OPEN ACCESS
201
ISSN 2356-5462
http://socj.telkomuniversity.ac.id/ijoict/
Intl. Journal on ICT
Vol. 11, No. 2, Dec 2025. pp. 201-211
doi:10.21108/ijoict.v11i2.9986

Synergy of Technology and Agriculture through the Development of a Web-Based Expert System for Cacao Pest and Disease Diagnosis Using the Certainty Factor Method

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Abstract

Cacao (Theobroma cacao L.) is one of the leading agricultural commodities that plays a vital role in Indonesia's economy. However, its productivity is often hindered by pest and disease attacks. On the other hand, the limited availability of agricultural experts and the difficulties faced by farmers in accessing guidance and information regarding plant diseases highlight the urgent need for a system that can assist in identifying problems quickly and accurately. This study aims to develop a web-based expert system capable of diagnosing pests and diseases in cacao plants using the Certainty Factor (CF) method. The system incorporates data on 9 types of diseases and 6 types of pests along with their symptoms. Diagnosis is performed by calculating certainty values based on a combination of expert confidence and user input using CF formulas. With a web-based interface, the system can be easily accessed by farmers via the internet. The diagnostic results of this system show a similarity rate of 93.33% with those of other studies. This finding indicates that the CF approach demonstrates competitive performance. Therefore, this system has the potential to serve as an effective tool in supporting cacao plant health management by farmers.

Keywords: Disease diagnosis, Cacao, Certainty factor method, Web-based expert system

I. INTRODUCTION

Cacao (Theobroma cacao L) is one of the agricultural commodities that plays a significant role in the national economy. In 2022, it ranked third among the top agricultural export commodities after palm oil and rubber. To enhance the productivity and quality of Indonesian cacao, the government, along with national cacao stakeholders, continues to make comprehensive improvements from upstream to downstream [1]. One of the main challenges in cacao cultivation is the attack of pests and diseases, which directly impacts yield reduction [2].

Efforts to control pests and diseases are key to ensuring the sustainability of cacao production. Early detection of such disturbances is essential to enable effective treatment [3]. Adequate knowledge allows farmers to quickly identify and address arising problems. However, in practice, limited access to experts and technical information often becomes a barrier for farmers.

With the advancement of information technology, expert systems have emerged as innovative tools that bridge the gap between farmers' needs for accurate disease and pest diagnosis and the limited availability of agricultural experts. Several previous studies have attempted to develop expert systems, each with specific

Received on 31 Oct 2025. Revised on 5 Jan 2026. Accepted and Published on 19 Jan 2026.

limitations. For instance, the study by Hadi et al. [4] applied the Forward Chaining and Naïve Bayes methods but did not consider uncertainty and the user's confidence level in the diagnostic process—factors that are crucial for handling diverse symptoms. Meanwhile, Meniati et al. [5] implemented the Certainty Factor (CF) method, but did not involve users in directly assigning confidence values, which made the system less representative of the user's perspective. Additionally, the study by Soge et al. [2] only covered a limited number of cacao pest and disease types, and thus did not fully reflect the complexity of issues faced by farmers in the field.

In this study, a web-based expert system for diagnosing pests and diseases in cacao plants is designed to be widely accessible to farmers via the internet, functioning as a virtual consultant that provides fast, accurate, and informative diagnoses based on observed symptoms. The CF method is used in this expert system as it can evaluate the degree of certainty of a fact, allowing for more accurate diagnostic results based on symptom weighting determined by experts [6]. Through this approach, it is expected that farmers can independently identify plant diseases and take appropriate action, thereby supporting increased productivity and the sustainability of the cacao agriculture sector in Indonesia.

II. LITERATURE REVIEW

Expert systems are a branch of artificial intelligence designed to emulate the reasoning and decision-making capabilities of human experts. In the agricultural sector, expert systems play an essential role in assisting farmers with automated, fast, and efficient diagnosis of plant diseases. Gupta and Mehta [7] emphasized that knowledge-based expert systems can mitigate the shortage of agricultural experts by providing structured diagnostic guidance through accessible digital platforms.

