Fishmeal Supplier Evaluation and Selection for Aquaculture Enterprise Sustainability with a Fuzzy MCDM Approach

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Abstract: In the aquaculture industry, feed that is of poor quality or nutritionally imbalanced can cause problems including low weight, poor growth, poor palatability, and increased mortality, all of which can induce a decrease in aquaculture production. Fishmeal is considered a better source of protein and its addition as an ingredient in the aquafeed makes aquatic animals grow fast and healthy. This means that fishmeal is the most important feed ingredient in aquafeed for the aquaculture industry. For the aquaculture industry in Taiwan, about 144,000 ton/USD $203,245,000 of fishmeal was imported, mostly from Peru, in 2016. Therefore, the evaluation and selection of fishmeal suppliers is a very important part of the decision-making process for a Taiwanese aquaculture enterprise. This study constructed a multiple criteria decision-making evaluation model for the selection of fishmeal suppliers using the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) approach based on the weights obtained with the entropy method in a fuzzy decision-making environment. This hybrid approach could effectively and conveniently measure the comprehensive performance of the main Peruvian fishmeal suppliers for practical applications. In addition, the results and processes described herein function as a good reference for an aquaculture enterprise in making decisions when purchasing fishmeal.

Keywords: aquaculture; fishmeal supplier selection; entropy; VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR); fuzzy logic

1. Introduction

On 17 September 2014, the Member States of the United Nations announced the Sustainable Development Goals (SDGs) as part of the 2030 Agenda for sustainable development. The 2030 Agenda set aims for the contribution and conduct of fisheries and aquaculture towards food security and nutrition, and the use of natural resources to ensure sustainable development in economic, social, and environmental terms. According to statistics from the Food and Agriculture Organization (FAO) of the United Nations, aquaculture provided only 7% of fish for human consumption in 1974, but this share has since increased to 26% in 1994, and 44% in 2014. Aquaculture has seen an impressive growth in the supply of farmed fish, which overtook that of wild-caught fish for human consumption in 2014 [1]. This makes the aquaculture industry an important source of aquatic food. Taiwan is one of the top 25 countries in this industry with a total production of 340,600 tons and ranked 19th in 2014 [1].

Aquafeed is a very significant factor for production in the aquaculture industry and it accounts for about 40–60% of the cultivation cost. In addition, the feed quality and its nutrient content greatly affects the growth of aquatic animals as poor-quality feed or nutrient imbalances can cause low

weight, poor growth, feed inefficiency, and increase the mortality rate. Therefore, it is very important to choose the best source of feed for sustainable development in aquaculture production. Fishmeal is considered the most nutritious, digestible source of protein for farmed-fish feed. Fishmeal is added to the aquafeed to ensure that the aquatic animals grow fast and healthy, and can improve the quality of the related aquaculture products. Effective screening of the source of this important raw material is necessary to maintain the quality of related products and establish inherent goodwill in the industry. Therefore, an aquaculture enterprise cannot consider price alone as the major consideration for procurement. Meeting the required quality, supplying the appropriate quantity, timely delivery, and long-term partnerships are all factors that should be considered for the evaluation and selection of fishmeal vendors. Taiwan's aquaculture industry imported about 144,000 ton/USD $203,245,000 of fishmeal from Peru, India, Thailand, and Vietnam in 2016. Peru is not only the world's leading exporter of fishmeal, but also the largest supplier for Taiwan's aquaculture industry. However, there are many suppliers of fishmeal in Peru and their supply capacity, product quality, delivery term, and cooperative attitude all vary. Therefore, setting up practical evaluation criteria and a method for the evaluation and selection of fishmeal suppliers from Peru would be helpful for Taiwan's aquaculture enterprises. An example of raw material supplier selection is also given to demonstrate the proposed solution to this kind of problem.

The problems of supplier evaluation and selection have received considerable attention in academic study and in practice. Numerous multiple criteria decision making (MCDM) approaches have been proposed to tackle the problem such as the analytic hierarchy process (AHP), analytic network process (ANP), mathematical programming, technique for order preference by similarity to ideal solution (TOPSIS), preference ranking organization method for enrichment of evaluations (PROMETHEE), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), and hybrid or extended fuzzy approaches (see Table 1) [2–32]. Amongst these methodologies, many approaches have used criteria weightings that have been determined by subjective evaluations by decision makers or experts for pairwise comparison or direct rating methods. Furthermore, for the VIKOR method, Opricovic and Tzeng [33] have described the advantages of its theory, and Opricovic and Tzeng [34] have compared it with other outranking methods, both of which illustrate the benefits of VIKOR. Therefore, to reduce uncertainties arising from subjective factors, this work adopted the entropy method to objectively determine the criteria weights. Then, based on the entropy weightings, the VIKOR approach was applied to process the performance rating of the alternatives. In addition, to capture and handle the human appraisal of ambiguity, uncertainty, and subjectivity, linguistic variables in the fuzzy sets were integrated into the supplier evaluation and selection process. This hybrid fuzzy MCDM technique was applied to evaluate and select fishmeal suppliers from Peru for Taiwan's aquaculture enterprise. The VIKOR approach was used based on weightings obtained with the entropy method in a fuzzy decision-making environment. The advantage of this approach was that we only needed to evaluate the merits of the alternatives based on linguistic variables under each criterion. These linguistic variables were converted into scores, which were then utilized to calculate the fuzzy entropy weights to help clarify the importance of the criteria. These weights were then applied with the fuzzy VIKOR approach to derive a comprehensive performance evaluation for the complex supplier selection problem. Thus, the overall scores for each supplier in each criterion can be obtained, and the selection decision made accordingly. This method is more effective and convenient in practical applications and provides better decision-making quality. This paper also discusses an empirical case study to demonstrate how an aquaculture enterprise can implement this solution. The results and processes provide a good reference to assist an aquaculture enterprise in Taiwan in the making of fishmeal purchasing decisions.

Table 1. Related research for supplier selection.

