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Fuzzy multi-criteria group decision making approach for grading of mulberry silk cocoons

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A multi-criteria group decision making method has been applied for grading of silk cocoons which employs the proficiency of three experts as decision makers to alleviate the fuzziness underlying in silk cocoon parameters. Fuzzy-TOPSIS approach of multi-criteria group decision making method has been used in this study. Four quality parameters of silk cocoon, viz. good cocoon percentage, cocoon weight, cocoon size and compactness are regarded as criteria. The 10 cocoon lots are ranked based on Fuzzy-TOPSIS method. The ranking of cocoon lots attained by this method shows a significant agreement with the ranks devised by the sericulture experts.

Keywords: Cocoon, Fuzzy TOPSIS approach, Mulberry silk, Multi-criteria decision making

1 Introduction

In mulberry sericulture, production of cocoon is considered to be one of the major components of its total activities. Raw silk is extracted from these cocoons and thus quality of cocoon has a great bearing on the production of ultimate resultant thread. Inferior quality cocoon results in the production of low-grade raw silk thread. Moreover, the major practitioners in sericulture are associated with farming community. Therefore, the importance of cocoon not only lies in the slender qualitative aspect but also in larger socio-economic facet. It is always warranted to have a sound cocoon pricing system like any agro-based product. In sericulture, though a long traditional practice, a sound cocoon grading or subsequent pricing system has not yet developed. It is also not a uniform system throughout the world. The major quantities of the cocoons are transacted on the basis of visual appearance. Even in the places where some sorts of cocoon grading systems are prevailing, the existing systems are not very scientific. Cocoons being a bio-material, are not confirmed to give a definite output against their characteristics. The crisp values are inadequate to describe real-life conditions because of variability or impreciseness exist in the cocoon parameters.

A single trait of silk cocoons does not govern overall quality of raw silk. A particular lot of cocoon may have superiority over others in terms of a particular trait, but the relative dominance may be counter balanced when other criterions are considered. So, Multi-Criteria Decision Making (MCDM) would be the right option for silk cocoon grading. In classical MCDM methods, the ratings and the weights of the criteria are known precisely[1-3]. Hwang and Yoon[1] developed Technique for order performance by similarity to ideal solution (TOPSIS), one of the widely used classical techniques for solving MCDM problems. Many researchers have approached MCDM problems of textile industries by TOPSIS method[1-8]. It bases upon the concept that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS) [1]. In the process of TOPSIS, the performance ratings and the weights of the criteria are given as crisp values. Endeavor has been made to generate hybrid model to overcome the inherent drawback of TOPSIS method[7,8].

In case of silk cocoon grading problem, due to the vague concepts frequently represented in decision data, crisp values are often inadequate to represent the decision matrix of the MCDM problem. Considering the vagueness presents in the cocoon data, a more holistic approach is required to assess the silk cocoons in a fuzzy environment when linguistic variables seem

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to be more potent than giving preference to perfect numerical values. Moreover, since implication of a particular criterion may not be the same with that of others, more realistic approach may be given to use linguistic assessments by putting proper weightage to the criteria. In this work, a fuzzy-TOPSIS method which is an extension of the concept of TOPSIS in the fuzzy environment has been used for grading of mulberry silk cocoons.

2 Methodology

2.1 Fuzzy Multi-Criteria Group Decision Making Method

In many circumstances, crisp data are insufficient to model real-life situations, because human assessments are often vague, and cannot be estimated with an exact numerical value[9, 10]. If such situation arises in a MCDM problem, the ratings and weights of the criteria may be assessed by means of linguistic variables. Chen[10] extended the concept of TOPSIS to develop a methodology for solving multi-person multi-criteria decision-making problems in fuzzy environment. Considering the fuzziness in the decision data and group decision-making process, linguistic variables are used to assess the weights of all criteria and the ratings of each alternative with respect to each criterion and accordingly the decision matrix is converted into a fuzzy decision matrix. Similar to the concept of TOPSIS, Chen[10] defined the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS). Consequently, using the vertex method, the distances of each alternative from FPIS as well as FNIS are calculated. Finally, a closeness coefficient of each alternative is determined for the purpose of ranking in preferential order. The higher value of closeness coefficient indicates that an alternative is closer to FPIS and farther from FNIS simultaneously.

The fuzzy-TOPSIS method proposed by Chen[10] is quite suitable for solving the group decision making problem under fuzzy environment, where the weights of different criteria and the ratings of the qualitative criteria are considered as linguistic variables. These linguistic variables can be expressed in positive triangular fuzzy numbers as shown in Table 1.