Among rule-based expert system approaches, the Certainty Factor (CF) method has been widely adopted to handle uncertainty inherent in symptom-based diagnosis. CF enables the representation of both expert belief and user confidence in observed symptoms, which is particularly important in agricultural settings where symptom observation is subjective and environmental conditions vary. Previous studies have successfully applied CF to diagnose diseases in rice [8], corn [9], chili [6,10], pepper [11], banana [12], rambutan [13], watermelon [14], oil palm [15], and rubber [16].

For cacao plants, Hadi et al. [1] applied Forward Chaining and Naïve Bayes to identify diseases based on observed symptoms but did not incorporate user uncertainty. Meniati et al. [2] achieved 90% diagnostic accuracy using CF, yet user confidence input was not considered. Soge et al. [3] employed fuzzy logic for cacao disease detection with promising results but limited disease coverage. These studies indicate that while symptom-based expert systems for cacao exist, mechanisms for integrating both expert certainty and user confidence remain limited.

From an implementation perspective, web-based expert systems enhance accessibility, scalability, and ease of knowledge updating. Quraish et al. [17] stated that web-based systems are more flexible than desktop applications, as they allow cross-device access and online data integration. Studies by Muslimah et al. [18] and Norasma et al. [19] reported that web-based expert systems in agriculture can accelerate the diagnostic process by up to 70% compared to conventional methods.

Based on this review, the development of a web-based expert system using the CF method that combines expert and user confidence is expected to improve diagnostic accuracy and broaden farmers' access to efficient, fast, and reliable cacao disease identification services.

III. RESEARCH METHOD

The web-based expert system for cacao disease diagnosis will be implemented through the stages given in Fig. 1.

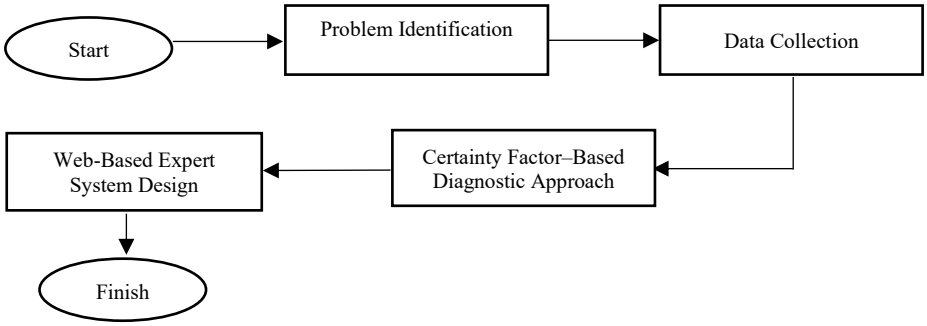


Fig. 1. Research Flowchart

A. Data Collection

Data were collected through observation, interviews, and a literature review. The findings revealed nine cacao plant diseases—black pod rot, stem canker, vascular streak dieback (VSD), root disease, swollen shoot, witches' broom, monilia pod rot, pink disease, and anthracnose—as well as six types of pests, namely cacao pod borer (CPB), mirid bugs, branch borer, looper caterpillar, chrysomelid beetles, and rats/squirrels. The collected data were subsequently utilized in the development of a web-based expert system for diagnosing cacao diseases using the CF method. In this study, the expert system employs the CF method to derive solutions based on observed symptoms, utilizing 44 symptoms correlated with 15 types of cacao plant diseases and pests as shown in Table 1 and Table 2.

B. Certainty Factor–Based Diagnostic Approach

The Certainty Factor–based diagnostic method is utilized in this study to handle uncertainty in the expert system's decision-making process. In this approach, each symptom is assigned a weight that reflects the combination of expert confidence and user observations. The basic steps in the CF calculation are as follows [20]:

