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Selection of Agricultural Techniques for Farmers in Northern Kedah Using the Fuzzy Analytic Hierarchy Process

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ABSTRACT

Agriculture plays a vital role in sustaining human life by maintaining land, cultivating crops, and raising livestock for food, medicine, and other uses. It also contributes significantly to national economies and global food security. This study uses the fuzzy analytic hierarchy process (FAHP) method to identify the most efficient agricultural practices for northern part of Kedah farmers, determine the criteria for efficient farming, evaluate alternatives, and rank them according to their effectiveness. Three alternatives, which are conventional, organic, and technological practices, as well as five criteria, including satisfaction, knowledge, environment, practicality, and economic, were evaluated. According to the findings, knowledge is the most important factor (weight: 0.5436), whereas satisfaction (0.0523) was considered less important. With a global weight of 44.32%, the technological approach was the most successful agricultural method among the alternatives. Organic methods were the least preferred (25.69%), while conventional methods came in second (29.99%). These results highlight how crucial knowledge and technology are to obtaining effective and sustainable farming methods. In addition to giving policymakers and organisations useful information for guiding investments and operations, this study offers farmers a structured framework for evaluating and carrying out appropriate farming practices. It draws attention to the necessity of region-specific solutions and provides a starting point for more study to improve methods of sustainable agriculture in other areas.

1. INTRODUCTION

Agriculture is defined as the practice of managing land, cultivating crops, raising livestock, and producing goods for food, medicine, and other uses that support human life. Globally, agriculture is essential for food security and economic development. As economic pressures and environmental challenges intensify,

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sustainable agricultural practices have become increasingly important (Liu et al., 2024). Agriculture generates income for individuals and organizations, including state governments, and provides employment opportunities that support livelihoods. Moreover, agricultural activities contribute to ecosystem balance by improving air quality and preserving wildlife habitats, thereby enabling species to thrive in their natural environments.

Over the years, agriculture has experienced significant advancements driven by technological innovations, improved farming methods, and increased productivity. These developments have enabled farmers to achieve higher crop yields and better resource management. The adoption of advanced technologies enhances the sustainability and efficiency of agricultural production. For instance, the use of drones has been shown to improve farmers' productivity and contribute to economic development. Compared with conventional machinery such as tractors, drones can reduce environmental pollution because they apply chemicals only when necessary, whereas tractors continuously emit exhaust fumes that contribute to air pollution.

Fertilizer also remains a key component in producing high-quality crops. In the current technological era, fertilizers have evolved into various forms, including chemical and organic types. The use of organic or biofertilizers improves soil health and promotes healthier crop production. In addition, emerging technologies such as soil sensors enable farmers to monitor soil moisture and nutrient levels for more precise irrigation and fertilization, thereby supporting the production of high-quality crops.

Malaysia is no exception in embracing agricultural technological development. In 2005, the fifth Prime Minister, Tun Abdullah Ahmad Badawi, emphasized the importance of agriculture and played a significant role in promoting biotechnology in the sector. His vision was to increase productivity and efficiency through technological adoption. Recognizing the value of modern agricultural technology, he introduced the National Biotechnology Policy in 2005 to strengthen the national agricultural economy and promote the growth of agriculturally based enterprises, particularly among Small and Medium-Sized Enterprises (SMEs) (Saiful et al., 2011). This initiative also aimed to encourage rural populations to remain engaged in agricultural activities, thereby contributing to national food security.

Food security has become a critical concern, particularly during global disruptions such as the coronavirus pandemic, when limitations on imports and exports affected many countries. Strengthening domestic agriculture can therefore reduce reliance on external food sources. In Kedah, rice cultivation is a central component of the state's economy, supported by extensive paddy fields and favourable climatic conditions. The region also supports diverse agricultural activities, including the cultivation of fruits, rubber, and oil palm. Malaysia is widely recognized as one of the world's leading palm oil producers (Palm Oil Industry in Malaysia – Statistics & Facts, 2024).

