SPECTA Journal of Technology Vol 8, No 3 December, 2024 pg: 250 - 260
DOI: https://10.35718/specta.v8i3.1255

SPECTA Journal of Technology
E-ISSN : 2622-9099
P-ISSN : 2549-2713
Homepage jurnal: https://journal.itk.ac.id/index.php/sjt

Expert System for Diagnosing Plant-disturbing Organisms on Rice Plants Using the Euclidean Probability Method and Bayes Theorem with Forward Chaining Inference Technique

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Received: 08/December/2024 Revised: 20/December/2024
Accepted: 21/December/2024 Published: 31/December/2024

To cite this article:
Azhar, N. F., Prihasto, B & Salsabila, N. R. N (2024). Expert System for Diagnosing Plant-disturbing Organism on Rice Plants Using the Euclidean Probability Method and Bayes Theorem with Forward Chaining Inference Technique. *SPECTA Journal of Technology, 8*(3), 250-260. **https://10.35718/specta.v8i3.1255**

Abstract

Rice is a basic human need that needs to be fulfilled continuously, especially in Indonesia. However, rice production decreased by 2.05% in 2023; the decline was influenced by the lack of rice fields and crop failure due to attacks by plant-disturbing organisms such as Blast, Brown Spot, and even Ricefield Rats. Therefore, expert system technology is useful to help create opportunities for progress in the agricultural sector in overcoming the decline in production. This research utilizes the best method between Euclidean Probability, Bayes` Theorem, and a combination of both in diagnosing plant-disturbing organisms in rice plants. The expert system works by analyzing the symptoms and characteristics of the plants using weight values obtained from the Analytical Hierarchy Process, comparing them with a database of known plant-disturbing organisms, and providing accurate diagnoses and management recommendations. The objectives are to determine which method provides the most accurate diagnosis and to explore how these methods can support sustainable agriculture. The combination of Bayes' theorem with Euclidean methods and Bayes' theorem alone achieved an agreement of 8 out of 10 cases with expert diagnoses. In comparison, the Euclidean method alone achieved an agreement of 9 out of 10 cases. The results demonstrate that the Euclidean Probability method offers a more accurate diagnosis, aligning with expert diagnoses in 9 of the 10 case studies, thus supporting its application in sustainable agricultural practices.

Keywords: Analytical Hierarchy Process, Bayes` Theorem, Euclidean Probability, Expert System, Rice Plant.

1. Introduction

Rice is one of the essential types of food needed continuously to meet fiber requirements and serve as a source of carbohydrates for the body (HilalullailyR et al., 2021). However, rice production in Indonesia experienced a decline of 2.05% throughout 2023 compared to the previous year (Badan Pusat Statistik Indonesia, 2023). This decline is influenced by several factors, such as the high rate of conversion of rice fields into residential areas or other uses, while the demand for food (rice) is also rising (Department of Food, Food Crops, and Horticulture East Kalimantan Province, 2020), and crop failures due to attacks by Plant-disturbing Organisms on rice plants (Ministry of Agriculture, Directorate General of Food Crops, 2020).

Plant-disturbing Organisms (PDO) that can attack rice plants during their growth process include Stem Borers, Brown Planthoppers, Sheath Blight, Blast, Brown Spot, Tungro, and Ricefields Rats. Some PDOs, such as Sheath Blight, Brown Spot, and Blast, are caused by fungal or bacterial infections, while

Stem Borers, Brown Planthoppers, Tungro, and Ricefields Rats are caused by pest populations that can harm all stages of rice development (Elisabeth et al., 2021). With the presence of various pest organisms, farmers need more knowledge about each type of pest, making it difficult to differentiate the onset of symptoms. Additionally, there is limited access to direct consultation with agricultural experts. On the other hand, when an expert visits each farm, not all agricultural areas can be covered quickly (Bianome et al., 2020).

A solution to address these issues is to develop a sustainable agriculture principle based on the Sustainable Development Goals (SDGs) through technology (Fitriani and Kuswadi, 2021), one product of sustainable agriculture is Biosaka, a plant extract solution used as a plant protection effort based on technology. In its application, Biosaka has been proven to improve the quality of rice production in Blitar (Raidar et al., 2023). Another form of sustainable agriculture is an expert system technology. Expert systems are a branch of Artificial Intelligence that represents expert knowledge to solve various human problems (Marlinda, 2021). Several studies have implemented the expert system using the Bayes` Theorem, and Euclidean Probability method to diagnose diseases in animals and plants. Bayes` Theorem method was used to diagnose rice plant pets (Kholifah et al, 2023). Euclidean Probability was used to diagnose diseases in edamame soybeans (Kurniawan, 2021), and rice plants (Wicaksono et al, 2022). The combined Bayes` theorem and Euclidean probability methods were used to diagnose Postular Psoriasis (Ramadhan, 2019).