Authors	Approaches	Field of Empirical Study
Tam and Tummala, 2001	AHP	Telecommunications company
Dulmin and Mininno, 2003	PROMETHEE-GAIA	Public road and rail transportation
Kumar et al., 2004	Fuzzy integer goal programming	Auto-parts company
Chen et al., 2006	Fuzzy TOPSIS	High-tech company
Kumar et al., 2006	Fuzzy programming	Auto-parts company
Gencer and Gürpinar, 2007	ANP	Electronic firm
Xia and Wu, 2007	AHP	CPU supplier
Sanayei et al., 2008	MAUT and LP	Automobile manufacturer
Yang et al., 2008	Fuzzy AHP	High-tech industries
Amin and Razmi, 2009	Fuzzy set theory	Internet service provider
Boran et al., 2009	Fuzzy TOPSIS	Automotive company
Wang et al., 2009	Fuzzy AHP and TOPSIS	Lithium-ion battery protection IC
Lin et al., 2010	ANP	Semiconductor industry
Chamodrakas et al., 2010	Fuzzy AHP and programming	Electronic marketplaces
Sanayei et al., 2010	Fuzzy VIKOR	Automobile part manufacturing
Shemshadi, et al., 2011	Fuzzy VKOR and Entropy	Petrochemical factory
Jahan et al., 2011	VIKOR	Health care
Amin et al., 2011	fuzzy SWOT and LP	Auto parts company
Kilincci and Onal, 2011	Fuzzy AHP	Washing machine company
Feng et al., 2011,	Multi-objective 0–1 programming	CSA company
Zhao and Yu, 2011	Information entropy	Petroleum enterprises
Vahdani et al., 2012	Locally linear neuro-fuzzy	Cosmetics industry
Chatterjee and Chakraborty, 2012	PROMETHEE II and Gray relation	Rotating machine part
Hsua et al., 2012	DANP with VIKOR	Decoration corporation
Chen and Chao, 2012	AHP and CFPR	Electronic company
Peng and Xiao, 2013	PROMETHEE and ANP	Bush materials
Zhao and Guo, 2014	fuzzy-entropy and fuzzy-TOPSIS	Thermal power equipment
Kuo et al., 2015	DANP with VIKOR	Green Electronics Company
Chung et al., 2016	ANP and IPA	Bicycle manufacturer
Yazdani et al., 2017	DEMATEL	Food-based production company
Wan et al., 2017	ANP and ELECTRE II	Auto manufacture company

The remainder of this paper is organized as follows. In Section 2, the criteria for raw material supplier selection are identified. In Section 3, the research methodology including fuzzy entropy and fuzzy VIKOR is introduced. Section 4 includes the numerical case study that uses a Taiwan aquaculture enterprise as an example, thus demonstrating the process of fishmeal supplier evaluation and selection from the proposed model, the procedure, and method. The results of the empirical research are also analyzed. In Section 5, some conclusions are offered.

2. Criteria for Fishmeal Supplier Selection

Supplier selection is the process of finding appropriate suppliers who are able to provide the buyer with the right quality products and/or services at an acceptable price and delivery time, and in the required quantities. This is one of the most critical activities in establishing an effective supply chain. Obviously, supplier selection is a multiple criteria decision making (MCDM) problem affected by several conflicting factors such as price, quality, delivery, and so on.

Historically, several methodologies have been developed for evaluating, selecting, and monitoring potential suppliers that take into account factors such as quality, logistics, and cost. Dickson [35], in one of the well-known studies on supplier selection, identified 23 important evaluation criteria for supplier selection. Barbarosoglu and Yazgac [36] helped a company find the proper supplier by adopting Dickson's criteria to evaluate supplier performance. In recent years, a number of researchers have begun to identify some of the relevant criteria. Ng [37] constructed a simple and effective supplier evaluation model to deal with problems of supplier selection with

supply variety, quality, delivery, and price as the evaluation criteria. Shemshadi et al. [17], Chen et al. [5], Boran et al. [12], and Yang et al. [10] identified product quality, effort to establish cooperation, the supplier's technical level, delay on delivery, price/cost, profitability of supplier, relationship closeness, technological capability, conformance quality, conflict resolution, delivery performance, supplier profile, and risk as factors for determining the best supplier. Chen and Kumar [38] established an evaluation model to obtain the best supplier with the result to be given to a company as a strategy reference. They proposed the following five criteria: overall cost of the product, quality of the product, service performance of supplier, supplier's profile, and risk factor. By consolidating several studies, Sanayei et al. [16] proposed five categories: product quality, on-time delivery, price/cost, supplier's technological level, and flexibility. Shyur and Shih [39] introduced evaluation indictors including on-time delivery, product quality, price/cost, facility and technology, responsiveness to customer needs, professionalism of salespeople, and quality of relationship into the supplier evaluation process. Ávila et al. [40] defined product cost, financial stability, synergy potential, logistics cost, payment flexibility, after sales service cost, and production capacity as supplier evaluation criteria. There have been a significant number of studies discussing supplier selection and a wide range of mathematical methods have been used to provide solutions for supplier selection, as shown in Table 1.

In this study, based on the principles espoused in [35] and in consultation with the management team of a typical aquaculture company in Taiwan, we listed 22 factors that are often used for evaluating fishmeal suppliers in Taiwan's aquaculture enterprise. To evaluate the importance of the factors from an expert viewpoint, questionnaires with responses given in the seven-point Likert scale (from one to seven) were used collect expert opinions, with preferences of very unimportant, essentially unimportant, weakly unimportant, fair, weakly important, essentially important, and very important. Seventeen experts with many years of work experience in Taiwan's aquaculture industry were invited to evaluate the importance of these 22 factors. The demographic information of these 17 respondents is summarized in Table 2. The Cronbach's α was 0.918, which represents excellent internal consistency reliability. The Kaiser-Meyer-Olkin (KMO) measuring sampling adequacy provides an index (between 0 and 1) of the proportion of variance among the variables that might be common variance. A high KMO indicates that sampling is adequate, indicating the existence of a statistically acceptable factor solution representing relationships between the parameters. In our study, the Kaiser-Meyer-Olkin (KMO) value was found to be 0.689, which was better than the suggested value of 0.6 [41]. The factors, as well as the importance of the factors, are summarized in Table 3. The importance values of the 22 factors fell in a range between 5.000 and 6.647. When the importance of factors was identified, it was unrealistic to consider all of the factors simultaneously given the limited time and resources. To improve the evaluation and selection process, 10 major factors were determined as the evaluation criteria given higher priority after discussion with the management team: "Stability of product quality"; "Stability of supply capability"; "Reasonableness of quoted price"; "Financial capability and condition"; "Flexibility in changing shipment schedule"; "Potential cooperation in the future"; "Operating control of pre-delivery"; "Satisfaction with claims for damages"; "Exactness for presenting documents to the bank"; and "Control capability of on-time delivery", as shown in Table 4.

