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Determination of Leaf Spot Disease Severity among Common Vegetables using Fuzzy Analytical Hierarchy Process (FAHP) and Sensitivity Analysis

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Leaf spot is one of the diseases affecting plants especially vegetables, in which they are occupied by the pathogens act on the leaves. The severity of leaf spot disease is generally determined based on human observation, but in nature, human judgment is subjective and not precise. In this paper, the fuzzy analytic hierarchy process (FAHP) model is utilized in determining the most severe leaf spot disease symptom among three common vegetables which are lettuce, cabbage, and brassica. Six experts in the area of plant pathology were interviewed to answer the designed questionnaire with the main criteria involved are color, size, and shape. The evaluation was made based on the selected photo sample of leaf spot disease of the vegetables attached with the questionnaire. The results show that the most severe leaf spot disease is on lettuce and the most important criterion to determine the seriousness of leaf spot disease symptom is the colour of the spot. The sensitivity analysis based on degree of fuzziness δ shows that the ranking of the decision remains unchanged with changes in degree of fuzziness $\delta \in (0, 0.5]$. The results can be used as a guide for farmers and agronomist in diagnosing the severity of leaf spot disease.

Keywords: fuzzy analytic hierarchy process; human judgment; leaf spot disease; sensitivity analysis; vegetables

I. INTRODUCTION

The plant disease might affect the quantity and quality of the food production. Monitoring the plant disease may produce more food with high quality. Blights, leaf spots, smuts, wilts, rusts and root rots are common symptoms of plants diseases. For example, infection of the foliage may cause leaf spots, blights, rusts, mildews, mosaic and so on (Agrios, 1997). Leaf spot is a mutual expressive term applied to diseases affecting the foliage of plants especially vegetables. According to Kirk and Wharton (2012), leaf spot is a general disease found in the majority of crop production area. Various diseases of leaf spot have parallel biology and related organization selection. Leaf spot disease occurs due to the pathogens act on the leaf. The pathogens are the natural agents that affect the plants (Koike *et al.*, 2003). Leaves are the significant part of the plant body and act as the main source for photosynthesis. Photosynthesis formulates energy for defence systems, nurtures growth and influences survival. The main function of leaves is to produce food for the plant. This activity occurs mostly in fully-grown leaves. Thus, the leaves are very significant to a plant's health and survival. Consequently, leaf spot diseases reduce the photosynthesis activity and weaken the plant since they infect the areas of the leaves where the

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photosynthesis takes place. Leaf spots happen in a broad range of colours, shapes and sizes depending on the plant affected, the particular organism involved, and the stage of progress. According to Douglas (1875), the typical leaf spots usually have rather brownish, black, or tan colours. Some spots are circular and irregular in shape, while some are heaved, loafer and give a leaf a shot-holed appearance. Some spots also have dissimilar yellow halos. The University of Minnesota (2018) states that the leaf spots disease symptoms may include raised or sunken, angular or rounded, and have smooth or fringed edges. The diseases turn the affected leaves into yellowish and odourless, followed by either drying up or falling off. The spots may be small, sunken or enlarged, and the velvety surface layer indicates the growth of fungus and spores (Agrios, 1997).

The analytic hierarchy process (AHP) technique developed by Saaty (1980) is a powerful decision-making tool for handling unstructured decisions with multi-criteria inputs. The AHP sorts out the complex decisions by organizing the criteria and options into a hierarchical system. The hierarchy is developed through pair-wise comparison of personal judgement instead of emphasis on the whole decision and criteria concurrently. However, the conventional AHP cannot reflect human thinking style as human judgement is vague, ambiguous and uncertain. Therefore, the fuzzy analytic hierarchy process (FAHP) was developed to work out on the issue. The FAHP method has been widely used to solve various decision-making problems such as in water management plan (Sradjevic & Medeiros, 2008), evaluation of teaching performance (Chen *et al.*, 2015), supplier selection of a gear motor company (Ayhan, 2013) and integrating geophysical data for mineral prospectivity map (Abedi *et al.*, 2013).