Despite the country's strong agricultural capacity, not all crops are suitable for every region due to variations in soil conditions, climate, and geography. Therefore, Kedah requires efficient and well adapted agricultural systems. Identifying the most suitable farming techniques for farmers in Kedah is essential to enhance profitability and strengthen national food security. Building upon the importance of agriculture in supporting economic growth and food security, the sector continues to face several practical challenges despite increasing interest and investment. One of the most critical concerns is the risk of investment losses and reduced yields resulting from inappropriate or poorly informed decisions when selecting farming techniques. Such inefficiencies may discourage farmers and limit the overall performance of the agricultural sector. To achieve optimal agricultural productivity, multiple and often conflicting factors must be considered, including economic viability, farmer knowledge, satisfaction, practicality of implementation, and environmental sustainability. In current practice however, these factors are frequently assessed in separation or based largely on subjective judgment. The absence of a comprehensive and systematic evaluation framework may lead to inconsistent decision making, inefficient resource utilization, and minimal farming outcomes.

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Farmers in Kedah are presented with several agricultural approaches, particularly technological, conventional, and organic farming methods. Each approach offers distinct advantages and limitations in terms of cost, productivity, environmental impact, and ease of implementation. Although technological farming may require higher initial investment, it demonstrates strong potential to enhance yield and operational efficiency. Therefore, a structured multi criteria decision making approach is necessary to determine the most suitable agricultural technique for the local context.

Accordingly, this study applies the fuzzy Analytic Hierarchy Process (FAHP) to evaluate the relevant criteria and rank the available agricultural techniques for farmers in the northern region of Kedah. The proposed framework aims to support more informed, objective, and systematic decision making toward improving agricultural efficiency and sustainability.

2. LITERATURE REVIEW

For this section, the fundamental concepts of the study are presented. It includes the concept of fuzzy AHP and the hierarchical framework of the criteria and alternatives used in this study.

2.1 Fuzzy AHP

The Analytic Hierarchy Process (AHP) is a widely recognized multi criteria decision making method that derives ratio scales from pairwise comparisons, which can be based on quantitative measurements or subjective assessments of preferences and perceptions (Saaty, 1987). It has been extensively applied in resource allocation, planning, dispute resolution, and sustainability related fields (Kumar & Pant, 2023). Lin (2020) highlighted that the classical AHP employs a nine-point scale to assess the relative importance of alternatives, with pairwise comparisons reflecting the priority of each option. AHP breaks down large problems into smaller, more manageable subproblems using a tree structure (Rouyendegh & Savalan, 2022).

While AHP provides a structured framework, it is limited in handling the inherent uncertainty and vagueness of human judgment. To address this, the fuzzy Analytic Hierarchy Process (FAHP) integrates fuzzy set theory, allowing decision makers to express preferences using linguistic variables (e.g., "low," "medium," "high"), which are then translated into fuzzy triangular numbers for systematic analysis. Pairwise fuzzy ratios using triangular membership functions and calculating partial fuzzy priorities can be done using the geometric mean method. This approach has been widely adopted in sustainability and agricultural studies to accommodate ambiguity in expert assessments (Bhatt et al., 2021).

Several studies have demonstrated the effectiveness of FAHP in agricultural decision making. By ranking criteria and alternatives using fuzzy triangular numbers, researchers are able to identify the most suitable techniques while considering multiple conflicting factors such as economic viability, environmental sustainability, practicality, knowledge, and satisfaction. The hierarchical framework employed in FAHP, which structures the decision problem into goal, criteria, and alternatives, provides a transparent and systematic approach for evaluating complex choices (Bhatt et al., 2021; Lin, 2020).

In the context of agriculture, FAHP has been increasingly applied to evaluate technological, conventional, and organic farming methods. Technological methods, though potentially costly, often yield higher productivity and efficiency, while conventional and organic methods offer alternative benefits such as cost effectiveness or environmental sustainability. The application of FAHP facilitates the incorporation of expert knowledge and regional context into decision making, ensuring that the selected agricultural technique aligns with both practical and sustainability objectives. Overall, the literature indicates that FAHP is a robust tool for multi criteria agricultural decision making. Its ability to integrate linguistic assessments, handle uncertainty, and provide a structured hierarchical evaluation makes it particularly suitable for studies aiming to identify the most efficient and context specific farming practices.

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2.2 Factors of effecting farming

Several studies have investigated the factors influencing effective farming. Emran et al. (2021) identified economic status as a key determinant of farm household livelihoods. Their study, based on a panel survey of 502 households across polder systems in coastal South Asia, employed factor analysis on 32 variables collected between 2005 and 2015. Five latent factors were extracted: farming challenges, economic status, crop management practices, asset endowment, and farm characteristics. The study emphasized that protecting agricultural land from non agricultural uses is essential to increasing annual crop yields.