Table 2. Demographic information of the experts who evaluated the criteria.

Demographic Information		Frequency
Gender	Male	3
	Female	14
Age	30–35	10
	35–40	3
	40–55	4
Working experience	Under 5	4
	5–10	6
	Above 10	7
Education level	College	3

	Bachelor	10
	Master	4
Occupation	Purchasing manager	2
	Purchasing specialist	15

Table 3. Importance of the 22 factors.

Factors	Importance	Ranking
1. The ratio of supply quantity to total purchase quantity	5.118	18
2. Stability of supply capability	6.235	2
3. Stability of product quality	6.647	1
4. Completeness of product packaging	5.294	15
5. Operating control of products before delivery	5.529	7
6. Control capability for on-time delivery	5.824	4
7. Records of claim for damages or complaints	5.000	22
8. Satisfaction with handling claims for damages	5.471	8
9. Efficiency of handling claims for damages	5.059	19
10. Facilities and equipment of production plant	5.059	19
11. Financial capability and condition	5.471	8
12. Efficiency of communication	5.176	17
13. Exactness in presenting documents to the bank	5.471	8
14. Operating control of shipping documents	5.353	13
15. Brand awareness	5.235	16
16. Reasonableness of quoted price	5.882	3
17. Reasonableness of shipping freight quotes	5.412	11
18. Flexibility and coordination of order modification	5.412	11
19. Flexibility for changing shipment schedule	5.706	5
20. Service attitudes of operational staff	5.353	13
21. Closeness of previous business relationship	5.059	19
22. Possibility of establishing long-term cooperation	5.588	6

Table 4. Fishmeal supplier selection evaluation criteria.

	Evaluation Criteria	Importance
C_1	Stability of product quality	6.647
C_2	Stability of supply capability	6.235
C_3	Reasonableness of quoted price	5.882
C_4	Control capability of on-time delivery	5.824
C_5	Flexibility for changing shipment schedule	5.706
C_6	Possibility of establishing long-term cooperation	5.588
C_7	Operating control of product before delivery	5.529
C_8	Satisfaction with handling claims for damages	5.471
C_9	Exactness for presenting documents to the bank	5.471
C_{10}	Financial capability and conditions	5.471

3. The Proposed Method

In the process of decision-making, decision-makers often make subjective judgments based on their own knowledge and experience in ambiguous or vague statements, such as good, poor, important, not important, and so on, given in linguistic terms. To deal with the ambiguity and subjectivity of human judgment, linguistic variables have been introduced with these judgments expressed by a membership function within a closed interval of [0, 1] as in fuzzy set theory [42]. Bellman and Zadeh [43] proposed a methodology for decision-making in a fuzzy environment to resolve the lack of precision in assigning the degree of importance of evaluation criteria and the ratings of alternatives based on the evaluation criteria. In this section, we introduce the concepts and processes used to define the linguistic variables, to calculate the entropy weights, and the VIKOR procedure.

3.1. Linguistic Variables and Fuzzy Numbers

A linguistic term or linguistic variable is one whose value is given by words or sentences expressed in a natural language. In this study, we used these kinds of expression in linguistic terms to evaluate the performance of selected alternatives regarding each criterion: "Very poor", "Poor", "Medium poor", "Fair", "Medium good", "Good", and "Very good", with respect to a trapezoidal fuzzy number (TFN) as proposed by [16] and [44]. A TFN is a fuzzy set $\tilde{A}$ on X if its membership function is a mapping $\mu_{\tilde{A}}(x):X \rightarrow [0,1]$. The membership function of a fuzzy number $\tilde{A}$ can be described as follows:

$$\mu_{A}(x) = \begin{cases} 0 & , \ x \leq a_1 \ or \ x \geq a_4 \\ (x-a_1)/(a_2-a_1) & , \ a_1 \leq x \leq a_2 \\ (a_4-x)/(a_4-a_3) & , \ a_3 \leq x \leq a_4 \\ 1 & , \ a_2 \leq x \leq a_3 \end{cases} \tag{1}$$

The trapezoidal fuzzy number can be denoted by $\tilde{A}=(a_1,a_2,a_3,a_4)$, where $\{(a_1,a_2,a_3,a_4)|a_1,a_2,a_3,a_4 \in R; a_1 \leq a_2 \leq a_3 \leq a_4\}$ which denotes the smallest possible, the most promising, and the largest possible values, respectively, as shown in Figure 1. Table 5 and Figure 2 show the corresponding TFN for each linguistic variable.
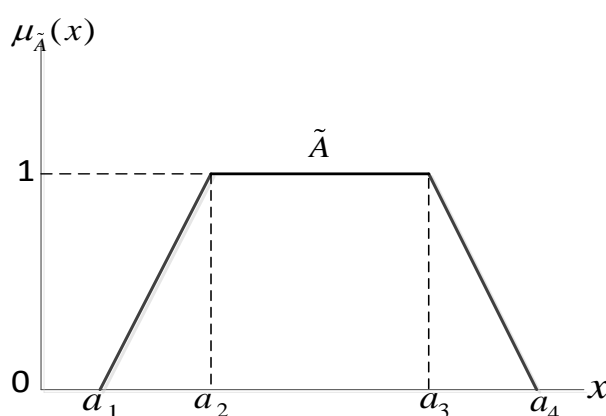

Figure 1. Trapezoidal fuzzy number $\tilde{A}$.
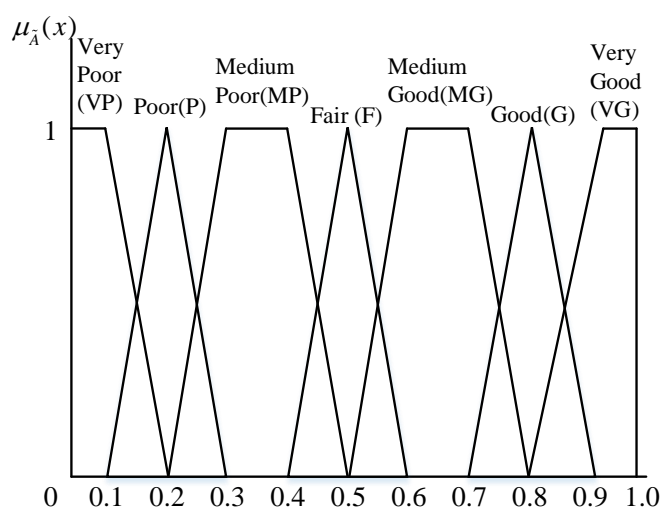
Figure 2. Linguistic variables for the fuzzy rates of alternatives.

