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A Novel Two-Stage Integrated Model for Supplier Selection of Green Fresh Product

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Abstract: The selection of fresh product suppliers is a multi-criteria decision making (MCDM) problem with great significant and application value. This requires trade-offs between multiple criteria to prove its ambiguity and uncertainty. Therefore, a novel two-stage fuzzy integrated MCDM method to select suitable suppliers is employed. In the first stage, two collective relationship matrixes are constructed by quality function development (QFD), and relationships among customer requirements (CRs), company strategies (CSs) as well as selection criteria are considered separately in the two matrixes. Subjective criteria weights are obtained by fuzzy best-worst method (BWM) appropriately. In the second stage, the objective criteria weights are obtained using Shannon's entropy method, and the fuzzy multi-objective optimization by ratio analysis plus the full multiplicative form (MULTIMOORA) is applied to rank suppliers. Finally, an application case is applied to prove the feasibility of the proposed method. These conclusions can help companies improve their CSs and increase their market competitiveness.

Keywords: green supplier selection; trapezoidal fuzzy numbers (TrFNs); best-worst method (BWM); Shannon entropy; green product; green supplier

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1. Introduction

Under the highly competitive environment, as the research focus of the supply chain (SC), the supplier's selection relates to the cost control, response speed, product quality and efficiency of the entire SC, which in turn affects customer satisfaction and the overall competitiveness of SC. Choosing the suitable supplier can achieve a stable cooperation relationship with the supplier and significantly improve customer satisfaction. However, in the traditional meaning, the important purpose of supply chain management (SCM) is to reduce the cost of SC. Nowadays, as non-profit organizations, governments, and people increase their awareness of environmental protection, companies cannot ignore environment-related factors if they want to gain a foothold in the global competition. Based on this background, the concept of green supply chain management (GSCM) has emerged and been widely discussed by many scholars [1–3]. GSCM is a SCM method based on the concept of sustainable development and ecological protection [4–7], which focuses on providing high-quality and environmentally-friendly products and services. Selecting the appropriate green supplier is the basis and prerequisite for establishing a green SC, which is an inevitable choice for achieving sustainable development. In view of the uncertainties and information limitations of the GSCM, fuzzy methods are used to select suppliers [8]. At the same time, due to the existence of qualitative and quantitative evaluation criteria [9–11], it is very necessary to establish a suitable and highly flexible supplier selection method [12–15].

The government has successively introduced various laws and regulations, and put forward more stringent requirements for the production process of fresh product companies in order to guarantee the quality of fresh products. This requires that fresh product companies must actively improve the product quality management level and integrate GSCM into the entire fresh product supply process in order to truly realize the GSCM. Recently, in the research field of fresh product supply chains, only few researchers have focused on the supplier selection [16–21]. Therefore, a novel two-stage integrated fuzzy multi-criteria decision making (MCDM) method is proposed for the selection of green suppliers of fresh products. This method can consider the interrelationships between the supplier selection criteria. In practice, it can also help companies identify customer requirements (CRs) and recognize the pros and cons of companies at the current stage. In this paper, the proposed method is elaborated based on comprehensive perspective. Concretely, in the first stage, the integrated attribute values (the real numbers and linguistic fuzzy variables coexist) are transformed into trapezoidal fuzzy numbers (TrFNs). Then the CRs are transformed into company strategies (CSs) by quality function development (QFD). The weight of quantitative assessment is obtained by fuzzy best-worst method (BWM). In the second stage, the Shannon entropy method is presented to obtain qualitative assessment. The multi-objective optimization by ratio analysis plus the full multiplicative form (MULTIMOORA) method is used to rank. Finally, an application case is illustrated to highlight the implementation, availability, and feasibility of the method. Furthermore, comparative analysis and sensitive analysis are also applied to validate the feasibility and efficiency of the method.

The rest of this paper is structured as follows. A literature review is presented in Section 2. The two-stage integrated MCDM method using TrFNs is proposed in Section 3. Subsequently, Section 4 is a case study on green fresh product supplier selection. Section 5 conducts the comparative and sensitivity analysis. The managerial implications are discussed in Section 6. Finally, Section 7 summarizes several conclusions and contributions, as well as suggestions for future work.

2. Literature Review

The literature is briefly reviewed in three different but relevant streams: fresh product SC, supplier selection criteria, and selection methods.

2.1. Fresh Product Supply Chain (SC)

In the traditional SC model, the loss caused by product quality is generally not considered. However, in the fresh product SC, fresh products such as vegetables, meat, etc., during the trading time, due to their perishable nature, fresh products become non-fresh as time passes, resulting in a decrease in saleable quantity. Therefore, some scholars have summarized and reviewed the research on the SC of perishable products such as fresh products [22,23].

In the research of fresh product SC, Ghoreishi et al. [24] assumed that the loss rate of fresh agricultural products was small, and established a metamorphic inventory model in which the metamorphic rate was time-varying and the repurchase rate was dependent on the time. Chang et al. [25] studied the model of external loss-sharing based on the revenue sharing and risk sharing of perishable products between suppliers and manufacturers. Calvo et al. [26] studied the SC ordering strategy of short life cycle products based on the incentive model in game theory. Kumar et al. [27] studied the ordering strategy of partial shortages under stochastic demand and the product's metamorphic rate as a fuzzy number. Samir et al. [28] assumed that the consumer's demand would change with the degree of deterioration of fresh product, and studied the management of fresh product inventory in this case. In summary, although quite a lot of literature has studied fresh agricultural products, perishable products and short life cycle products, their research focused on inventory management and ordering strategies. There is less research on the SC of fresh product based on the combination of CRs and CSs with an integrated MCDM method.

2.2. Supplier Selection Criteria

Nowadays, research on supplier selection criteria and decision models has received extensive attention from scholars and rich results have been obtained. These research works addressed various aspects of supplier decision-making that focused on green themes and sustainability in SC management [16,29–32]. A considerable amount of research has already addressed the trade-off between the weights of these criteria aim to select the optimal solution for specific problem variables and constraints [33].

In research into the traditional supplier selection, by comparing the selection of criteria by Dickson and Weber [34], certain criteria (such as price, delivery time, production equipment, production capacity, and technical capability) are most widely used for selection. Among the green supplier selection literature, scholars have introduced some new concerns. Govindan et al. [16] reviewed the GSCM and proposed that the environmental management system (EMS) is the most considerable criteria compared to other related criteria. Akman [35] presented a two-stage supply assessment concept method (economic criteria and green criteria) for evaluating green suppliers. Sarkis and Dhavale [36] believed that the supplier's choice was crucial to the achievement of sustainable SC partnerships, and proposed a supplier assessment and selection framework using the the triple bottom line approach (TBL). Grimm et al. [37] described the SCM and constructed an evaluation framework from a green perspective. A concept method was proposed to measure how well sub-supplier management complies with sustainability standards. Trapp and Sarkis [38] proposed a mathematic model considering supplier selection, supplier development and sustainability issues. From these studies, we can conclude that green and sustainability criteria are used increasingly.

In our research, we construct the green supplier selection criteria from seven aspects, namely *QA* (quality adaptation), *P* (price), *ENRC* (energy and natural resource consumption), *DS* (delivery speed), *GD* (green design), *RRR* (reuse and recycling rate), and *PP* (production and planning). The established criteria were used and suppliers were evaluated in conjunction with green supplier criteria. The weights of each criterion is evaluated and weighted according to the proposed method.

2.3. Supplier Selection Methods

Numerous researchers have developed a variety of supplier selection methods from single methods to integrated methods. Integrated methods using two or more techniques have attracted more interest due to their practicality and flexibility [39]. The most popular objective and subjective MCDM methods of green supplier selection are analyzed as follows.

Using the analytic hierarchy process (AHP) and analytic network process (ANP) to obtain the subjective importance coefficient of supplier evaluation criteria is widely applied for research [40,41]. For the above methods, some necessary pairwise comparisons should be performed at the appropriate level of accuracy, which requires consistent user participation and consistency of judgment [42]. In addition, the number of suppliers criteria included in the comparative assessment is preferably limited to nine to avoid jeopardizing the consistency of human judgment [43]. In order to enable companies to effectively plan their products and services and adapt to a market-oriented environment, the goals set by the company need to consider CRs. QFD has a wide range of applications that can transform CRs into CSs and help companies provide competitive products and services [21,44–46]. However, one of the major limitations of conventional QFD methods is the application of absolute priority to determine the relative weights of CRs. To overcome this defect, the AHP and ANP have been integrated with QFD to select suppliers [40,44]. However, it still requires a tedious cumbersome pair comparison between elements. Therefore, we will consider combining QFD with fuzzy BWM to reduce the cumbersome nature of pairwise comparisons. BWM is a subjective method that was first developed by Rezaei to determine the priority of the standard [47]. BWM has several significant advantages. One is to provide a structured pairwise comparison matrix, which only requires the comparison of two vectors rather than acomplete pairwise comparison. Compared with AHP, the time of comparison is significantly reduced. Second, the method can be combined easily with other MCDM methods [48,49]. In addition, Guo and Zhao proposed fuzzy BWM using triangular fuzzy numbers [50]. This proposed method facilitates decision makers (DMs) to determine the priorities of criteria through qualitative judgment.