Duvaleix et al. (2020) highlighted the importance of environmentally friendly practices in modern agricultural systems. Their research examined the influence of producer organizations and quality labels on farmers' adoption of sustainable practices in the olive oil industry in Crete, Greece, and the pig industry in Brittany, France. Through qualitative interviews with supply chain stakeholders, they found that quality labels and producer organizations can incentivize environmentally responsible farming practices, even if the labels are not explicitly designed to improve environmental outcomes.

Tripathi et al. (2024) explored the role of information sharing, extension services, and agricultural education in improving farming practices. Conducted in Tanzania's East Usambara Mountains, the study demonstrated that farmers' awareness of biodiversity, pests, and natural enemies significantly influenced their use of sustainable land management techniques. Farmers engaged in year round farming, diversified cropping, and conservation agriculture showed higher knowledge levels and more effective pest management, highlighting the importance of inclusive training programs targeting less experienced and none community supported agriculture farmers.

Liu et al. (2024) emphasized the role of practical experience in enhancing agricultural sustainability and national food security. Their research examined energy and resource intensive farming practices, analyzing sustainable agriculture frameworks such as agroecology and the circular economy. The study also reviewed precision agriculture and organic farming as techniques that can improve both productivity and environmental sustainability. They concluded that evidence based policies and integrated strategies are essential to advance sustainable agriculture at the national level.

Zhang and Yang (2022) investigated farmers' satisfaction with Sustainable Rural Development (SRD) techniques in Guangdong Province, China. Using Hierarchical Linear Modelling (HLM) on survey data from 599 farmers in 57 villages, they found that satisfaction was influenced by both individual level factors (62.14%) and village level characteristics (37.86%), including ecological liability, rural traditions, and governance efficiency. The study highlighted that enhancing farmer engagement and strengthening community level activities can improve satisfaction with sustainable agricultural initiatives.

Based on these studies, five key factors influencing effective farming are identified: economic viability, environmental sustainability, knowledge, practicality, and satisfaction. These factors form the basis for evaluating and ranking agricultural techniques in this study using the fuzzy Analytic Hierarchy Process (FAHP). By integrating these factors into a hierarchical framework, the study aims to identify the most effective agricultural techniques for farmers in northern Kedah.

2.3 Alternatives of agricultural techniques

Several studies have examined the different approaches to agricultural production. Conventional agriculture is often used as a reference point or benchmark for comparing alternative farming methods. Sumberg and Giller (2022) argued that the term "conventional agriculture" has limited analytical significance and primarily serves to normalize particular activities. They emphasized that labeling methods as "conventional" or "alternative" oversimplifies complex farming systems and may impede discussions about sustainable agriculture. Instead, the focus should be on specific farming practices and their

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sustainability outcomes rather than broad categorical labels. Highlighting the ways in which diverse farming systems can support sustainable practices provides a better understanding of agriculture in future.

Organic farming, in contrast, avoids the use of chemical fertilizers and pesticides and relies on natural inputs such as plant residues and animal waste to enhance soil fertility (Azarbad, 2022). Studies have shown that organic practices can improve soil health and microbial resilience, especially in the face of climate change. However, organic farming often faces challenges such as lower yields and increased land requirements compared to conventional methods. Research examining soil microbe plant interactions indicates that microbes play a key role in enhancing crop stress tolerance and overall productivity, suggesting that microbiological approaches can partially offset the yield gap in organic systems.

Technological or smart farming employs modern technologies to increase efficiency, sustainability, and productivity (Sharma et al., 2022). Innovations such as big data analytics, machine learning, iInternet of things (IoT), robotics, and cyber physical systems are applied to optimize conventional farming practices. Technological farming can enhance decision making, reduce resource wastage, and improve overall agricultural output. Despite its high initial costs, smart farming represents a promising avenue for addressing the challenges of modern agriculture, including climate variability and resource limitations.

Based on the literature, three primary alternatives emerge for evaluation in this study: conventional farming, organic farming, and technological farming. These alternatives provide a range of practices with distinct advantages and limitations, which must be systematically assessed to identify the most effective and sustainable farming methods for farmers in northern Kedah.

