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On the Use of Multi-criteria Decision Making Model for Selecting the Important Criteria in Meliponiculture

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Abstract Meliponiculture is an activity of raising stingless bees to obtain bee products, mainly honey. Honey production by bees varies depending on various factors which also affect its amount and quality. Meliponiculturists practiced beekeeping in many ways to maximise honey production and its quality such as by considering location of beekeeping, apiary, flowers and plants. Nevertheless, there are many criteria that should be considered in meliponicultures in analysing its importance in producing good quality and quantity of honey. As it involves multiple conflicting criteria, different multi-criteria decision making (MCDM) techniques can be effectively applied to solve such type of problem. Thus, this paper applied MCDM techniques namely as Analytical Hierarchy Process (AHP), Fuzzy Analytical Hierarchy Process (FAHP) and Weighted Sum Method (WSM) to rank the criteria. A set of questionnaires with nine criteria is distributed to meliponiculturists. The criteria were selected based on previous studies of apiculture and opinions from meliponiculture experts from Mardi Alor Setar. The criteria are (1) flowers and plants, (2) water and hydrology, (3) land features, (4) apiary, (5) human activities, (6) pest, (7) wind and humidity, (8) road network, and (9) temperature. The results were analysed based on individual and group ranking. Both individual and group results provide a slightly different ranking by using the MCDM techniques. This study provides an insight on the factors which affect the honey production and its quality in meliponiculture industry which could help optimizing the honey production.

Keywords Meliponiculture, Multicriteria Decision Making Techniques, Fuzzy Analytical Hierarchy Process, Scoring Model, Stingless Bee

1. Introduction

Meliponiculture comes from the Latin word ‘meliponini’ means stingless bee (*Trigona spp.*) and ‘culture’ [1]. It is an activity where meliponiculturists raise stingless bees to collect beeswax, honey, and bee bread to be commercialized. The stingless bees are also raised as pollinating agent for crops such as flowers and fruits [2]. Stingless bee species are harmless to human and considered as domesticated animals [3]. In Malaysia, most stingless bee species is known as ‘*lebah kelulut’*, usually black in colour and sized 3-5 mm which is much smaller than *Apis* (honeybees). Stingless bees honey has high commercial value in Malaysia and considered as an alternative of sting bees honey because it offers better health benefit [4]. Demand of this honey also increased as people are more aware of its advantages [5].

The physicochemical properties of honey are diverse according to origin of geographical or botanical and fruit or flower season [6]. Cortes [7] and Rao et al. [8] added that honey production depends on type of flowers that the bees frequent. These factors result in production of honey with different colour, pH, ash and water content although the bee species are similar [6]. Previous studies have shown that criteria such as land use [9], flowers abundance [10], road network, and water [11] give major impact in honey yield. Amount of water at the location of apiaries also is one of important criteria that need to be taken care of, since plants require enough source of water for running flowers. Since there is high demand of honey, the importance of these criteria should be considered in order to raise honey production. However, meliponiculturists practiced their own way that suits their preferences and have no specific sets of criteria in location selection of meliponiculture. There are many criteria that should be considered in meliponiculture to produce good quality and quantity of honey. As it involves multiple conflicting criteria, different multicriteria decision-making (MCDM) techniques can be effectively applied to solve such type of problem [12-13].

Therefore, a comparative analysis of three MCDM techniques which are Analytical Hierarchy Process (AHP), Fuzzy Analytical Hierarchy Process (FAHP) and Weighted Sum Method (WSM) was conducted to solve the selection of important criteria in meliponiculture and their relative ranking performances are compared.

This paper is organised as follows. The introduction on meliponiculture is presented in Section 1. The literature review on the criteria related to meliponiculture and previous methodologies for criteria selection are discussed in Section 2. Section 3 describes the MCDM techniques to rank the criteria. Section 4 discusses the results and analysis of the constructed MCDM techniques. Finally, Section 5 draws the conclusion of this study.