If a decision group has K experts, then the importance of the criteria and the rating of alternatives with respect to each criterion can be calculated as follows:

Table 1 — Linguistic variables for importance of weight of each criterion and ratings

Linguistic variables	Triangular fuzzy numbers
Weight criterion	
Very low (VL)	(0, 0, 0.1)
Low (L)	(0, 0.1, 0.3)
Medium low (ML)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Medium high (MH)	(0.5, 0.7, 0.9)
High (H)	(0.7, 0.9, 1)
Very high (VH)	(0.9, 1, 1)
Rating	
Very poor (VP)	(0, 0, 1)
Poor (P)	(0, 1, 3)
Medium poor (MP)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Medium good (MG)	(5, 7, 9)
Good (G)	(7, 9, 10)
Very good (VG)	(9, 10, 10)

$$\tilde{x}_{ij} = \frac{1}{K}\left[\tilde{x}_{ij}{}^{1} + \tilde{x}_{ij}{}^{2} + \cdots + \tilde{x}_{ij}{}^{K}\right] \quad \ldots (1)$$

$$\tilde{w}_{ij} = \frac{1}{K}\left[\tilde{w}_{ij}{}^{1} + \tilde{w}_{ij}{}^{2} + \cdots + \tilde{w}_{ij}{}^{K}\right] \quad \ldots (2)$$

where $\tilde{x}_{ij}^{K}$ and $\tilde{w}_{ij}^{K}$ are the rating and the importance weight of the K^{th} decision maker.

The decision matrix for fuzzy multi-criteria group decision-making problem can be concisely expressed as

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{21} \cdots & \tilde{x}_{2n} \\ \vdots & \vdots \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} \; \cdots & \tilde{x}_{mn} \end{bmatrix} \quad \ldots (3)$$

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \ldots \ldots \ldots, \tilde{w}_n] \quad \ldots (4)$$

where $\tilde{x}_{ij}, \forall ij$ and $\tilde{w}_j$, j=1, 2,..., n are linguistic variables. These linguistic variables can be described by triangular fuzzy numbers, $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$. If B and C denote the set of benefit and cost criteria respectively, the normalized fuzzy decision matrix is represented as:

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad \ldots (5)$$

where $\tilde{r}_{ij}$ can be expressed as:

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), j \in B;$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), j \in C;$$

where $c_j^* = \max_i c_{ij}, \quad j \in B$ and

$a_j^- = \min_i a_{ij}, \quad j \in C.$

The weighted normalized fuzzy decision matrix can be expressed as:

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{m \times n} i = 1,2, \ldots\ldots, m; \; j = 1,2, \ldots., n \qquad \ldots (6)$$

where $\tilde{v}_{ij} = \tilde{r}_{ij}(\cdot)\widetilde{w}_j$.

The elements $\tilde{v}_{ij}, \forall i, j$ are normalized positive triangular fuzzy numbers and their ranges belong to the closed interval (0-1).

The fuzzy positive ideal solution (FPIS, A^*) and fuzzy negative ideal solution (FNIS, A^-) are defined as:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*), \qquad \ldots (7)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-), \qquad \ldots (8)$$

Where $\tilde{v}_j^* = (1,1,1)$ and $\tilde{v}_j^- = (0,0,0)$, $j = 1, 2, \ldots, n$.

The separation distances from each alternative from A^* and A^- can be estimated by using vertex method as:

$$d_i^* = \sum_{j=1}^n d\left(\tilde{v}_{ij}, \tilde{v}_j^*\right), \; i = 1,2, \ldots m, \qquad \ldots (9)$$

$$d_i^- = \sum_{j=1}^n d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right), \; i = 1,2, \ldots m, \qquad \ldots (10)$$

where $d(\cdot,\cdot)$ is the distance measurement between two fuzzy numbers. For example, if

$\widetilde{m} = (m_1, m_2, m_3)$ and $\tilde{n} = (n_1, n_2, n_3)$are the two fuzzy numbers, then the distance between $\widetilde{m}$ and $\tilde{n}$ can be calculated as

$$d(\widetilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}\left[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2\right]}$$

A closeness coefficient (CC_i) is defined to determine the ranking order of all alternatives once the d_i^* and d_i^- of each alternative A_i (i=1, 2,…,m) are calculated. The closeness coefficient of each alternative is calculated as

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i = 1,2, \ldots, m \qquad \ldots (11)$$

Obviously, an alternative A_i is closer to the FPIS (A*) and farther from FNIS(A^-) as CC_i approaches to 1. Therefore, the ranking order of all alternatives can be determined according to the CC_i.

