. Susheela and L. M. Cathleen, "Factors affecting microbial load and profile of potential pathogens and food spoilage bacteria from household kitchen tables," *Canadian Journal of Infectious Diseases and Medical Microbiology*, vol. 2016, Article ID 3574149, 6 pages, 2016.

[47] R. M. W. Yeung and J. Morris, "Food safety risk: consumer perception and purchase behaviour," *British Food Journal*, vol. 103, no. 3, pp. 170–187, 2001.

[48] C. Hawkes, "Sales promotions and food consumptionnure," *Nutrition Reviews*, vol. 67, no. 6, pp. 333–342, 2009.

[49] R. Mo, W. Yeung, and Morris J., *Food Safety Risk: Consumer Food Purchase Models*, Cranfield University, Bedfordshire, UK, 2002.

[50] B. Bilska, M. Wrzosek, D. Kołozyn-Krajewska, and K. Krajewski, "Risk of food losses and potential of food recovery for social purposes," *Waste Management*, vol. 52, pp. 269–277, 2016.

[51] H. Wei, University B. W., Study on supermarket food safety risk management based on supply chain, Logistics Technology, 2013.

[52] X. Gellynck, W. Verbeke, J. Viaene et al., "Quality management in the food supply chain: how does the food industry interact with consumers, retailers and public authorities?" in *Proceedings of the Quality assurance, risk management and environmental control in agriculture and food supply networks: Proceedings of the 82nd Seminar of the European Association of Agricultural Economists (EAAE) held in Bonn*, 2003.

[53] V. Hill, "Government regulation of food quality: international and in france and the US," in *A Kaizen Approach to Food Safety*, pp. 53–82, Springer International Publishing, Berlin, Germany, 2014.

[54] B. F. V. Waarden, *Ttraditions, transactions, and trust: the public and private regulation of food*, Ansell, Richmond, Australia, 2005.

[55] D. K. Casey, "Three puzzles of private governance: global gap and the regulation of food safety and quality," *SSRN Electronic Journal*, 2009.

[56] V. Mceachern, A. Bungay, S. B. Ippolito et al., "4–Regulatory verification of safety and quality control systems in the food industry," *Auditing in the Food Industry*, vol. 73, no. 23, pp. 29–51, 2001.

[57] G. Skogstad, "Regulating food safety risks in the European Union:a comparative perspective," in *What's the Beef*, pp. 213–236, 2006.

[58] J. Zhou and S. Jin, "Overview of food safety management in China," in *Food Safety Management in China: A Perspective from Food Quality Control System*, pp. 1–32, 2015.

[59] S.-H. Wang, M.-T. Lee, P.-A. Château, and Y.-C. Chang, "Performance indicator framework for evaluation of sustainable tourism in the Taiwan coastal zone," *Sustainability*, vol. 8, no. 7, article 652, 2016.

[60] C. Deng, J. Liu, Y. Liu, and Z. Yu, "A fuzzy comprehensive evaluation for metropolitan power grid risk assessment," in *Proceedings of the 2016 International Conference on Smart Grid and Clean Energy Technologies, ICSGCE '16*, pp. 1–5, IEEE, Chengdu, China, 2016.

[61] J. An, "Evaluating the electric power utilities' risk based on an improved FCEM under the smart grid environment," in *Proceedings of the 2010 International Conference on Computer, Mechatronics, Control and Electronic Engineering*, pp. 468–471, IEEE, Changchun, China, 2010.

[62] L. Gong and C. Jin, "Fuzzy comprehensive evaluation for carrying capacity of regional water resources," *Water Resources Management*, vol. 23, no. 12, pp. 2505–2513, 2009.

[63] T. J. Dukes, B. M. Schmidt, and Y. Yu, "FMECA-based analyses: A SMART foundation," in *Proceedings of the 2017 Annual Reliability and Maintainability Symposium*, 2017.

[64] A. Certa, F. Hopps, R. Inghilleri, and C. M. La Fata, "A Dempster-Shafer Theory-based approach to the Failure Mode, Effects and Criticality Analysis (FMECA) under epistemic uncertainty: application to the propulsion system of a fishing vessel," *Reliability Engineering & System Safety*, vol. 159, pp. 69–79, 2017.

[65] J. M. Sun, M. l. Zhao, M. X. Zhang, and Y. H. Hu, "Investigation report on construction of quality and safety inspection system of agricultural products in Henan Province," *Journal of Henan Agriculture*, vol. 4, pp. 22-23, 2016.

[66] A. Fearne, S. Hornibrook, and S. Dedman, "The management of perceived risk in the food supply chain: a comparative study of retailer-led beef quality assurance schemes in Germany and Italy," *International Food and Agribusiness Management Review*, vol. 4, no. 1, pp. 19–36, 2009.

[67] S. L. Ting, Y. K. Tse, G. T. S. Ho, S. H. Chung, and G. Pang, "Mining logistics data to assure the quality in a sustainable food supply chain: a case in the red wine industry," *International Journal of Production Economics*, vol. 152, pp. 200–209, 2014.

[68] C. Chen, J. Zhang, and T. Delaurentis, "Quality control in food supply chain management: an analytical model and case study of the adulterated milk incident in China," *International Journal of Production Economics*, vol. 152, pp. 188–199, 2014.