2. Literature Review

2.1. Criteria on Meliponiculture

Production of stingless bee honey is influenced by various criteria. Flowers and plants are known as main food source for bee colonies. This is because bees need flowers to produce more honey [14-16]. Honey from available plants in surrounding is sucked by bee and will be carried to its hive. In locating apiaries, land features are also one of the important factors. Bees like shady area to forage honey [17,14]. Also, if apiaries of bees are located at low landed area, high pressure of water might endanger the apiaries. However, Goodman [16] states that apiaries also can be located at backyard. Estoque and Murayama [9] in their paper specified that nectar and pollen source are contributed by the land features factor, which come from agriculture, secondary forest, agroforestry, residential area with gardens and grassland. Plus, they also consider land elevation, distance between river and apiaries, distance between road and apiaries.

The natural factors also may affect the meliponiculture which includes rainfall, wind, and temperature. Water resource is being considered as a factor which influence honey production as it supports flower growth [14,16]. Therefore, the amount of rainfall is also considered in this criterion. The wind factor also is considered as a criterion where it may danger apiaries that located at low land [18]. Stingless bees are less active in cooler weather. Extreme temperature (below 10 degree Celcius and more than 37 degree Celcius) can give difficulties for bees to obtain honey from flowers [19]. Honey production of stingless bees in Malaysia seems do not really affected by extreme low temperature as in the four seasons countries since Malaysia experiences heat and rain all around the year. However, extremely hot temperature can cause honey production of stingless bee colonies depleted and the queen migrates to other places. Consequently, honey production of meliponiculturists reduced [20].

Number of apiaries may determine the quantity of honey production [16]. Apiaries may consist of the same or different bee species. Beekeepers believe that the distance of log sequence [15] and placement of apiaries matter if bee species are different to avoid them from entering the wrong apiaries. If stingless bees return to a wrong apiary, fight between two distinct species will happen and endangered the entire colonies and honey.

Other factors are human activities, pest and pesticide, and road network. Dzapete [14] includes proximity of human activities as one of the factors that influence honey production. Even though, stingless bees may bite if their apiaries were disturbed but it is harmless. On the other hand, some beekeepers may encounter presence of pests [14]. It is either pest to protect the bee colonies or flower resources itself. MARDI [20] reported that there exist the attack of black soldier fly and *Haptoncus* beetles which are a big threat to stingless bee species. Even though precautionary steps are taken such as usage of pesticide, honey production could be affected at that time. Maris [17] added road network as a factor in influencing honey production. It is believed that the nearer the road network and apiary, the higher honey will be produced [21]. This study considers population density as the key to human activities. Table 1 presents the summary of criteria in beekeeping presented in the literature.

Table 1. Summary of criteria in beekeeping presented in previous studies

Criteria	Author(s)
Flowers and plants	Dzapete [14], Manning and Boland [15], Goodman [16]
Land use	Maris et al. [17], Dzapete [14], Goodman [16], Estoque and Murayama [9]
Rainfall	Dzapete [14], Goodman [16]
Wind	Nino [18]
Temperature	Abou-Shaara [19], MARDI [20]
Apiary	Manning and Boland [15], Goodman [16]
Human activities	Dzapete [14]
Pests and pesticide	Dzapete [14], MARDI[20]
Road network	Pantoja et al. [21], Maris et al. [17]

2.2. Methods for Ranking the Criteria

MCDM techniques were found in the literature to be the methods for ranking the criteria and have been applied in problems related to budget allocation [22], land selection [12], lecturer selection [23], site selection of solid waste disposal [24], and many more. Akinci et al. [12] applied AHP and Geographical Information System (GIS) to locate suitable land for agriculture by considering land use capability class, soil depth, erosion degree of beekeeping areas and other soil properties. Maris et al. [17] also applied GIS and AHP to locate suitable site for beekeeping in Selangor. The study considered hydrology features, road networks, topography features, nectar class criteria in pairwise comparison to calculate its preference weight that affect suitability.