The organization of multi-criteria group decision making with fuzzy method is illustrated by the following 9 steps:

Step 1− Formation of decision-makers group for identification of the evaluation criteria.

Step 2− Decision makers choose the appropriate linguistic variables for the weights of the criteria and the linguistic ratings for alternatives with respect to each criteria.

Step 3− Construction of aggregated fuzzy weight $\widetilde{w}_j$ of criterion C_j, and aggregated fuzzy rating $\tilde{x}_{ij}$ of alternative A_i under criterion C_j, as mentioned in Eqs (1) and (2).

Step 4− Construct the fuzzy decision matrix ($\widetilde{D}$) and the normalized fuzzy decision matrix ($\tilde{R}$), as shown in Eqs. (3) and (5).

Step 5− Construct the weighted normalized fuzzy decision matrix ($\tilde{V}$), as calculated in Eq. (6).

Step 6− Determine FPIS (A*) and FNIS (A^-), as illustrated in Eqs (7) and (8).

Step 7− Calculate the distance of each alternative from FPIS and FNIS, as calculated in Eqs (9) and (10).

Step 8− Calculate CC_i of each alternative, as per Eq. (11).

Step 9− According to the CC_i values, the ranking order of all alternatives can be determined.

2.2 Grading of Silk Cocoons Using Fuzzy-TOPSIS Approach

Ten lots of mulberry multi-bivoltine silk cocoons A_1, A_2…A_{10} are collected from the silk cocoon market. A committee of three decision makers *DM1*, *DM2* and *DM3* having sufficient knowledge and expertise in the field of sericulture has been formed for grading the cocoon and select the most suitable lot. Four benefit criteria of cocoons are considered, such as good cocoon % (C_1), weight (C_2), size (C_3), and compactness (C_4). All these four criteria are subjectively assessed by the three decision makers. Good cocoons are most suitable for reeling or extraction of raw silk. Good cocoon (%) is a measure of percentage of reelable non-defective cocoons present in a lot. The cocoon size and weight are the measures of average volume and weight of a cocoon in the lot. The compactness of cocoon is indicating the average texture, dryness and hardness of cocoons. All these cocoon quality parameters have direct bearing on raw silk output as well as reeling and they influence the silk quality positively. The hierarchical structure of this multi-person multi-criteria decision making problem is displayed in Fig.1. Fuzzy-TOPSIS method proposed by Chen[10,11] has been applied to this cocoon grading problem and the computational procedure in step-by-step is summarized as follows:

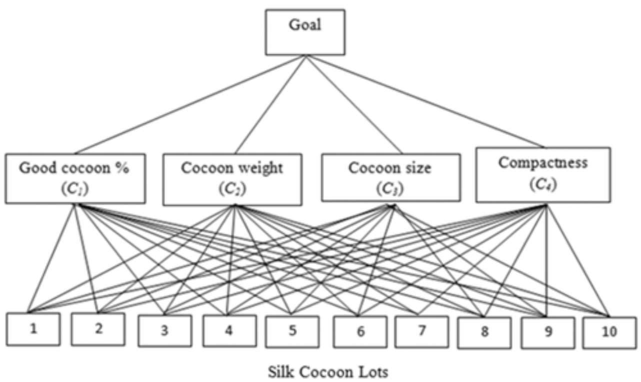

Fig. 1 — Hierarchical structure

Table 2 — Iimportance weight of criteria

Criteria	*DM1*	*DM2*	*DM3*
Good cocoon (C_1)	VH	VH	H
Cocoons weight (C_2)	M	M	VH
Cocoon size (C_3)	L	M	L
Compactness (C_4)	H	VH	VH

Step 1─ Three decisionmakers used seven linguistic weighting variables, viz. very low, low, medium low, medium, medium high, high and very high as shown in Table 1 to assess the importance of the four criteria. The importance weight of the criteria evaluated by the decision makers is depicted in Table 2.

Step 2─ The decision makers usedseven linguistic rating variables, viz. very poor, poor, medium poor, fair, medium good, good and very good as shown in Table 1 for rating of cocoon lots with respect to each criterion. The ratings of the alternatives, i.e. cocoon lots, decided by *DM1*, *DM2* and *DM3* considering each criterion is presented in Table 3.