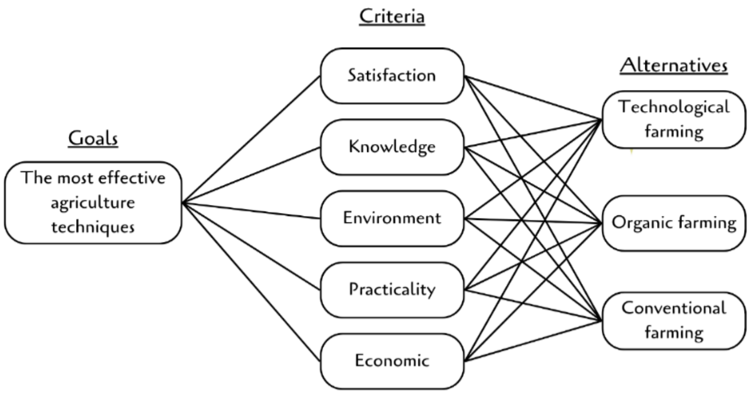

Fig. 1. Hierarchical framework of criteria and alternatives used to evaluate agricultural techniques using FAHP

3. METHODOLOGY

This section details the methods used in the study:

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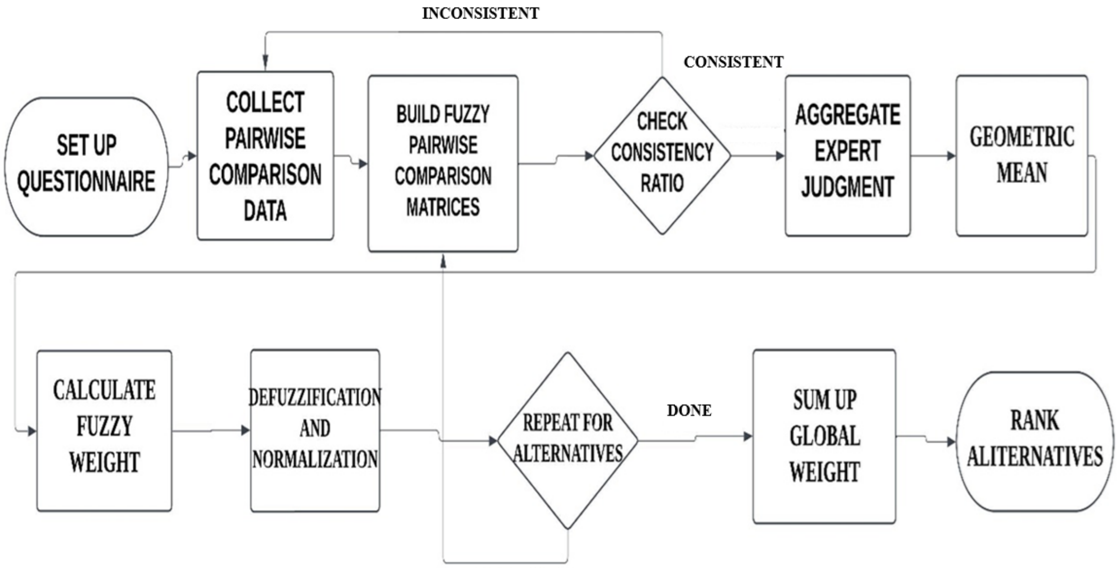

Fig. 2. Flowchart of the methodology

Step 1: Problem structuring and questionnaire design

Clearly state the goal or decision problem. Criteria and alternatives are established following the goal's declaration. The relative value of each criterion and alternative is determined using pairwise comparison. Linguistic factors for assessing the relative importance of criteria and their triangular fuzzy scale are indicated in Table 1.

Table 1. Linguistic factors for assessing the relative importance of criteria

Saaty Scale	Definition	Fuzzy Triangular Scale
1	Equally important (Eq. Imp.)	(1, 1, 1)
3	Weakly important (W. Imp.)	(2, 3, 4)
5	Fairly important (F. Imp.)	(4, 5, 6)
7	Strongly important (S. Imp.)	(6, 7, 8)
0	Absolutely important (A. Imp.)	(9, 9, 9)
2		(1, 2, 3)
4	The intermittent values between the two	(3, 4, 5)
6	adjacent scales	(5, 6, 7)
8		(7, 8, 9)

Source: Abd Aziz et al. (2025)

Step 2: Data collection

Distribute the questionnaire to several decision-makers or experts. Compile the comparisons for every element pair at every level of the classification. When experts complete the form, make sure it is clear by providing examples or scenarios.