In Malaysia, there is a very uncommon experiment related to the severity of leaf spot disease among vegetables by using FAHP. There is a lack of systematic method to evaluate the severity of leaf spot disease symptom. The regular methods that are usually used to judge and observe the performance of leaf spot disease are through the evaluation of human judgment and observation. Nevertheless, human judgment and observation are very subjective, vague, imprecise and inaccurate. Thus, the aim of this paper is to evaluate the severity of leaf spot diseases symptom among three common vegetables which are lettuce, cabbage and brassica by using FAHP method. The sensitivity analysis based on the level of vagueness (Zhu *et al.*, 1999; Tang & Lin, 2011) is conducted to investigate the sensitivity of the decision ranking towards the changes of input. The outcome of this research is useful for experts as a guide in judging healthy vegetables. A better observation will help experts and farmers in making decision.

The arrangement of the remaining parts of the paper is as follows: the basic reviews on FAHP is presented in Section 2. This is followed by the case study on the ranking of severity of leaf spot diseases symptom in Section 3. Section 4 discusses the results and Section 5 is a conclusion of the paper.

II. PRELIMINARIES

This section emphasizes some basic definitions of triangular fuzzy numbers (TFNs) and Fuzzy AHP (FAHP) from Buckley (1985) as well as the degree of fuzziness from Zhu *et al.* (1999) and Tang and Lin (2011).

A. Triangular Fuzzy Numbers (TFNs)

A triangular fuzzy number (TFN) denotes as $\tilde{M}=(a,b,c)$, has a membership function as

$$\mu_{\tilde{M}}(x)=\begin{cases}\dfrac{x-a}{b-a}, & a\le x\le b\\ \dfrac{c-x}{c-b}, & b\le x\le c\\ 0, & \text{Otherwise}\end{cases}$$

and shown in Figure 1.

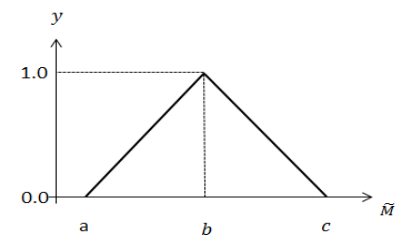

Figure 1. A triangular fuzzy number $\tilde{M}$.

The arithmetic operations of two triangular fuzzy numbers (TFNs) $A_1=(a_1,b_1,c_1)$ and $A_2=(a_2,b_2,c_2)$ are as follows:

Addition:

$$A_1 \oplus A_2 = (a_1, b_1, c_1) \oplus (a_2, b_2, c_2)$$
$$= (a_1 + a_2, b_1 + b_2, c_1 + c_2)$$

Multiplication:

$$A_1 \otimes A_2 = (a_1, b_1, c_1) \otimes (a_2, b_2, c_2)$$
$$= (a_1 \cdot a_2, b_1 \cdot b_2, c_1 \cdot c_2)$$

whereby $a_1, a_2, b_1, b_2, c_1, c_2 > 0$.

Division:

$$A_1 \oslash A_2 = (a_1, b_1, c_1) \oslash (a_2, b_2, c_2)$$
$$= \left(\frac{a_1}{c_2}, \frac{b_1}{b_2}, \frac{c_1}{a_2}\right)$$

whereby $a_1, a_2, b_1, b_2, c_1, c_2 > 0$.

B. Fuzzy Analytic Hierarchy Process (FAHP)

The FAHP embeds the fuzzy concept to the basic AHP. In FAHP, linguistic statement is used for pair-wise comparison which represented by fuzzy numbers. Laarhoven and Pedrycz (1983), Buckley (1985) and Chang (1996) have proposed the pair-wise comparison techniques using fuzzy numbers in solving multi-criteria decision-making (MCDM). In this paper, the geometric mean by Buckley's method (1985) is implemented in determining the fuzzy weight for each attribute. The steps of the procedure are given as follows:

Step 1: A group of decision-makers evaluates the criteria using the pair-wise comparison in TFNs form from Table 1.

