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ANALYSIS OF THE EFFECT OF SUNLIGHT INTENSITY AND CONIDIUM DENSITY ON EDAMAME RUST DISEASE (PHAKOPSORA PACHYRHIZI) IN IMMATURE OIL PALM AREAS

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Abstract

This study aims to analyze the effect of sunlight intensity and conidium density on the intensity of leaf rust disease caused by *Phakopsora pachyrhizi* in edamame plants grown in immature oil palm areas. The study used a quantitative descriptive approach by observing sunlight intensity, conidium density, and disease intensity. The data were analyzed using multiple linear regression with SPSS after log transformation of the disease intensity variable to meet the normality assumption. The Kolmogorov-Smirnov test showed an Asymp. Sig. value of 0.200, indicating that the data were normally distributed. The model also showed no multicollinearity, as indicated by a Tolerance value of 0.904 and a VIF of 1.106, and no heteroscedasticity pattern was found in the residual scatterplot. The regression produced the equation Y = 0.830 + 0.000000039X1 + 0.033X2. Sunlight intensity did not have a significant partial effect, whereas conidium density had a positive and significant effect on disease intensity. Simultaneously, both variables had a significant effect, with an F-statistic of 440.049 and an R Square value of 0.954.

Keywords: Edamame, Sunlight Intensity, Oil Palm, Phakopsora pachyrhizi.

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is a major plantation commodity in Indonesia that contributes substantially to the agricultural sector and national income (Simanjuntak et al., 2025). In immature oil palm areas, the use of inter-row spaces through an intercropping system can serve as a strategy to improve land-use efficiency. One potential intercrop is edamame (*Glycine max* (L.) Merr.), which has economic value, high protein content, and increasing market demand (Gunawan et al., 2025). Edamame cultivation faces a major constraint in the form of plant disease. One important disease affecting soybean and edamame is leaf rust caused by *Phakopsora pachyrhizi*. Infection by this pathogen produces spots and pustules on leaves, disrupts photosynthesis, accelerates leaf abscission, and may ultimately reduce crop yield (Hossain et al., 2024; Murithi et al., 2021). Therefore, understanding the factors that influence disease development is important as a basis for disease management in the field.

Leaf rust development is influenced by environmental factors and inoculum availability. Sunlight intensity plays a role in shaping the plant microclimate, whereas conidium density determines the likelihood of infection in healthy leaf tissue. High sunlight intensity may reduce spore viability under certain conditions, while shaded and humid conditions support spore germination and pathogen penetration (Krah & Bässler, 2021; Yu et al., 2023). High conidium density increases the chance of contact between spores and host tissue, thereby increasing disease severity, particularly under high-humidity conditions (Tapia et al., 2025). Based on this background, the present study was directed toward analyzing the effect of sunlight intensity and conidium density on the intensity of edamame leaf rust disease. This article presents the research findings in the IJSET scientific article format by adjusting the research description and the SPSS regression results obtained.

LITERATURE REVIEW

Edamame and the Cropping System in Oil Palm Areas

Edamame is a vegetable soybean harvested at the young pod stage. This plant has an upright to semi-upright stem, trifoliate leaves, and a growth system influenced by both genetic and environmental factors. Morphological characteristics such as leaf area, stomatal density, and photosynthetic efficiency are closely related to the plant's ability to capture light and produce yield (Dhakal et al., 2021).

In immature oil palm areas, edamame intercropping can support more productive land utilization. However, changes in sunlight intensity caused by oil palm shade can affect the microenvironment around the plants, including humidity and leaf surface temperature, which are associated with the development of foliar diseases (Gunawan et al., 2025; Tapia et al., 2025).

***Phakopsora pachyrhizi* and Leaf Rust Disease**

Phakopsora pachyrhizi is an obligate pathogen that causes leaf rust disease in soybean and edamame. This pathogen produces urediniospores or conidia as the main inoculum source. Spores deposited on the leaf surface germinate under suitable environmental conditions, form germ tubes, penetrate leaf tissue, and subsequently develop rust pustules as new sources of spores (Hossain et al., 2024; Meilinda, 2021).