1. Calculating the Initial CF
   The CF is calculated based on the confidence values provided by the expert and the user regarding a specific symptom or fact. It is computed using the following formula:
   $$CF = CF_{expert} \times CF_{user} \quad (1)$$
2. Combining Multiple CF Values
   If there are multiple pieces of evidence (e.g., e_1 and e_2) supporting the same hypothesis (h_1), the CF values are combined using the following formula:
   $$CF_{combine}(CF_1, CF_2) = CF[h_1, e_1] + CF[h_1, e_2] \times (1 - CF[h_1, e_1]) \quad (2)$$
   The result of this calculation is referred to as previous CF (CF_{old}), which can be further combined with additional evidence (e.g., e_3) using the same formula (see, Eq. (2)).
3. Calculating the Final Confidence Percentage
   The final CF value is then converted into a percentage using the following equation:
   $$Confidence\ Percentage = CF_{combine} \times 100\% \quad (3)$$

The user's confidence levels are defined as follows: not sure = 0; slightly possible = 0.1; between not sure and possible = 0.2; nearly possible = 0.3; possible = 0.4; between possible and most likely = 0.5; most likely = 0.6; between most likely and almost certain = 0.7; almost certain = 0.8; between almost certain and certain = 0.9; and certain = 1. The values represent variations in the user's confidence level regarding the presence of specific symptoms observed in cacao plants, which are used to support disease and pest diagnosis. Meanwhile, the expert's confidence level, as presented in Table 1 and Table 2, is determined proportionally based on the number of reference sources mentioning each symptom out of the four primary sources used in this study [21]–[24]. The certainty factor is calculated as the ratio between the number of sources reporting a given symptom and the total number of primary references, adopting a probability-inspired evidence aggregation approach. For instance, a symptom mentioned in only one of the four sources is assigned a certainty factor value of 0,25. This approach was adopted because obtaining direct input from multiple plantation experts was challenging, and

relying on a single expert could introduce bias. Unlike in medical science, where diagnostic standards are well-established and consistent, symptom interpretation in plantation disease identification tends to be less explicit and varies among experts.

TABLE 1
WEIGHT VALUES OF SYMPTOMS IN CACAO DISEASES

No.	Disease	Code	Symptoms Name	Expert CF
1	Fruit Rot	G1	The fruit color changes to dark brown or blackish	0,5
		G2	The seeds become rotten	0,5
		G3	The fruit becomes rotten and watery	0,75
2	Stem Canker	G4	The stem appears darker or blackish	0,25
		G5	The stem swells	0,25
		G6	The stem becomes rotten and wet	0,5
3	Vascular Streak Dieback (VSD)	G7	The leaves turn yellow with small green spots	0,75
		G8	The leaves fall off	0,75
		G9	The branches appear leafless	0,75
		G10	The surface of the branch bark becomes rough and mottled	0,25
4	Root Disease	G7	The leaves turn yellow with small green spots	0,5
		G11	The leaves wilt	0,5
		G12	The leaves dry up	0,5
		G8	The leaves fall off	0,25
		G13	White fungal threads are present on the roots	0,5
		G14	A dark reddish-brown coating is found on the roots	0,5
		G15	Soil crust is attached to the roots	0,5
		G16	The roots become rotten, soft, and watery	0,5
5	Swollen Shoot	G17	The fruit turns green with pink or dark green patches	0,25
		G6	The stem becomes rotten and wet	0,25
		G18	The roots swell	0,25
6	Witches' Broom Disease	G19	The fruit becomes swollen and slimy	0,25
		G20	The branches appear broom-like and blackened	0,25
7	Monilia Fruit Rot	G19	The fruit becomes swollen and slimy	0,25
		G21	The fruit turns brown and is covered with dirty white fungus	0,25
		G22	When cut longitudinally, immature fruits show brown, gray, or black streaks	0,25
		G2	The seeds become rotten	0,25
		G23	The seeds disintegrate	0,25
8	Upas Fungus	G12	The leaves dry up	0,25
		G13	White fungal threads are present on the roots	0,25
		G14	A dark reddish-brown coating is found on the roots	0,25
		G24	The branches appear shiny, resembling a spider web, with black discoloration underneath	0,25
9	Anthracnose	G25	Irregular brown spots appear on young leaves	0,25
		G7	The leaves turn yellow with small green spots	0,25
		G14	A dark reddish-brown coating is found on the roots	0,25
		G13	White fungal threads are present on the roots	0,25
		G12	The leaves dry up	0,25
		G26	The fruit becomes small	0,25
		G27	The fruit becomes hard	0,25
		G28	The fruit becomes dry	0,25