Step 3: Construction of fuzzy pairwise comparison matrices

The pairwise contribution matrices are depicted in Eq. (1).

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$$\tilde{A}^k = \begin{bmatrix} \tilde{d}_{11}^k & \tilde{d}_{12}^k & \cdots & \tilde{d}_{1n}^k \\ \tilde{d}_{21}^k & \tilde{d}_{22}^k & & \tilde{d}_{2n}^k \\ \vdots & & \cdots & \vdots \\ \tilde{d}_{n1}^k & \tilde{d}_{n2}^k & \cdots & \tilde{d}_{nn}^k \end{bmatrix} \tag{1}$$

Step 4: Consistency Ratio (CR)
Before calculating the weights of the criteria and alternatives, a consistency test must be conducted to ensure that the decision maker's judgments are coherent. Inconsistencies may occur when preferences are contradictory. Such inconsistencies can reduce the reliability of the results and should therefore be minimized. The Consistency Ratio (CR) is used to evaluate the level of consistency. The consistency in the pairwise comparison matrix is measured by the Consistency Index in Eq. (2).

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

λ_{max} is the largest eigenvalue of the comparison matrix while n is the number of criteria or alternatives. The random index, or RI, is a function of the matrix size, or the quantity of criteria or alternatives. Table 2 shown the mean random consistency index.

Table 2. Mean random consistency index

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

Source: Deng et al. (2023)

The consistency ratio (CR) is calculated as:

$$CR = \frac{CI}{RI} \tag{3}$$

The consistency ratio needs to be lower than 0.1. If the Consistency Ratio (CR) is less than 0.1, the decision maker's judgments are considered consistent and acceptable. However, if the CR exceeds 0.1, the level of inconsistency is deemed too high, and the judgments should be revised to improve consistency.

Step 5: Aggregation of expert judgments
When multiple decision makers are involved, their preferences are aggregated using the arithmetic mean,

$$\tilde{d}_{ij} = \frac{\sum_{k=1}^{K} \tilde{d}_{ij}^k}{K} \tag{4}$$

as illustrated in Eq. (4), where *K* represents the number of experts.

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From the averaged values, the pairwise comparison matrix is updated as shown in Eq. (5).

$$\tilde{A} = \begin{bmatrix} \tilde{d}_{11} & \cdots & \tilde{d}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{d}_{n1} & \cdots & \tilde{d}_{nn} \end{bmatrix} \tag{5}$$

Step 6: Computation of geometric mean (GM)
Eq. (6) presents the computation of the generalized geometric mean for fuzzy comparison values across all criteria.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{1/n}, i = 1, 2, \ldots, n. \tag{6}$$

where $\tilde{r}_i$ denotes the vector summation of the geometric mean and *n* is the number of factors. The triangular fuzzy number is altered with the discovery of the vector summation's inverse.

Step 7: Determination of fuzzy weights criterion (FWC)
The FWC is obtained by multiplying $\tilde{r}_i$ with the reverse vector.

$$\widetilde{w}i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \ldots\ldots\ldots \oplus \tilde{r}_n)^{-1} \tag{7}$$

Step 8: Defuzzification M_I
Fuzzy numbers are converted into crisp values using a defuzzification process.

$$M_I = \frac{lw_i + mw_i + uw_i}{3} \tag{8}$$

Step 9: Normalization N_I
The normalization of M_I is calculated.

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \tag{9}$$

The same procedure is followed for the alternatives.

Step 10: Calculation of global weights.
Sum the global weights to obtain the overall score for each alternative:

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$$W_{ij} = \sum_{i=1}^{n} (w_i \cdot w_j) \tag{10}$$

Step 11: Ranking of alternatives.
Rank the alternatives based on their overall scores to identify the best option.