Although subjective approaches can be applied to identify the criteria weights, the assessment procedure may be affected by inconsistencies, human errors and other factors owing to the different knowledge and experience of the DMs. Objective methods, such as information entropy, can be used to be the weighting method to eliminate artificial uncertainty and get more realistic results. In particular, Shannon entropy can be used to determine the degree of confusion in system information and effectiveness. Taking into account the attributes of this research indicator, Shannon's concept has the ability to be used as a weight calculation method [51].

In terms of alternative supplier ranking, widely used methods include TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), VIKOR (VIsekriterijumska Optimizacija I Kompromisno Resenje) and COPRAS (Complex Proportional Assessment) [52–57]. Different from the common MCDM methods, Baležentis et al. [58] presented a MULTIMOORA method for supplier evaluation and ranking. It includes the ratio system (RS), the maximal objective reference point (MORP) and multiplicative form (MF) [59]. In practice, MULTIMOORA is proved to be the insensitivity method of multi-objective optimization (MOO) and high frequency used to solve MCDM problems under an uncertainty environment, because there is no other method that can meet all the robustness conditions of MOO [58,60]. Therefore, MULTIMOORA was used for company operation evaluation in many cases [61,62]. Although MULTIMOORA offers many effective and practical solutions to deal with complex and actual MCDM issues under uncertain environments, so far, no research has been done to combine fuzzy MULTIMOORA with other fuzzy evaluation methods for comprehensive assessment of green fresh product suppliers.

In conclusion, by synthesizing multiple MCDM methods, a selection model with specific functions and characteristics can be constructed, and this method has been increasingly used by scholars due to its high degree of flexibility. In order to realize the suitable supplier selection under a fuzzy environment, a comprehensive two-stage selection method composed of QFD, fuzzy BWM, the Shannon entropy weight method and the MULTIMOORA method was proposed. This research is helpful for fresh product supplier selection considering qualitative and quantitative criteria. In the first stage, two collective relationship matrixes were constructed by QFD, and the relationship between CRs and CSs was considered separately, taking into account their outstanding characteristics. Fuzzy BWM can appropriately derive the subjective criteria weights. In the second stage, Shannon entropy measurement was proposed to get objective criteria weights. Meanwhile, fuzzy MULTIMOORA was applied to rank suppliers according to each criterion. Taking into account the advantages of these methods, the developed two-stage integrated MCDM method can derive more robust and comprehensive results [63]. An application example is created to test the provided method. Comparing the proposed method with TOPSIS, VIKOR and COPRAS, and sensitivity analysis can also confirm the feasibility and effectiveness of the proposed method.

3. The Novel Integrated Two-Stage Multi-Criteria Decision Making (MCDM) Method

This paper focuses on selection of green fresh products suppliers. Supplier selection includes two stages: the establishment of criteria and the presentation of the selection method. In the first stage, two matrices were constructed based on QFD. The relationship among CRs, CSs, and selection criteria was considered separately in the two matrices. Meanwhile, the fuzzy BWM was obtained to calculate the priority of CRs, CSs and the subjective criteria weights. In the second stage, Shannon's entropy method was used to obtain the objective criteria weights, and the supplier was ranked using the fuzzy MULTIMOORA. The exhaustive steps of the proposed two-stage integrated method are shown in Figure 1.

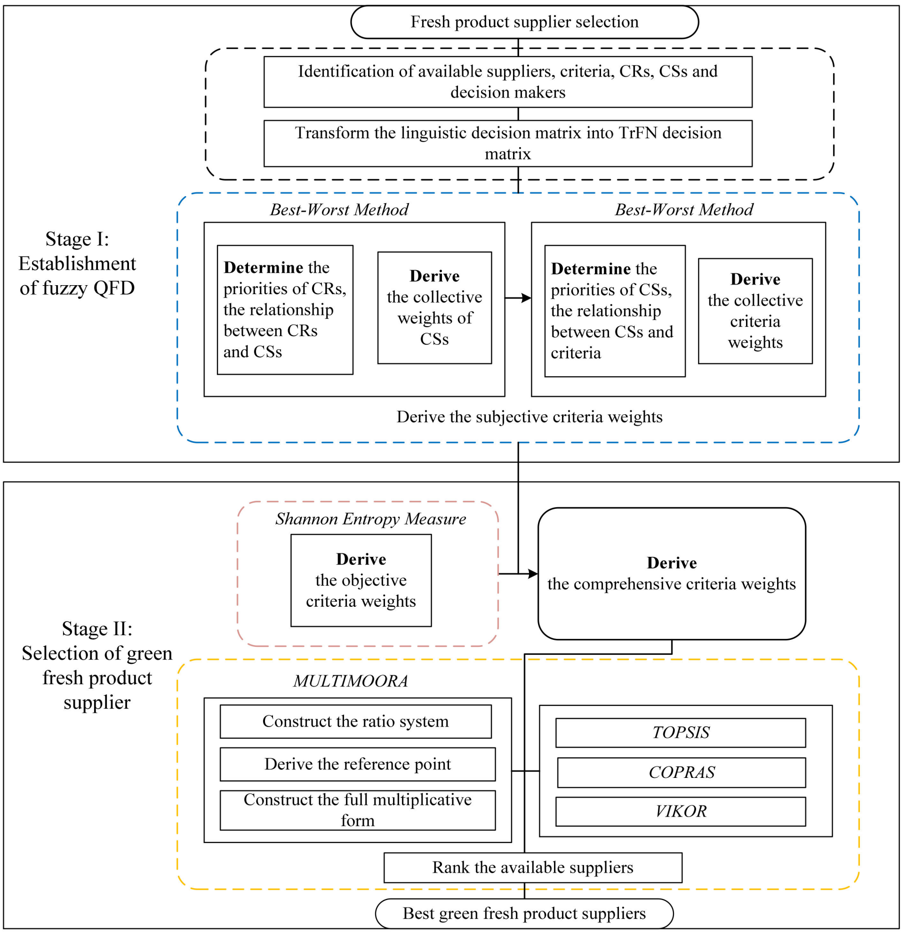


Figure 1. Assessment framework of proposed approach.

3.1. Fuzzy Set Theory

In the selection process, the data information that people get when dealing with practical problems often has uncertainty, language variables can be used in situations where it is difficult to describe these conditions using traditional quantitative expressions [64], such as interval numbers (INs), triangular fuzzy numbers (TFNs), trapezoidal fuzzy numbers (TrFNs), etc. It is proved that TrFNs are the most commonly applied types of fuzzy numbers. It is characterized by $\widetilde{A} = [a_1, a_2, a_3, a_4]$. The corresponding membership function is demonstrated as follows [65].

$$\mu_{\widetilde{A}}(x) = \begin{cases} \frac{x-a_1}{a_2-a_1}\mu_{\widetilde{A}}, a_1 \le x < a_2; \\ \mu_{\widetilde{A}}, a_2 \le x \le a_3; \\ \frac{a_4-x}{a_4-a_3}\mu_{\widetilde{A}}, a_3 < x \le a_4 \\ 0, \quad otherwise. \end{cases} \tag{1}$$

where, a_1, a_2, a_3 and a_4 are the vectors of the fuzzy number.

Definition 1. *For two positive TrFNs parameterized by* $\widetilde{A} = [a_1, a_2, a_3, a_4]$ *and* $\widetilde{B} = [b_1, b_2, b_3, b_4]$ *for* $A > 0$, $B > 0$. *After that, the algebraic operations for the TrFNs are demonstrated as follows:*

Addition operation:

$$\widetilde{A} \oplus \widetilde{B} = [a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4] \tag{2}$$

Subtraction operation:

$$\widetilde{A} \Theta \widetilde{B} = [a_1 - b_1, a_2 - b_2, a_3 - b_3, a_4 - b_4] \tag{3}$$

Multiplication operation:

$$\widetilde{A} \otimes \widetilde{B} = [a_1 b_1, a_2 b_2, a_3 b_3, a_4 b_4] \tag{4}$$

Division operation:

$$\widetilde{A} \varnothing \widetilde{B} = \left[\frac{a_1}{b_1}, \frac{a_2}{b_2}, \frac{a_3}{b_3}, \frac{a_4}{b_4}\right] \tag{5}$$

Scalar Multiplication:

$$\lambda \widetilde{A} = [\lambda a_1, \lambda a_2, \lambda a_3, \lambda a_4] \tag{6}$$

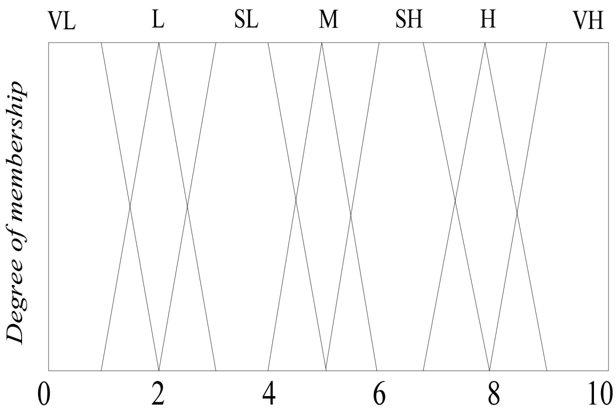
Distance between two TrFNs:

$$d\left(\widetilde{A}, \widetilde{B}\right) = \sqrt{\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2 + (a_4 - b_4)^2\right]/4} \tag{7}$$

Definition 1. *Converting fuzzy numbers to crisp numbers is a significant step in the application of fuzzy numbers. The centroid-based defuzzified value is as follows [66].*

$$A = defuzz\left(\widetilde{A}\right) = \frac{-a_1 \times a_2 + a_3 \times a_4 + \frac{1}{3}(a_4 - a_3)^2 - \frac{1}{3}(a_2 - a_1)^2}{-a_1 - a_2 + a_3 + a_4} \tag{8}$$

DMs can use linguistic term sets with different granularities and membership functions to transform their opinions. In this paper, we use seven-point TrFNs to characterize the weights of indicators and the ratings for green fresh product suppliers as shown in Figure 2. In addition, the experience and knowledge of DMs in the field varies from person to person. Therefore, considering this factor, we weight them based on the years of experiences they have. These linguistic terms can be mapped by TrFNs, as shown in Figure 3.



