An Approach to Selection of Agricultural Product Supplier Using Pythagorean Fuzzy Sets

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The selection of agricultural product supplier is an important link to optimize the supply chain management of agricultural products. Due to the uncertainty factors and the lack of decision-makers' cognition, the selection of agricultural products suppliers has become a very complex and difficult work. Therefore, in order to effectively deal with these problems, this study proposes an agricultural product supplier selection algorithm based on the Pythagorean fuzzy power Bonferroni mean operator under Pythagorean fuzzy environment. In this method, first, the power operator and Bonferroni mean operator are combined and embedded in the Pythagorean fuzzy sets to build a Pythagorean fuzzy power Bonferroni mean operator. Then, a multiattribute decision-making method based on the operator proposed in this paper is proposed. Finally, an analysis of examples of agricultural product supplier selection is given to verify the rationality and effectiveness of this method.

1. Introduction

The sources of safety problems of agricultural products mainly include excessive use of pesticides and chemical fertilizers in agricultural production, environmental pollution caused by “three wastes” in the processing of agricultural products, environmental degradation caused by water loss and soil erosion in the ecological environment, excessive use of additives in food production and processing, and food packaging materials that do not meet the requirements. In addition, primary agricultural and livestock products, such as fruits, vegetables, meat, eggs, and aquatic products, are perishable and obviously affected by geography and seasons, and there is a certain degree of time-space separation between supply and demand, which will also cause safety problems of agricultural products. Therefore, the supply of agricultural products is closely related to people’s life and production and has been concerned by various countries for a long time [1, 2]. At present, a large number of enterprises, such as supermarkets, catering enterprises, and agricultural products processing enterprises, faced with the problem of selection of agricultural products suppliers [3]. The purchase of agricultural products is the starting point and key link of the supply chain of agricultural products. The price, cold-chain transportation, distance, production standards, and other aspects of agricultural products will ultimately affect the market competitiveness of terminal products of fresh agricultural products supply chain [4]. How to select a reasonable supplier has become one of the concerns of many agricultural products-related enterprises.

Many internal and external uncertainty factors of enterprise need to be considered in the selection process of agricultural products suppliers, which is also affected by the subjective preferences of decision-makers. Therefore, the selection of agricultural products suppliers is essentially a fuzzy multiattribute decision-making problem. Fuzzy multiattribute decision-making problem has always been a hot topic in the field of decision-making and has attracted the attention of many scholars [5–10]. The fuzzy set theory proposed by Zadeh [11] lays the foundation for practical operation of fuzzy multiattribute decision-making problems. With the continuous research of fuzzy set theory, Atanassov put forward the intuitionistic fuzzy set theory [12]. After that, many scholars have extended the
intuitionistic fuzzy set [13–19]. Among them, Yager proposed that the Pythagorean fuzzy set is one of the important research studies [18, 19]. Compared with the intuitionistic fuzzy set, the Pythagorean fuzzy set has stronger information representation ability and is more close to the practical problems. Once the Pythagorean fuzzy set is put forward, it has gained widespread attention in academic circles.

Many scholars mainly focus on the study of the extended form of the Pythagorean fuzzy set, including the study of the information integration operator of the Pythagorean fuzzy set and the fuzzy multiattribute decision-making based on Pythagoras. For example, Garg [20] improved the score function, which can better compare the sizes of Pythagorean fuzzy numbers. He et al. [21] studied the Pythagorean hesitant fuzzy integration operator and its decision-making application. In view of the important role of the integration operator in the Pythagorean hesitant fuzzy multiattribute decision-making and the imperfection of the integration operator, He et al. [21] systematically studied the Pythagorean hesitant fuzzy integration operator. Gou et al. studied the continuity and differentiation of Pythagorean fuzzy numbers. Peng et al. [22] combined the properties of Pythagorean fuzzy set and parameterization of the soft set, constructed the Pythagorean fuzzy soft set, introduced the properties of the Pythagorean fuzzy soft set and discussed its decision-making application, and then discussed its DeMorgan’s law. Zhao and Wang [23] proposed a multi-attribute decision-making method based on the Hamacher operator in view of the multiattribute decision-making problem of dual hesitant Pythagorean fuzzy uncertain linguistic information. Then, based on the Hamacher operator, Zhao and Wang [23] defined the operation rule between dual hesitant Pythagorean fuzzy uncertain linguistic variables. He et al. [24] applied the power average operator to the Pythagorean fuzzy decision-making environment, defined the average operator of the Pythagorean fuzzy power, orderly weighted the average operator of Pythagorean fuzzy power, geometric operator of Pythagorean fuzzy power and orderly weighted geometric operator of Pythagorean fuzzy power, and then studied their properties, respectively. In the latest research progress, Chen [25] published a paper on proposing a new Pythagorean Chebyshev distance measure and established a practical method for eliminating and selecting the conversion based on Chebyshev distance measure. Shakeel et al. [26] defined the Einstein operator on the Pythagorean trapezoidal fuzzy set and expanded it into two average aggregation operators. Ullah et al. [27] proposed the concept of the complex Pythagorean fuzzy set (CPFS) in view of the limitation of the complex fuzzy set and complex intuitionistic fuzzy set. Yang and Chang [28] defined the new concept of the interval-valued Pythagorean normal fuzzy set and developed a series of aggregation operators for addressing the interval-valued Pythagorean normal fuzzy information. Harish [29] presented a Pythagorean fuzzy neutrality aggregation operator. Han et al. [30] developed an interval-valued Pythagorean prioritized operator from the perspective of game theory.