Therefore, this research offers a new approach by seeking the most optimal method among Euclidean Probability, Bayes` Theorem, and their combination with forward chaining inference techniques, which has not yet been applied in diagnosing pests disturbing rice crops. The author's contribution to this research is calculating the weight values using the Analytical Hierarchy Process and applying the Bayes` theorem method, Euclidean probability, and a combination of both approaches to determine the most optimal method among them. Through expert system technology, it is hoped that accurate diagnoses can be provided, helping farmers address the decline in rice production and integrating the concept of sustainable agriculture.

2. Methods

2.1 Expert System

An expert system is a branch of artificial intelligence that involves designing computer applications or systems to assist humans in decision-making and problem-solving within specific fields. This assistance is based on the knowledge, experience, and analytical methods acquired from experts in the field. Expert systems work by providing decisions for new cases using an initialized knowledge base, eliminating the need for continuous involvement of experts (Hayadi, 2018). In its implementation, various methods are used, including:

a. Bayes` Theorem

   Bayes` Theorem is a method that links rules with probability values to reach a decision based on the cause-and-effect relationship of an event (Panggabean & Wijaya, 2022). This concept considers information obtained from one event to estimate the occurrence of another event. In 2022, Wicaksono et al. researched diagnosing pests and diseases in rice plants using a web-based Euclidean Probability method, which achieved an accuracy of 94% following expert diagnoses from 100 sample cases.

b. Euclidean Probability

   Euclidean Probability is an approach that measures the probability of a problem based on various influencing factors (Ramadhan & Fatimah, 2018). Research related to pest diagnosis in rice plants conducted by Prasetyaningrum in 2020 achieved an accuracy of 85% in the system diagnosis, consistent with expert diagnoses based on 20 test samples.

2.1.1 Inference Technique

Inference is the procedure of concluding reasoning based on a database (Ramadhan & Fatimah, 2018). One of them is Forward Chaining, which is a decision-making technique that begins by matching known facts to the IF-THEN rule parts. The process ends when there are no more matching rules.

DOI: https://10.35718/specta.v8i3.1255

2.2 Analytical Hierarchy Process (AHP)

This method solves problems by considering the validity value up to a tolerance limit for inconsistencies as criteria and alternatives in decision-making. The AHP method organizes specific criteria into a priority scale, allowing it to consistently provide the most optimal alternative weights based on the desired objectives (Priadi et al., 2022).

2.3 Method Performance

The accuracy formula is used to calculate how accurately a system or model makes predictions. The formula is:

$$\text{Accuracy} = \frac{\sum \quad Correct\ Predictions}{\sum \quad All\ Predictions} \ .100\% \qquad (1)$$

where The Correct Prediction represents the count of instances where the system or model's predictions are correct or match the actual outcomes. and The All Predictions refers to the total count of predictions made by the system or model, including both correct and incorrect predictions.

3. Proposed Method Expert System Using Euclidean Probability and Bayes` Theorem

The diagnosis process of the system begins by converting symptom categories into values using AHP (Analytical Hierarchy Process) and then processing them through each respective method. The system's diagnosis results will be validated against the original diagnosis made by experts.

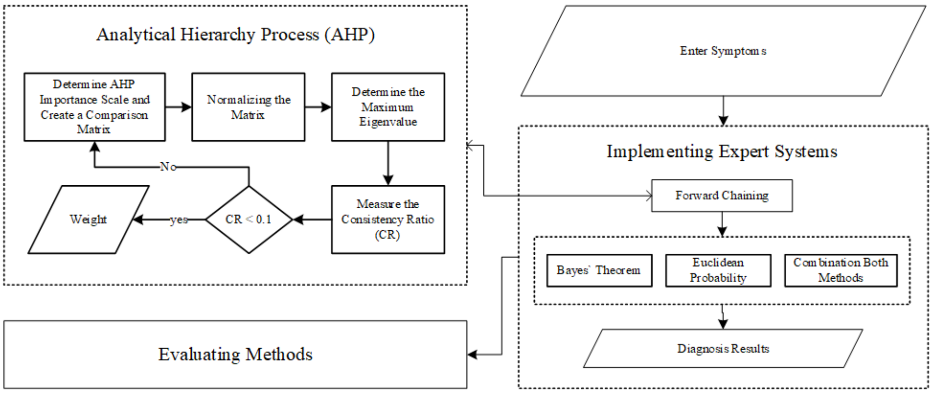

Figure 1: Framework Model

The main framework of this study comprises three steps: Calculating Symptom Weights, Implementing Expert Systems, and Evaluating Methods, as illustrated in Figure 1.