Sari and Ceylan [13] applied AHP in finding suitable site for beekeeping in Konya. Few criteria are considered which are slope, elevation, aspect, distance to water resources, roads and settlements, precipitation and flora. Argin et al. [25] applied AHP and PROMETHEE I to find the most suitable offshore wind farm location. Viswanath Dhanisetty, Verhagen and Curran [26] employed multi-criteria weighted decision making called weighted sum method for operational maintenance processes applied to a Boeing 777 outboard flap damage case, using real maintenance and operational data. Alanazi, Abdullah and Larbani [27] presented a mathematical model of Dynamic Weighted Sum Method which does not required complex operations and can be applied in various fileds. Budiharjo, Windarto, and Muhammad [28] used weighted sum model and multi attribute decision making weighted product methods to select the best elementary school in Indonesia.

Erbas et al. [29] applied Fuzzy AHP and TOPSIS to locate optimal siting of vehicle charging stations in Ankara involving 15 criteria from different perspectives. Ali et al. [30] applied Fuzzy AHP and GIS to determine most optimal onshore wind farm site selection in South Korea. The study considered seven different site selection criteria, including the slope of the land, the distance to roads and wind. The study also considered restriction zoning such as military zones, wetlands, etc. for exclusion. Ayodele et al. [31] applied multi-criteria GIS-based model for wind farm site selection in Nigeria using interval type-2 fuzzy analytic hierarchy process.

Many studies have implemented MCDM especially AHP to solve criteria selection problem in raising sting bees [9, 13, 17]. This technique is suitable to rank criteria related to meliponiculture if the meliponiculturists are certain about their evaluations. Since uncertainty in judgement of meliponiculturists also existed, FAHP should also be considered to rank these criteria. This is because FAHP provides more relaxed judgement and respond to ambiguity much better. Moreover, WSM is one of the simplest and most commonly used MCDM methods. This method is also used to solve the criteria selection in meliponiculture.

3. Methodology

The process of ranking the criteria of meliponiculture in this study was conducted through three phases which are (1) criteria identification, (2) data collection through questionnaire, and (3) ranking by using MCDM techniques. In the first phase, criteria in beekeeping were reviewed and gathered from previous studies. The criteria were validated through interviews with meliponiculturists and meliponiculture expert from MARDI, Alor Setar. A set of questionnaires was developed based on the criteria and distributed to meliponiculturists in Malaysia through social media to determine the importance of the criteria. The questionnaire is divided into two parts. The first part aims to collect background information of the respondents. In the second part, respondents are required to state the level of importance from 1 to 9 based on Likert scale, where 1 represents least important and 9 represents extremely important.

In the third phase, MCDM techniques were constructed which involves C-AHP, FAHP and WSM. The following subsections discuss the techniques in detail.

3.1. Compromised-Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is used when decision makers may have difficulties in accurately determining the various factor weights and evaluations. This process was developed by Thomas L. Saaty [32] which involves pairwise comparisons. The decision maker starts by laying out the overall hierarchy of the decision. This hierarchy reveals the factors to be considered as well as the various alternatives in the decision. Then, a number of pairwise comparisons are done, which result in the determination of factor weights and factor evaluations. They are the same types of weights and evaluations. As before, the alternative with the highest total weighted score is selected as the best alternative. This study employed Compromised – Analytical Hierarchy Process method as an approach to solve inconsistency issue of standard AHP [33].

Suppose C = $[c_{ij}]_{nxn}$ is a pairwise comparison matrix of size n x n, w is criterion and b is the different between two criterion i and j. The value of c_{ij} is determined as follows:

Let $b = w_i - w_j$.