Table 1. Triangular fuzzy conversation scale (Kahraman *et al.*, 2004)

Linguistic variables	Positive triangular fuzzy scale	Positive reciprocal triangular fuzzy scales
Equally important (E)	(1, 1, 1)	(1, 1, 1)
Weakly importance (W)	(2/3,1,3/2)	(2/3,1,3/2)
Fairly strong importance (FS)	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more importance (VS)	(5/2,3,7/2)	(2/7,1/3,2/5)
Absolutely more importance (A)	(7/2,4,9/2)	(2/9,1/4,2/7)

The pair-wise comparison matrix (PCM) A^k for each decision-maker individually is given in Equation (1) where a_{ij}^k is the k^{th} decision maker's preferences of i^{th} criterion over j^{th} criterion whereby n refer to the number of criterion and K refer to the number of decision-makers. a_{ij}^k is in TFNs form with $a_{ij}^k = (l_{ij}^k, m_{ij}^k, u_{ij}^k)$.

$$A^k = \begin{bmatrix} a_{11}^k & a_{12}^k & \cdots & a_{1n}^k \\ a_{21}^k & \cdots & \cdots & a_{2n}^k \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1}^k & a_{n2}^k & \cdots & a_{nn}^k \end{bmatrix} \quad (1)$$

Step 2: The PCM in Equation (1) is aggregated based on Ahyan (2013) as $M_{ij} = (l_{ij}, m_{ij}, u_{ij})$ whereby

$$l_{ij} = \frac{\sum_{k=1}^{K} l_{ij}^k}{K}, m_{ij} = \frac{\sum_{k=1}^{K} m_{ij}^k}{K} \text{ and } u_{ij} = \frac{\sum_{k=1}^{K} u_{ij}^k}{K} \quad (2)$$

Step 3: The geometric mean of fuzzy comparison values for each criterion i is calculated as follows:

$$r_i = \left(\prod_{j=1}^{n} M_{ij}\right)^{\frac{1}{n}} = (l_i, m_i, u_i) \quad (3)$$

Step 4: The fuzzy weight for each criterion i is calculated as follows:

$$W_i = \left(\frac{l_i}{\sum_{i=1}^{n} u_i}, \frac{m_i}{\sum_{i=1}^{n} m_i}, \frac{u_i}{\sum_{i=1}^{n} l_i}\right) = (l_{wi}, m_{wi}, u_{wi}) \quad (4)$$

Step 5: Defuzzify the fuzzy weight of each criterion i using Chou and Chang's (2008) as follows:

$$M_i = \frac{l_{wi} + m_{wi} + u_{wi}}{3} \quad (5)$$

Step 6: Normalize the defuzzified weight of each criterion i as follows:

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \quad (6)$$

Through normalization, the weight vector is given as follows:

$$W = (N_1, N_2, \cdots, N_n)^T \quad (7)$$

C. Degree of Fuzziness

According to Zhu *et al.* (1999), the values of l_{ij} and u_{ij} in the aggregated PCM in Eq. (2) (l_{ij}, m_{ij}, u_{ij}) describe the fuzziness of the judgement, as shown in Figure 2.

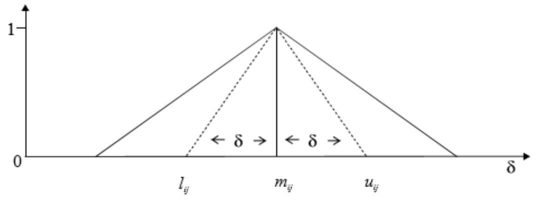

Figure 2. Degree of fuzziness δ (Zhu *et al.*, 1999, Tang & Lin, 2011)

The degree of fuzziness δ has the characteristic of $m_{ij} - l_{ij} = u_{ij} - m_{ij} = \delta$. For a modal value m_{ij}, the TFN is defined as ($mij - \delta$, mij, $mij + \delta$) with its reciprocal TFN as $\left(\frac{1}{m_{ij}+\delta}, \frac{1}{m_{ij}}, \frac{1}{m_{ij}-\delta}\right)$.