It can be seen from the above literature that up to now, the research of the Pythagorean fuzzy set has made some achievements, but it still has room to expand in the field of the information aggregation operator and its application. Therefore, this study proposes the average operator of Pythagorean fuzzy power Bonferroni, which will be applied to the study of agricultural product supplier selection, so as to build a decision-making support framework for agricultural product supplier selection based on the Pythagoras power Bonferroni average operator. The main contributions of this study are as follows:

1. The average operator of Pythagorean fuzzy power Bonferroni was proposed.
2. A decision-making algorithm for agricultural product supplier selection was proposed based on the Pythagorean fuzzy power Bonferroni average (PFPBA) operator.

The other contents of this paper are as follows: part 2 reviews the basic concepts, algorithms, and distance measures of Pythagorean fuzzy. Part 3 puts forward the Pythagorean fuzzy power Bonferroni mean operator and analyzes its properties. Part 4 constructs a multiattribute decision-making method based on the average operator of the Pythagorean fuzzy power Bonferroni mean operator. Part 5 gives an example to verify the validity and rationality of the method. Part 6 summarizes some conclusions.

2. Pythagorean Fuzzy Sets

Definition 1 (see [18, 19]). Assuming that X is a nonempty general set, the expression of the Pythagorean fuzzy set A defined on X is

\[ A = \{ x, u_A(x), v_A(x) \mid x \in X \} \]

where \( u_A(x) : X \rightarrow [0, 1] \) and \( v_A(x) : X \rightarrow [0, 1] \) represent the membership function and nonmembership function of A and \( \forall x \in X, u_A(x)^2 + v_A(x)^2 \leq 1 \). In addition, the hesitancy degree is defined as \( \pi(x) = \sqrt{1 - u_A(x)^2 - v_A(x)^2} \).

For simplicity, \( p_A(x) = (u_A(x), v_A(x)) \) is called a Pythagorean fuzzy number. Assuming that \( p_i = (u_i, v_i) (i = 1, 2) \), \( \lambda = (u_p, v_p) \) is three Pythagorean fuzzy numbers, and \( \lambda \) is any real number greater than or equal to 0, then the following operation rules are specified:

\[
\begin{align*}
(1) \quad p_1 \oplus p_2 &= (\sqrt{u_1^2 + u_2^2 - u_1^2u_2^2}, v_1v_2) \\
(2) \quad p_1 \otimes p_2 &= (u_1u_2, \sqrt{v_1^2 + v_2^2 - v_1v_2^2}) \\
(3) \quad \lambda p &= (\sqrt{1 - (1 - u^2)^2}, v^p) \\
(4) \quad p^\lambda &= (\sqrt{1 - (1 - v^2)^2}, u^p)
\end{align*}
\]

Therefore, the following conclusions can be drawn:

\[
\begin{align*}
(1) \quad a_1 \oplus a_2 &= a_2 \oplus a_1 \\
(2) \quad a_1 \otimes a_2 &= a_2 \otimes a_1 \\
(3) \quad \lambda (a_1 \oplus a_2) &= \lambda a_1 \oplus \lambda a_2 \\
(4) \quad (a_1 \otimes a_2)^\lambda &= a_1^\lambda \otimes a_2^\lambda \\
(5) \quad \lambda a_1 + \lambda a_2 &= (\lambda_1 + \lambda_2)a \\
(6) \quad a^{11} \oplus a^{12} &= a^{11+12}
\end{align*}
\]
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Definition 2 (see [18-19]). Assuming $p = (u, v)$ is a Pythagorean fuzzy number, the score function of $p$ is defined as $S(p) = u^2 - v^2$, and the exact function of $p$ is defined as $H(p) = u^2 + v^2$. For any two Pythagorean fuzzy numbers $p_1 = (u_1, v_1)$ and $p_2 = (u_2, v_2)$, the definitions are as follows:

1. If $S(p_1) > S(p_2)$, then $p_1 > p_2$
2. If $S(p_1) = S(p_2)$, then $p_1 = p_2$ when $H(p_1) = H(p_2)$
3. If $H(p_1) > H(p_2)$, then $p_1 > p_2$

Definition 3 (see [18, 19]). Assuming that $p_1 < p_2$, $a_i = (u_i, v_i)$ and $a_j = (u_j, v_j)$ are any two Pythagorean fuzzy numbers, then the standard hamming distance $d(a_i, a_j)$ of $a_1$ and $a_2$ can be defined as

$$d(a_i, a_j) = \left[ \frac{|u_i^2 - u_j^2| + |v_i^2 - v_j^2| + |\pi_1 - \pi_2|}{2} \right]$$

where $\pi_1 = \sqrt{1 - u_i^2 - v_i^2}$ and $\pi_2 = \sqrt{1 - u_j^2 - v_j^2}$.

3. PFPBA Operator

Definition 4 (see [31]). Assuming $s$ and $t$ are nonnegative real numbers that are not both zero and $a_i (i = 1, 2, \ldots, n)$ is a series of nonnegative real numbers, if

$$\text{PFPBA} (a_1, a_2, a_3, \ldots, a_n) = \left[ \frac{1}{n(n-1)} \sum_{i,j=1,i\neq j}^n \left\{ \left( \frac{n(1 + T(a_i))}{\sum_{i=1}^n (1 + T(a_i))} a_i \right)^s \left( \frac{n(1 + T(a_j))}{\sum_{j=1}^n (1 + T(a_j))} a_j \right)^t \right\} \right]^{(1/s+t)}$$

Definition 5. Assuming that $s$ and $t$ are nonnegative real numbers that are not both zero, $a_i (i = 1, 2, \ldots, n)$ is the set of a group of Pythagorean fuzzy numbers, and $a_i = (u_i, v_i) (i = 1, 2, \ldots, n)$, and $q \geq 1$. Then, the Pythagorean fuzzy power Bonferroni mean (PFPBA) operator can be defined as

$$\text{PFPBM} (a_1, a_2, a_3, \ldots, a_n) = \left[ \frac{1}{n(n-1)} \sum_{i,j=1,i\neq j}^n \left\{ \left( \frac{n(1 + T(a_i))}{\sum_{i=1}^n (1 + T(a_i))} a_i \right)^s \left( \frac{n(1 + T(a_j))}{\sum_{j=1}^n (1 + T(a_j))} a_j \right)^t \right\} \right]^{(1/s+t)}$$

where $T(a_i) = \sum_{j=1}^n \text{Sup}(a_i, a_j) (i = 1, 2, \ldots, n)$ and $\text{Sup}(a_i, a_j)$ indicates the supporting degree of $a_i$ and $a_j$ and meets the following conditions:

1. $\text{Sup}(a_i, a_j) \in [0, 1]$
2. $\text{Sup}(a_i, a_j) = \text{Sup}(a_j, a_i)$
3. $\text{Sup}(a_i, a_j) \geq \text{Sup}(c, d)$ if and only if $|a_i - b| \geq |c - d|$

Definition 6. Assuming that $a_i = (u_i, v_i) (i = 1, 2, \ldots, n)$ is the Pythagorean fuzzy number and $s$ and $t$ are nonnegative real numbers that are not both zero, then the integration value of these Pythagorean fuzzy numbers obtained by using the PFPBA operator is still a Pythagorean fuzzy number, and
According to the Definition 3, it is easy to prove that the above formula is true by mathematical induction.