Linguistic terms	TrFNs
Very Low(VL)	(0,0,1,2)
Low(L)	(1,2,2,3)
Slightly Low(SL)	(2,3,4,5)
Medium(M)	(4,5,5,6)
Slightly High(SH)	(5,6,7,8)
High(H)	(7,8,8,9)
Very High(VH)	(8,9,10,10)

Figure 2. Membership functions and linguistic terms for pair-wise comparisons of criteria.

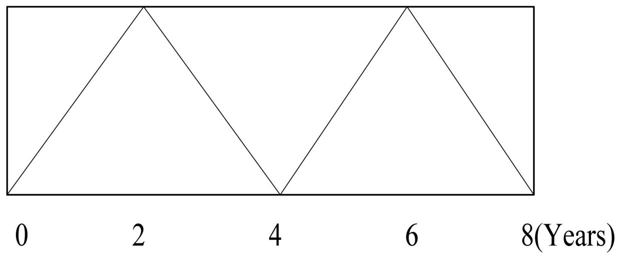


Figure 3. Representation of decision makers' (DMs) experience using linguistic term.

3.2. Fuzzy Best-Worst Method and Subjective Weights

BWM was proposed by Rezaei [47]. This method is a very effective subjective method for obtaining weights (see Figure 4).Compared with $n(n-1)/2$ times of AHP, the BWM is only $2n-3$ times [50]. In addition, the final weights are highly robust. Moreover, the CI (consistency index) is needed for checking the consistency. The maximum possible value of CI corresponding to the linguistic terms is shown in Table 1. The detailed steps are as follows:

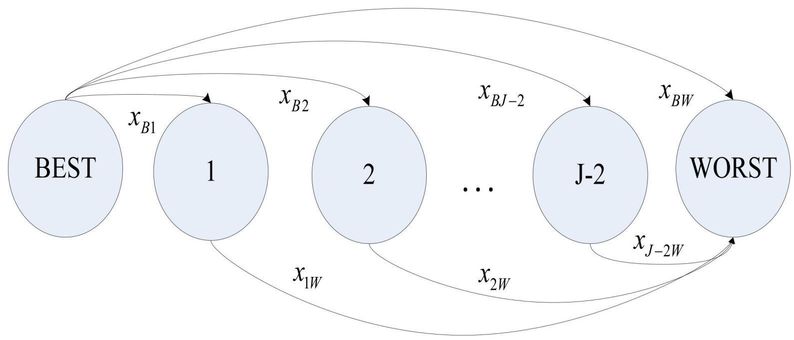


Figure 4. Reference comparisons.

Step 1. Define the decision criteria $\{c_1, c_2, \ldots, c_J\}(j = 1, 2, \ldots, J)$.

Step 2. Select the best criterion x_B and the worst criterion x_W.

Step 3. Obtain the priority $\widetilde{x}_{Bj}$ of the best criterion x_B over all the other criteria j and the priority $\widetilde{x}_{jW}$ of the other criteria j over the worst criterion $\widetilde{x}_W$ (particularly, $\widetilde{x}_{BB} = 1$, $\widetilde{x}_{WW} = 1$). The priorities are converted to TrFNs by the language terms in Table 1. The best to others (BO) and the others to worst (OW) vectors are expressed as follows:

$$\widetilde{X}_B = (\widetilde{x}_{B1}, \widetilde{x}_{B2}, \ldots, \widetilde{x}_{BJ}) \tag{9}$$

$$\widetilde{X}_W = (\widetilde{x}_{1W}, \widetilde{x}_{2W}, \ldots, \widetilde{x}_{JW}) \tag{10}$$

Step 4. Obtain the optimal weight vector $\left(\widetilde{x}_1^{w*}, \widetilde{x}_2^{w*}, \ldots, \widetilde{x}_J^{w*}\right)$. The optimal fuzzy criterion weight is the one where, for every fuzzy pair $\widetilde{x}_B^w / \widetilde{x}_j^w = \widetilde{x}_{Bj}$ and $\widetilde{x}_j^w / \widetilde{x}_W^w = \widetilde{x}_{jW}$, the following formulas should be satisfied:

$$\begin{gathered} \min \xi \\ s.t. \left| \frac{\widetilde{x}_B^w}{\widetilde{x}_j^w} - x_{Bj} \right| \leq \xi \\ \left| \frac{\widetilde{x}_j^w}{\widetilde{x}_W^w} - x_{jW} \right| \leq \xi \\ \sum_j x_j^w = 1 \\ x_j^w \geq 0, \text{for all } j.. \end{gathered} \tag{11}$$

Using Equation (11), the weight vector $\left(\widetilde{x}_1^{w*}, \widetilde{x}_2^{w*}, \ldots, \widetilde{x}_J^{w*}\right)$ and CI ξ^* are calculated. ξ^* cannot exceed the maximum possible CI value. Table 1 lists the largest possible CI for different linguistic variables. In addition, the Consistency Ratio (CR) equals to $\widetilde{\xi}^{k*}/\mathrm{CI}$. When CR < 0.1, the calculation result is acceptable, the closer the CR is to 0, the stronger the consistency [59].

Table 1. Linguistic terms and corresponding consistency index (CI) values.

Linguistic Terms	EI (Equally Important)	WI (Weakly Important)	FI (Fairly Important)	I (Important)	VI (Very Important)	AI (Absolutely Important)
TrFNs	(1,1,1,1)	(2/3,1,3/2,2)	(3/2,2,5/2,3)	(5/2,3,7/2,4)	(7/2,4,9/2,5)	(9/2,5,11/2,6)
CI	3.00	3.80	5.29	6.69	8.04	9.35

3.3. Shannon Entropy and Objective Weights

Objective weights can be obtained using the entropy method. The Shannon entropy is proposed by Shannon that is suitable for calculating the relative importance of criteria [51,67], the corresponding steps are as follows:

Step 1. Standardize the criterion:

$$P_{ij} = \frac{x_{ij}}{\sum\limits_{j} x_{ij}} \tag{12}$$

Step 2. Obtain the divergence of each criterion:

$$div_j = 1 - \ln(J)^{-1} \sum_{j=1}^{J} P_{ij} \ln_{(P_{ij})} \tag{13}$$

Step 3. Derive the normalized objective weights of criteria:

$$w_j^0 = \frac{div_j}{\sum_{j=1}^{J} div_j} \tag{14}$$

3.4. Multi-Objective Optimization by Ratio Analysis Plus the Full Multiplicative Form (MULTIMOORA) and Supplier Ranking

The MULTIMOORA method is used to solve supplier selection of green fresh product by ranking the alternatives, i.e., suppliers [58]:

Step 1. Transform the initial matrix into a normalized matrix:

$$\overline{x}_{ij} = \frac{x_{ij}}{\sum_{i=1}^{I} x_{ij}^2} \tag{15}$$

where, matrix x_{ij} are the original criteria values of alternatives $i = 1, 2, \ldots, I$; $\overline{x}_{ij}$ is a dimensionless value of x_{ij}.

Step 2. The RS.

The priority of the supplier, according to the relative significance $\overline{y}_i$ of supplier i with regard to criteria j can be obtained as follows:

$$\overline{y}_i = \sum_{j=1}^{g} \overline{x}_{ij} w_j - \sum_{j=g+1}^{n} \overline{x}_{ij} w_j \tag{16}$$

where the parameters, which's footnote is $j = 1, \ldots, g$, $j = g+1, \ldots, n$, are the maximized criteria and the minimized criteria respectively; w_j is the weights of criteria.

Step 3. The MORP.

In order to express MORP, the ideal supplier needs to be determined, it includes the benefit and cost criteria. Then, the Min-Max metric is used to rank the suppliers:

$$\underset{(i)}{Min}\left\{\underset{(j)}{\max}\left|r_j - \overline{x}_{ij}w_j\right.\right\} \tag{17}$$

Step 4. The MF.