III. DETERMINE THE SEVERITY OF LEAF SPOT DISEASE SYMPTOM USING FAHP

In this paper, the goal is to determine the severity of leaf spot disease symptom among three vegetables which are lettuce (Le), cabbage (Ca) and brassica (Br). The decision-making group consists of six experts from the plant pathology area - three lecturers and two plantation staffs from Plantation Department at one higher institution in the East Coast of Malaysia, and one expert from Malaysian Agricultural Research and Development Institute (MARDI) farm. The hierarchical structure is shown in Figure 3.

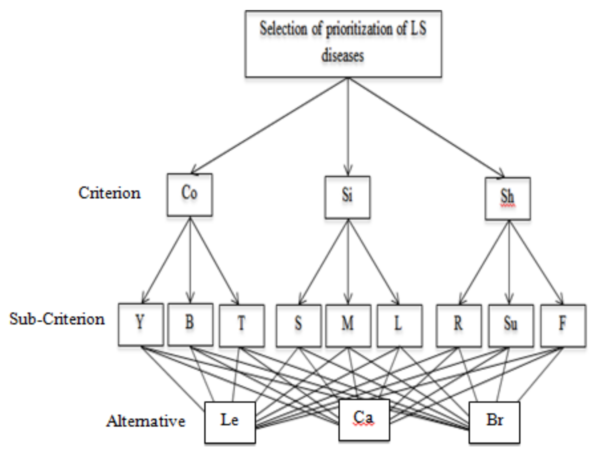

Figure 3. Hierarchical structure of determination of leaf spot disease

The samples of leaf spot disease on each vegetable were collected and the photos of the samples were taken. The photos of the samples were used in the evaluation due to the condition of the fresh samples that would gradually become wilt in a longer period of time, thus affecting the respected symptoms for the evaluation purposes. The head of experts selected the three best photo samples of each vegetable for the evaluation purposes. Three main criteria were considered, and they are colour (Co), size (Si) and shape (Sh) of the leaf spot. The sub-criteria with respect to Co are defined as Yellow (Y), Brown (B) and Tan (T). Meanwhile, Small (S), Medium (M) and Large (L) are the sub-criteria for Si, and Rounded (R), Sunken (S) and Fringed (F) are the sub-criteria for Sh. Table 2 shows the fuzzy PCM by Expert 1.

Table 2. The fuzzy PCM by Expert 1

Criteria	Co	Si	Sh
Co	(1,1,1)	(5/2,3,7/2)	(5/2,3,7/2)
Si	(2/7,1/3,2/5)	(1,1,1)	(5/2,3,7/2)
Sh	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(1,1,1)

IV. RESULTS AND DISCUSSION

The aggregated fuzzy PCM for all experts based on Eq. 2 is shown in Table 3.

Table 3. The aggregated fuzzy PCM by all experts

Criteria	Co	Si	Sh
Co	(1,1,1)	(1.5133,1.7767, 2.05)	(2.2983,2.7217, 3.15)
Si	(1.1450,1.3317, 1.5333)	(1,1,1)	(1.2633,1.4433, 1.6333)
Sh	(0.6467,0.7617, 0.8983)	(1.2633,1.4433, 1.6333)	(1,1,1)

Based on Table 3 and Eq. 3, we get

r_{Co} = (1.5151,1.6910,1.8622),

r_{Si} = (1.1309,1.2433,1.3580),

r_{Sh} = (0.938,1.032,1.1363).

