

ANALYSIS OF THE EFFECTS OF WIND SPEED AND CONIDIAL DENSITY ON LEAF RUST DISEASE (PHAKOPSORA PACHYRHIZI) IN IMMATURE OIL PALM PLANTATION AREAS

Kania Yustika Pakpahan¹, Guntoro², Nurliana³

Plant Protection Study Program, Faculty of Science and Technology,
Indonesian Oil Palm Institute of Technology, Medan

E-mail: kaniayustika3@gmail.com, guntoro@itsi.ac.id, nurliana@itsi.ac.id

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Abstract

This study aimed to analyze the effects of wind speed and conidial density on edamame leaf rust disease caused by *Phakopsora pachyrhizi* in immature oil palm plantation areas. The research was conducted at the Oil Palm Practice Farm of the Indonesian Oil Palm Institute of Technology, Deli Serdang, North Sumatra, through wind speed measurement, conidial observation using a spore trap, and disease intensity assessment. The data were analyzed using multiple linear regression with SPSS through classical assumption tests, t-test, F-test, and the coefficient of determination. The results showed that the regression model met the normality assumption, had no multicollinearity, and showed no indication of heteroscedasticity. Partially, wind speed did not have a significant effect on disease intensity ($p = 0.437$), whereas the number of conidia had a significant effect ($p < 0.001$). Simultaneously, both variables had a significant effect on disease intensity ($F = 442.472$; $p < 0.001$), with an R Square value of 0.955. These findings indicate that conidial density is an important indicator in the development of edamame leaf rust disease.

Keywords: Edamame; Leaf rust; Wind speed; Conidia; *Phakopsora pachyrhizi*

INTRODUCTION

Oil palm is a strategic commodity that plays an important role in the national economy (Rahmawati, 2023). During the immature phase, the space between oil palm rows can still be used for intercrops, including edamame. Land utilization through intercropping can improve land-use efficiency, expand income sources, and support food diversification based on economically valuable commodities (Judijanto, 2024). Edamame (*Glycine max* (L.) Merr.) is soybean harvested when the seeds are still immature. This crop has good nutritional and economic value, but its productivity can be constrained by disease attacks (Fitri et al., 2025). One of the important diseases in edamame and soybean is leaf rust caused by the fungus *Phakopsora pachyrhizi*. This disease can develop rapidly because the pathogen produces large numbers of uredospores that are easily dispersed by wind (Hossain et al., 2024).

The development of leaf rust disease is determined not only by the presence of the pathogen but also by environmental factors that support infection. Wind speed is associated with the movement of spores from inoculum sources to healthy plants (Santiago-Pérez et al., 2022), whereas conidial density indicates the amount of inoculum available in the air. When dispersed spores encounter a moist leaf surface and a susceptible host, the likelihood of infection increases (Longo Sartor Zagui et al., 2024). Studies on the effects of wind speed and conidial density are important because these two variables can be used as a basis for monitoring disease risk (Santiago-Pérez et al., 2022). This information is needed to determine more appropriate control timing, particularly in edamame intercropping systems in young oil palm areas that have distinctive microclimatic conditions, such as high humidity, dense canopy, and air circulation that changes according to plant age (Belinelli et al., 2022). This study aimed to analyze the effects of wind speed and conidial density on the intensity of edamame leaf rust disease in immature oil palm plantation areas. The results are expected to support the development of disease management strategies based on environmental monitoring and inoculum density.

LITERATURE REVIEW

Edamame and Intercropping Systems in Immature Oil Palm Plantations

Edamame is a leguminous crop that can adapt to various land conditions as long as its requirements for light, water, and nutrients are met (Fitri et al., 2025). In immature oil palm plantation areas, edamame can be cultivated as an intercrop because light intensity between oil palm rows remains relatively sufficient. This system has the potential to increase land productivity before the oil palm canopy fully closes (Judijanto, 2024). Intercropping systems can also affect microclimatic conditions. The oil palm canopy, weeds around the crop area, and soil surface cover by mulch can influence humidity, temperature, and air flow (Belinelli et al., 2022). These conditions need to be considered because foliar pathogens generally develop more rapidly in humid environments with poor air circulation (Uge et al., 2023).