3.1 Calculating Symptoms Weight

The weighting process using the AHP method is explained through the following points:

1. Determine the criteria comparison matrix that represents the priority levels between one criterion and another based on the standard AHP importance scale shown in Table 1.

Table 1: AHP Importance Scale

Assigned value	Definition
1	Equally important
3	Weak importance
5	Strong importance
7	Demonstrated Importance
9	Weak importance
2, 4, 6, 8	Intermediate values

Source: Adapted from Saaty (1980). The Analytical Hierarchy Process.

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2. Normalize the comparison matrix by dividing each value by the total sum of the criteria, calculate the average of each vector to obtain priority weights, determine the maximum eigenvalue by summing normalized values, and analyze consistency to ensure the weights are reliable and free from inconsistencies (Saaty, 1980). Measurement involves calculating the consistency index using the following equation:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (2)$$

where CI is the Consistency Index, λ_{max} is the largest eigenvalue of the n-ordo matrix, and n is the size of the matrix itself. Furthermore, the consistency ratio value by determining the limit of the Consistency Random Index according to the order n matrix shown in Table 2.

Table 2: Consistency Random Index

n	**RI**
1	0,00
2	0,00
3	0,58
4	0,90
5	1,12
6	1,24
7	1,32
8	1,41
9	1,45
10	1,49
11	1,51
12	1,58

Source: Adapted from Saaty (1980), The Analytical Hierarchy Process.

Consistency Ratio is obtained through equation 4.

$$CR = \frac{CI}{RI} \quad (3)$$

where CR represents the Consistency Ratio, CI is the consistency index, and RI is the random consistency index. If the CR value is more than 0,1 then the weight result is suspected to be inconsistent with the value of the comparison matrix (accepted by Saaty and Forman).

3.2 Implementing Expert Systems

a. Forward Chaining

In expert systems, this technique is used to match described symptoms with potential diseases that may affect plants. Each time a symptom matches the IF part of a rule, the THEN part of that rule is executed, which may contain a provisional diagnosis or further steps to be taken. This process continues until no more rules can be applied or until the system reaches a suitable final diagnosis. Through this systematic approach, the expert system can identify the most likely diseases affecting the plants based on the existing symptoms and provide recommendations for appropriate treatment or management actions.

b. Bayes` Theorem

The application of Bayes` Theorem is outlined in the following stages.

1. Determine the probability value of each hypothesis (H) according to the number i present, using equation (1)

$$P(H_i) \quad (4)$$

2. Multiply the probability result of each hypothesis (H) by the probability of the evidence (E) corresponding to the hypothesis, as shown in equation (2).

$$P(E|H_i).P(H_i) \quad (5)$$

3. Determine the probability value of the evidence (E) irrespective of any hypothesis by summing all the previous multiplication results.

$$\sum \quad P(E|H_i).P(H_i) \qquad (6)$$

4. Calculate the probability value of the hypothesis (H) given a set of evidence (E). This process is described by the following equation (4).

$$P(H_i|E) = \frac{P(E|H_i).P(H_i)}{\sum_{i=1}^{n} P(E|H_i).P(H_i)} \qquad (7)$$

5. Compute the Bayes` value using equation (5).

$$_{=1} \quad bayes = bayes_1 + \ldots + bayes_n \qquad (8)$$

Where $P(H_i|E)$ is the posterior probability, $P(E|H_i)$ is the likelihood (the probability of the evidence E given that hypothesis H_i is true), $P(H_i)$ is the prior probability of the hypothesis not considering any evidence, $\sum_{i=1}^{n} P(E|H_i).P(H_i)$ is the marginal likelihood of the evidence not considering any hypothesis, and Bayes` value is the combination of the posterior probability with the original evidence value.

c. Euclidean Probability

The formula for Euclidean Probability is represented by Equation (5).