From Equation 4, we obtain

W_{Co} = (1.5151×0.2295, 1.6910×0.2521, 1.8622×0.2793)
= (0.3478, 0.4263, 0.5200)

W_{Si} = (1.1309×0.2295, 1.2433×0.2521, 1.3580×0.2793)
= (0.2596, 0.3135, 0.3792)

W_{Sh} = (0.938×0.2295, 1.032×0.2521, 1.1363×0.2793)
= (0.2146, 0.2602, 0.3173)

The defuzzified fuzzy weight M_i and normalized weight N_i for each criterion i are computed by Equation 5 and 6, respectively and shown in Table 4.

Table 4. The defuzzified fuzzy weight and normalized weight vector

Criteria	W_i			M_i	N_i
Co	0.3478	0.4263	0.5200	0.4314	0.4259
Si	0.2596	0.3135	0.3792	0.3174	0.3134
Sh	0.2146	0.2602	0.3173	0.2641	0.2607
			Total	1.0129	

Therefore, the weight vector from Table 4 is computed as $W_G = (0.4259, 0.3134, 0.2607)^T$.

The aggregated evaluation of the sub-criteria Co, Si and Sh are presented in Tables 5, 6 and 7, respectively. The sub-criteria for Co are yellow (Y), brown (B) and tan (T) and the sub-criteria for Si are small (S), medium (M) and large (L). Meanwhile, the sub-criteria for Sh are Rounded (R), Fringed (F) and Sunken (S).

Table 5. Aggregated judgement of the sub-attributes of color (Co) by all experts

Co	Y	B	T
Y	(1,1,1)	(0.6548,0.7778, 0.9167)	(0.6548,0.7778, 0.9167)
B	(2.1310,2.5556, 2.9833)	(1,1,1)	(0.6548,0.7778, 0.9167)
T	(2.1310,2.5556, 2.9833)	(2.1310,2.5556, 2.9833)	(1,1,1)

Table 6. Aggregated judgement of the sub-attributes of size (Si) by all experts

Si	S	M	L
S	(1,1,1)	(0.2857,0.3333, 0.4)	(0.2857,0.3333, 0.4)
M	(2.5,3,3)	(1,1,1)	(0.2857,0.3333, 0.4)
L	(2.5,3,3.5)	(2.5,3,3.5)	(1,1,1)

Table 7. Aggregated judgement of the sub- attributes of shape (Sh) by all experts

Sh	R	F	S
R	(1,1,1)	(0.4083,0.4417, 0.5)	(0.7767,0.8867, 1.0167)
F	(2.2500,2.6667, 3.0833)	(1,1,1)	(1.0267,1.2200, 1.4333)
S	(1.8817,2.2217, 2.5667)	(1.7633,2.1100, 2.4667)	(1,1,1)

In a similar manner with the previous calculation, we get

$W_{Co} = (0.2135,0.3167,0.4698)^T$,

$W_{Si} = (0.1362,0.2816,0.5821)^T$ and

$W_{Sh} = (0.1892,0.3810,0.4298)^T$.

The weight vector for colour (Co) criterion indicates that tan (T) colour has the highest weight followed by brown (B) and yellow (Y) in determining the severity of leaf spot disease symptom. For size (Si) criterion, large (L) spot obviously has the highest weight compared to medium and small spot. Meanwhile, for shape (Sh) criterion of the spot, the sunken shaped has the highest weight compared to fringed and rounded shaped.

The aggregated judgement of the sub-attributes to types of colour namely yellow, brown and tan for each vegetable are shown in Tables 8, 9 and 10, respectively.