Leaf Rust Disease and Inoculum Sources

Soybean leaf rust is caused by *P. pachyrhizi*, which is known as an aggressive pathogen (Hossain et al., 2024). Initial symptoms appear as small spots on leaves and then develop into brown to orange pustules. Under severe infection, leaves turn yellow, dry out, and fall, thereby reducing the photosynthetically active leaf area (Uge et al., 2023). The main inoculum source of this disease is uredospores or conidia formed on infected leaf tissue. Mature spores can be released into the air and move to other plants (Santiago-Pérez et al., 2022). When the number of conidia is high, the chance of spores adhering to the leaf surface also increases. Therefore, conidial observation using a spore trap can serve as an important approach for predicting disease risk (Hossain et al., 2024).

Wind Speed and Infection Dynamics

Wind plays a role in carrying spores from one point to another. However, infection success is not always directly determined by wind speed alone because spores require moist leaf conditions to germinate. In areas with high humidity, spores that have been deposited on the leaf surface can germinate more easily and form infection structures (Hossain et al., 2024). Inoculum density, humidity, and leaf surface conditions are interrelated. Wind can expand spore distribution, whereas conidial density determines inoculum pressure (Santiago-Pérez et al., 2022). The combination of these factors can explain why leaf rust epidemics may increase during certain periods, especially when the crop is in the vegetative to early generative stage, which provides abundant young leaves as host tissue (Longo Sartor Zagui et al., 2024).

METHODS

The research was conducted at the Oil Palm Practice Farm of the Indonesian Oil Palm Institute of Technology, Williem Iskandar Street, Kenangan Baru, Percut Sei Tuan District, Deli Serdang Regency, North Sumatra. The research location is situated at coordinates 3.616702° N and 98.709846° E, at an elevation of approximately 27 m above sea level. The study was conducted for three months, from March to May 2026. The materials used included edamame seeds, planting media, basal fertilizer, water, vaseline, lactophenol cotton blue, fungicide, and insecticide as needed. The equipment used included an anemometer, spore trap, object glass, cover glass, microscope, camera, stationery, and SPSS software for data analysis.

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Kania Yustika Pakpahan et al.



Figure 1. Spore trap

The spore trap was placed in the crop area to capture airborne conidia. Object glasses coated with vaseline were installed on the spore trap so that conidia could adhere to the glass surface. Samples were then observed under a microscope to count the number of conidia captured during the observation period. Wind speed was measured using an anemometer in the morning, afternoon, and late afternoon. Measurements were taken near the crop area so that the data obtained represented the crop microclimate. Disease intensity was observed using a 0-4 scale based on the proportion of leaf area showing disease symptoms.

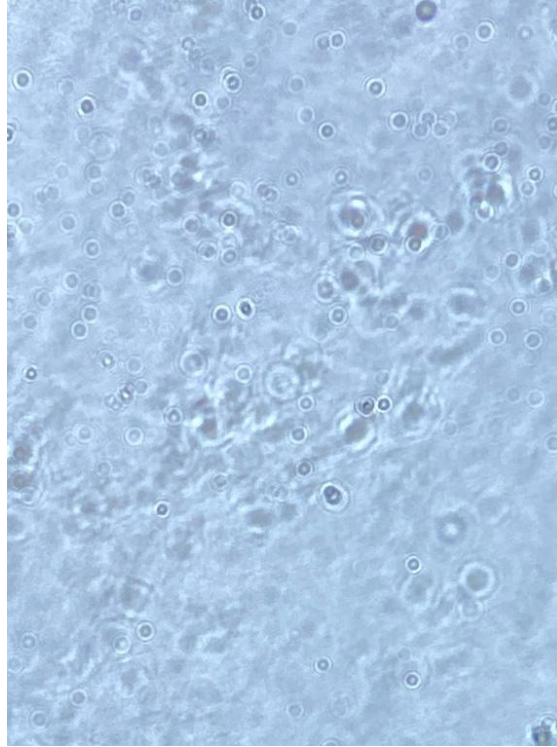


Figure 2. Microscopic observation of conidia

Microscopic observation was used to confirm the presence of spore particles captured by the trap. In the microscopic image, round to elliptical particles were observed scattered across the field of view. Counting was carried out consistently so that conidial count data could be compared with disease intensity on the plants. Data were analyzed using multiple linear regression with the model $Y = a + b_1X_1 + b_2X_2$, where Y represents log-transformed disease intensity, X_1 represents wind speed, and X_2 represents the number of conidia. The classical assumption tests included normality, multicollinearity, and heteroscedasticity. Hypothesis testing was conducted using the t-test, F-test, and coefficient of determination at a 5% significance level (Ali et al., 2022).

RESULTS AND DISCUSSION

Field conditions showed that edamame plants grew in an open area between rows of young oil palms. This planting system allows air movement among plants, while at the same time the surrounding environment still has relatively high humidity due to the presence of vegetation and oil palm canopy. These conditions can support spore deposition on leaf surfaces (Belinelli et al., 2022).