$$\sqrt{(E_1.NBE_1)^2 + (E_2.NBE_2)^2 + \ldots + (E_n.NBE_n)^2} \qquad (9)$$

where EP represents the Euclidean Probability, E is the condition value ranging between 0 and 1, NBE is the weight of evidence, and n n is the number of objects.

d. Combination of Bayes` Theorem and Euclidean Probability Methods

This approach uses both methods to determine how likely something is to happen based on different evidence. First, it calculates the posterior probability, then used as the evidence weight (NBE). This weight is then used in the Euclidean Probability equation, where each symptom's weight is turned into a condition value (E). This method has been used in a study titled *Expert System for Detection of Pustular Psoriasis Using a Combination of Theorems* by Puji Sari Ramadhan, 2019.

3.3 Evaluating Methods

The evaluation of the method involves comparing the diagnosis provided by the expert system with the diagnosis given by a human expert. This comparison helps to assess the accuracy and reliability of the expert system's diagnostic capabilities by examining how closely its conclusions align with those of an established expert in the field.

4. Results and Discussion

This expert system for diagnosing PDO on rice plants uses the forward chaining method as its decision rule. Two methods were used to diagnose plant-disturbing organisms in rice: the Euclidean Probability method and Bayes' Theorem. The evaluation involved comparing the system's diagnostic results with expert diagnoses and calculating the accuracy percentage using the formula (1) to compare each method's performance.

Rules will be established using the dataset from the open-source platform Zenodo, published by Fahrul Agus et al., and have been adjusted by experts on plant-disturbing organisms (PDO) specifically for rice plant disease. The dataset includes 57 symptoms of rice plant-disturbing organisms (PDO), 10 types of rice plant-disturbing organisms (PDO), and correlations between symptoms and rice PDO. The details of the symptoms and rice PDO data are outlined in Table 3 and Table 4.

Table 3: Rice Plant-disturbing Organisms Data

Code	**Plant-disturbing Organisms**
P01	Blast

Code	Plant-disturbing Organisms
P02	Brown Spot
P03	Narrow Brown Spot
P04	Sheath Bligh
P05	False Smut
P06	Grassy Stunt
P07	Bacterial Leaf Bligh
P08	Tungro
P09	Brown Planthopper
P10	Ricefields Rat

Table 4: List of Symptoms of Rice Plant-disturbing Organisms

Code	Symptoms
G01	drib
G02	ıtches on leaves and leaf midribs
G03	ghtly white and the edges are brown or reddish brown
G04	icles
G05	tions, neck panicles, panicles and grains
…	…
G57	

The code "P" in Table 3 and the subsequent tables represents "Penyakit" (Disease), the code "G" in Table 4 and the subsequent tables represent "Gejala" (Symptom), while the numbers 01, 02, etc., represent the numbering of each data. Based on the data on plant-disturbing organisms and the symptoms experienced by rice plants, the correlation between them is summarized in the decision table of symptoms and rice PDO in Table 5.

Table 5: Decision Table of Symptoms and Rice Plant-Disturbing Organisms

No	**Symptom's Code**	**PDO's Code**										**Symptom Categories***
		P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	
1	G01	✓										Uncertain
2	G02	✓										Certain
3	G03	✓										Certain
4	G04	✓										Possible
5	G05	✓										Uncertain
…	**…**											**…**
57	G57										✓	Certain

**The values for symptom categories were obtained through discussions with a plant-disturbing organisms (PDO) expert, Mrs. Aswita Br Peranginangin, SP., as a Field Agricultural Extension Worker at Dinas Pangan Pertanian Perikanan of Balikpapan City.*

3.2 Weight Value Calculation (using AHP)

To convert symptom categories into values for applying the symptom weighting validation test, the Analytical Hierarchy Process (AHP) method is used with the following steps:

1. Determine the importance of values based on discussions with experts, which involve subjective judgments but still consider the general subjective tolerance limits from experts. The determined values are as follows:
   a. Symptoms possibly triggering a PDO are three times more important than those uncertainly triggering a PDO.

   b. Symptoms possibly triggering a PDO are five times more important than those uncertainly triggering a PDO.
2. The pairwise comparison matrix based on the determined importance values is shown in Table 6.