Table 8. The fuzzy judgement matrix of sub-attributes of Yellow colour by all experts

	Le	Ca	Br
Le	(1,1,1)	(0.8250,0.9417, 1.0833)	(0.6583,0.7750, 0.9167)
Ca	(2.1200,2.5417, 2.9650)	(1,1,1)	(1.4133,1.6933, 1.9950)
Br	(2.1317,2.5550, 2.9833)	(1.2283,1.4983, 1.7833)	(1,1,1)

Table 9. The fuzzy judgement matrix of sub-attributes of Brown colour by all experts

	Le	Ca	Br
Le	(1,1,1)	(1.7633,2.1100, 2.4667)	(0.6583,0.7750, 0.9167)
Ca	(1.0267,1.2200, 1.4333)	(1,1,1)	(1.0267,1.2200, 1.4333)
Br	(2.1317,2.5550, 2.9833)	(1.7633,2.1100, 2.4667)	(1,1,1)

Table 10. The fuzzy judgement matrix of sub-attributes of Tan colour by all experts

	Le	Ca	Br
Le	(1,1,1)	(2.5,3,3.5)	(1.5133,1.7767, 2.05)

Ca	(0.29,0.33,0.4)	(1,1,1)	(0.29,0.33,0.4)
Br	(1.1450,1.3317, 1.5333)	(2.5,3,3.5)	(1,1,1)

In a similar manner, we obtain

$W_Y = (0.2208,0.3972,0.3820)^T$,

$W_B = (0.2897,0.2806,0.4297)^T$ and

$W_T = (0.4571,0.1274,0.4155)^T$.

Using the same procedure, the weight vector of sub-attributes with respect to types of size namely small, medium and large for each vegetable are given as follows: $W_S = (0.3669,0.2626,0.3706)^T$,

$W_M = (0.2135,0.4698,0.3167)^T$ and

$W_L = (0.5657,0.1749,0.2595)^T$.

The weight vector of sub-attributes with respect to types of shape namely rounded, sunken and fringed for each vegetable are given as follows:

$W_R = (0.2146,0.4257,0.3598)^T$,

$W_{Su} = (0.3903,0.1950,0.4146)^T$ and

$W_F = (0.3922,0.3654,0.2424)^T$.

The priority weights for the criteria and sub-criteria of each alternative are summarized in Tables 11 to 14.

Table 11. Comparison of Colour Priority Weight by all experts

	Y	B	T	Alternative priority weight
Weight	0.2135	0.3167	0.4698	
Alternative				
Lettuce	0.2208	0.2897	0.4571	0.3536
Cabbage	0.3972	0.2806	0.1274	0.2335
Brassica	0.382	0.4297	0.4155	0.4128

Table 12. Comparison of Size Priority Weight by all experts

	S	M	L	Alternative priority weight
Weight	0.1362	0.2816	0.5821	
Alternative				
Lettuce	0.3669	0.2135	0.5657	0.4394
Cabbage	0.2626	0.4698	0.1749	0.2699
Brassica	0.3706	0.3167	0.2595	0.2907

Table 13. Comparison of Shape Priority Weight by all experts

	R	Su	F	Alternative priority weight
Weight	0.1892	0.381	0.4298	
Alternative				
Lettuce	0.2146	0.3903	0.3922	0.3579
Cabbage	0.4257	0.1950	0.3654	0.3119
Brassica	0.3598	0.4146	0.2424	0.3302

Table 14. Comparison of Goal Priority Weight by all experts

	Co	Si	Sh	Alternative priority weight
Weight	0.4259	0.3134	0.2607	
Alternative				
Lettuce	0.3536	0.4394	0.3579	0.3816
Cabbage	0.2335	0.2699	0.3119	0.2655
Brassica	0.4128	0.2907	0.3302	0.3530

Based on Table 14, lettuce is the most severe vegetable affected by leaf spot disease followed by brassica and cabbage.