Step 3─ In this step, the linguistic evaluations, shown in Tables 2 and 3 are converted into triangular fuzzy numbers to construct fuzzy decision matrix and fuzzy weights presented in Table 4.

Step 4─ The normalized fuzzy decision matrix is constructed.

Step 5─ The weighted normalized fuzzy decision matrix is constructed.

Step 6─ FPIS (A^*)and FNIS (A^-) are determined as:

A^* = [(1,1,1), (1,1,1), (1,1,1), (1,1,1)] and

A^-= [(0,0,0), (0,0,0), (0,0,0), (0,0,0)]

Step 7─ The distance of each alternative from FPIS and FNIS is calculated.

Table 3 — Ratings by decision makers

Alternatives	Good cocoon (C_1)			Cocoons weight (C_2)			Cocoon size (C_3)			Compactness (C_4)		
	DM1	*DM2*	*DM3*	*DM1*	*DM2*	*DM3*	*DM1*	*DM2*	*DM3*	*DM1*	*DM2*	*DM3*
1	P	F	MP	P	MP	F	G	MG	MG	G	G	G
2	MP	F	F	P	F	MG	MG	F	MP	G	MG	VG
3	G	MG	VG	P	MP	F	MG	F	MP	VG	VG	VG
4	MG	MG	G	P	MP	F	MG	F	MP	G	G	MG
5	P	F	MP	P	F	MG	MG	F	F	MG	G	MG
6	MG	MG	G	P	F	MG	MG	F	MP	F	MG	F
7	VP	P	P	F	MG	MG	MG	F	F	VP	G	VP
8	VP	VP	VP	MP	F	MG	MG	F	F	MP	MP	MP
9	VP	VP	P	F	G	G	G	MG	MG	MP	P	MP
10	VP	VP	VP	MG	G	G	MG	F	F	VP	P	P

Table 4 — Fuzzy decision matrix and fuzzy weights

Alternatives	C_1	C_2	C_3	C_4
1	(1.33, 3.00,5.00)	(1.33, 3.00, 5.00)	(5.67, 7.67, 9.33)	(7.00, 9.00, 10.00)
2	(2.33, 4.33, 6.33)	(2.67, 4.33, 6.33)	(3.00, 5.00, 7.00)	(7.00, 8.67, 9.67)
3	(7.00, 8.67, 9.67)	(1.33, 3.00, 5.00)	(3.00, 5.00, 7.00)	(9.00, 10.00, 10.00)
4	(5.67,7.67,9.33)	(1.33, 3.00, 5.00)	(3.00, 5.00, 7.00)	(6.33, 8.33, 9.67)
5	(1.00, 3.00, 5.00)	(2.67, 4.33, 6.33)	(3.67, 5.67, 7.67)	(5.67, 7.67, 9.33)
6	(5.67,7.67,9.33)	(2.67, 4.33, 6.33)	(3.00, 5.00, 7.00)	(3.67, 5.67, 7.67)
7	(0, 0.67, 2.33)	(4.33, 6.33, 8.33)	(3.67, 5.67, 7.67)	(2.33, 3.00, 4.00)
8	(0, 0, 1.00)	(3.00, 5.00, 7.00)	(3.67, 5.67, 7.67)	(1.00, 3.00, 5.00)
9	(0, 0.33, 1.67)	(5.67,7.67,9.00)	(5.67,7.67,9.33)	(0.67, 2.33, 4.33)
10	(0, 0, 1.00)	(6.33, 8.33,9.67)	(3.67, 5.67, 7.67)	(0, 0.67, 2.33)
Weights	(0.83, 0.97, 1.00)	(0.50, 0.67, 0.80)	(0.10, 0.23, 0.43)	(0.83, 0.97, 1.00)

Table 5 — Closeness coefficient and rank of lots

Lot No.	CC_i	Rank by model	Rank by decision makers		
			DM1	*DM2*	*DM3*
1	0.407	5	3	5	4
2	0.433	4	5	6	2
3	0.524	1	1	1	1
4	0.473	2	2	3	6
5	0.393	6	4	4	5
6	0.445	3	6	2	3
7	0.278	8	10	7	10
8	0.242	10	8	10	8
9	0.287	7	7	8	7
10	0.243	9	9	9	9
Rank correlation coefficient			0.84	0.93	0.82

Step 8– The closeness coefficient (CC_i) of each alternative is measured.
Step 9– The cocoon lots are ranked in the descending order of CC_i which is represented in Table 5.