The utility of the suppliers S_i can be calculated as follows:

$$S_i = \frac{A_i}{B_i} \tag{18}$$

where A_i and B_i are calculated for benefit criteria and cost criteria, respectively. A_i and B_i are calculated as follows:

$$A_i = \prod_{j=1}^{g} w_j\overline{x}_{ij}, B_i = \prod_{j=g+1}^{n} w_j\overline{x}_{ij}. \tag{19}$$

3.5. The Proposed Integrated Two-Stage MCDM Method

A two-stage method is presented in this subsection. This method integrates QFD, fuzzy BWM, Shannon entropy and fuzzy MULTIMOORA. Supposed I alternatives, namely, $a_i(i = 1, 2, \ldots, I)$; J criteria, namely, $c_j(j = 1, 2, \ldots, J)$; K DMs denoted as $DM_k(k = 1, 2, \ldots, K)$; some other notations, such as, P CRs and Q CSs, namely, $CR_p(p = 1, 2, \ldots, P)$ and $CS_q(q = 1, 2, \ldots, Q)$, respectively. Finally, the corresponding fuzzy weight of DMs denotes as $\widetilde{g}^k(k = 1, 2, \ldots, K)$.

Stage 1. Derive the subjective criteria weights

In this stage, the two QFD matrixes $\widetilde{H}_1$ and $\widetilde{H}_2$ are constructed. $\widetilde{H}_1$ indicates the relationships between CRs and CSs, $\widetilde{H}_2$ represents the relationship between CSs and the selection criteria. The output of $\widetilde{H}_1$ is the input for the matrix $\widetilde{H}_2$ as shown in Figure 5. Then the subjective criteria weights are calculated. The detailed procedure is described in the following.

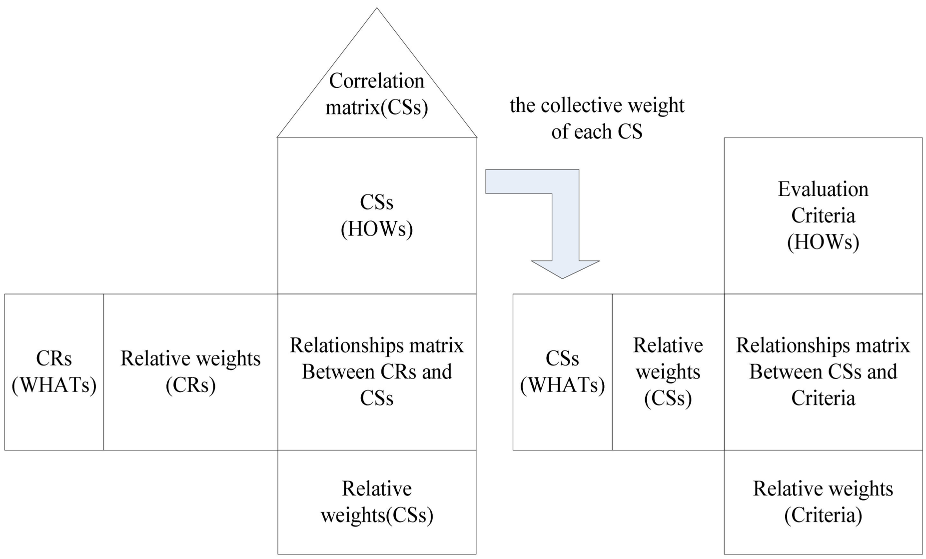


Figure 5. Representation of the quality function development (QFD) process.

Step 1. Determine the best criteria and worst criterion, separately.

After recognizing CRs, those criteria separately expressed by CR_B^k and CR_W^k are determined by DMs.

Step 2. Execute the comparisons.

The BO vector and OW vector of DM_k are derived as follows:

$$\widetilde{A}^k_{B,CR} = \left(\widetilde{a}^k_{B1}, \widetilde{a}^k_{B2}, \ldots, \widetilde{a}^k_{BP}\right) \tag{20}$$

$$\widetilde{A}^k_{W,CR} = \left(\widetilde{a}^k_{1W}, \widetilde{a}^k_{2W}, \ldots, \widetilde{a}^k_{PW}\right) \tag{21}$$

where, $\widetilde{a}^k_{Bp} = \left(\widetilde{a}^k_{Bp}, \widetilde{b}^k_{Bp}, \widetilde{c}^k_{Bp}, \widetilde{d}^k_{Bp}\right)$ and $\widetilde{a}^k_{pW} = \left(\widetilde{a}^k_{pW}, \widetilde{b}^k_{pW}, \widetilde{c}^k_{pW}, \widetilde{d}^k_{pW}\right)$ are represented by TrFNs. Particularly, $\widetilde{a}^k_{BB} = (1,1,1,1), \widetilde{a}^k_{WW} = (1,1,1,1)$.

Step 3. Gain the optimal solutions.

The optimal solution is derived, and the fuzzy priorities of customer requirements can be obtained below [50]:

$$\begin{array}{l} \min \widetilde{\xi}^k \\ s.t. \left| \frac{\left(a^k_{CR,B}, b^k_{CR,B}, c^k_{CR,B}, d^k_{CR,B}\right)}{\left(a^k_{CR,p}, b^k_{CR,p}, c^k_{CR,p}, d^k_{CR,p}\right)} - \left(a^k_{Bp}, b^k_{Bp}, c^k_{Bp}, d^k_{Bp}\right) \right| \le \left(\xi^k, \xi^k, \xi^k, \xi^k\right) \\ \left| \frac{\left(a^k_{CR,p}, b^k_{CR,p}, c^k_{CR,p}, d^k_{CR,p}\right)}{\left(a^k_{CR,W}, b^k_{CR,W}, c^k_{CR,W}, d^k_{CR,W}\right)} - \left(a^k_{pW}, b^k_{pW}, c^k_{pW}, d^k_{pW}\right) \right| \le \left(\xi^k, \xi^k, \xi^k, \xi^k\right) \\ \sum_{p=1}^{P} e^k_{CR,p} = 1 \\ a^k_{CR,p} \le b^k_{CR,p} \le c^k_{CR,p} \le d^k_{CR,p} \\ a^k_{CR,p} \ge 0, p = 1, 2, \ldots, P \end{array} \tag{22}$$

where $e^k_{CR,p} = defuzz\left(\widetilde{e}^k_{CR,p}\right)$, denote the defuzzified collective priorities of CRs, which is calculated by using Equation (8); $\widetilde{e}^k_{CR,B} = \left(a^k_{CR,B}, b^k_{CR,B}, c^k_{CR,B}, d^k_{CR,B}\right)$ and $\widetilde{e}^k_{CR,W} = \left(a^k_{CR,W}, b^k_{CR,W}, c^k_{CR,W}, d^k_{CR,W}\right)$ denote the priority of CR^k_B, CR^k_W, which is determined by DMs.

By using Equation (22), the optimal solutions $\left(\widetilde{e}^{k*}_{CR,1}, \widetilde{e}^{k*}_{CR,2}, \ldots, \widetilde{e}^{k*}_{CR,P}\right)$ and the corresponding optimal CI (namely, $\widetilde{\xi}^{k*}$) are derived.

Step 4. Calculate the collective priorities of CRs.

$$\begin{array}{l} \widetilde{e}^*_{CR,p} = \overset{K}{\underset{k=1}{\oplus}} \left(\widetilde{e}^{k*}_{CR,p} \otimes \widetilde{G}^k\right) \\ = \left(\sum_{k=1}^{K}\left(a^{k*}_{CR,p} \times a^k_g\right), \sum_{k=1}^{K}\left(b^{k*}_{CR,p} \times b^k_g\right), \sum_{k=1}^{K}\left(c^{k*}_{CR,p} \times c^k_g\right), \sum_{k=1}^{K}\left(d^{k*}_{CR,p} \times d^k_g\right)\right) \end{array} \tag{23}$$

$$e^*_{CR,p} = defuzz\left(\widetilde{e}^*_{CR,p}\right) \tag{24}$$

where $\widetilde{e}^*_{CR,p}$ denote the collective priorities of CRs; $e^*_{CR,p}$ present the collective priorities in crisp values of CRs.

Step 5. Calculate the collective criteria weights of CSs.

DMs rate the relationship degree between CRs and CSs using linguistic terms. The relationship matrix of DM_k is denoted by $\widetilde{H}^k_1 = \left(\widetilde{h}^k_{1,pq}\right)_{P\times Q}$, in which $\widetilde{h}^k_{1,pq} = \left(a^k_{1,pq}, b^k_{1,pq}, c^k_{1,pq}, d^k_{1,pq}\right)$.

The collective relationship matrix $\widetilde{H}_1 = \left(\widetilde{h}_{1,pq}\right)_{P\times Q}$ can be calculated as follows:

$$\widetilde{H}_1 = \overset{K}{\underset{k=1}{\oplus}} \left(\widetilde{H}^k_1 \otimes \widetilde{G}^k\right) = \left(\overset{K}{\underset{k=1}{\oplus}} \left(\widetilde{h}^k_{1,pq} \otimes \widetilde{g}^k\right)\right)_{P\times Q} \tag{25}$$

where, $\widetilde{h}_{1,pq} = \left(\sum_{k=1}^{K}\left(a^k_{1,pq} \times a^k_g\right), \sum_{k=1}^{K}\left(b^k_{1,pq} \times b^k_g\right), \sum_{k=1}^{K}\left(c^k_{1,pq} \times c^k_g\right), \sum_{k=1}^{K}\left(d^k_{1,pq} \times d^k_g\right)\right)$.