If $b = 0;\ then\ c_{ij} = 1$

If $b > 0;\ then\ c_{ij} = b + 1$

If

$$b < 0\ then\ c_{ij} = \frac{1}{1-b} \quad (1)$$

For example, suppose that rating given by respondent for criterion i, w_i is 7, and criterion j, w_j is 6. Since subtraction of w_i and w_j is 1, third premise of Eq. 1 is applied, where c_{ij} = 1 + 1 = 2. On the other hand, suppose the weight for criterion i, w_i and criterion j, w_j are both rated the same, for example, 7. Thus, subtraction of w_i and w_j is 0 and first premises of Eq. 1 is applied, where c_{ij} = 1. This is consistent with Saaty's pairwise comparison value, which indicates equally preferred.

The lower triangular matrix is filled in by reciprocate the upper diagonal, by using Eq. 2:

$$c_{ji} = \frac{1}{c_{ij}} \quad (2)$$

Pairwise matrix, C obtained in this phase will be used in calculating relative importance weight in AHP and FAHP. In order to find relative importance weight of each criterion, priority vector need to be computed first. Each column of pairwise matrix needs to be sum. Next, normalization of the matrix was conducted which each element of the matrix with each column sum should be 1. The priority vector is calculated by dividing all rows. Finally, consistency checking is performed by computing Consistency Index, CI and consistency ratio, CR according to Eq. 3 and 4:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

$$CR = \frac{CI}{RI} \quad (4)$$

where λ_{max} is the maximum eigenvalue, n is size of comparison matrix. CI value calculated from Eq. 3 is plugged into Eq. 4 to find consistency ratio, CR. Random consistency index, RI is retrieved from Table 3. A matrix is considered consistent if the CR is below than 10%.

Table 3. Random Consistency Index, RI

Number of criteria, *n*	**Random Consistency Index, *RI***
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

3.2. Fuzzy Analytical Hierarchy Process

Fuzzy AHP integrates fuzzy set theory to AHP which include vagueness of human judgement in an evaluation [34]. Fuzzy AHP is the extension of AHP, where it is usually used to determine rank of criteria due to vagueness in decision making process. In fuzzy AHP, fuzzy numbers are converted into Triangular Fuzzy Numbers (TFNs) and reciprocal TFNs Scale. Each number has its own linguistic variables that align with AHP. Fuzzy AHP involves four steps. In step one, fuzzy pairwise comparison matrix based on pairwise comparison matrix, C is established by using TFNs according to Table 4.

In the next step, fuzzy relative importance weight is calculated by using geometric mean method as given in Eq. 5 where r_i is the geometric mean, a is Triangular Fuzzy Number in each row and n is number in row.

$$\tilde{r}_i = (\tilde{a}_{i1} \times a_{i2} \times \ldots \tilde{a}_{in})^{1/n} \quad (5)$$

Step three involves the defuzzification of fuzzy relative importance weights, dW_i. Let the fuzzy evaluation for criterion i is (l_i, m_i, u_i), where l represents lowest value, m is middle value and u is highest value of fuzzy relative importance weights.

$$dW_i = \frac{(u_i - l_i) + (m_i - l_i)}{3} + l_i \quad (6)$$

Table 4. Table of Fuzzy Numbers and its Scale

Linguistic Terms	AHP scale	Triangular Fuzzy Numbers (TFNs) Scale	Reciprocal Triangular Fuzzy Number (TFNs) Scale
Extreme strongly preferred	1	(1,1,2)	(1/2,1,1)
Intermediate	2	(1,2,3)	(1/3,1/2,1)
Very strongly preferred	3	(2,3,4)	(1/4,1/3,1/2)
Intermediate	4	(3,4,5)	(1/5,1/ 4,1/3)
Strongly preferred	5	(4,5,6)	(1/6,1/5,1/4)
Intermediate	6	(5,6,7)	(1/7,1/6,1/5)
Moderately preferred	7	(6,7,8)	(1/8,1/7,1/6)
Intermediate	8	(7,8,9)	(1/9,1/8,1/7)
Equally preferred	9	(8,9,9)	(1/9,1/9,1/8)

Table 5. Relative important weight of criteria by using individual AHP, FAHP and WSM