3 Results and Discussion

After determining the linguistic variables for importance of weights and ratings of alternatives, the steps of fuzzy-TOPSIS method are followed as explained earlier. The closeness coefficient values (CC_i) for all 10 lots of silk cocoons are estimated based on which the rank is assigned to each lot. The CC_i values and corresponding ranking for different lots are given in Table 5. It is observed that the best alternative (lot no. 3) has a CC_i value of 0.524 and the worst alternative (lot no. 8) has a CC_i value of 0.242.

For validation purpose, the silk cocoon lots are ranked separately by the decision makers *DM1*, *DM2* and *DM3* based on their individual judgments which are tabulated in Table 5. The coefficient of concordance amongst the judgements of the decision makers *DM1*, *DM2* and *DM3* is measured to verify the degree of agreement between them. The coefficient of concordance (*W*) is calculated using the following equation[12]:

$$W = \frac{12S}{r^2 n(n-1)(n+1)} \quad \ldots (12)$$

where r is the number of decision makers; n, the number of silk cocoon lots; $S = \sum(R_i - \bar{R})^2$; R_i, is the sum of the ranks given to the i[th] object; and $\bar{R}$, the mean of these rank sums. Thus, using Eq. (12), W is computed as follows:

$$W = \frac{12\sum(R_i - \bar{R})^2}{r^2 n(n-1)(n+1)} = \frac{12 \times 628.5}{3^2 \times 10 \times (10-1)(10+1)} = 0.85$$

The coefficient of concordance is obtained as 0.85 which indicates a high degree of association between the judgments of three decision makers. It is, however, possible that a high value of W is obtained purely by chance when the decision makers assign the ranks at random. To settle this point, a test of significance using F-distribution is conducted. The calculated value of F is measured using the following equation[12]:

$$F = \frac{(r-1)W'}{(1-W')} = 10.73 \quad \ldots (13)$$

where $W' = \frac{12(S-1)}{r^2 n(n-1)(n+1)+24}$ … (14)

The calculated value of F is then compared with the tabled value of F at k_1 and k_2 degrees of freedom, where

$$k_1 = n - 1 - \frac{2}{r} \quad \ldots (15)$$

and

$$k_2 = (r-1)k_1 \quad \ldots (16)$$

The values of k_1 and k_2 are obtained as 8.33 and 16.67 respectively, using the Eqs (15) and (16). The tabled value of Fat the nearest tabular entry of degrees of freedom, i.e. k_1= 8 and k_2= 20 with 1% level of significance is observed to be 3.6. As the calculated value of F (10.73) is greater than the tabled value of F (3.6), the null hypothesis of no association is rejected and therefore it can be inferred that high degree of association is present amongst the judgments of *DM1*, *DM2* and *DM3*.

The rank correlation coefficients (R_s) are determined between the ranks of cocoons lots as obtained from the fuzzy-TOPSIS method and ranks of cocoon lots according to the decision makers using the following equation[6]:

$$R_s = 1 - \frac{6\sum D_a^2}{n(n^2-1)} \quad \ldots (17)$$

where D_a is the absolute difference between two ranking; and n, the total number of alternatives. The rank correlation coefficients are obtained as 0.84, 0.93 and 0.82, which shows a high degree of agreement between the proposed methods and decision of experts for cocoon grading. The significance test for R_s is also carried out at 1% level of significance[12]. The critical value of $R_s$at 1% significance level is 0.78 at n = 10, which is lower than the calculated values of the rank correlation coefficient as mentioned above. Therefore, it can be deduced that the rank correlation coefficients obtained between the proposed method and decision of experts is indeed associated.

4 Conclusion

A multi-person multi-criteria decision making method based on fuzzy-TOPSIS approach has been used for grading of silk cocoons. Three experts of sericulture field have been selected as decision makers to encounter the ambiguity exist in the silk cocoon parameters. The linguistic variables for the importance weights of the criteria and ratings of the cocoon lots with respect to each criterion are meticulously decided by the expert group. The rank of silk cocoons lots obtained by the fuzzy-TOPSIS method shows a high agreement with the judgements of all decision makers. Hence, the proposed method appears to be very much suitable for highly heterogenic silk cocoon material to solve the MCDM problem under fuzzy environment. The multi-criteria group decision making method based on fuzzy-TOPSIS approach is easy to implement and empowered to embrace the impreciseness of parameters. Therefore, this approach can be adopted forgrading of other bio-materials as well.

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