TABLE 2
WEIGHT VALUES OF SYMPTOMS IN CACAO PEST

No.	Pest	Code	Symptoms Name	Expert CF
1	Cacao Pod Borer	G29	The fruit color becomes mottled yellow and green	0,75
		G30	Small borer holes appear on the fruit surface	0,5
		G31	Cacao beans are small in size	0,5
		G32	Cacao beans are shriveled or empty	0,25
		G33	Cacao beans turn blackish in color	0,25
		G34	Cacao beans stick together	0,75
2	Fruit-Sucking Bug	G35	Brownish-black puncture marks are visible on the fruit surface	0,5
		G11	The leaves wilt	0,25
		G8	The leaves fall off	0,25
		G36	The branches dry out and defoliate	0,5
		G37	The fruit surface becomes cracked and wrinkled	0,25
		G28	The fruit becomes dry	0,5
3	Branch and Fruit Borer	G11	The leaves wilt	0,5
		G13	White fungal threads appear on the roots	0,5
		G38	Holes appear in the branches	0,75
4	Looper Caterpillar	G39	Leaves have holes	0,5
		G40	The branches wilt	0,25
		G41	The branches dry up	0,25
		G42	The branches die	0,25
5	*Chrysomelidae* leaf beetle	G43	The cacao fruit development process is slow	0,25
		G12	The leaves dry up	0,25
		G11	The leaves wilt	0,25
		G39	Leaves have holes	0,5
6	Rats / Squirrels	G44	The fruit has holes	0,5

C. Web-Based Expert System Design

Following the formulation of the CF–based diagnostic method, the next stage involves designing and implementing the web-based expert system. This system was developed to enable farmers and agricultural practitioners to diagnose cacao diseases and pests efficiently through an accessible, user-friendly online platform. The web-based diagnostic workflow is presented in Fig. 2.

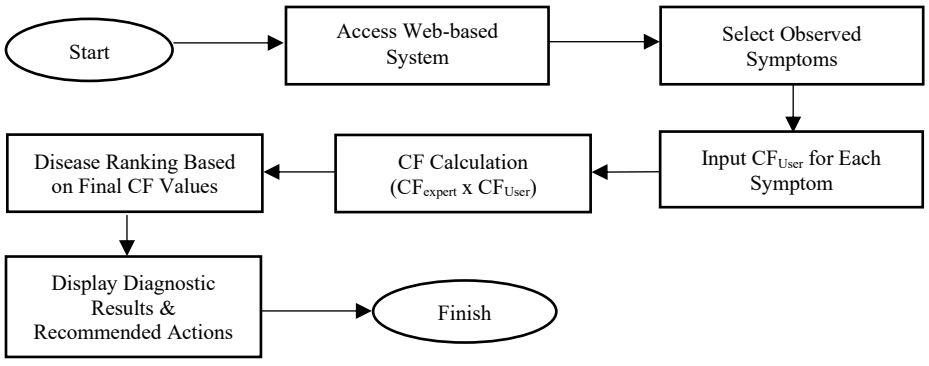


Fig. 2. Web-based Diagnostic Workflow.

The expert system was designed as a web-based application to ensure accessibility and ease of use for users. It was developed using the **Next.js 13** framework with **TypeScript** as the primary programming language, and styled with **Tailwind CSS** and **shadcn/ui** components. To enhance user experience, **Framer Motion** was integrated for smooth interface animations, while **Recharts** was employed to visualize diagnostic results through intuitive charts and progress indicators.

IV. RESULTS AND DISCUSSION

This section presents the results of the implementation of the web-based expert system and discusses the system's diagnostic performance using the CF method. The results demonstrate how user inputs in the form of observed symptoms and confidence values are processed by the system to produce diagnostic conclusions. An example of user input is provided, consisting of 10 selected symptoms with CF values representing the user's level of confidence, as shown in Table 3.