Then, the collective weights of CSs can be calculated as follows:

$$\begin{aligned}\widetilde{e}_{1,q} &= \sum_{p=1}^{P}\left(e^{*}_{CR,p} \times \widetilde{h}_{1,pq}\right)\\ &= \left(\sum_{p=1}^{P}\left(e^{*}_{CR,p} \times a^{k}_{1,pq}\right), \sum_{k=1}^{K}\left(e^{*}_{CR,p} \times b^{k}_{1,pq}\right), \sum_{k=1}^{K}\left(e^{*}_{CR,p} \times c^{k}_{1,pq}\right), \sum_{k=1}^{K}\left(e^{*}_{CR,p} \times d^{k}_{1,pq}\right)\right)\end{aligned} \tag{26}$$

$$e_{1,q} = defuzz\left(\widetilde{e}_{1,q}\right) \tag{27}$$

where, $\widetilde{e}_{1,q}$ denote the fuzzy collective weights of CSs, $e_{1,q}$ denote the deffuzified collective weights of CSs.

The second matrix $\widetilde{H}_2$ represents the relationship of the CSs and the criteria. The output of the collective priorities in Step 5 is used as input of the next step. Steps 6–10 output the collective criteria weights, which comprise the subjective criteria weights. The relationship matrix of DMs is established after identifying the criteria. The relationship matrix of DM_k is defined by $\widetilde{H}^{k}_{2} = \left(\widetilde{h}^{k}_{2,qj}\right)_{Q\times J}$, where $\widetilde{h}^{k}_{2,qj} = \left(\widetilde{a}^{k}_{2qj}, \widetilde{b}^{k}_{2qj}, \widetilde{c}^{k}_{2qj}, \widetilde{d}^{k}_{2qj}\right)$.

Steps 6–9. Similar to Steps 1–4, the collective priorities of CSs can be calculated as follows:

$$\begin{aligned}\widetilde{e}^{*}_{CS,q} &= \mathop{\oplus}_{k=1}^{K}\left(\widetilde{e}^{k*}_{CS,q} \otimes \widetilde{g}^{k}\right)\\ &= \left(\sum_{k=1}^{K}\left(a^{k*}_{CS,q} \times a^{k}_{g}\right), \sum_{k=1}^{K}\left(b^{k*}_{CS,q} \times b^{k}_{g}\right), \sum_{k=1}^{K}\left(c^{k*}_{CS,q} \times c^{k}_{g}\right), \sum_{k=1}^{K}\left(d^{k*}_{CS,q} \times d^{k}_{g}\right)\right)\end{aligned} \tag{28}$$

$$e^{*}_{CS,q} = defuzz\left(\widetilde{e}^{*}_{CS,q}\right) \tag{29}$$

where, $\widetilde{e}^{*}_{CS,q}$ represent the fuzzy collective priorities of CSs; $e^{*}_{CS,q}$ denote the defuzzified collective priorities of CSs.

Step 10. Calculate the subjective weights of criteria.

DMs measure the relationship rate between CSs and the corresponding criteria using linguistic terms. The second QFD matrix of DM_k is denoted by $\widetilde{H}^{k}_{2} = \left(\widetilde{h}^{k}_{2,pq}\right)_{Q\times J}$, where $\widetilde{h}^{k}_{2,qj} = \left(a^{k}_{2,qj}, b^{k}_{2,qj}, c^{k}_{2,qj}, d^{k}_{2,qj}\right)$.

The collective QFD matrix $\widetilde{H}_2 = \left(\widetilde{h}_{2,qj}\right)_{Q\times J}$ can be obtained as shown below:

$$\widetilde{H}_2 = \mathop{\oplus}_{k=1}^{K}\left(\widetilde{H}^{k}_{2} \otimes \widetilde{G}^{k}\right) = \left(\mathop{\oplus}_{k=1}^{K}\left(\widetilde{h}^{k}_{2,qj} \otimes \widetilde{g}^{k}\right)\right)_{Q\times J} \tag{30}$$

where $\widetilde{h}_{2,qj} = \left(\sum_{k=1}^{K}\left(a^{k}_{2,qj} \times a^{k}_{g}\right), \sum_{k=1}^{K}\left(b^{k}_{2,qj} \times b^{k}_{g}\right), \sum_{k=1}^{K}\left(c^{k}_{2,qj} \times c^{k}_{g}\right), \sum_{k=1}^{K}\left(d^{k}_{2,qj} \times d^{k}_{g}\right)\right)$.

The collective criteria weights of criteria can be calculated as shown below:

$$\begin{aligned}\widetilde{e}_{2,j} &= \sum_{q=1}^{Q}\left(e_{1,q} \times \widetilde{h}_{2,qj} \times e^{*}_{CS,q}\right)\\ &= \left(\sum_{q=1}^{Q}\left(e^{*}_{CS,q} \times a^{k}_{2,qj}\right), \sum_{k=1}^{K}\left(e^{*}_{CS,q} \times b^{k}_{2,qj}\right), \sum_{k=1}^{K}\left(e^{*}_{CS,q} \times c^{k}_{2,qj}\right), \sum_{k=1}^{K}\left(e^{*}_{CS,p} \times d^{k}_{2,qj}\right)\right)\end{aligned} \tag{31}$$

$$e_{2,j} = defuzz\left(\widetilde{e}_{2,j}\right) \tag{32}$$

where, $\widetilde{e}_{2,j}$ denote the fuzzy collective criteria weights, $e_{2,j}$ represent the collective criteria weights in crisp values.

The collective criteria weights and the subjective weights are different in magnitude. Therefore, the collective criteria weights should be normalized and the subjective criteria weights can be obtained as follows:

$$e^{s}_{j} = \frac{e_{2,j}}{\sum_{j=1}^{J} e_{2,j}} \tag{33}$$

Stage 2. Selection of green fresh product supplier

In the second stage, the objective weights are determined by the Shannon entropy method. Furthermore, the fuzzy MULTIMOORA method is used for ranking all of the green fresh product suppliers.

Step 1. Obtain the standardized decision matrix.

Qualitative and quantitative methods are both involved in the criteria. The qualitative method is expressed as linguistic variable alternatives to the criteria converted to TrFNs by referring to Table 2. Quantitative evaluations were expressed in terms of crisp values converted to TrFNs by the idea of Yao and Wu [68]. For a crisp value a, the corresponding TrFN is (a, a, a, a). Then the fuzzy decision matrix of DM_k on alternative a_i to each criterion c_j is derived $\widetilde{X}^k = \left(\widetilde{x}_{ij}^k\right)_{I \times J}$, where $\widetilde{x}_{ij}^k = \left(\widetilde{a}_{ij}^{x,k}, \widetilde{b}_{ij}^{x,k}, \widetilde{c}_{ij}^{x,k}, \widetilde{d}_{ij}^{x,k}\right)$.

Step 2. To keep the ranges of standardized TrFNs belong to the interval $[0, 1]$, the standardized fuzzy decision matrix of DM_k is represented as $\widetilde{Y}^k = \left(\widetilde{y}_{ij}^k\right)_{I \times J}$, in which $\widetilde{y}_{ij}^k = \left(a_{ij}^{y,k}, b_{ij}^{y,k}, c_{ij}^{y,k}, d_{ij}^{y,k}\right) = \left(\frac{a_{ij}^{x,k}}{\sqrt{\sum_{i=1}^{I}\left(d_{ij}^{x,k}\right)^2}}, \frac{b_{ij}^{x,k}}{\sqrt{\sum_{i=1}^{I}\left(d_{ij}^{x,k}\right)^2}}, \frac{c_{ij}^{x,k}}{\sqrt{\sum_{i=1}^{I}\left(d_{ij}^{x,k}\right)^2}}, \frac{d_{ij}^{x,k}}{\sqrt{\sum_{i=1}^{I}\left(d_{ij}^{x,k}\right)^2}}\right)$.

Step 3. Calculate the collective matrix.

The collective matrix $\widetilde{Y} = \left(\widetilde{y}_{ij}\right)_{I \times J}$ by using the simple arithmetic is shown below:

$$\widetilde{Y} = \mathop{\oplus}_{k=1}^{K}\left(\widetilde{Y}^k \otimes \widetilde{G}^k\right) = \left(\mathop{\oplus}_{k=1}^{K}\left(\widetilde{y}_{ij}^k \otimes \widetilde{g}^k\right)\right)_{I \times J} \tag{34}$$

where $\widetilde{y}_{ij} = \left(a_{ij}^y, b_{ij}^y, c_{ij}^y, d_{ij}^y\right) = \left(\sum_{k=1}^{K}\left(a_{ij}^k \times a_g^k\right), \sum_{k=1}^{K}\left(b_{ij}^k \times b_g^k\right), \sum_{k=1}^{K}\left(c_{ij}^k \times c_g^k\right), \sum_{k=1}^{K}\left(d_{ij}^k \times d_g^k\right)\right)$.

Step 4. Obtain the objective criteria weights by using Shannon entropy method.