		Flowers & Plants	Water & Hydrology	Land	Apiary	Human Activities
A	C-AHP	0.111 (1)	0.111 (1)	0.111 (1)	0.111 (1)	0.111 (1)
	FAHP	0.104 (9)	0.106 (8)	0.108 (7)	0.110 (6)	0.111 (5)
	WSM	0.111 (1)	0.111 (1)	0.111 (1)	0.111 (1)	0.111 (1)
B	C-AHP	0.143 (1)	0.081 (3)	0.021 (4)	0.143 (1)	0.143 (1)
	FAHP	0.136 (1)	0.129 (2)	0.017 (4)	0.136 (1)	0.136 (1)
	WSM	0.125 (1)	0.111 (2)	0.056 (4)	0.125 (1)	0.125 (1)
		Pests & Pesticide	**Wind & Humidity**	**Road Network**	**Temp**	
A	C-AHP	0.111 (1)	0.111 (1)	0.111 (1)	0.111 (1)	
	FAHP	0.113 (4)	0.115 (3)	0.116 (2)	0.118 (1)	
	WSM	0.111 (1)	0.111 (1)	0.111 (1)	0.111 (1)	
B	C-AHP	0.143 (1)	0.115 (2)	0.143 (1)	0.143 (1)	
	FAHP	0.136 (1)	0.115 (3)	0.136 (1)	0.136 (1)	
	WSM	0.125 (1)	0.083 (3)	0.125 (1)	0.125 (1)	

Table 6. Relative important weight of criteria using group AHP, FAHP and WSM

	Flowers & Plants	Water & Hydrology	Land	Apiary	Human Activities
C-AHP	0.168 (1)	0.117 (3)	0.070 (8)	0.140 (2)	0.095 (5)
FAHP	0.149 (1)	0.122 (4)	0.072 (8)	0.142 (2)	0.103 (6)
WSM	0.134 (1)	0.115 (3)	0.092 (6)	0.122 (2)	0.107 (5)
	Pests & Pesticide	**Wind & Humidity**	**Road Network**	**Temp**	
C-AHP	0.072 (7)	0.106 (4)	0.093 (6)	0.140 (2)	
FAHP	0.072 (8)	0.113 (5)	0.099 (7)	0.128 (3)	
WSM	0.092 (6)	0.111 (4)	0.107 (5)	0.122 (2)	

Next, step three involves normalization of relative weight obtained in step two to ensure that matrix obtained is effectively compared by using Eq. 7, where $w_i$is the new fuzzy relative importance weight, while dW_i is defuzzzified weight. Finally, consistency check is performed similar as in AHP.

$$w_i = \frac{dW_i}{\sum_i^n dW_i} \quad (7)$$

3.3. Weighted Sum Method

Weighted Sum Method (WSM) is amongst the earliest and widely used MCDM method [27]. In this method, an aggregated weighted is required to capture the importance of the contributing criteria for a decision. The criterion weights can range from 0 to 1 and the sum of all the criterion weights must be equal to 1. The weights are fully customizable by the decision maker to show the importance of a criterion [26].

In this paper, scoring model is applied to calculate the score of criteria in beekeeping to maximize honey production where it is rated by meliponiculturists. Scoring model has two simple steps. Firstly, attribute score rated by meliponiculturists was obtained through questionnaire. Secondly, the attribute score is multiplied with weight of criteria to calculate, S_i based on Eq. 8;

$$S_i = \sum_{j=1}^{n} g_{ij} w_j$$

for

$$i = 1, 2, 3, \ldots, m \qquad (8)$$

where w_j is weight of criterion j, g_{ij} is attribute score rated by meliponiculturists for alternative i criterion j, and S_i is total score for alternative i.

In this paper, w_j is 1 since all criteria are assumed to have equal weight of importance. All weighted scores are then normalized to get compatible weight comparison between AHP and FAHP.