4. RESULT AND DISCUSSION

4.1 Data

The data for this study were collected using a systematic approach to ensure reliability and accuracy. Three experts were intentionally selected as the main respondents. These respondents were individuals with extensive experience in the agricultural sector, primarily in the northern region of Kedah. The respondents included the Deputy Regional Manager of the Muda Agricultural Development Authority (MADA), a Field Supervisor from Felda Guar Napai, and an experienced cultivator. A structured questionnaire was developed as the primary instrument for gathering feedback for the fuzzy AHP approach. The questionnaire comprised three components: demographic data, pairwise comparisons of criteria, and comparisons of criteria with alternatives. Microsoft Excel was used to process the collected data for analysis.

4.2 Consistency ratio

The consistency ratio (CR) is method used to evaluate the consistency of a set of pairwise comparisons. This section presents the consistency ratio for each expert. By verifying that the experts' pairwise comparisons are logically coherent, the CR ensures the validity of the resulting judgments. Inconsistent pairwise comparisons may adversely affect the study outcomes by introducing ambiguity and reducing the accuracy of the findings. Therefore, the consistency test was carefully performed to ensure the reliability of the analysis. The consistency test was conducted for each pairwise comparison, and the corresponding CR values were calculated for all relevant matrices. By minimizing potential errors in expert judgment, this procedure enhances the robustness of the decision making process. Two separate consistency tests were required: the criteria consistency test and the alternatives with respect to criteria consistency test. A pairwise comparison matrix is considered acceptable when the CR value is less than 0.10, indicating an adequate level of consistency. If inconsistency is detected, the experts are required to review and revise their judgments. This iterative procedure is essential for maintaining the validity of the fuzzy AHP approach and ensuring that the final rankings are based on consistent and well aligned comparisons.

4.3 Criteria consistency ratio

The consistency ratio of each expert's criterion is the first consistency ratio to be computed. The consistency ratio was computed based on the criteria pairwise comparison obtained from the structured questionnaire that had been answered by the experts. The respondent's view was converted into a pairwise comparison matrix as the first step in computing the consistency ratio. Table 3 displays the pairwise comparison matrix for expert l.

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Table 3. Pairwise comparison matrix expert 1

Criteria	Satisfaction	Knowledge	Environment	Practicality	Economic
Satisfaction	1.00	0.11	0.20	0.50	1.00
Knowledge	9.00	1.00	3.00	9.00	7.00
Environment	5.00	0.33	1.00	4.00	4.00
Practicality	2.00	0.11	0.25	1.00	1.00
Economic	1.00	0.14	0.25	1.00	1.00
Total Column	18.00	1.70	4.70	15.50	14.00

Table 4. Normalized matrix for expert 1

Criteria	Satisfaction	Knowledge	Environment	Practicality	Economic
Satisfaction	0.055555556	0.065420561	0.042553191	0.032258065	0.07142857
Knowledge	0.5	0.588785047	0.638297872	0.580645161	0.5
Environment	0.277777778	0.196261682	0.212765957	0.258064516	0.28571429
Practicality	0.111111111	0.065420561	0.053191489	0.064516129	0.07142857
Economic	0.055555556	0.08411215	0.053191489	0.064516129	0.07142857

Table 5. Weight of each criterion for expert 1

Criteria	Weight
Satisfaction	0.053443189
Knowledge	0.561545616
Environment	0.246116844
Practicality	0.073133572
Economic	0.065760779

Table 6. Weighted sum value for expert 1

Criteria	Satisfaction	Knowledge	Environment	Practicality	Economic	Weighted Sum Value
Satisfaction	0.053443189	0.062393957	0.049223369	0.036566786	0.06576078	0.267388
Knowledge	0.480988699	0.561545616	0.738350532	0.658202151	0.46032545	2.899412
Environment	0.267215944	0.187181872	0.246116844	0.292534289	0.26304312	1.256092
Practicality	0.106886377	0.062393957	0.061529211	0.073133572	0.06576078	0.369704
Economic	0.053443189	0.080220802	0.061529211	0.073133572	0.06576078	0.334088

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Table 7. Ratio of weighted criteria for expert 1

Criteria	Ratio of Weighted Criteria
Satisfaction	5.003220921
Knowledge	5.163271455
Environment	5.103641202
Practicality	5.055187178
Economic	5.080346652

$$\text{Ratio of Weighted Criteria for Satisfaction} = \frac{0.26738808}{0.053443189} = 5.003220921$$

Table 8. Consistency index for expert 1

Lambda Max	5.081133482
Consistency Index	0.02028337

Table 9. Consistency ratio for expert 1

Random Consistency Index (RI)	1.12
Consistency Ratio (CR)	0.018110152

Table 10. Consistency ratio for every expert

Expert	Consistency Ratio for Criteria
Expert 1	0.018110152
Expert 2	0.064207867
Expert 3	0.072009827

Table 10 shows the consistency ratio for every expert. All the experts' ratios were consistent as they were less than 0.1.