TABLE 3
EXAMPLE OF USER INPUT CONSISTING OF SELECTED SYMPTOMS AND THEIR CORRESPONDING CF VALUES REPRESENTING THE USER'S CONFIDENCE LEVELS

No.	Selected Symptom	Code	Description	CF User
1	The stem appears darker or blackish	G4	Most Likely	0.6
2	The branches appear leafless	G9	Possible	0.4
3	Branches wilt	G40	Almost Certain	0.8
4	Fruits become hard	G27	Almost Certain	0.8
5	The leaves wilt	G11	Certain	1
6	The leaves fall off	G8	Most Likely	0.6
7	The leaves dry up	G12	Possible	0.4
8	The seeds disintegrate	G23	Certain	1
9	White fungal threads are present on the roots	G13	Possible	0.4
10	The fruit turns brown and is covered with dirty white fungus	G21	Certain	1

After the user provides the input information, the system calculates the total CF value. The following list presents the identified diseases and pests in descending order of their CF values:

1. Root disease — CF value of 0.728
2. Vascular Streak Dieback (VSD) — CF value of 0.615
3. Branch and Fruit borer — CF value of 0.600
4. Anthracnose — CF value of 0.541
5. Monilia Fruit Rot — CF value of 0.438
6. Upas fungus — CF value of 0.426
7. Fruit-sucking bug — CF value of 0.362
8. *Chrysomelidae* leaf beetle — CF value of 0.325
9. Looper Caterpillar — CF value of 0.200
10. Stem canker — CF value of 0.150
11. Fruit rot — CF value of 0
12. Swollen shoot — CF value of 0
13. Witches' Broom Disease — CF value of 0
14. Cacao pod borer — CF value of 0
15. Rats and squirrels — CF value of 0

Based on the calculation results presented above, the system diagnosed that the cacao plant was infected with root disease, which obtained the highest CF value. To evaluate the performance of the developed expert system, a comparison was made with a previous study [4] that employed the forward chaining and naïve Bayes methods for diagnosing cacao plant diseases. The comparison results are presented in Table 4. Based on testing using 15 data samples, the CF method produced 14 diagnoses consistent with the comparative methods. The similarity rate was calculated as follows:

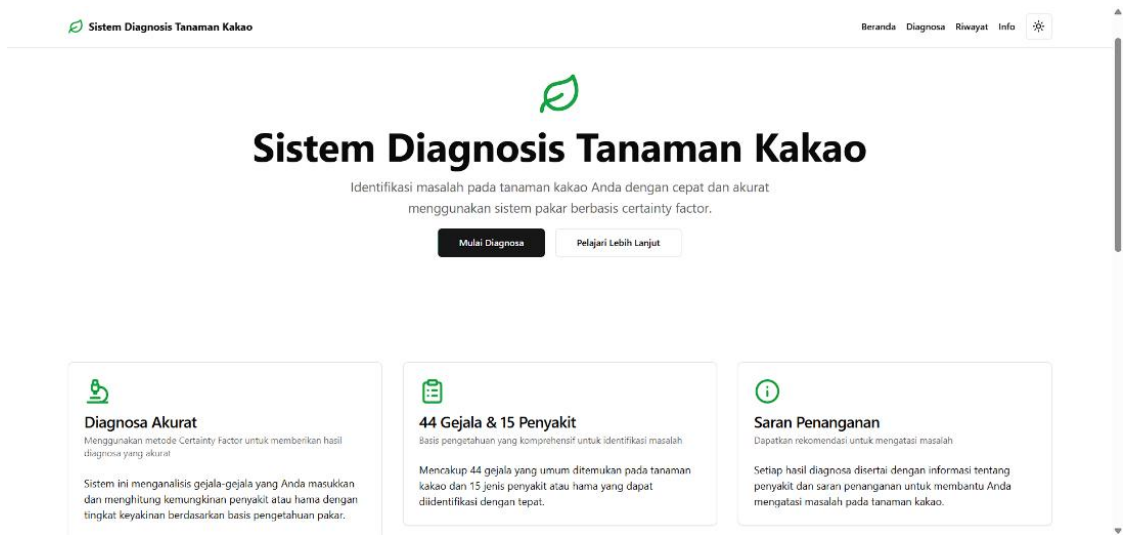
$$Similarity\ rate = \frac{14}{15} \times 100 = 93{,}33\%. \quad (4)$$

Based on testing using 15 data samples, the CF method used in this study produced 14 diagnoses consistent with those of the comparative methods, resulting in a similarity rate of 93.33%. This finding demonstrates that the developed expert system achieves a high degree of accuracy and reliability in diagnosing cacao plant diseases and pests, showing that the CF approach effectively handles uncertainty within the diagnostic process. The inference process implemented in the expert system reflects the diagnostic reasoning typically performed by human experts, but it is executed systematically and more rapidly through a computerized system.