Table 15. Comparison of Prioritization by all experts

Main Criteria	Sub-criterion (Colour)	Sub-criterion (Size)	Sub-criterion (Shape)	Alternatives
Sh ≺ Si ≺ Co	Y ≺ B ≺ T	S ≺ M ≺ L	R ≺ Su ≺ F	Ca ≺ Br ≺ Le

Table 15 summarizes the result obtained by the six experts. For the main criteria, colour is the most important criterion compared to size and shape of the leaf spot disease symptom. Meanwhile, for sub-criterion of colour, tan represents the most significant indication of disease severity compared to brown and yellow. The large size of spot on leaf spot disease symptom is displayed as the most severe indication of disease compared to medium and small spot. For the shape of the spot, fringed shows the most important sub-criterion on severity followed by sunken and rounded. Besides that, lettuce is found to be the most severely infected by leaf spot disease compared to brassica and cabbage.

V. SENSITIVITY ANALYSIS

The sensitivity analysis for the ranking of criteria and alternatives based on the degree of fuzziness are carried out for $\delta \in (0, 0.5]$. The procedure of sensitivity analysis for normalized defuzzified weight is shown in Figure 4.

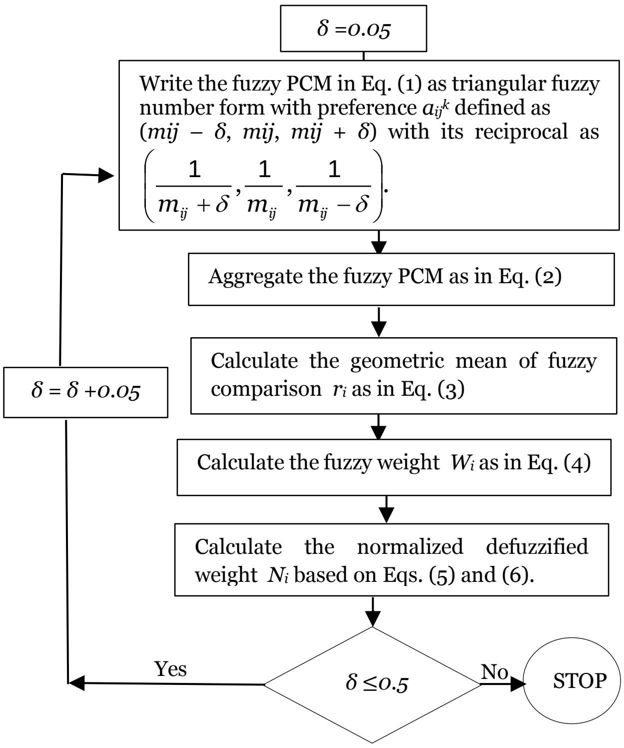

Figure 4. Flow of sensitivity analysis process

As an example, we choose $\delta = 0.3$. The fuzzy PCM towards goal by Expert 1 is shown in Table 16.

Table 16. The fuzzy PCM by Expert 1 for $\delta = 0.3$

Criteria	Co	Si	Sh
Co	(1,1,1)	(2.7,3,3.3)	(2.7,3,3.3)
Si	(0.3,0.33,0.37)	(1,1,1)	(2.7,3,3.3)
Sh	(0.3,0.33,0.37)	(0.3,0.33,0.37)	(1,1,1)

Furthermore, the aggregated fuzzy PCM and the normalized defuzzified weight are shown in Tables 17 and 18, respectively.

Table 17. The aggregated fuzzy PCM by all experts for $\delta = 0.3$

Criteria	Co	Si	Sh
Co	(1,1,1)	(1.67,1.78,1.94)	(2.47,2.72,2.98)
Si	(1.22,1.33,1.45)	(1,1,1)	(1.33,1.44,1.56)
Sh	(0.68,0.76,0.84)	(1.33,1.44,1.56)	(1,1,1)

Thus, we get

r_{Co} = (1.6, 1,69, 1.79), r_{Si} = (1.17, 1,24, 1.31),

r_{Sh} = (0.97, 1.03, 1.09).