Step 4.1. Normalization of criteria which yields the projection value of criteria, and $\widetilde{Z}_{ij} = \left(\widetilde{z}_{ij}\right)_{I \times J}$ is transformed to $Z_{ij} = \left(z_{ij}\right)_{I \times J}$, which is calculated by Equation (38).

$$\widetilde{Z}_{ij} = \left(\widetilde{z}_{ij}\right)_{I \times J} = \left(\frac{\widetilde{y}_{ij}}{\sum_{i=1}^{I}\widetilde{y}_{ij}}\right)_{I \times J} \tag{35}$$

$$z_{ij} = defuzz\left(\widetilde{z}_{ij}\right) \tag{36}$$

where z_{ij} denote the collective criteria weights in crisp values.

Step 4.2. Calculate the divergence of criteria.

$$div_j = 1 - -\frac{1}{\ln J}\sum_{j=1}^{J} z_{ij} \ln z_{ij} \tag{37}$$

Step 4.3. Derive the normalized objective criteria weights.

$$e_j^0 = \frac{div_j}{\sum_{j=1}^{J} div_j} (j = 1, 2, \ldots, J) \tag{38}$$

Step 5. Derive the combination of the subjective and objective criteria weights.

By Equations (35) and (42), the subjective weights as well as the objective weights are obtained respectively. The combined criteria weights are calculated as follows [68].

$$e_j = \left(e_j^s + \lambda e_j^o\right) / \sum_{j=1}^{J} \left(e_j^s + \lambda e_j^o\right) \tag{39}$$

where λ expresses the subjective weights for the relative effectiveness of the objective weights, its value range is set to $\lambda \in [0.3, 3]$. Generally, the value is set as $\lambda = 1$, which shows that the subjective weights and objective weights are the same in the importance synthesis.

Step 6. Rank all suppliers.

The fuzzy MULTIMOORA is used as shown below:

Step 6.1. Derive the RS.

$$\widetilde{RS}_i = (\widetilde{rs}_1, \widetilde{rs}_2, \ldots, \widetilde{rs}_i) = \sum_{j=1}^{g} e_j \widetilde{y}_{ij} - \sum_{j=g+1}^{J} e_j \widetilde{y}_{ij} \tag{40}$$

$$rs_i = defuzz(\widetilde{rs}_i) \tag{41}$$

where g is the number of beneficial criteria; $J - g$ are the number of cost criteria; e_j denote the combined criteria weights, which are yielded by Equation (43); RS_i represent the utility of supplier.

Step 6.2. Obtain the MORP.

The MORP is based on the weighted fuzzy decision matrix $\widetilde{R} = \left(\widetilde{r}_{ij}\right)_{I \times J}$. The normalized $\widetilde{r}_{ij} = \left(a_{ij}^r, b_{ij}^r, c_{ij}^r, d_{ij}^r\right) = \left(e_j a_{ij}^y, e_j b_{ij}^y, e_j c_{ij}^y, e_j d_{ij}^y\right)$ is within $[0,1]$. Therefore, the MORP is defined as $\widetilde{r}_j^* = (1,1,1,1)$ for the benefit criterion and $\widetilde{r}_j^* = (0,0,0,0)$ for the cost criterion. Moreover, Equation (7) can be used to obtain the maximal deviation from the MORP for each supplier.

$$RP_i = \max_j d\left(\widetilde{r}_{ij}, \widetilde{r}_j^*\right) \tag{42}$$

Then, the suppliers are sorted in ascending order by RP_i.

Step 6.3. Construct the MF.

The overall utility $\widetilde{MF}_i$ can be obtained as shown below:

$$\begin{aligned}\widetilde{MF}_i &= \frac{\prod_{j=1}^{g} (r_{ij})^{e_j}}{\prod_{j=g+1}^{J} (r_{ij})^{e_j}} \\ &= \left(\frac{\prod_{j=1}^{g} (a_{ij})^{e_j}}{\prod_{j=g+1}^{J} (d_{ij})^{e_j}}, \frac{\prod_{j=1}^{g} (b_{ij})^{e_j}}{\prod_{j=g+1}^{J} (c_{ij})^{e_j}}, \frac{\prod_{j=1}^{g} (c_{ij})^{e_j}}{\prod_{j=g+1}^{J} (b_{ij})^{e_j}}, \frac{\prod_{j=1}^{g} (d_{ij})^{e_j}}{\prod_{j=g+1}^{J} (a_{ij})^{e_j}} \right)\end{aligned} \tag{43}$$

$$mf_i = defuzz\left(\widetilde{mf}_i\right) \tag{44}$$

where $\prod_{j=1}^{g} (r_{ij})^{e_j}$ represent the benefit criteria outcome of a_i with g being the maximized criteria number; $\prod_{j=g+1}^{J} (r_{ij})^{e_j}$ represent the cost criteria outcome of a_i with $J - g$. The suppliers are then sorted in descending order through MF_i.

Step 6.4. Rank the alternatives.

The dominance analysis approach is used to summarize the three values provided by MULTIMOORA [58].

Table 2. Customer requirements (CRs), company strategies (CSs) and criteria.

	CRs		*CSs*		**Criteria**
Q	Quality	*FS*	Financial stability	*QA*	Quality Adaptation
TSS	Test Standard of Security	*ENMS*	Environmental Management Systems	*P*	Price
P	Price	*WDP*	Waste Disposal Program	*ENRC*	Energy and Natural Resource Consumption
CRN	Corporate Reputation	*MC*	Management Commitment	*DS*	Delivery Speed
CPS	Capability of Product Supply	*QCS*	Quality Control Systems	*GD*	Green Design
SCR	Sufficiency of Consumer Response	*M*	Manufacturing	*RRR*	Re-use and Recycle Rate
		F	Facility	*PP*	Production Planning
		RL	Reverse Logistics		

4. Case Study

The supplier selection analysis involves a company that supplies a range of fresh product. Pitaya, pineapple, red delicious, cherry and other fruits are the company's main business products. The data is used in this section to compare supplier selection analysis. The purpose is to complete supplier selection analysis for every product purchase.

For a specific fresh product, the company orders the product from a large planting base, that is, each supplier. After the order is generated, the company will contact its alternative suppliers, who are responsible for picking, packaging, and then transporting it to destinations such as Japan and the United States. The company is a direct customer and the producer will be a supplier. Through the initial screening process, five fresh product suppliers were identified. For the supplier's choice, the decision maker must very carefully assess the needs of all customers and consider how each supplier can fully achieve these goals.

Five different supplier samples are provided to the company. In order to get accurate assessments, four DM_1, DM_2, DM_3, DM_4 are invited to form an expert group to make the evaluation.

The decision group includes a senior manager of a fresh agricultural production organization, a manager of a fresh product company, a decision-making professor and a public sector official, who all have extensive experience and knowledge in the field of fresh product. In addition, according to their different working years, this study adds their respective weights to their evaluations as shown in Figure 3. An inexperienced DM is given $(0,0,2,4)$, while a general experience DM is given $(0,2,6,8)$, and an experienced DM is given $(4,6,8,8)$. In addition, the weights of DMs are $(\tilde{g}^1, \tilde{g}^2, \tilde{g}^3, \tilde{g}^4)$, here, $\tilde{g}^1 = (0,2,6,8)$, $\tilde{g}^2 = (0,2,6,8)$, $\tilde{g}^3 = (4,6,8,8)$ and $\tilde{g}^4 = (4,6,8,8)$. Six CRs, eight CSs and seven evaluation criteria are selected through market research, as shown in Table 2.

Customer requirements refer to a broad and in-depth understanding of the actual needs of customers to help companies make the right decisions. In actual life, customers prefer to buy fresh and healthy ingredients, and get a product experience that has just been freshly picked from the orchard, so their first concern is the quality factor of fresh products such as size, shape, color, elasticity and odor. Secondly, whether the implementation standards for production of fresh products are strict, whether there are pesticide residues, and whether the detection of heavy metal content, microorganisms, mycotoxins, etc. meets the requirements (TSS) are also of great concern to customers. Any customer is very concerned about price; they all prefer to buy fresh and healthy fresh products at the lowest price, so there is more demand for products with good quality and low prices (P). Moreover, the company's credit, prestige, and overall recognition level in the industry (CRN), as well as the ability to provide fresh product in terms of quality and quantity (CPS), and the ability to effectively perceive, respond quickly, and effectively meet CRs are also the important customer demand for a satisfied fresh company.

In response to CRs, eight CSs and seven evaluation criteria are also selected according to the literature survey. Seven evaluation criteria, namely *QA*, *P*, *ENRC*, *DS*, *GD*, *RRR* and *PP* are explained as follows. The essence of the argument about *QA* is to understand quality from the perspective of customer use. *P* refers to the quotation per unit of agricultural products provided by the supplier. *ENRC* are the total amount of resources consumed by suppliers to provide products. *DS* refers to the supplier's cold chain transport speed to ensure the fresh products' arrival at the target company. It is numerically equal to the distance traveled in unit time. *GD* refers to the ecological guarantee and the ability to reduce packaging materials. *RRR* refers to the ratio of the sum of the quality of discarded products that can be recycled (including re-use, recycling, and energy recovery) to the quality of recovered waste products. *PP* refers to suppliers who can reasonably formulate production plans so that products can be supplied with quality and quantity. *P* and *ENRC* are criteria to be minimized and the remaining are criteria to be maximized.