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Kania Yustika Pakpahan et al.

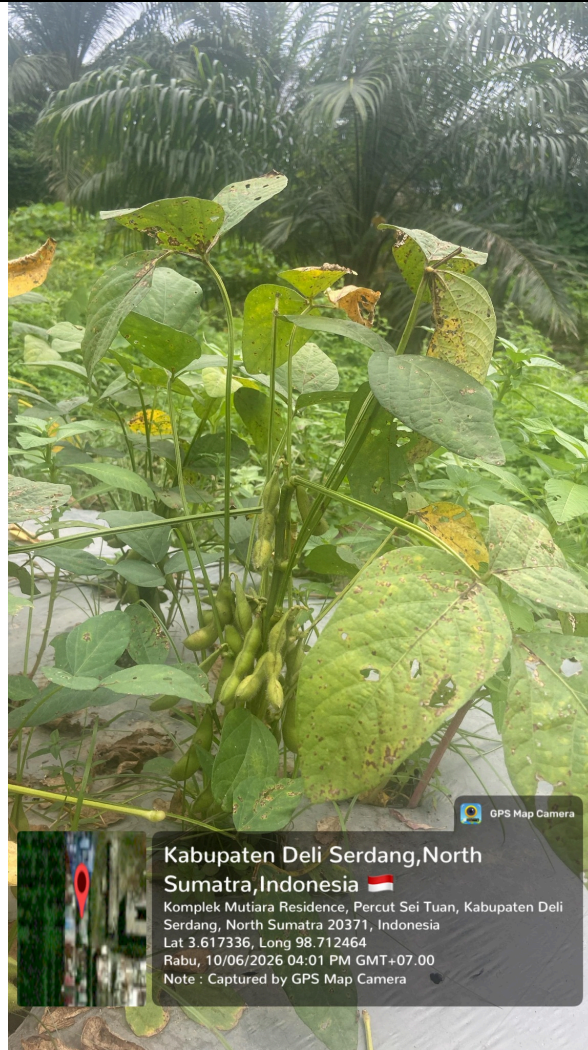


Figure 3. Condition of edamame plants with leaf spot symptoms in the research area

Symptoms observed in the field ranged from small spots to spreading spots on leaves. Some leaves showed yellowish discoloration and tissue damage along the leaf margins. These symptoms indicate disruption of photosynthetic tissue. If disease intensity increases, damaged leaves may dry out and fall more rapidly, potentially reducing the plant's ability to form pods (Hossain et al., 2024).



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Kania Yustika Pakpahan *et al.*

Figure 4. Variation in leaf spot symptoms on edamame leaves from relatively mild to severe conditions

Figure 4 shows variation in symptom severity on several leaves. Relatively healthy leaves were dark green with few spots, whereas leaves with more severe symptoms showed more numerous spots, discoloration, and holes caused by tissue damage. This variation is an important basis for assessing disease intensity because observations evaluate not only the presence or absence of symptoms, but also the severity level in each leaf category (Uge *et al.*, 2023).



Figure 5. Edamame plants at the pod formation stage as a comparison of growth conditions

Plants at the pod formation stage still require healthy leaves to support photosynthesis and seed filling. Therefore, leaf rust infection at this stage must be carefully considered because leaf loss can affect yield. Relatively healthy plants were used as a comparison to assess visual differences between plants with mild symptoms and plants showing more obvious leaf damage (Fitri *et al.*, 2025).

Classical Assumption Test

The classical assumption test was conducted before interpreting the multiple linear regression to ensure that the model met the normality requirement, had no multicollinearity, and showed no indication of heteroscedasticity. Based on the SPSS output, the Kolmogorov-Smirnov Asymp. Sig. values for Wind Speed, Number of Conidia, and Disease Intensity were 0.067, 0.200, and 0.200, respectively. Because all significance values were greater than 0.05, the data met the normality assumption. The residual histogram and Normal P-P Plot also showed a residual pattern approaching a normal distribution (Ali *et al.*, 2022).

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Kania Yustika Pakpahan et al.