W_{Co} = (0.382, 0.426, 0.478)

W_{Si} = (0.279, 0.312, 0.35)

W_{Sh} = (0.232, 0.259, 0.291)

Table 18. The defuzzified weight and normalized weight vector for $\delta = 0.3$

Criteria	W_i			M_i	N_i
Co	0.382	0.426	0.478	0.429	0.427
Si	0.279	0.312	0.35	0.314	0.312
Sh	0.232	0.259	0.291	0.261	0.26
			Total	1.004	

Figure 5 shows the normalized defuzzified weight for $\delta \in (0, 0.5]$.

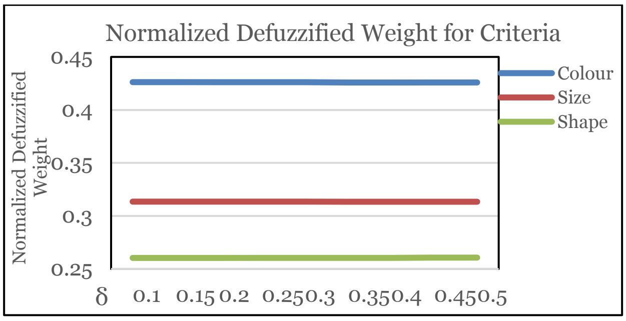

Figure 5. Sensitivity analysis for defuzzified weight of criteria when δ changed

In similar manner, the fuzzy PCM with respect to color, size and shape for all experts is defined as a triangular fuzzy number with $\delta \in (0, 0.5]$, and finally the normalized defuzzified alternative weight can be obtained for $\delta \in (0, 0.5]$ as shown in Figure 6. Based on Figure 5, for $\delta \in (0, 0.5]$, the values of priority of defuzzified weight of colour are the highest compared to size and shape. This shows that, when the degree of fuzziness changed for $\delta \in (0, 5]$, the priority ranking of the criteria remains unchanged as Sh $\prec$ Si $\prec$ Co. Similarly, based on Figure 6, Lettuce has the absolute dominant preference, followed by cabbage and brassica. This indicates that when the degree of fuzziness changes for $\delta \in (0, 0.5]$, the ranking of the decision analysis on the severity of vegetables infected by leaf spot disease remains unchanged as Ca $\prec$ Br $\prec$ Le.

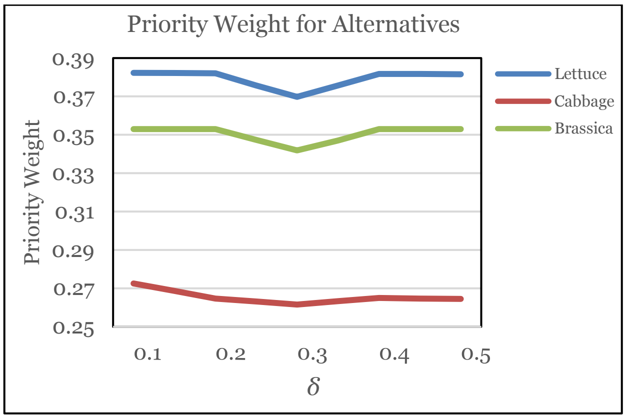

Figure 6. Sensitivity analysis for alternatives when δ changed

VI. CONCLUSION

This paper utilized the Fuzzy AHP method in determining the severity of leaf spot disease symptom among three common vegetables which are lettuce, brassica and cabbage. Based on experts' opinion, lettuce is found to have the highest seriousness of leaf spot disease followed by brassica and cabbage. This study also found that the most important criteria to evaluate the seriousness of the leaf spot disease is through the color of the leaf spot followed by the size and shape. The sensitivity analysis shows that the FAHP method is robust for the selection of severity of leaf spot disease as the changes in degree of fuzziness $\delta \in (0, 0.5]$, does not influence the final decision. The ranking of priority alternatives and criteria remains unchanged with changes in degree of fuzziness. The results of this research can provide additional information in the field of plant pathology. The information can also be a guidance for farmers and agronomist in diagnosing the severity of leaf spot disease symptom. As an extension of this study, the sensitivity analysis based on the input preference can be used and the comparison of results can be made.

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