Based on collective background information of five suppliers and the rate is given by the DMs, the CR_B^k, CR_W^k, CS_B^k and CS_W^k were determined based on the company background information of five suppliers and the evaluation results provided by the decision group, as shown in Table 3. $\widetilde{A}_{B,CR}^k$,$\widetilde{A}_{W,CR}^k$, $\widetilde{A}_{B,CS}^k$ and $\widetilde{A}_{W,CS}^k$ are shown in Tables 4 and 5. After the corresponding CRs determines the CSs, the linguistic terms shown in Table 2 are used to represent the correlation assessment between CRs and the corresponding CSs to establish the first QFD matrix, as shown in Table 6. The range of language terms determines the degree of relationship. In particular, the blank element indicates that there is no relationship between CRs and CSs. In the same way, the second QFD matrix is established, as shown in Table 7, which demonstrates the degree of relationship between CSs and the corresponding criteria. Finally, according to the background information of the five suppliers, the suppliers are evaluated by five DMs. The calculation results are listed in Table 8. Since the form of DMs is a linguistic term, we need to convert linguistic terms to corresponding TrFNs according to the rules shown in Table 1 and Figure 2. The two-stage decision method proposed is applied to this case. The detailed solution steps are as shown below:

Stage 1. Derive the subjective criteria weights

$\widetilde{A}_{B,CR}^k$, $\widetilde{A}_{W,CR}^k$, $\widetilde{A}_{B,CS}^k$ and $\widetilde{A}_{W,CS}^k$ can be collected into $\widetilde{A}_{B,CR}$, $\widetilde{A}_{W,CR}$, $\widetilde{A}_{B,CS}$ and $\widetilde{A}_{W,CS}$ using Equations (20) and (21). DM's optimal solution and the optimal CI can be obtained. The results are acceptable because the values of the consistency ratio are all below 0.1. The fuzzy collective priorities of the CRs can be calculated and expressed as $\widetilde{e}_{CR,1}^*$ = (0.3754, 1.8741, 5.6328, 10.2744), $\widetilde{e}_{CR,2}^*$ = (0.5449, 2.9109, 10.6813, 21.7885), $\widetilde{e}_{CR,3}^*$ = (0.4048, 1.8645, 7.0667, 12.4848), $\widetilde{e}_{CR,4}^*$ = (0.3036, 1.4240, 4.4778, 8.4931), $\widetilde{e}_{CR,5}^*$ = (0.1560, 0.6938, 2.1468, 4.3733), $\widetilde{e}_{CR,6}^*$ = (0.1650, 0.7750, 2.3543, 4.2982). Then, e_{CR}^* = (0.1712, 0.3426, 0.2053, 0.1391, 0.0702, 0.0716).

After the collective relationship between the CRs and CSs is obtained by Equation (25), the collective CSs weights are obtained by Equation (26).

Then, e_1 = (3.2724, 2.2107, 1.5170, 4.6807, 4.1323, 4.1071, 2.4394, 1.8209). Using Equation (28), the collective priorities of CSs can be obtained as $\widetilde{e}_{CS,1}^*$ = (0.2727, 1.5626, 5.1966, 10.3455), $\widetilde{e}_{CS,2}^*$ = (0.2821, 1.3288, 4.3797,8.3510), $\widetilde{e}_{CS,3}^*$ = (0.2356, 1.1271, 3.7303, 7.4155), $\widetilde{e}_{CS,4}^*$ = (0.4077, 2.4179, 7.7427, 17.0088), $\widetilde{e}_{CS,5}^*$ = (0.1964, 0.9180, 2.8988, 5.5564), $\widetilde{e}_{CS,6}^*$ = (0.2416, 1.1051, 3.4990, 6.6200), $\widetilde{e}_{CS,7}^*$= (0.1204, 0.5357, 1.7249, 3.1286), $\widetilde{e}_{CS,8}^*$ = (0.1682, 0.6805, 2.0790, 3.9177). Then, e_{CS}^* = (0.1726, 0.1359, 0.1168, 0.2643, 0.0826, 0.1110, 0.0508, 0.0660).

The collective relationship between CSs and the corresponding criteria and the collective relative weights of CSs are obtained by Equations (32)–(34). Then, the subjective criteria weights are obtained using Equation (33). The results are demonstrated in Table 9.

Stage 2. Selection of green fresh product supplier

Firstly, the normalized fuzzy matrix of DMs can be obtained using Equation (36). Then, the corresponding fuzzy collective matrix can be calculated through Equation (34). Finally, the objective and the combination criteria weights can be obtained using Equations (38)–(42). The calculation results are shown in Table 9.

Equations (40)–(44) are applied to obtain the result of the suppliers ranking. The suppliers ranking is obtained based on the dominance analysis approach. The calculation results are listed in Table 10. The suppliers ranking is $a_2 \succ a_5 \succ a_1 \succ a_4 \succ a_3$ and the supplier with the best performance is a_2.

Table 3. The *CR*s and *CS*s identified by DMs.

	CR_B^k	CR_W^k	CS_B^k	CS_W^k
DM_1	*TSS*	*SCR*	*MC*	*RL*
DM_2	*TSS*	*CPS*	*MC*	*F*
DM_3	*TSS*	*SCR*	*MC*	*F*
DM_4	*TSS*	*CPS*	*MC*	*F*

Table 4. The best to others (BO) vectors of *CR*s and *CS*s identified by *DM*s.

	$\widetilde{A}_{B,CR}^k$							$\widetilde{A}_{B,CS}^k$								
	Best	***Q***	***TSS***	***P***	***CRN***	***CPS***	***SCR***	**Best**	***FS***	***EMS***	***WDP***	***MC***	***QCS***	***M***	***F***	***RL***
DM_1	*TSS*	WI	EI	FI	I	VI	AI	*MC*	WI	FI	FI	EI	I	I	VI	AI
DM_2	*TSS*	WI	EI	WI	FI	AI	VI	*MC*	WI	WI	WI	EI	I	FI	AI	VI
DM_3	*TSS*	FI	EI	WI	FI	VI	AI	*MC*	WI	FI	FI	EI	I	FI	AI	VI
DM_4	*TSS*	FI	EI	WI	I	AI	VI	*MC*	FI	WI	WI	EI	VI	FI	AI	VI

Table 5. The others to worst (OW) vectors of *CR*s and *CS*s identified by *DM*s.

	$\widetilde{A}_{W,CR}^k$							$\widetilde{A}_{W,CS}^k$								
	Worst	***Q***	***TSS***	***P***	***CRN***	***CPS***	***SCR***	**Worst**	***FS***	***EMS***	***WDP***	***MC***	***QCS***	***M***	***F***	***RL***
DM_1	SCR	I	AI	VI	FI	WI	EI	RL	AI	I	WI	VI	WI	I	WI	EI
DM_2	CPS	I	AI	VI	WI	EI	FI	F	VI	I	FI	AI	WI	FI	EI	WI
DM_3	SCR	VI	AI	I	FI	WI	EI	F	I	VI	WI	AI	FI	FI	EI	FI
DM_4	CPS	VI	AI	VI	FI	EI	WI	F	VI	I	FI	AI	WI	FI	EI	WI

Table 6. Correlation assessments of DMs on CRs and CSs.

	FS				*EMS*				*WDP*				*MC*				*QCS*				*M*				*F*				*RL*			
	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4
Q	H	SH	SH	H	VL	L	VL	SL	L	L	VL	L	H	VH	VH	H	VH	VH	H	VH	H	H	H	VH	SH	SH	H	SH	M	SH	SL	SL
TSS	L	VL	VL	VL	H	H	H	VH	VL	VL	VL	VL	H	VH	H	H	H	VH	H	SH	SH	H	H	H	SL	SL	L	SL	SL	L	L	VL
P	H	VH	VH	VH	L	L	VL	L	SH	H	H	H	H	VH	SH	H	H	M	H	H	SH	M	SH	H	H	H	VH	SH	M	SH	SH	M
CR	VH	H	VH	H					L	L	L	VL	SH	H	SH	H	H	SH	SH	SH	M	SH	H	H					L	VL	VL	VL
CPS	SH	VH	H	VH	VL	L	VL	L					M	M	SH	SH	L	L	VL	VL	SL	SL	M	M					VL	L	VL	L
SCR	SL	L	L	L									H	SH	H	H	L	SL	L	L	VL	VL	VL	L	VL	L	VL	VL				

Table 7. Correlation assessments of DMs on CSs and criteria.