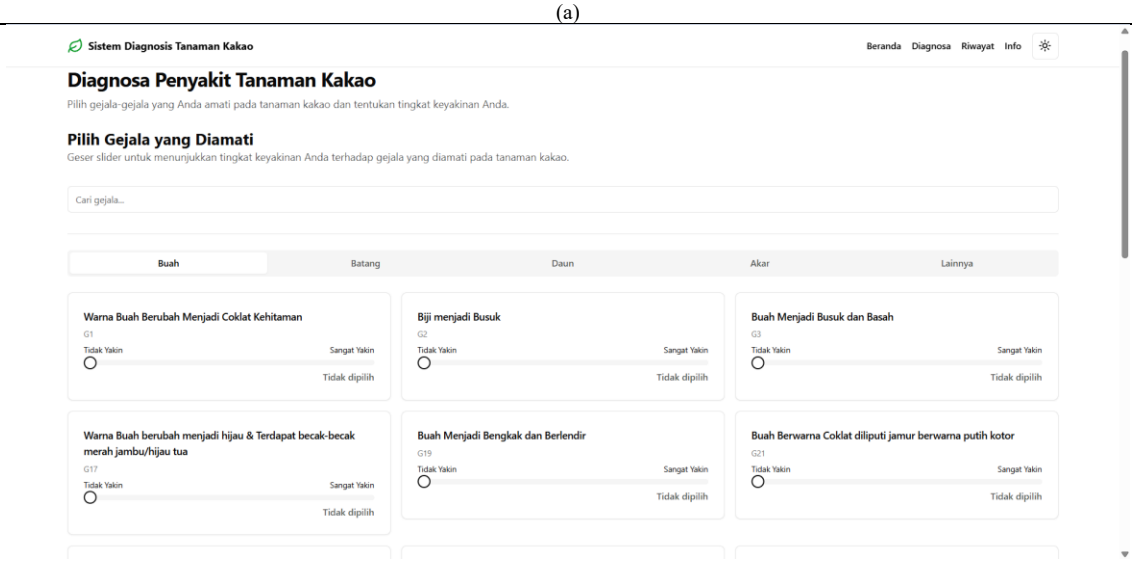
TABLE 4
COMPARISON OF DIAGNOSTIC RESULTS BETWEEN THE PROPOSED EXPERT SYSTEM AND THE PREVIOUS STUDY [4]

No.	Symptom Code	Previous Study by [4]	Our Results	Similarity
1	G1, G29, G31, G32	Cacao Pod Borer	Cacao Pod Borer	Consistent
2	G29, G31, G32	Cacao Pod Borer	Cacao Pod Borer	Consistent
3	G1, G28, G37, G40, G36	Fruit-Sucking Bug	Fruit-Sucking Bug	Consistent
4	G1, G28, G37	Fruit-Sucking Bug	Fruit-Sucking Bug	Consistent
5	G38, G39	Branch and Fruit Borer	Branch and Fruit Borer	Consistent
6	G39, G42	Looper Caterpillar	Looper Caterpillar	Consistent
7	G11, G39	*Chrysomelidae* leaf beetle	*Chrysomelidae* leaf beetle	Consistent
8	G44	Rats / Squirrels	Rats / Squirrels	Consistent
9	G3, G1	Fruit Rot	Fruit Rot	Consistent
10	G3, G1, G9	Fruit Rot	Fruit Rot	Consistent
11	G9, G12	*Vascular Streak Dieback (VSD)*	*Vascular Streak Dieback (VSD)*	Consistent
12	G9, G12, G25	*Vascular Streak Dieback (VSD)*	*Vascular Streak Dieback (VSD)*	Consistent
13	G4, G6	Stem Canker	Stem Canker	Consistent
14	G1, G9, G25, G11	Anthracnose	*Vascular Streak Dieback (VSD)*	Different
15	G7, G16, G13	Root Disease	Root Disease	Consistent