4.4 Alternative-criteria consistency ratio

Table 11. The consistency ratio of alternative with respect to the criteria

Alternative and Criteria	Expert 1	Expert 2	Expert 3
Alternative-Satisfaction	0.074500566	0.069483795	0.008864126
Alternative-Knowledge	0.00886021	0.069658287	0.028151113
Alternative-Environment	0.028151113	0.035754687	0.008864126
Alternative-Practicality	0.035754687	0.035754687	0.05206047
Alternative-Economic	0.008872666	0	0.035899666

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Three experts evaluated the alternatives' consistency ratios regarding the criteria which are shown in Table 11. Satisfaction, knowledge, environment, practicality, and economic criteria are among the variables taken into consideration. Values below 0.1 indicate satisfactory consistency.

4.5 Weight of criteria and alternatives

The fuzzy AHP approach is conducted after the consistency test. The weight for each criterion and alternative related to each criterion is determined by using the average contribution matrix from the three experts. The fuzzy geometric means for each computation is first calculated to establish the weight. Next, the weight is calculated using the methodology formula.

Table 12. Average contribution matrix for criteria

Criteria	Satisfaction	Knowledge	Environment	Practicality	Economic
Satisfaction	(1, 1, 1)	(0.11, 0.12, 0.12)	(0.24,0.34, 0.58)	(0.19, 0.24, 0.41)	(0.5, 0.57, 0.75)
Knowledge	(8.22, 8.64, 9)	(1, 1, 1)	(4.67,5.67, 6.67)	(3.17, 3.22, 3.33)	(5, 6, 7)
Environment	(1.71, 2.90, 4)	(0.15, 0.18, 0.21)	(1, 1, 1)	(1.07, 1.41, 1.74)	(1.39, 2.07, 2.75)
Practicality	(2.45, 4.15, 5.40)	(0.30, 0.31, 0.32)	(0.57,0.71, 0.93)	(1, 1, 1)	(3.67, 4.33, 5)
Economic	(1.33, 1.76, 2)	(0.14, 0.17, 0.20)	(0.36,0.48, 0.72)	(0.2, 0.23, 0.27)	(1, 1, 1)

The first step in the method is to compile the expert provided pairwise comparison values for each criterion. Next, we compute the means of fuzzy numbers for all experts to determine the average contribution for each pairwise comparison. This methodology guarantees the reduction of individual biases or inconsistencies in assessments, resulting in a unified and identical matrix. The average contribution matrix, which shows the experts' aggregate opinions is shown in Table 12. The average value obtained from the fuzzy numbers provided by the experts for each pair of criteria is represented by a value in the matrix. Each criterion's geometric mean is determined after the average contribution matrix has been acquired.

Table 13. Geometric mean for criteria

Criteria		Ri	
Satisfaction	0.303427367	0.352449209	0.464787674
Knowledge	3.602986383	3.937582168	4.258195603
Environment	0.825610562	1.08305044	1.326245733
Practicality	1.091756872	1.317466063	1.513371099
Economic	0.424920418	0.504993409	0.601207253
Total	6.248701602	7.195541289	8.163807362
Reciprocal	0.160033246	0.138974951	0.122491866
Reciprocal Increasing	0.122491866	0.138974951	0.160033246

The geometric mean of the fuzzy comparison value is shown in Table 13. The value is separated into three columns, each of which represents the fuzzy number's lower, middle, and upper values. After summing up all the values, the reciprocal of each overall geometric mean value is calculated. Lastly, the order of these reciprocals is ascending. The fuzzy comparison value's geometric mean, Ri, can be found using the formula in eq. (6). Each criterion's weight is established using eq. (7).