Table 5. Fuzzy linguistic assessment variables.

Linguistic Variables	Trapezoidal Fuzzy Number (TFN)
Very poor, VP	(0.0, 0.0, 0.1, 0.2)
Poor, P	(0.1, 0.2, 0.2, 0.3)
Medium poor, MP	(0.2, 0.3, 0.4, 0.5)
Fair, F	(0.4, 0.5, 0.5, 0.6)
Medium good, MG	(0.5, 0.6, 0.7, 0.8)
Good, G	(0.7, 0.8, 0.8, 0.9)
Very good, VG	(0.8, 0.9, 1.0, 1.0)

The algebraic operations for the two TFNs (addition, subtraction, multiplication, division and reciprocity) applied in this study were based on the arithmetic of special fuzzy numbers as introduced by [44].

After the evaluation process in the fuzzy environment, the results are still in the fuzzy number format. Therefore, it is necessary to further conduct defuzzification to transform the fuzzy numbers to crisp numbers. Based on the center of area (COA) method, TFN $\tilde{A} = (a_1, a_2, a_3, a_4)$ was defuzzified to a crisp value ($C_{\tilde{A}}$) as the centroid value of TFN $\tilde{A}$, as follows:

$$
\begin{aligned}
C_{\tilde{A}} &= \frac{\int_{a_1}^{a_4} x \mu_{\tilde{A}}(x) dx}{\int_{a_1}^{a_4} \mu_{\tilde{A}}(x) dx} \\
&= \frac{\int_{a_1}^{a_2} x(\frac{x - a_1}{a_2 - a_1}) dx + \int_{a_2}^{a_3} x dx + \int_{a_3}^{a_4} x(\frac{a_4 - x}{a_4 - a_3}) dx}{\int_{a_1}^{a_2} \frac{x - a_1}{a_2 - a_1} dx + \int_{a_2}^{a_3} 1 dx + \int_{a_3}^{a_4} \frac{a_4 - x}{a_4 - a_3} dx} = \frac{a_3^2 + a_4^2 + a_3 a_4 - a_1^2 - a_2^2 - a_1 a_2}{3(a_3 + a_4 - a_1 - a_2)}
\end{aligned}
\tag{2}
$$

3.2. Group Decision Making

A good decision-making process is not only comprised of arbitrary decisions made by individuals, but also requires a combination of professional judgments. In this study, for the sustainable management of an enterprise, we developed a method for the evaluation and selection process of fishmeal suppliers to obtain the appropriate and correct results. The group multiple criteria decision making (GMCDM) method includes the following elements: (1) m possible suppliers, $A = \{A_1, A_2, \cdots, A_m\}$; (2) n evaluation criteria, $C = \{C_1, C_2, \cdots, C_n\}$; and (3) k decision-makers, $D = \{D_1, D_2, \cdots, D_k\}$. The performance evaluation matrix of the supplier $A_i (i = 1, 2, \cdots, m)$ with respect to criteria $C_j (j = 1, 2, \cdots, n)$ by decision-maker D_k using the fuzzy linguistic assessment variables can be constructed as follows:

$$
\tilde{E}^k = \left[\tilde{e}_{ij}^k \right]_{m \times n} =
\begin{array}{c}
\begin{array}{ccc} C_1 & \cdots & C_n \end{array} \\
\begin{array}{c} A_1 \\ \vdots \\ A_m \end{array}
\begin{pmatrix} \tilde{e}_{11}^k & \cdots & \tilde{e}_{1n}^k \\ \vdots & \ddots & \vdots \\ \tilde{e}_{m1}^k & \cdots & \tilde{e}_{mn}^k \end{pmatrix}_{m \times n}
\end{array}
\quad i = 1, 2, \cdots, m; \quad j = 1, 2, \cdots, n; \quad k = 1, 2, \cdots r
\tag{3}
$$

where $\tilde{e}_{ij}^k = (e_{1ij}^k, e_{2ij}^k, e_{3ij}^k, e_{4ij}^k)$.

Therefore, for the k decision makers conducting the group evaluation process, the aggregated fuzzy performance rating of alternatives with respect to each criterion as an integrated fuzzy decision matrix $\tilde{E}$ can be calculated as:

$$\tilde{E} = [\tilde{e}_{ij}]_{m \times n} = \begin{bmatrix} \tilde{e}_{11} & \tilde{e}_{12} & \cdots & \tilde{e}_{1n} \\ \tilde{e}_{21} & \tilde{e}_{22} & \cdots & \tilde{e}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{e}_{m1} & \tilde{e}_{m2} & \cdots & \tilde{e}_{mn} \end{bmatrix} = [(e_{1ij}, e_{2ij}, e_{3ij}, e_{4ij})]_{m \times n}$$

$$= \begin{bmatrix} (e_{111}, e_{211}, e_{311}, e_{411}) & (e_{112}, e_{212}, e_{312}, e_{412}) & \cdots & (e_{11n}, e_{21n}, e_{31n}, e_{41n}) \\ (e_{121}, e_{221}, e_{321}, e_{421}) & (e_{122}, e_{222}, e_{322}, e_{422}) & \cdots & (e_{12n}, e_{22n}, e_{32n}, e_{42n}) \\ \vdots & \vdots & \ddots & \vdots \\ (e_{1m1}, e_{2m1}, e_{3m1}, e_{4m1}) & (e_{1m2}, e_{2m2}, e_{3m2}, e_{4m2}) & \cdots & (e_{1mn}, e_{2mn}, e_{3mn}, e_{4mn}) \end{bmatrix},$$

where

$$e_{1ij} = \min_{k}\{e_{1ij}^{k}\}; \quad e_{2ij} = \frac{1}{r}\sum_{k=1}^{r} e_{2ij}^{k}; \quad e_{3ij} = \frac{1}{r}\sum_{k=1}^{r} e_{3ij}^{k}; \quad e_{4ij} = \max_{k}\{e_{4ij}^{k}\} \tag{4}$$

3.3. Determination of Criteria Weightings

Shannon [45] introduced the concept of entropy into information theory, which is used to measure information and uncertainty, and to characterize and signal uncertainty for the information sources. If the entropy of an evaluation criterion is smaller, the amount of information provided by the criterion is greater, and the greater the role in the comprehensive evaluation process, the higher the weight. The entropy weight method mainly uses the uncertainty represented by the entropy value as determined by information theory to calculate the decision information that can be transmitted by each evaluation criterion, then obtains the relative weights between the criteria. The relative weight calculated by the entropy weight method is obtained by using the evaluation information for each alternative under each evaluation criterion where there are no subjective factors. In other words, this is an objective weight. For this study, the processes of computing entropy weights were as follows:

(1) According to the established fuzzy decision evaluation matrix $\tilde{E}$, the fuzzy decision evaluation matrix was defuzzified to a crisp value matrix by

$$\tilde{E} = \left[\tilde{e}_{ij}\right]_{m \times n} \rightarrow F = \left[f_{ij}\right]_{m \times n} \tag{5}$$

where $\left[f_{ij}\right]_{m \times n} = \begin{matrix} & C_1 & \cdots & C_n \\ A_1 & \left(f_{11} & \cdots & f_{1n} \right. \\ \vdots & \vdots & \ddots & \vdots \\ A_m & \left. f_{m1} & \cdots & f_{mn} \right)_{m \times n} \end{matrix}$ $i = 1, 2, \cdots, m; \quad j = 1, 2, \cdots, n$

(2) Normalize the evaluation matrix.

$$R = \left[r_{ij}\right]_{n \times m} = \begin{matrix} & C_1 & \cdots & C_n \\ A_1 & \left(r_{11} & \cdots & r_{1n} \right. \\ \vdots & \vdots & \ddots & \vdots \\ A_m & \left. r_{m1} & \cdots & r_{mn} \right)_{m \times n} \end{matrix} \qquad r_{ij} = \frac{f_{ij}}{\sum\limits_{i=1}^{m} f_{ij}}, \quad i = 1, 2, \cdots, m; \ j = 1, 2, \cdots, n \tag{6}$$

(3) Calculate the Shannon entropy value of each evaluation criterion:

$$H_j = \left(-\frac{1}{\ln m}\right)\sum_{i=1}^{m} r_{ij} \ln r_{ij}, \quad i = 1, 2, \ldots, m; \ j = 1, 2, \ldots n \tag{7}$$

(4) The entropy weights of each evaluation criterion w_j were found as follows:

$$w_j = \frac{1 - H_j}{\sum\limits_{j=1}^{n} (1 - H_j)}, \quad i = 1, 2, \ldots, m; \ j = 1, 2, \ldots n; \quad W = (w_1, w_2, \ldots, w_n), \ \sum_{j=1}^{n} w_j = 1 \tag{8}$$

3.4. Evaluation and Selection of Alternatives

The VIKOR method proposed by [46] is one of the optimal compromise solution methods used in multiple criteria decision making. The basic concept is to define the positive ideal solution and the negative ideal solution. The so-called positive ideal solution refers to the best alternatives with respect to each evaluation criterion, while the negative ideal solution consists of the worst alternatives for each evaluation criterion. The alternatives are then prioritized by comparing the evaluation values of each alternative with their closeness to the positive ideal solution. To calculate the closeness of the alternatives to the positive ideal solution, the values of the evaluation criteria must be aggregated. In VIKOR, the aggregating function was developed from the *L_p-metric* through a compromise programming method [47] that focuses on ranking and selecting from a set of alternatives to determine a compromise solution that provides the maximum group utility for the majority, and a minimum of individual regret for the opponent, which can help the decision makers reach a final decision. The processes of applying VIKOR for alternative selections are as follows:

(1) Determine the evaluation values of the best and the worst alternatives/suppliers for each criterion *j*: f_j^+ and f_j^-

$$f_j^+ = \max_i f_{ij}; \quad f_j^- = \min_i f_{ij} \qquad i = 1, 2, \cdots, m; \quad j = 1, 2, \cdots, n \tag{9}$$

(2) Compute the weighted distance ratio to the best value for every alternative/supplier with respect to each criterion: S_i and R_i

$$S_i = \sum_{j}^{n} w_j \left(\frac{f_j^+ - f_{ij}}{f_j^+ - f_j^-} \right), \tag{10}$$

$$R_i = \max_j \left(w_j \left(\frac{f_j^+ - f_{ij}}{f_j^+ - f_j^-} \right) \right). \tag{11}$$

(3) Compute the values Q_i as follows:

S_i is the weighted summation of the distance to the best evaluation value of alternative *i* with respect to all criteria; R_i is calculated by the maximum weighted distance to the best evaluation value of alternative *i* with respect to the *j*th criterion; and S_i refers to the overall benefits of the *i*th alternative where the smaller the value, the larger the benefits. That is, $S^+ = \min S_i$, and $S^- = \max S_i$. R_i refers to the individual regret of the *i*th alternative where the smaller the value, the smaller the individual regret of the opponent. That is, $R^+ = \min R_i$, and $R^- = \max R_i$. Thus, the index Q_i is based on the consideration of both the group utility and individual regret of the opponent

$$Q_i = v \left(\frac{S_i - S^+}{S^- - S^+} \right) + (1 - v) \left(\frac{R_i - R^+}{R^- - R^+} \right) \tag{12}$$

where *v* is introduced as a weight for the strategy of maximum group utility, whereas 1 − *v* is the weight of the individual regret of the opponent.

(4) Rank the alternatives by sorting the values S_i, R_i and Q_i in ascending order.

(5) Propose as a comprise solution, alternative $A^{(1)}$, which is best ranked by the measure *Q* (minimum), if the following two conditions are satisfied:

C1 Acceptable advantage:

$$Q\left(A^{(2)}\right)-Q\left(A^{(1)}\right)\geq DQ={1}/{m-1} \tag{13}$$

where $A^{(2)}$ is the alternative in the second position in the ranking list bounded by Q and DQ.

C2 Acceptable stability in decision-making:

The alternative $A^{(1)}$ must also be the best ranked by S and/or R. This compromise solution is stable within a decision-making process, which could be the strategy of maximum group utility (when $v > 0.5$ is needed), or "by consensus" $v \approx 0.5$, or "with veto" ($v < 0.5$). Here, v is the weight of the decision-making strategy of the maximum group utility. If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of

(a) Alternatives $A^{(1)}$ and $A^{(2)}$ only if condition C2 is not satisfied;

(b) Alternatives $A^{(1)}, A^{(2)}, \cdots, A^{(m)}$, if condition C1 is not satisfied. $A^{(m)}$ is determined by the relation $Q(A^{(m)})-Q(A^{(1)})<DQ$ for maximum m (the positions of these alternatives are "in closeness").