Typical symptoms of leaf rust are characterized by the appearance of brownish pustules on the leaf surface, especially on the underside of leaves. Severe infection can cause leaves to turn yellow, dry out, and fall prematurely. This condition reduces the plant's photosynthetic capacity and may interfere with productivity (Murithi et al., 2021).

The Role of Light Intensity and Conidium Density

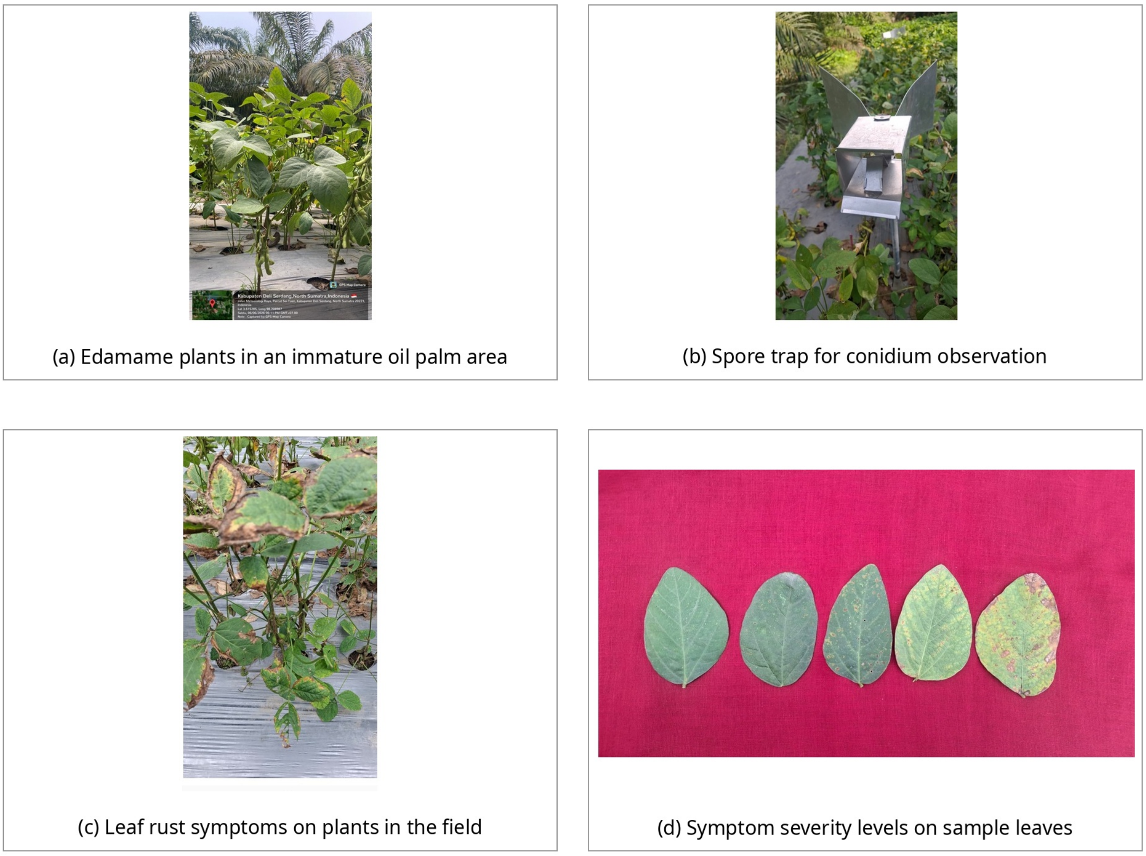
Sunlight intensity is an abiotic factor that affects plant growth as well as pathogen development. Light can influence temperature, microhumidity, and spore viability. Under high-light conditions, leaf surfaces tend to become drier, thereby reducing the opportunity for spore germination. Conversely, shaded conditions can maintain leaf humidity and increase the likelihood of pathogen infection (Krah & Bässler, 2021; Yu et al., 2023).

Conidium density is an indicator of the amount of inoculum available in the air or around the crop. The higher the number of conidia, the greater the possibility that spores will attach to the leaf surface and initiate infection. Thus, the interaction between light conditions and conidium availability is an important component in explaining the dynamics of leaf rust disease (Hossain et al., 2024; Mwelasi et al., 2025).