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Table 14. Fuzzy weight of the criterion

Criteria		Weight	
Satisfaction	0.037167384	0.048981612	0.07438148
Knowledge	0.441336526	0.54722529	0.681452864
Environment	0.101130579	0.150516882	0.212243409
Practicality	0.133731337	0.183094782	0.242189689
Economic	0.052049295	0.070181434	0.096213148

The relative fuzzy weight for each criterion is shown in Table 14. With values ranging from 0.0372 to 0.0744, the satisfaction criterion has the lowest relative fuzzy weight indicating that it is the least important component of the criteria. With scores ranging from 0.4413 to 0.6815, the knowledge criterion has the highest weight of all the criteria.

Table 15. Defuzzified and normalized fuzzy weight of criterion

Criteria	Defuzzified	Normalized
Satisfaction	0.053510159	0.052257788
Knowledge	0.55667156	0.543643026
Environment	0.15463029	0.151011269
Practicality	0.186338603	0.181977469
Economic	0.072814626	0.071110447
Total	1.023965237	1

Table 15 illustrates the defuzzified and normalized value for fuzzy weight of criterion. Eq. (8) is used to obtain the defuzzified value.

Defuzzified value for Satisfaction $= \frac{0.037167384+0.048981612+0.07438148}{3} = 0.053510159$.

Finding the normalized value is necessary since the sum of the defuzzified values exceeds 1. The normalized value is obtained as below using Eq. (9).

Normalized value for Satisfaction $= \frac{0.053510159}{1.023965237} = 0.052257788$.

Table 16. Weight for criteria

Criteria	Weight	Rank
Satisfaction	0.052257788	5
Knowledge	0.543643026	1
Environment	0.151011269	3
Practicality	0.181977469	2
Economic	0.071110447	4

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Table 16 above shows the weight assigned to each criterion. With a weight of 0.5436, the knowledge criteria show the highest weight, indicating how important it is in the assessment procedure. Among the criteria that were analyzed, the satisfaction criterion has the lowest weight with 0.0523, indicating that it plays a limited role. According to this weight distribution, the knowledge criteria have the most impact, whereas satisfaction is given the least weight. Through efficient knowledge management, farms may implement innovative techniques, increase the use of resources, and effectively address environmental issues (Tumwebaze et al., 2025).

4.6 Weight of alternatives-criteria

Table 17. Alternatives' rank

Alternatives	Weight (%)	Rank
Conventional	29.99	2
Organic	25.69	3
Technological	44.32	1

The alternatives are ranked according to their relative weights, which are shown as percentages in Table 17. With the largest weight of 44.32%, the technological alternative comes in first place, indicating that it is the most popular choice out of the three. Second place goes to the conventional alternatives with 29.99%. With the lowest weight, which is 25.69%, the organic alternative comes in the third spot and is the least popular of the three.

5. CONCLUSION

This study used the fuzzy AHP method to determine the most efficient agricultural practices for farmers in Kedah by evaluating five main criteria: satisfaction, knowledge, environment, practicality, and economic factors. The results show that knowledge is the most important criterion, highlighting the importance of farmers' understanding and skills in achieving efficient farming. Practicality and environmental factors also play important roles, while economic and satisfaction factors are less influential in the decision-making process. Among the alternatives evaluated, the technological approach is identified as the most effective agricultural practice, followed by conventional methods, while organic farming ranks last. These findings suggest that adopting technology-based practices can improve agricultural efficiency and environmental management in Kedah. This study provides a useful decision-making framework for farmers, policymakers, and related organisations in selecting suitable agricultural strategies. However, the findings are limited to the northern region of Kedah and may not be fully applicable to other areas due to differences in local conditions and expert opinions. Future studies should include wider geographical coverage, more criteria, and a larger group of experts to strengthen the reliability and applicability of the results.

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7. CONFLICT OF INTEREST STATEMENT

The authors declare that this research was conducted in the absence of any personal, commercial, or financial conflicts of interest, and that there are no conflicts of interest with the funders.

8. AUTHORS' CONTRIBUTIONS

Khairu Azlan Abd Aziz: Supervision, conceptualisation, development of methodology, and formal analysis; **Wan Suhana Wan Daud**: Data interpretation, manuscript writing, and final editing.; **Mohd Fazril Izhar Mohd Idris**: Conceptualisation, methodology development, and formal analysis; **Rizauddin Saian**: Language editing and contribution to the interpretation of results; **Ammar Zakwan Mohd Afandi** Literature review, data collection, simulation of results, and validation.

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