Table 1. Summary of Classical Assumption Test Results Based on SPSS Output

Classical assumption test	Variable/indicator	SPSS output value	Criterion	Conclusion
Normality	Wind speed; number of conidia; disease intensity	K-S/Sig.: 0.1267/0.067; 0.1109/0.200; 0.0627/0.200	Sig. > 0.05	Normal
Multicollinearity	Wind speed and number of conidia	Tolerance = 0.878; VIF = 1.139	Tolerance > 0.10; VIF < 10	No multicollinearity
Heteroscedasticity	SRESID-ZPRED scatterplot	Residual points are randomly distributed around the zero line	No specific pattern formed	No heteroscedasticity

Based on Table 1, all data met the classical assumptions. The Tolerance values for the Wind Speed and Number of Conidia variables were both 0.878, while their VIF values were both 1.139. These values indicate that multicollinearity did not occur. In the heteroscedasticity test, the scatterplot between the Regression Standardized Predicted Value and the Regression Standardized Residual showed that the residual points were randomly distributed around the zero line and did not form any specific pattern. Thus, the regression model was appropriate for further testing (Ali et al., 2022).

Multiple Linear Regression Results

The multiple linear regression results showed an R value of 0.977, an R Square value of 0.955, and an Adjusted R Square value of 0.953. These values indicate that the model has a very strong ability to explain variation in leaf rust disease intensity. The regression model summary is presented in Table 2 (Ali et al., 2022).

Table 2. Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.977	0.955	0.953	0.07380

Based on Table 2, the R Square value of 0.955 means that 95.5% of the variation in disease intensity can be explained by wind speed and the number of conidia, while the remaining 4.5% is explained by other factors outside the model, such as humidity, temperature, rainfall, canopy condition, and plant resistance (Belinelli et al., 2022; Uge et al., 2023). The F-test was used to determine the simultaneous effect of wind speed and the number of conidia on disease intensity. The F-test results are presented in Table 3.

Table 3. F-test Results of Multiple Linear Regression

Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Regression	4.820	2	2.410	442.472	0.000
Residual	0.229	42	0.005	-	-
Total	5.048	44	-	-	-

The calculated F value of 442.472 with a significance value of 0.000 indicates that wind speed and the number of conidia simultaneously had a significant effect on the intensity of edamame leaf rust disease. Therefore, the regression model was appropriate for explaining the relationship between the two independent variables and the dependent variable. The t-test was used to determine the partial effect of each independent variable. The regression coefficients, t-test results, and multicollinearity results are presented in Table 4.

Table 4. Regression Coefficients, t-test, and Multicollinearity

Variable	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
Constant	-1.194	0.044	-	-27.114	0.000	-	-
Wind speed	0.028	0.036	0.027	0.784	0.437	0.878	1.139
Number of conidia	0.033	0.001	0.967	27.588	0.000	0.878	1.139

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Kania Yustika Pakpahan et al.

Based on these results, the regression equation obtained is as follows:

$$Y = -1.194 + 0.028X_1 + 0.033X_2 \quad (1)$$

Notes: Y = disease intensity, X₁ = wind speed, and X₂ = number of conidia.

The wind speed coefficient was positive at 0.028, but its significance value was 0.437, which is greater than 0.05. This indicates that wind speed partially had no significant effect on disease intensity in this research model. Biologically, wind still acts as a medium for spore transport, but symptom development after spores land on leaves is still influenced by humidity, leaf wetness duration, and plant tissue susceptibility (Hossain et al., 2024). The number of conidia had a positive coefficient of 0.033 with a significance value of 0.000. This means that the higher the number of conidia available in the crop environment, the greater the intensity of edamame leaf rust disease. The beta value of 0.967 indicates that the number of conidia was the most dominant variable in the regression model (Santiago-Pérez et al., 2022; Pakpahan, 2026). These results are consistent with the concept of plant disease epidemiology, which states that inoculum density is an important factor in determining the probability of infection. The more spores available in the air, the greater the likelihood that spores will adhere to leaves and initiate new infections. In edamame intercropping systems in immature oil palm plantation areas, information on the number of conidia can serve as an early indicator for estimating disease risk and determining more appropriate control timing (Hossain et al., 2024; Longo Sartor Zagui et al., 2024).

CONCLUSION

The multiple linear regression model used in this study met the classical assumptions, namely normally distributed data, no multicollinearity, and no visual indication of heteroscedasticity. Partially, wind speed did not have a significant effect on the intensity of edamame leaf rust disease, whereas the number of conidia had a significant effect and was the most dominant factor in the model. Simultaneously, wind speed and the number of conidia had a significant effect on disease intensity, with an R Square value of 0.955. Monitoring the number of conidia should be incorporated into the early warning strategy for edamame leaf rust disease, particularly in immature oil palm plantation areas that implement intercropping systems. Further studies are recommended to include humidity, temperature, rainfall, and leaf wetness duration variables so that the disease prediction model becomes more comprehensive.

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Kania Yustika Pakpahan **et al.**

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