METHODS

The research was conducted at the Practice Garden of the Indonesian Oil Palm Institute of Technology (ITSI), Medan, in an immature oil palm area located at coordinates 3.616702° N and 98.709846° E, with an elevation of approximately 27 meters above sea level. The research activities were designed for the period from January to April 2026. The materials used included edamame seeds, planting media, fertilizer, fungicide, insecticide, water, vaseline, plastic mulch, and lactophenol cotton blue. The equipment used included a lux meter, object glass slides, cover glasses, spore traps, a Bunsen burner, a compound microscope, a mobile phone camera, stationery, and SPSS software for data processing.

Edamame was planted on beds with a spacing of 30 cm × 20 cm. Observations began when the plants were 30 days after planting. Sunlight intensity was measured using a lux meter in the morning, at midday, and in the afternoon. Conidia were counted using spore traps installed in the crop area; the trapped spores were then observed and counted using a compound microscope. The development of leaf rust disease was observed using a severity scale from 0 to 4. Scale 0 indicated no symptoms, scale 1 indicated symptoms covering about 25% of the leaf area, scale 2 indicated infection of more than 25% to 50%, scale 3 indicated infection of more than 50% to 75%, and scale 4 indicated infection of more than 75% of the leaf surface. Disease intensity was calculated based on the proportion of leaves in each infection category.



(a) Edamame plants in an immature oil palm area

(b) Spore trap for conidium observation

(c) Leaf rust symptoms on plants in the field

(d) Symptom severity levels on sample leaves

Figure 1. Research documentation: (a) edamame plants in an immature oil palm area, (b) spore trap installation for conidium observation, (c) leaf rust symptoms on plants in the field, and (d) symptom severity levels on sample leaves.
Source: Research documentation, 2026; symptom interpretation and spore dynamics were adapted from Hossain et al. (2024), Murithi et al. (2021), Tapia et al. (2025), Krah & Bässler (2021), and Yu et al. (2023).

The documentation in Figure 1 shows the field conditions used to observe the relationship among sunlight intensity, conidium density, and leaf rust disease intensity. Edamame plants in immature oil palm areas showed microclimatic variation caused by shading, making periodic light observations necessary. Spore traps were used to capture airborne conidia because spore density is the main inoculum source in leaf rust development. Leaf symptoms such as chlorosis, brownish spots, necrosis, and drying of leaf margins indicate the progression of disease, which can reduce the photosynthetic capacity of the plant. This condition is consistent with the explanation that *Phakopsora pachyrhizi* develops through spores as the main inoculum source, while humidity and light also influence the success of pathogen infection (Hossain et al., 2024; Murithi et al., 2021; Tapia et al., 2025).

Data were analyzed using multiple linear regression, with the dependent variable being leaf rust disease intensity in log-transformed form (Y) and the independent variables being sunlight intensity (X1) and conidium density (X2). Prior to regression analysis, the data were tested through classical assumptions, including the Kolmogorov-Smirnov normality test, multicollinearity testing using Tolerance and Variance Inflation Factor (VIF) values, and heteroscedasticity testing using a residual scatterplot. Partial testing was conducted using the t-test, simultaneous testing using the F-test, and the explanatory ability of the model was assessed using the coefficient of determination (R Square).

RESULTS AND DISCUSSION

Classical Assumption Tests

Classical assumption tests were conducted to ensure that the regression model was appropriate for use. The disease intensity variable was analyzed in log-transformed form because the initial results did not meet the normality assumption. After transformation, all variables showed significance values greater than 0.05.

Table 1. One-Sample Kolmogorov-Smirnov Normality Test Results

		Sunlight Intensity	Conidium Density	Disease Intensity (Log)
N		45	45	45
Normal Parameters	Mean	262786.467	16.933	1.403
	Std. Deviation	189643.506	9.880	0.339
Most Extreme Differences	Absolute	0.107	0.111	0.063
	Positive	0.107	0.111	0.057
	Negative	-0.091	-0.095	-0.063
Test Statistic		0.107	0.111	0.063
Asymp. Sig. (2-tailed)		0.200	0.200	0.200

Based on Table 1, the Asymp. Sig. values for sunlight intensity, conidium density, and log-transformed disease intensity were each 0.200. These values are greater than 0.05, indicating that the data were normally distributed and met the requirements for multiple linear regression analysis.