Some basic properties of the average operators of Pythagorean fuzzy power Bonferroni are discussed as follows:

(1) (Power equitability) Assuming that $\alpha_i = (u_i, v_i)$ ($i = 1, 2, \ldots, n$) is the Pythagorean fuzzy number and $\alpha_1 = \alpha_2 = \ldots = \alpha_n = \alpha$, then

$$\text{PFPBA}(a_1, a_2, a_3, \ldots, a_n) = \alpha. \quad (6)$$

(2) (Permutation invariance) Assuming that $\alpha_i = (u_i, v_i)$ ($i = 1, 2, \ldots, n$) is the Pythagorean fuzzy number and $\beta_1, \beta_2, \beta_3, \ldots, \beta_n$ is any permutation and combination of $\alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_n$, then

$$\text{PFPBA}(a_1, a_2, a_3, \ldots, a_n) = \text{PFPBA}(\beta_1, \beta_2, \beta_3, \ldots, \beta_n). \quad (7)$$

(3) (Boundedness) Assuming that $\alpha_i = (u_i, v_i)$ ($i = 1, 2, \ldots, n$) is the Pythagorean fuzzy number, $\beta_i = (n(1 + T(a_i))/\sum_{j=1}^{n}(1 + T(a_j)))/a_i$, $\beta^+ = \max(\beta_i)$, and $\beta^- = \min(\beta_i)$, then

$$\beta^- \leq \text{PFPBA}(a_1, a_2, a_3, \ldots, a_n) \leq \beta^+. \quad (8)$$

4. Multiattribute Decision-Making Model Based on the PFPBA Operator

In the problem of Pythagorean fuzzy information multiattribute decision-making, assume that there are $n$ alternative schemes $X = (x_1, x_2, x_3, \ldots, x_n)$ and $m$ decision attributes $C = (c_1, c_2, c_3, \ldots, c_m)$. The experts provide the evaluation information of Pythagorean fuzzy and set the attribute value of the scheme $x_i$ under the attribute of $c_j$ to be $a_{ij}$. In which $a_{ij}$ is the Pythagorean fuzzy number, and then, the decision matrix of Pythagorean fuzzy $M = (a_{ij})_{nm}$ can be obtained. $u_{ij}$ and $v_{ij}$ represent the value of membership degree and nonmembership degree of the attribute $j$ of the alternative scheme $i$. A decision method based on Pythagorean fuzzy information is proposed as follows in combination with the Pythagorean fuzzy power Bonferroni operator, and the specific steps are illustrated in Figure 1:

Step 1: use the PFPBA operator to integrate the attribute values of schemes

Step 2: calculate the score function of each scheme according to Definition 2

Step 3: sort the schemes according to the score function

Step 4: select the best scheme according to the scheme ranking

5. Example Analysis of Agricultural Product Supplier Selection

5.1. Calculation Process. The safety of agricultural products is a major livelihood issue. Countries have raised their standards for the production and processing of agricultural products, and ordinary people have also raised their awareness of consumption of agricultural products. In order to adapt to the rapidly changing market demand of agricultural products, reduce the operating costs of agricultural production enterprises, and improve the core competitiveness of the company, enterprises need to select appropriate agricultural products suppliers for cooperation. When selecting suppliers, enterprises often need to define their own needs and select appropriate suppliers according to their own needs. In addition, as the concept of green agricultural products has been strongly advocated and gradually gained popularity in recent years, enterprises should also consider environmental protection and implement the strategy of sustainable development when selecting suppliers for cooperation. An agricultural product enterprise in a city intends to select a supplier as a stable source of supply for agricultural products. After preliminary market research, it selects suppliers from multiple perspectives and selects four suppliers with core competitiveness, which are represented with $X = (x_1, x_2, x_3, x_4)$, respectively. The decision-maker evaluates four suppliers from 4 aspects: $C_i$ green technology level (including pollution control level and environmental planning ability), $C_2$ product advantage (including product...
price, product quality, and the product warranty period), $C_3$ risk bearing capacity (including the company’s capital scale and enterprise prospect), and $C_4$ enterprise production ability (including the company’s equipment quantity and production efficiency) to select the best supplier. After consultation, the expert group gives the following decision matrix as shown in Table 1:

### Table 1: Pythagorean fuzzy decision matrix.

|   | $C_1$        | $C_2$        | $C_3$        | $C_4$        |
|---|--------------|--------------|--------------|--------------|
| $x_1$ | <0.899, 0.301> | <0.703, 0.601> | <0.497, 0.796> | <0.602, 0.299> |
| $x_2$ | <0.402, 0.698> | <0.893, 0.202> | <0.802, 0.106> | <0.503, 0.302> |
| $x_3$ | <0.801, 0.402> | <0.703, 0.491> | <0.6, 0.202>   | <0.693, 0.401> |
| $x_4$ | <0.697, 0.205> | <0.807, 0.200> | <0.8, 0.401>   | <0.605, 0.602> |