Fig. 3 and Fig. 4 show the web-based expert system for diagnosing cacao diseases using the CF method. Accessible online, the system is designed for farmers to independently perform diagnoses. Fig. 3(a) shows the home page, which serves as the landing page and provides an overview of the system's objectives, benefits, and navigation to its main features, along with the diagnosis page where users can select observed symptoms (see Fig. 3(b)). Meanwhile, Fig. 4 presents three integrated components: (a) the diagnosis results page, listing diseases and pests in descending order of CF values with corresponding confidence percentages; (b) the diagnosis history page, which records previous results for ongoing plant health monitoring; and (c) the disease description page, containing detailed information on the identified disease or pest, its associated symptoms, and recommended treatments. The interface is designed to be simple, informative, and user-friendly to facilitate effective use by farmers.



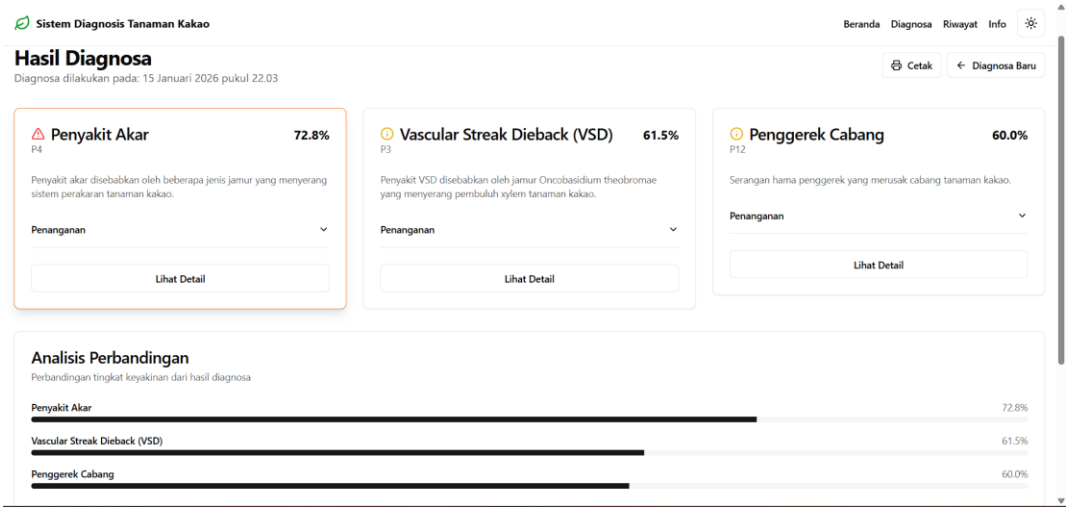
(a)



(b)

Fig. 3. Display of the Cacao Disease Detection Expert System Website: (a). Home Page and (b). Disease Diagnosis Page

Nevertheless, this study has several limitations. The knowledge base was developed without direct elicitation from multiple domain experts, which may limit the representation of tacit field knowledge and local disease variability. Consequently, a probability-based approach was applied to determine expert certainty factor values based on literature frequency, and system performance was evaluated through comparison with previous studies using a similarity rate. These limitations highlight the need for further validation and refinement in future research.