4. Case Study

For aquaculture enterprises, the most important ingredient in the aquafeed is fishmeal. There was a slight decline in global fishmeal production and trade in 2017, but global production is still concentrated among a few top producers. Peru accounts for one-fifth of global production and remains the world's largest producer and exporter of fishmeal, accounting for nearly one-third of the global trade. There are two periods of time where fishing is allowed in the northern and central oceanic areas near Peru. The first period begins around April and runs to July, and the second fishing period starts from November and goes to January of the following year. The government of Peru realizes the importance of protecting its natural oceanic resources and has decided to reduce their fishing quota; therefore, fishermen must fish on the basis of published quotas, which has directly contributed to competitive tension in the supply side of the fisheries, causing a sharp fall in fishmeal production. Due to a decrease in supply due to the fishing quota, the fishmeal market is becoming more competitive. As a result, many small fishmeal factories in Peru have merged into larger main suppliers. About 80% of fishmeal production is now centralized.

To illustrate the proposed method, we considered an example where the managerial board of an aquaculture enterprise in Taiwan has to procure fishmeal for their aquatic stock. There are four main fishmeal companies in Peru considered as possible suppliers (see Table 6), and 10 important factors (as identified in Section 2) for evaluating these companies. To hedge risks, a committee of thirteen experts (decision-makers) with many years of work experience in the aquaculture industry of Taiwan was formed to select the most suitable fishmeal companies. Profiles of these experts are shown in Table 7.

Table 6. Profiles of candidate fishmeal suppliers.

Condition	A_1	A_2	A_3	A_4
Status	Listed	Non-Listed	Non-Listed	Non-Listed
Incorporation Date	25 July 1994	1 August 1945	13 January 1986	5 February 2006
Total Employees	2073	3502	7444	1495
Plants	5	16	9	7
Products	Fishmeal Fish oil	Fishmeal Fish oil	Fishmeal Fish oil Canned food Frozen food	Fishmeal Fish oil Frozen fish

Table 7. Profiles of experts evaluating the alternatives.

Demographic Information		Frequency
Gender	Male	3
	Female	10
Age	30–35	6
	35–40	3
	40–55	4
Working experience	Under 5	4
	5–10	6
	Above 10	3
Education level	College	3
	Bachelor	8
	Master	2
Occupation	Purchasing manager	2
	Purchasing specialist	11

The proposed model applied for fishmeal supplier selection for a firm operating in the field of aquaculture was comprised of the following steps:

Step 1: Using linguistic variable, thirteen decision makers were asked to rate the candidates with respect to each criterion (see Table 5). The ratings of the four suppliers by the decision makers under the various criteria are shown in Table 8.

Step 2: The linguistic evaluations shown in Tables 9 was converted into trapezoidal fuzzy numbers. Then, the aggregated fuzzy rating of alternatives as calculated by Equation (4) to construct the fuzzy decision matrix, as shown in Table 10. Then, the data in Table 11 were defuzzified by Equation (2) and normalized by Equation (6). Table 11 shows these processes for calculating the weight of each criterion.

Step 3: With the normalized values in Table 11, the entropy method was applied to determine the weight of each criterion by Equations (7) and (8). The crisp values for the decision matrix and the weight of each criterion were computed as shown in the bottom part of Table 11.

Step 4: Equation (9) was used to determine the best and the worst values of each criterion for the rating of all suppliers from upper part of Table 11, and the results are shown in the upper part of Table 12.

Step 5: The values of S_i, R_i, and Q_i were calculated by Equations (10)–(12) for the four candidate suppliers, as shown in Table 13.

Step 6: The suppliers were ranked by S, R, and Q in decreasing order as shown in Table 9.

Step 7: As seen in Table 9, supplier A_2 was ranked as the best by Q, but condition C1 was not satisfied $Q(A^{(2)}) - Q(A^{(1)}) < \dfrac{1}{4-1}$. Therefore, A_2 and A_1 were both appropriate choices.

Table 8. Linguistic evaluation of suppliers with respect to criteria by the decision-makers.

Expert/Criteria		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
D_1	A_1	G	MG	G	G	G	G	F	F	MG	G
	A_2	G	G	G	G	G	VG	MG	MG	MG	MG
	A_3	VG	MG	MG	MG	MG	MG	F	MG	MG	MG
	A_4	G	G	MG	MG	MG	VG	G	MG	MG	G
D_2	A_1	G	VG	G	G	G	VG	G	G	G	G
	A_2	MG	G	G	G	G	VG	MG	MG	MG	MG
	A_3	G	G	G	G	G	G	MG	MG	MG	MG
	A_4	G	G	MG	MG	MG	G	MG	F	F	G
D_3	A_1	G	G	VG	G	MG	VG	F	MG	MG	MG
	A_2	MG	VG	VG	G	G	VG	F	MG	MG	MG
	A_3	VG	MG	MG	MG	MG	G	F	MG	MG	MG
	A_4	VG	VG	G	G	G	VG	G	MG	MG	VG
D_4	A_1	G	G	VG	MG	MG	VG	F	MG	MG	MG
	A_2	MG	VG	VG	G	G	VG	F	MG	MG	MG
	A_3	VG	MG	MG	MG	MG	G	F	MG	MG	MG
	A_4	VG	VG	G	G	G	VG	G	MG	MG	VG
D_5	A_1	G	G	VG	MG	MG	VG	F	MG	MG	MG
	A_2	G	VG	VG	G	G	VG	F	MG	MG	MG
	A_3	VG	MG	MG	MG	MG	G	F	MG	MG	MG
	A_4	G	G	G	G	G	VG	G	MG	MG	G
D_6	A_1	G	G	VG	G	MG	VG	F	MG	F	MG
	A_2	MG	VG	VG	G	G	VG	MG	MG	MG	MG
	A_3	VG	MG	MG	MG	MG	G	F	F	MG	MG
	A_4	VG	VG	G	G	G	VG	G	MG	MG	G
D_7	A_1	G	G	VG	G	MG	VG	F	MG	MG	MG
	A_2	G	VG	VG	G	G	VG	MG	MG	MG	G
	A_3	VG	MG	MG	MG	MG	G	F	F	F	MG
	A_4	VG	VG	G	G	G	VG	G	MG	MG	G
D_8	A_1	G	G	VG	G	MG	VG	F	MG	MG	G
	A_2	MG	VG	VG	G	G	VG	MG	MG	MG	VG
	A_3	VG	MG	MG	MG	MG	G	F	F	F	MG
	A_4	VG	VG	G	MG	G	VG	G	MG	MG	G
D_9	A_1	MG	G	MG	MG	G	G	MG	F	MG	MG
	A_2	MG	G	MG	MG	G	G	G	F	MG	MG
	A_3	MG	MG	MG	F	MG	G	F	MP	F	MG
	A_4	MG	G	MG	MG	G	G	MG	F	MG	MG
D_{10}	A_1	MG	G	MG	MG	MG	G	MG	MG	MG	G
	A_2	MG	G	MG	MG	G	G	MG	F	MG	MG
	A_3	VG	VG	MG	MG	MG	G	MG	F	F	MG
	A_4	MG	MG	MG	F	F	F	F	F	F	F
D_{11}	A_1	G	G	G	G	MG	VG	F	MG	MG	MG
	A_2	MG	VG	VG	G	G	G	F	MG	MG	MG
	A_3	G	G	MG	MG	MG	G	MG	F	F	MG
	A_4	F	F	F	F	F	F	F	F	F	F
D_{12}	A_1	MG	G	MG	MG	G	G	MG	F	MG	MG
	A_2	MG	G	MG	MG	G	G	MG	F	MG	MG
	A_3	MG	G	MG	MG	G	G	MG	F	MG	MG
	A_4	MG	G	MG	MG	G	G	MG	F	MG	MG
D_{13}	A_1	G	G	VG	G	MG	VG	F	MG	MG	MG
	A_2	MG	VG	VG	G	G	VG	MG	MG	MG	MG
	A_3	VG	MG	MG	MG	MG	G	F	MG	MG	MG
	A_4	VG	G	G	G	G	VG	G	MG	MG	G