Step 1: according to the actual situation, establish the Pythagorean fuzzy decision matrix, as shown in Table 1:

Step 2: use the integration operator PFPBA to calculate the comprehensive attribute value of each scheme, and meanwhile, we take $s = t = 1$, and the comprehensive attribute value of each scheme is calculated as follows:

$$
x_1 = (0.6872, 0.5181),
$$
$$
x_2 = (0.5141, 0.3327),
$$
$$
x_3 = (0.7035, 0.3813),
$$
$$
x_4 = (0.7302, 0.3598)
$$

Step 3: the score of each scheme is calculated as $s_{x_1} = 0.2038$, $s_{x_2} = 0.1536$, $s_{x_3} = 0.3495$, $s_{x_4} = 0.4038$, respectively.

Step 4: after comparison of score values, it can be known according to $s_{x_1} > s_{x_3} > s_{x_1} > s_{x_2}$ that the scheme $s_{x_1}$ is the best one.

### 5.2 Comparison with Different Methods

(1) When the Pythagorean fuzzy power average operator is used to integrate these attribute values:
Step 1: Establish the Pythagorean fuzzy decision matrix according to actual situation, as shown in Table 1.
Step 2: Use the Pythagorean fuzzy power average operator to calculate the comprehensive attribute value of each scheme. Then, the comprehensive attribute value of each scheme can be calculated:

\[
x_1 = (0.9856, 0.0264),
x_2 = (0.9529, 0.0019),
x_3 = (0.9816, 0.0079),
x_4 = (0.9878, 0.0042),
\]

\[
x_1 = (0.2206, 0.8464),
x_2 = (0.0673, 0.6122),
x_3 = (0.2439, 0.6877),
x_4 = (0.2832, 0.6525)
\]

Step 3: The score value of each scheme can be calculated as \( s_{x_1} = 0.9707, s_{x_2} = 0.9080, s_{x_3} = 0.9634, s_{x_4} = 0.9758 \), respectively.
Step 4: After comparison of score values, it can be known according to \( s_{x_1} > s_{x_2} > s_{x_3} > s_{x_4} \) that the scheme \( s_{x_1} \) is the best one.

(2) When the average operator of Pythagorean fuzzy Bonferroni mean is used to integrate these attribute values:
Step 1: establish the Pythagorean fuzzy decision matrix according to actual situation, as shown in Table 1
Step 2: use the Pythagorean fuzzy Bonferroni mean operator to calculate the comprehensive attribute value of each scheme with \( s = t = 1 \) as follows:
Step 3: the score value of each scheme can be calculated as \( s_{x_1} = -0.6677, s_{x_2} = -0.3703, s_{x_3} = -0.4134, s_{x_4} = -0.3456 \), respectively
Step 4: after comparison of score values, it can be known that the scheme \( s_{x_3} \) is the best one.

From the above results, it can be known that the results of the method proposed in this paper are the same as the optimal scheme based on the Pythagorean fuzzy power average operator, but their total order is not the same, and it is also different from the sorting results based on the Pythagorean fuzzy Bonferroni mean operator. The reason for this difference is that the two methods do not consider the heterogeneity between attributes and their impact on the evaluation results. Therefore, the method proposed in this paper has strong advantages.

6. Conclusion
Considering the uncertain information faced in the selection of agricultural product suppliers, this study proposes a multiattribute decision-making method based on the Pythagorean fuzzy power Bonferroni mean operator. In this method, the heterogeneous relationship between attributes and the abnormal value of evaluation information are fully considered, and the power operator and Bonferroni average operator are integrated and introduced into the Pythagorean fuzzy information environment to construct an agricultural product supplier selection algorithm based on the Pythagorean fuzzy power Bonferroni mean operator. This algorithm has a strong ability in dealing with uncertain information, and at the same time, it considers the influence of the internal relationship between attributes on the decision results and avoids the adverse effect of the extreme value in the evaluation information on the ranking results through the PA operator. In the future, this study can be combined with other operators, such as Muirhead mean operator and Hamy mean operator, to propose more extensive Pythagorean fuzzy information aggregation operators. At the same time, the operators proposed in this paper can also be applied in other practical decision-making fields, such as traffic route selection, enterprise performance evaluation, and human resource management.

Data Availability
The data used to support the findings of this study are included within the article.

Conflicts of Interest
The authors declare that they have no conflicts of interest.

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