	FS				*EMS*				*WDP*				*MC*				*QCS*				*M*				*F*				*RL*			
	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4
QD	L	VL	VL	VL	SH	SH	H	SH					H	H	SH	H	SH	M	SH	SH	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	L	VL
P	VH	VH	VH	H					VL	VL	VL	VL	SL	SL	SL	SL																
ENRC	VL	VL	VL	L	SL	SL	L	L					SH	H	H	SH					SL	M	SH	L	SL	SL	M	SL				
DS																	SH	SH	H	H	SL	M	SH	L	SL	SL	M	SL				
GD	H	M	SH	M									VH	H	H	SH																
RRR					SH	H	H	SH	SH	M	SH	M	L	L	VL	VL	SL	L	SL	SL	SL	M	H	SH					VH	VH	VH	VH
PP																	H	M	H	SL	SL	SH	H	L	SH	H	SH	H				

Table 8. Assessments of DMs on suppliers with respect to criteria.

	a_1				a_2				a_3				a_4				a_5			
	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4	DM_1	DM_2	DM_3	DM_4
QD	SH	SL	SH	SH	H	H	H	H	SH	SH	SH	SH	SL	M	SL	SH	M	H	SH	SH
P	3				2				3.5				2.5				2.5			
ENRC	M	M	M	SL	SL	L	SL	VL	H	M	SH	SL	SH	SH	M	M	M	SH	M	SH
DS	100				80				115				90				100			
GD	SH	SH	SH	H	SH	M	H	SH	SL	SL	SH	M	H	VH	VH	H	H	H	VH	H
RRR	85%				90%				95%				97%				92%			
PP	SH	M	SL	SH	M	SH	SH	SL	SL	SH	SH	M	SL	SL	M	SL	SL	M	SL	SH

Table 9. Criteria weights (when $\lambda = 1$).

	QD	*P*	*ENRC*	*DS*	*GD*	*RRR*	*PP*
e_j^s	0.2129	0.1341	0.1828	0.0737	0.1781	0.1420	0.0763
e_j^o	0.1346	0.1545	0.1241	0.1563	0.1404	0.1576	0.1325
e_j	0.1738	0.1443	0.1535	0.1150	0.1593	0.1498	0.1044

Table 10. Ranking result of suppliers.

	S(RS_i)	**Ranking**	RP_i	**Ranking**	**S(MF_i)**	**Ranking**	**Final Ranking**
a_1	3.3708	3	1.6309	3	1.0165	3	3
a_2	4.4770	1	1.1696	5	1.2188	1	1
a_3	2.9621	5	1.9039	1	0.9648	5	5
a_4	3.2914	4	1.5916	4	0.9936	4	4
a_5	3.6141	2	1.6409	2	1.0381	2	2

5. Results and Discussion

The MULTIMOORA method is compared with the COPRAS, the VIKOR and the TOPSIS. The results of comparative suppliers ranking are shown in Figure 6. Obviously, although the rankings of the suppliers are slightly different, the best supplier obtained by the four methods is still a_2 and the worst supplier is a_3. As a result, this comparative analysis validates the robustness and effectiveness of the MULTIMOORA method.

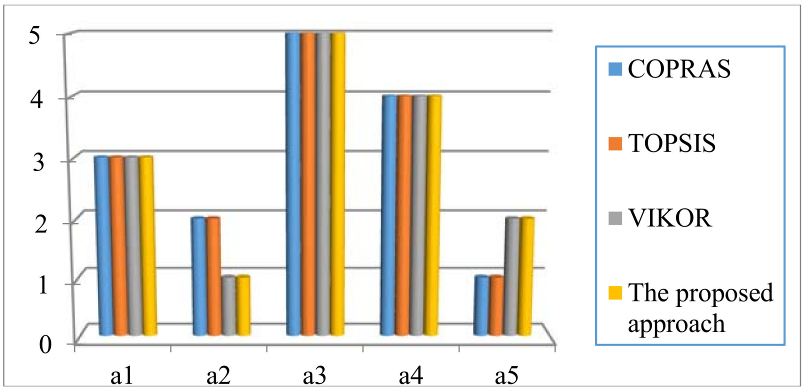


Figure 6. Comparative ranking of suppliers.

Sensitivity analysis includes the impact of the variable values of λ on the ranking of suppliers. In order to study the change of the rank of, varying λ were set.

The ranking results with varying λ of supplier ranking are demonstrated in Figure 7. The ranking of suppliers is $a_2 \succ a_5 \succ a_1 \succ a_4 \succ a_3$, when $0.3 < \lambda < 3$. Although the value of λ is changed, the best and worst choices are still a_2 and a_3, respectively. Therefore, this result proves the applicability of this method.

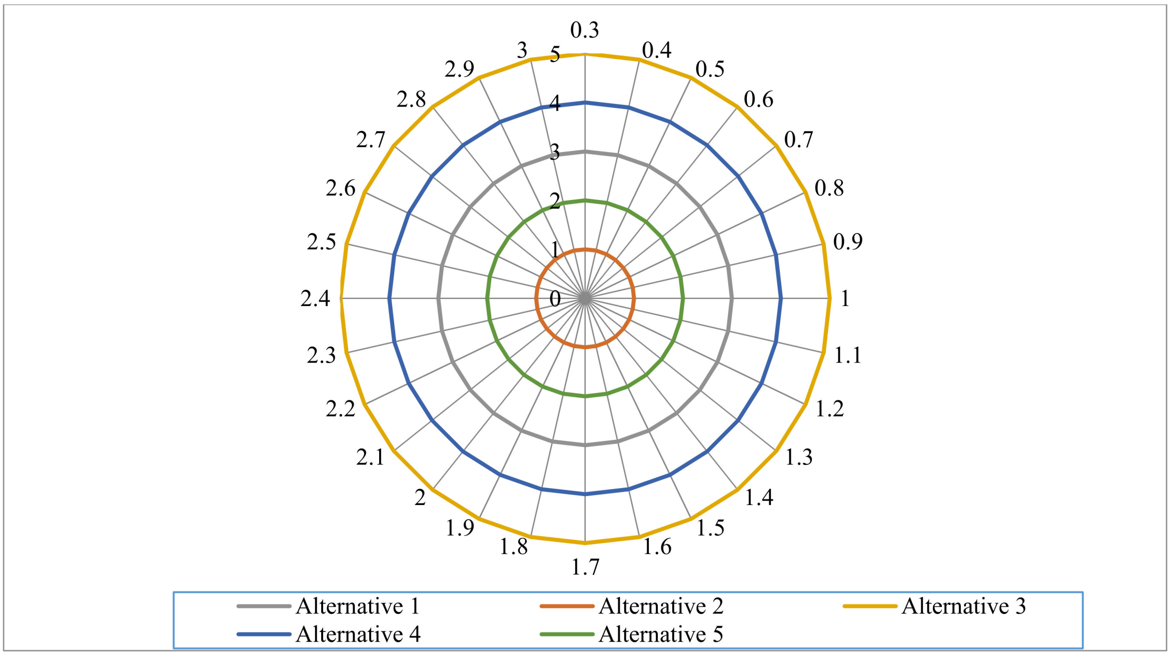


Figure 7. The radar plot showing the ranking results with varying λ.

6. Managerial Implications

The proposed two-stage method has provided solutions and recommendations for studying the advantages and disadvantages of the fresh product GSCM. Furthermore, the model makes contributions to fresh product companies for improving competitive performance.

(1) For CRs, the test standard of security (*TSS*) is assigned the highest priority of 0.3426, it proves that customers attach much significance to the test standard of product security. Therefore, a fresh product company should provide high-standard products to customers. Moreover, people not only prefer product security but also pay attention to the price of fresh product. Thus, managers are recommended to reduce product prices on the premise of guaranteeing security standards.

(2) The *MC* (management commitment) is the most critical CSs and has a priority of 0.2643 in performance evaluation. As shown in Table 6, since the MC has the highest internal correlation with *Q* (quality), the *MC* in the CSs can make a reasonable and effective response to the *Q* in the CRs. Therefore, company managers must not only focus on the quality of products and services, but also put more emphasis on management commitments. For example, companies can try to help employees implement their career planning as much as possible to achieve their desired life.

In sum, this proposed method is a customer-oriented work that can improve the performance of fresh product companies. Other related industry companies can refer to the proposed method to enhance their business competition. In addition, due to the applicability of the proposed method, they can also modify the CRs and CSs according to the company's specific situation.

7. Conclusions

GSCM has become a significant concern for green fresh product companies to gain competitive advantage. Thus, a novel two-stage integrated MCDM method is established to comprehensively select the optimal fresh product supplier and provide advice for companies to improve their production, service and management. The improvements of this MCDM method are as follows.

(1) Qualitative and quantitative criteria are all considered in selection criteria. Meanwhile, fuzzy set theory is used to evaluate the criteria.

(2) The proposed method integrates QFD, fuzzy BWM, Shannon entropy and fuzzy MULTIMOORA. Among this proposed method, fuzzy BWM is applied to derive the subjective criteria weights.

Shannon entropy is used to obtain objective weights. Thus, a composite selection process is established to take into account the priorities of CRs and CSs. In addition, the subjective and objective weights are all considered, which makes the selection procedure more accurate.

(3) In order to select the suppliers, the fuzzy MULTIMOORA method and other three ranking approaches are implemented. The results, showed in Section 4, illustrate that the proposed method is applicable when selecting the fresh product supplier. Meanwhile, by changing the value of parameters λ, the proposed method is further proved to be reasonable and robust.

(4) The method illustrated with a numerical example, might be a practical solution for enhancing the management level of fresh product supply companies. Thus, the results of this study may be the most convincing choice.

This research also has some limitations, which provide an opportunity for further research. In order to accommodate the management needs in the selection of fresh product supplier in the future, evaluation criteria need to be further improved, it should be more feasible than the existing research. In addition, game theory and Taguchi loss function can be used in the integrated method to solve MCDM problems from a different perspective.

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