Table 9. Fuzzy numbers of supplier evaluations with respect to the criteria.

Expert		C_1	C_2	C_3	C_4	C_5
D_1	A_1	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_2	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
D_2	A_1	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_2	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_4	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
D_3	A_1	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
D_4	A_1	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
D_5	A_1	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
D_6	A_1	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
D_7	A_1	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
D_8	A_1	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
D_9	A_1	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	A_2	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
D_{10}	A_1	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)
D_{11}	A_1	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)
D_{12}	A_1	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	A_2	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	A_4	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
D_{13}	A_1	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
Expert		C_6	C_7	C_8	C_9	C_{10}
D_1	A_1	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)

	A_2	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_3	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
D_2	A_1	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)
	A_2	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)
D_3	A_1	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)
D_4	A_1	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)
D_5	A_1	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
D_6	A_1	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
D_7	A_1	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
D_8	A_1	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	A_2	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.8, 0.9, 1.0, 1.0)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
D_9	A_1	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.2, 0.3, 0.4, 0.5)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
D_{10}	A_1	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
	A_2	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)
D_{11}	A_1	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)
D_{12}	A_1	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
D_{13}	A_1	(0.8, 0.9, 1.0, 1.0)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_2	(0.8, 0.9, 1.0, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_3	(0.7, 0.8, 0.8, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)
	A_4	(0.8, 0.9, 1.0, 1.0)	(0.7, 0.8, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)

Table 10. Aggregated Fuzzy numbers of supplier evaluations with respect to the criteria.

	C_1	C_2	C_3	C_4	C_5
A_1	(0.5, 0.754, 0.777, 0.9)	(0.5, 0.792, 0.808, 1.0)	(0.5, 0.808, 0.885, 1.0)	(0.5, 0.723, 0.762, 0.9)	(0.5, 0.662, 0.731, 0.9)
A_2	(0.5,0.646,0.723,0.9)	(0.7, 0.862, 0.923, 1.0)	(0.5, 0.815, 0.900, 1.0)	(0.5, 0.754, 0.777, 0.9)	(0.7, 0.800, 0.800, 0.9)
A_3	(0.5,0.838,0.923,1.0)	(0.5, 0.669, 0.746, 1.0)	(0.5, 0.615, 0.708, 0.9)	(0.4, 0.608, 0.692, 0.9)	(0.5, 0.631, 0.715, 0.9)
A_4	(0.4,0.777,0.846,1.0)	(0.4, 0.800, 0.846, 1.0)	(0.4, 0.700, 0.738, 0.9)	(0.4, 0.677, 0.715, 0.9)	(0.4, 0.723, 0.738, 0.9)
	C_6	C_7	C_8	C_9	C_{10}
A_1	(0.7, 0.869, 0.938, 1.0)	(0.4, 0.546, 0.569, 0.9)	(0.4, 0.592, 0.662, 0.9)	(0.4, 0.608, 0.692, 0.9)	(0.5, 0.662, 0.731, 0.9)
A_2	(0.7, 0.869, 0.938, 1.0)	(0.4, 0.585, 0.646, 0.9)	(0.4, 0.577, 0.654, 0.8)	(0.5, 0.600, 0.700, 0.8)	(0.5, 0.638, 0.731, 1.0)
A_3	(0.5, 0.785, 0.792, 0.9)	(0.4, 0.531, 0.562, 0.8)	(0.2, 0.531, 0.585, 0.8)	(0.4, 0.562, 0.623, 0.8)	(0.5, 0.600, 0.700, 0.8)
A_4	(0.4, 0.815, 0.877, 1.0)	(0.4, 0.708, 0.731, 0.9)	(0.4, 0.562, 0.623, 0.8)	(0.4, 0.577, 0.654, 0.8)	(0.4, 0.738, 0.769, 1.0)

Table 11. Aggregated values and weights of supplier evaluations.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
	Defuzzified									
A_1	0.723	0.767	0.786	0.715	0.699	0.871	0.618	0.641	0.650	0.699
A_2	0.694	0.867	0.791	0.723	0.800	0.871	0.637	0.606	0.650	0.725
A_3	0.800	0.734	0.685	0.650	0.689	0.730	0.581	0.521	0.597	0.650
A_4	0.741	0.744	0.675	0.666	0.678	0.753	0.674	0.597	0.606	0.719
	Normalized									
A_1	0.244	0.247	0.268	0.260	0.244	0.270	0.246	0.271	0.260	0.250
A_2	0.235	0.278	0.269	0.262	0.279	0.270	0.254	0.256	0.260	0.260
A_3	0.270	0.236	0.233	0.236	0.241	0.226	0.231	0.220	0.239	0.233
A_4	0.251	0.239	0.230	0.242	0.236	0.233	0.269	0.252	0.242	0.257
	Entropy weights									
H_j	0.9990	0.9984	0.9980	0.9993	0.9984	0.9976	0.9990	0.9980	0.9994	0.9994
$1-H_j$	0.0010	0.0016	0.0020	0.0007	0.0016	0.0024	0.0010	0.0020	0.0006	0.0006
w_j	7.2%	11.8%	14.7%	5.4%	12.0%	17.5%	7.7%	14.9%	4.0%	4.8%