Table 6: Pairwise Comparison Matrix

Criteria	C1	C2	C3
C1	*1,000*	*0,333*	*0,200*
C2	*3,000*	*1,000*	*0,333*
C3	*5,000*	*3,000*	*1,000*
otal (∑)	*9,000*	*4,333*	*1,533*

Where:
C1 = Uncertain
C2 = Possible
C3 = Certain

3. Normalize the pairwise comparison matrix by dividing each criterion value by the total sum of the criteria, then calculate the average for each criterion. The results are shown in Table 7.

Table 7: Matrix Normalization

	iority Weight (PW)	**Total (∑).PW**
C1	*0,106*	*0,955*
C2	*0,260*	*1,129*
C3	*0,633*	*0,971*

4. Determine the maximum eigenvalue by accumulating the products of the sum with the weight values.

$$\lambda_{max} = 3{,}055$$

5. Measure the consistency ratio to assess the consistency of the criterion comparison values. For a matrix size (n) of 3, the Consistency Random Index (RI) is 0.58.
   a. *Consistency Index* (CI)

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

$$CI = \frac{(3{,}055 - 3)}{(3 - 1)}$$

$$CI = 0{,}028$$

   b. *Consistency Ratio* (CR)

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

$$CR = \frac{0{,}028}{0{,}58}$$

$$CR = 0{,}048$$

A CR value of 0.048 indicates that the value is < 0,1. Therefore, the comparison matrix is considered consistent, and the weights can be used to represent the value of each symptom criterion with the following parameters.
Uncertain = *0,106*
Possible = *0,260*
Certain = *0,633*

4.3 Expert System Methods Implementation

For example, the selected symptoms chosen by the user are shown in Table 8.

DOI: https://10.35718/specta.v8i3.1255

Table 8: Study Case

No	Case's Code	Symptom's Code	Symptoms	Diagnose
1	C01	G32	Few grains are produced	*Unknown*
2		G33	Plant growth is stunted	
3		G37	Many tillers, stiff like brooms, but not productive	

Trace potential plant-disturbing organisms (PDO) attackers using forward chaining techniques. Based on the mentioned symptoms, it is suspected that the PDO of the rice plants are Grassy Stunt (P6), and Tungro (P8). The results are shown in Table 9.

Table 9: Forward Chaining Results

Plant-Disturbing Organisms	Symptoms	Weight
Grassy Stunt (P06)	G32	$0,260$
	G33	$0,633$
	G37	$0,260$
Tungro (P08)	G32	$0,260$
	G33	$0,633$

Next, the method is applied to determine which PDO has a higher likelihood between the two, to conclude the accurate diagnosis. The steps for each method are explained in the following points.

1. Bayes` Theorem

   The implementation of the Bayes` Theorem method is carried out according to the previously explained steps. The calculation results are shown in Table 10.

   Table 10: Bayes` Theorem Method Calculation Results

PDO	i	Symptoms	$P(H_i)$	$P(E\|H_i).P(H_i)$	$P(E)$	$P(H_i\|E)$	Bayesian Value
Grassy Stunt (P06)	1	G32	$0,226$	$0,059$	$0,465$	$0,126$	$0,539$
	2	G33	$0,549$	$0,347$		$0,747$	
	3	G37	$0,226$	$0,059$		$0,126$	
Tungro (P08)	1	G32	$0,291$	$0,076$	$0,525$	$0,145$	$0,579$
	2	G33	$0,709$	$0,449$		$0,855$	

   Based on the input symptoms, the highest Bayesian value obtained is 0.579. This means that the rice plant is diagnosed with Tungro (P08).

2. Euclidean Probability

   The Euclidean Probability method is implemented by calculating the square root of the sum of squares of the product of condition values and evidence weights for each symptom. The symptom codes indicating Grassy Stunt (P06) are G32, G33, G34, G35, G36, and G37. The symptom codes indicating Tungro are G32, G33, G43, G44, G45, G46, and G47. Therefore, the condition value (E) for symptom codes not input (G32, G33, and G37) is 0. The calculation results are shown in Table 11.

   Table 11: Euclidean Probability Method Calculation Results

Submitted December 2024, Revised December 2024, Accepted December 2024, Published December 2024

PDO	n	Symptoms	E_n	NBE_n	EP
Grassy Stunt (P06)	1	G32	1	$0,260$	$0,733$
	2	G33	1	$0,633$	
	3	G34	0	$0,106$	
	4	G35	0	$0,106$	
	5	G36	0	$0,106$	
	6	G37	1	$0,260$	
Tungro (P08)	1	G32	1	$0,260$	$0,685$
	2	G33	1	$0,633$	
	3	G43	0	$0,260$	
	4	G44	0	$0,106$	
	5	G45	0	$0,106$	
	6	G46	0	$0,106$	
	7	G47	0	$0,106$	

Based on the input symptoms, the highest Euclidean probability value obtained is 0.733. This indicates that the rice plant is diagnosed with Grassy Stunt (P06).