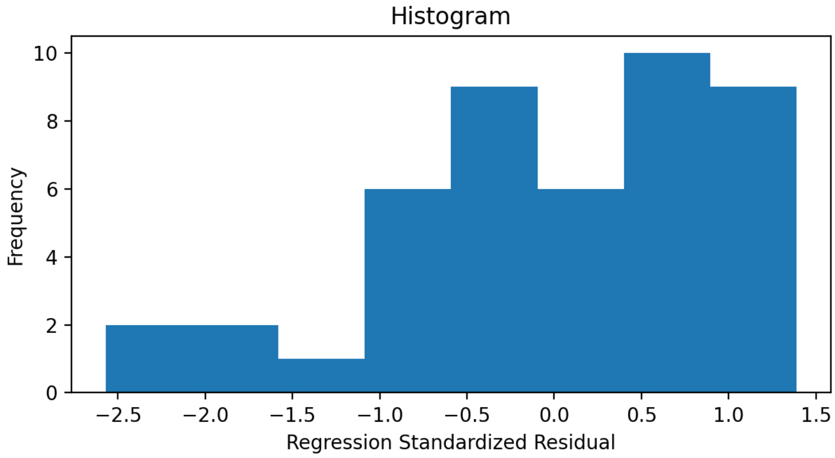


Figure 2. Histogram of Regression Standardized Residuals

Table 2. Multicollinearity Test Results

Variable	Tolerance	VIF	Description
Conidium Density	0.904	1.106	No multicollinearity
Sunlight Intensity	0.904	1.106	No multicollinearity

The Tolerance values of the two independent variables were 0.904, greater than 0.10, and the VIF values were 1.106, lower than 10. Therefore, no multicollinearity symptoms were found between sunlight intensity and conidium density in the regression model.

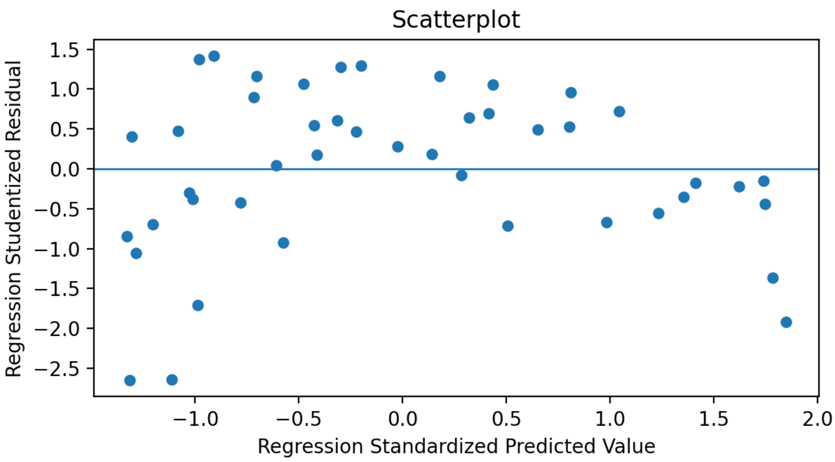


Figure 3. Scatterplot of Regression Studentized Residuals by Regression Standardized Predicted Values

Based on Figure 3, the residual points were distributed around the zero line and did not form a particular pattern. This distribution indicates that the regression model did not exhibit heteroscedasticity symptoms; therefore, the model was suitable for hypothesis testing.

Multiple Linear Regression Results

Table 3. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	0.977	0.954	0.952	0.074	0.954	440.049	2	42	0.000

Table 3 shows an R value of 0.977, indicating a very strong relationship between the independent variables and leaf rust disease intensity. The R Square value of 0.954 indicates that 95.4% of the variation in leaf rust disease intensity can be explained by sunlight intensity and conidium density, while the remaining 4.6% is explained by other factors outside the research model.

Table 4. F-Test Results (ANOVA)

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	4.818	2	2.409	440.049	0.000
Residual	0.230	42	0.005		
Total	5.048	44			

The F-test results in Table 4 show an F-statistic of 440.049 with a significance value of 0.000. Because the significance value is lower than 0.05, sunlight intensity and conidium density simultaneously have a significant effect on the intensity of edamame leaf rust disease.