Table 12. The best and the worst values for each criterion and the *S* value of the suppliers.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
f^+	0.800	0.867	0.791	0.723	0.800	0.871	0.674	0.641	0.650	0.725
f^-	0.694	0.734	0.675	0.650	0.678	0.730	0.581	0.521	0.597	0.650
	S value									
A_1	0.052	0.089	0.006	0.006	0.100	0.000	0.046	0.000	0.000	0.017
A_2	0.072	0.000	0.000	0.000	0.000	0.000	0.030	0.044	0.000	0.000
A_3	0.000	0.118	0.134	0.054	0.109	0.175	0.077	0.149	0.040	0.048
A_4	0.040	0.110	0.147	0.042	0.120	0.146	0.000	0.055	0.034	0.004

Table 13. The values and rankings of *S*, *R*, and *Q* of each fishmeal supplier.

	S_i	Ranking	R_i	Ranking	Q_i	Ranking
A_1	0.3154	2	0.0998	2	0.247	2
A_2	0.1460	1	0.0720	1	0.000	1
A_3	0.9038	4	0.1745	4	1.000	4
A_4	0.6968	3	0.1469	3	0.729	3

These results showed that the difference between the *Q* value of A_2 and A_1 was not satisfied with Equation (13), therefore, two candidate suppliers, A_2 and A_1, are both appropriate choices. A_1 represents the largest fishmeal supplier in Peru, and A_2 is the second largest, and they both owned and operated 16 and 5 fishmeal plants, respectively, in 2011. About 80% of fishmeal production is produced by main 7 suppliers in Peru. In 2011, the largest fishmeal supplier (A_1) produced approximately 350,000 tons of fishmeal (27% of the total exported production), while A_2 produced approximately 200,000 tons (15.4% of total exported production). Obviously, plant size and capacity are of concern.

Regarding the criteria weights, an entropy method was applied to obtain objective weights from the supplier evaluation results. This was different from other methods like AHP, where weights are based on the subjective opinions given by experts. The entropy method results showed that the top three most important criteria were: (1) the possibility of establishing long-term cooperation, C_6 (0.17); (2) reasonableness of the quoted price, C_3 (0.15); and (3) satisfaction with claims for damages C_8 (0.15). The implication of these results is that aquaculture enterprises are concerned about a reduction in the quantities of fishmeal they can purchase due to a decrease in natural ocean resources. Therefore, their desire is to maintain long-term relationships with their supplier to ensure the quantity of supply. This not only affects the amount of aquaculture production, but also the sustainability of those operations. In addition, the reasonableness of the quoted price is also of concern. If the quoted price is too high, it will not attract purchasers to make procurement decisions and will hurt the profits of aquaculture. As seen from the weighting priorities, the related quality criterion C_1 (Stability in product quality) ranked 7th with a weighting of only 7.2%. This showed that controlling the supply of fishmeal resources was more important to the aquaculture industry than the quality requirements. Fishmeal is a special raw material and market demand is greater than supply, therefore making the selection requirements different than usual.

5. Conclusions

In this study, four Peruvian main fishmeal suppliers were evaluated by thirteen experts, which is a typical supplier selection problem often encountered in practice. Fuzzy set theory was an appropriate tool for dealing with this kind of problem. In real decision-making processes, the decision-maker is often unwilling or unable to express their preferences precisely in numerical values, so evaluations are very often expressed in linguistic terms. In this paper, an extension of the VIKOR method with entropy weighting measures in a fuzzy environment was proposed to deal with the qualitative criteria for suitable supplier selections.

From a management perspective, this study dealt with a very practical issue for the aquaculture industry in the selection of fishmeal suppliers, given that fishmeal is a very important raw material. According to the description of the interviewers, the supplier selection processes in this industry are based on personal experience or interpersonal relationships, and lack a scientific or systematic model on which to base these decisions. Given this situation, the management of important raw material suppliers has become less systematic, and does not effectively assess changes in the existing supplier's performance, which results in those suppliers with poor performance being more difficult to manage. Therefore, this study provides a management or evaluation tool for the industry in the event that a supplier is required to improve their performance. At the same time, to implement a concise and efficient questionnaire survey for these practitioners, a suitable research approach must be provided. The proposed method used in this study is expected to be able to obtain relevant information to effectively measure the weights of the evaluation criteria and the performance of the candidate suppliers through a simple questionnaire survey. That is, this study adopted the VIKOR approach based on entropy weights in a fuzzy decision-making environment. Not only can the entropy method reduce uncertainties arising from subjective factors, but also the advantage of this hybrid approach is that the merits of the alternatives can be evaluated with one questionnaire. This can greatly reduce the number of interviews with these fairly busy practitioners, which makes the application of this approach in the practical industry more effective and convenient. Thus, this framework for supplier selection in aquaculture should be helpful in making some progress in the management of the industry.

In addition, the use of fuzzy theory in this study to represent the fuzziness of human decision-making provides judgment linguistic variables that correspond to trapezoidal fuzzy numbers. For future work, if considering the dynamic and interactive group decision-making process, reference can be made to the model proposed by [48]. Alternatively, if future studies wish to consider the interactive consensus analysis of group decision making, it can refer to the integrated linguistic operator weighted average (ILOWA) approach introduced by [49] to obtain more detailed observations and discussion.

It is also worth considering, however, that, when selecting the best supplier, an awareness that all raw materials come from marine resources that can only be provided sustainably under sustainable fishing should be considered. The problem discussed here was based on how aquaculture enterprises make decisions to select the appropriate suppliers. However, if marine resources decrease, aquaculture enterprises will face a lack of raw materials to produce the relevant products, so income might not be enough to operate sustainably. In 2014, the contribution of the aquaculture sector to the supply of fish for human consumption overtook that of wild-caught fish for the first time. The importance of aquaculture in the future is clearly evident, and the best source of protein in the feed is provided by fishmeal. The question of how to provide high quality protein substitutes without relying on wild-caught fish is another topic worthy of discussion.

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