3. Combination of Bayes` Theorem and Euclidean Probability Methods
   Combining Bayes` Theorem and Euclidean Probability methods is carried out according to the previously explained steps. The calculation results are shown in Table 12.

Table 12: Combination Method Calculation Results

PDO	i	Symptoms	$P(H_i)$	$P(E\|H_i).P(H_i)$	$P(E)$	$P(H_i\|E) = NBE_n$	E_n	EP
Grassy Stunt (P06)	1	G32	$0,226$	$0,059$	$0,465$	$0,126$	$0,260$	$0,476$
	2	G33	$0,549$	$0,347$		$0,747$	$0,633$	
	3	G37	$0,226$	$0,059$		$0,126$	$0,260$	
Tungro (P08)	1	G32	$0,291$	$0,076$	$0,525$	$0,145$	$0,260$	$0,543$
	2	G33	$0,709$	$0,449$		$0,855$	$0,633$	

Based on the input symptoms of rice plant-disturbing organisms (PDO), the highest value obtained is 0.543. This indicates that the rice plant is diagnosed with Tungro (P08).

4.4 Method Evaluation

The final step is to validate the diagnostic results from the method implementation to ensure they align with the actual opinions provided by experts regarding the various symptoms presented. Through testing 10 case studies, including the calculations displayed, the comparison can be seen in Table 13.

Table 13: Case Studies Validation

No	Case's Code	Symptom's Code	Bayes` Theorem Result	Euclidean Probability Result	Combination Method Result	Expert Result
1	C01	G32, G33, G37	Tungro	Grassy Stunt	Tungro	Grassy Stunt
2	C02	G01, G02, G06	Blast	Blast	Blast	Blast
3	C03	G20, G38, G07	Bacterial Leaf Blight	Bacterial Leaf Blight	Bacterial Leaf Blight	Bacterial Leaf Blight
4	C04	G46, G47, G32	Tungro	Tungro	Tungro	Tungro
5	C05	G15, G12, G09	Brown Spot	Brown Spot	Brown Spot	Brown Spot

6	C06	G20, G22, G39, G21	Sheath Bligh	Sheath Bligh	Sheath Bligh	Sheath Bligh
7	C07	G27, G30, G31	False Smut	False Smut	False Smut	False Smut
8	C08	G01, G20, G24, G25	Sheath Bligh	Sheath Bligh	Sheath Bligh	Sheath Bligh
9	C09	G08, G07, G04	Blast	Blast	Blast	Sheath Bligh
10	C10	G26, G20, G21, G44	Sheath Bligh	Sheath Bligh	Sheath Bligh	Sheath Bligh

Based on the validation results of 10 case studies with experts, the alignment of method implementation results is as follows: Bayes` Theorem was accurate in 8 cases, Euclidean Probability was accurate in 9 cases, and the combination of both methods was accurate in 8 cases. The accuracy percentages are shown in Table 14.

Table 14: Method Accuracy Value

	Bayes` Theorem	**Euclidean Probability**	**Combination of Bayes` Theorem and Euclidean Probability**
Accuracy	80%	90%	80%

Based on the results obtained from Table 14, the Euclidean probability method achieved better accuracy compared to Bayes' theorem and the combination methods. This is due to the Euclidean method's ability to handle data variation or patterns more effectively. Additionally, this method reduces the likelihood of classification errors that are often encountered with traditional probabilistic methods such as Bayes' theorem.

5. Conclusion

Diagnosis of plant-disturbing organisms in rice plants using the Euclidean probability method and Bayes' theorem shows different performances after expert validation. The combination of Bayes' theorem with Euclidean methods and Bayes' theorem alone both achieved an 80% agreement, while the Euclidean method alone achieved a 90% agreement. Therefore, the Euclidean Probability method is optimal for a plant-disturbing organisms (PDO) expert system using forward chaining, with a 90% accuracy that matches expert diagnoses for 10 test cases. This method is hoped that it can effectively support sustainable agriculture by helping farmers address the decline in rice production in future research.

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