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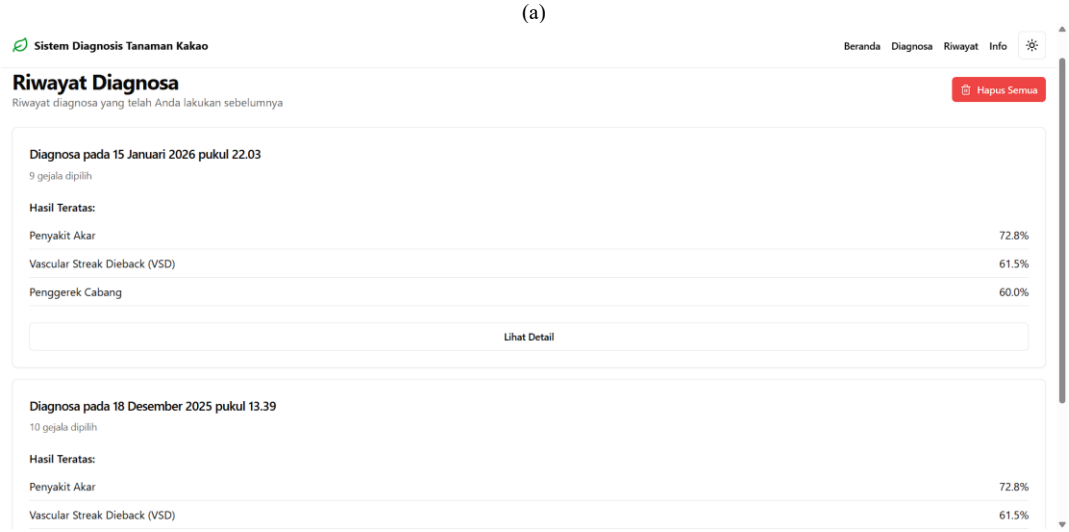

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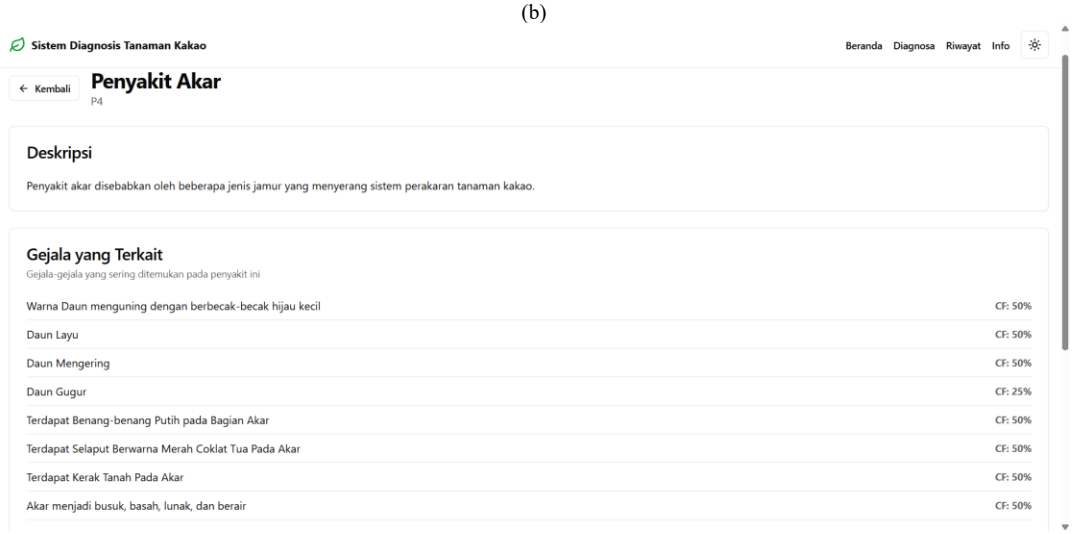

(c)

Fig. 4. Display of the Cacao Disease Detection Expert System Website: (a). Disease Diagnosis Results Page; (b). Diagnosis History Page; and (c). Disease Description Page with Symptoms and Treatments.

V. CONCLUSION

This study successfully developed a web-based expert system for diagnosing pests and diseases in cacao plants using the Certainty Factor (CF) method. The system was constructed based on nine diseases and six pests along with their associated symptoms, primarily derived from authoritative literature and official guidelines. By combining expert and user confidence levels through CF calculations, the system provides accurate and interpretable diagnostic results while improving farmers' access to agricultural knowledge and addressing expert availability constraints.

DATA AND COMPUTER PROGRAM AVAILABILITY

Data and program used in this paper can be accessed in the following site mathworks.com or github.com.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Rina Ratianingsih, Maulidyani Abu, and Abdul Mahatir Najar for their valuable suggestions and insightful discussions that greatly contributed to the improvement of this study.

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