4. Results

Questionnaires for determining the importance of criteria in raising stingless bee were distributed to meliponiculturists through social media. This study received ten responds and the responses were evaluated by using the proposed MCDM techniques. The weights of criteria based on individuals and group by using the proposed MCDM techniques are given in Tables 5 and 6.

Table 5 shows the comparison of relative weight of criteria by using C-AHP, FAHP and WSM for two individual respondents, i.e., respondent A and B where the criteria ranking are presented in bracket. All the three methods show various results of weight rank. The absolute weight differences between C-AHP, FAHP and WSM are less than 0.1.

For individual A, the respondent ranked all nine criteria as equally important, which eventually calculated by using C-AHP as one. However, when tabulated by using FAHP, the rank changed. The most important criterion is temperature, followed by road network, wind and humidity, pests and pesticide, human activities, apiary, land and water and hydrology. The least important criterion is flowers and plants. FAHP tabulates different rank because it provides more relax calculation thus makes the rank more concise.

For individual B, criteria flowers and plants, apiary, human activities, pests and pesticides, road network, and temperature are rated as one which means it is the most important criteria in meliponiculture. In C-AHP, wind and humidity ranked as second most important criteria, followed by water and hydrology. This is contradicting with ranking from FAHP, but similar to WSM. Land is calculated as the fourth most important criterion in all three MCDM methods.

Based on this comparative analysis, it is concurred that ranking of individual A is vary from individual B. This is due to human judgement and different meliponiculture location. Individual A locates its meliponini at front yard of the house, while individual B raise meliponini at orchard. The contrast land structure and ambiance give slightly different needs for meliponiculturists to practice meliponiculture.

Result of group ranking was calculated by averaging each relative important weight of criteria at the early step and followed the same step for each method. Based on group analysis presented in Table 6, the ranks produced by AHP, FAHP and WSM show that meliponiculturists prefer flowers and plants as major criteria contributes to honey production. All respondents agree that apiary ranked as the second most important criteria, however slightly different for temperature where FAHP ranked temperature in the third place. It is then followed by water and hydrology. The least important criteria computed by all methods are land, with additional pest criteria by FAHP and WSM. Ranking of group analysis is more comprehensive and easier to apply for ranking important criteria in meliponiculture since it includes variety location.

5. Conclusions

This paper presents criteria selection in meliponiculture by using MCDM techniques namely as C-AHP, FAHP and WSM. There are nine criteria in meliponiculture that have been identified from the literature and interviews with meliponiculture experts which could help to maximize honey productions. C-AHP was applied to determine relative weight of the criteria by ranking. By using FAHP, more relaxed calculation is taking into account when assessing the weights of the criteria since FAHP is able to assess uncertainties in judgment. WSM is evaluated by multiplying the relative weight and attribute score rated by the respondents. Comparison analysis has been performed and it is found that all calculations tabulated different results between individual and group analysis. This is due to human judgement at their own practice of meliponiculture and expert opinions.

To sum up, group result is more conclusive than individual results. Based on all three techniques, the first four ranking are quite the same which are flowers and plants, apiary, temperature and water and hydrology.

Therefore, in order to raise colonies of meliponini, meliponiculturists in Malaysia should provide various types of flowers and plants as it is the main food source for meliponini. A good amount of apiary should be taken into consideration to increase larger honey production in short time. Furthermore, suitable temperature plays subtle role in meliponiculture to ensure best niche for meliponini. As rainy season decreases the amoun t of flowers and plants, meliponiculturists are advised to place their apiaries into more suitable shed so that meliponini can still forage and produce honey. All these methods can be employed to help meliponiculturists to select criteria for determining suitable location in meliponiculture. However, FAHP is the best method to be employed in selecting criteria location for meliponiculture since it is more precise.

While this paper focused on bigger radius of location, there is a possibility that the ranking may differ for smaller radius of meliponiculture area. In the future, more MCDM methods can be applied and compared through statistical analysis to make precise judgement and choosing the most suitable location of meliponiculture thus increasing honey production.

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