Table 5. t-Test Results and Regression Coefficients

Model/Variable	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
(Constant)	0.830	0.024		34.216	0.000		
Conidium Density	0.033	0.001	0.970	28.008	0.000	0.904	1.106
Sunlight Intensity	3.874E-08	6.186E-08	0.022	0.626	0.535	0.904	1.106

Based on Table 5, the multiple linear regression equation obtained was Y = 0.830 + 0.000000039X1 + 0.033X2. In this equation, Y represents log-transformed leaf rust disease intensity, X1 represents sunlight intensity, and X2 represents conidium density.

The regression coefficient of sunlight intensity was 0.000000039, indicating a positive direction of relationship; however, the t-statistic was 0.626 with a significance value of 0.535, which is greater than 0.05. This means that sunlight intensity did not have a significant partial effect on leaf rust disease intensity. These results suggest that changes in sunlight intensity in the observed data were not strong enough to independently explain variation in disease intensity.

Conidium density had a regression coefficient of 0.033, with a t-statistic of 28.008 and a significance value of 0.000. These values indicate that conidium density had a positive and significant effect on leaf rust disease intensity. Every one-unit increase in conidium density increased disease intensity in log form by 0.033 units, assuming the other variable remained constant.

Table 6. Regression Residual Statistics

Residual Statistics	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	0.963	2.014	1.403	0.331	45
Std. Predicted Value	-1.329	1.848	0.000	1.000	45
Residual	-0.190	0.103	0.000	0.072	45
Std. Residual	-2.569	1.388	0.000	0.977	45
Cook's Distance	0.000	0.164	0.025	0.042	45

The residual statistics show that the mean residual value approached zero, namely 0.000, indicating that the model prediction error was relatively balanced. The maximum Cook’s Distance value of 0.164 remained within a range that did not indicate an extreme influence of any single observation on the overall model.

Discussion

The results showed that conidium density was the main factor explaining the increase in leaf rust disease intensity. Biologically, a higher number of conidia increases the chance of spores attaching to the leaf surface, germinating, and penetrating host tissue. This condition supports the development of rust pustules, which then produce new spores and accelerate the infection cycle. This pattern is consistent with the characteristics of *Phakopsora pachyrhizi* as a rust pathogen that uses spores as the main inoculum in its infection cycle (Hossain et al., 2024; Mwelasi et al., 2025).

Sunlight intensity in this model did not show a significant partial effect. This may be due to insufficient variation in light intensity, the presence of other environmental factors such as humidity and temperature that were not included in the model, and the possibility that inoculum density was more dominant in explaining variation in disease intensity. Light remains relevant as an environmental factor because it can influence fungal metabolism and the leaf-surface microclimate, but its contribution in this model was not as strong as that of conidium density (Krah & Bässler, 2021; Yu et al., 2023; Tapia et al., 2025). Simultaneously, sunlight intensity and conidium density had a significant effect on disease intensity. This finding indicates that edamame leaf rust development is influenced not only by inoculum availability but also by environmental conditions that regulate the success of infection. The high coefficient of determination shows that the regression model had a strong ability to explain variation in the observed data.

The practical implication of these findings is that leaf rust disease management should be directed toward reducing inoculum sources and monitoring spore density in the field. Microenvironmental regulation through plant spacing, crop sanitation, and routine observation can help reduce the likelihood of infection. In edamame intercropping systems in immature oil palm areas, disease control should consider the dynamics of light, humidity, and conidium density in an integrated manner (Hossain et al., 2024; Tapia et al., 2025).

CONCLUSION

Based on the results of multiple linear regression analysis, the research model met the classical assumptions because the log-transformed data were normally distributed, showed no multicollinearity, and did not exhibit heteroscedasticity symptoms. Sunlight intensity did not have a significant partial effect on the intensity of edamame leaf rust disease, whereas conidium density had a positive and significant effect. Simultaneously, sunlight intensity and conidium density had a significant effect on leaf rust disease intensity, with an F-statistic of 440.049 and a significance value of 0.000. The R Square value of 0.954 indicates that 95.4% of the variation in disease intensity can be explained by these two variables. Conidium density was the most dominant variable in the model; therefore, monitoring and controlling inoculum sources should be a priority in managing edamame leaf rust disease in immature oil palm areas.

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