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ANALYSIS OF THE EFFECTS OF SUNLIGHT INTENSITY AND CONIDIAL DENSITY ON EDAMAME LEAF RUST (*PHAKOPSORA PACHYRHIZI*) IN AN IMMATURE OIL PALM PLANTATION

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Abstract
This study aimed to analyze the effects of sunlight intensity and conidial density on the severity of leaf rust caused by *Phakopsora pachyrhizi* in edamame cultivated in an immature oil palm plantation. A quantitative descriptive approach was employed, involving observations of sunlight intensity, conidial counts, and disease severity. The data were analyzed using multiple linear regression in SPSS after the disease severity variable was log-transformed to meet the normality assumption. The Kolmogorov-Smirnov test yielded an Asymp. Sig. value of 0.200, indicating that the data were normally distributed. The model showed no multicollinearity (Tolerance = 0.904; VIF = 1.106) and no discernible heteroscedasticity pattern in the residual scatterplot. The regression equation was Y = 0.830 + 0.000000039X1 + 0.033X2. Sunlight intensity had no significant partial effect, whereas conidial density had a positive and significant effect on disease severity. Simultaneously, both variables had a significant effect, with F = 440.049 and R Square = 0.954.

Keywords: Edamame, sunlight intensity, oil palm, *Phakopsora pachyrhizi*.

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is one of Indonesia's major plantation commodities and contributes substantially to the agricultural sector and national income (Simanjuntak et al., 2025). In immature oil palm plantations, inter-row spaces can be utilized through intercropping to improve land-use efficiency. Edamame (*Glycine max* (L.) Merr.) is a promising intercrop because of its economic value, high protein content, and increasing market demand (Gunawan et al., 2025).

Edamame production faces major constraints from plant diseases. One important disease of soybean and edamame is leaf rust caused by *Phakopsora pachyrhizi*. Infection by this pathogen produces leaf spots and pustules, disrupts photosynthesis, accelerates defoliation, and may ultimately reduce crop yield (Hossain et al., 2024; Murithi et al., 2021). Therefore, understanding the factors that influence disease development is essential for establishing effective field management strategies.

Leaf rust development is influenced by environmental factors and inoculum availability. Sunlight intensity shapes the crop microclimate, whereas conidial density determines the likelihood of infection in healthy leaf tissue. High sunlight intensity may reduce spore viability under certain conditions, while shaded and humid environments support spore germination and pathogen penetration (Krah & Bässler, 2021; Yu et al., 2023). High conidial density increases the probability 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 analyzed the effects of sunlight intensity and conidial density on the severity of edamame leaf rust. This paper presents the findings in the IJSET scientific article format, with the research description and SPSS regression results adjusted accordingly.

LITERATURE REVIEW

Edamame and Intercropping in Oil Palm Plantations

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

In immature oil palm plantations, edamame intercropping can support more productive land use. However, changes in sunlight intensity caused by oil palm shading may alter the crop microenvironment, including humidity and leaf-surface temperature, both of 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 in soybean and edamame. The pathogen produces urediniospores or conidia as its principal inoculum. Spores on the leaf surface germinate under favorable environmental conditions, form germ tubes, penetrate leaf tissue, and subsequently produce rust pustules that serve as new sources of spores (Hossain et al., 2024; Meilinda, 2021).

Typical leaf rust symptoms include brownish pustules on the leaf surface, particularly on the underside. Severe infection may cause leaves to yellow, dry, and fall prematurely. These effects reduce the plant's photosynthetic capacity and may consequently impair productivity (Murithi et al., 2021).

Roles of Sunlight Intensity and Conidial Density

Sunlight intensity is an abiotic factor that influences both plant growth and pathogen development. Light affects temperature, microhumidity, and spore viability. Under high-light conditions, leaf surfaces tend to dry more rapidly, which may reduce the probability of spore germination. In contrast, shaded conditions can maintain leaf moisture and increase the likelihood of pathogen infection (Krah & Bässler, 2021; Yu et al., 2023).

Conidial density indicates the amount of inoculum available in the air or surrounding the crop. As conidial density increases, the probability that spores will land on the leaf surface and initiate infection also increases. Thus, the interaction between light conditions and inoculum availability is an important component in explaining the dynamics of leaf rust disease (Hossain et al., 2024; Mwelasi et al., 2025).

METHODS

The study was conducted at the Practice Farm of Institut Teknologi Sawit Indonesia (ITSI), Medan, in an immature oil palm plantation located at 3.616702° N and 98.709846° E, approximately 27 m above sea level. Field activities were carried out from March to May 2026.

The materials included edamame seed, growing media, fertilizers, fungicides, insecticides, water, petroleum jelly, plastic mulch, and lactophenol cotton blue. The equipment included a lux meter, microscope slides, coverslips, spore traps, a Bunsen burner, a compound microscope, a mobile phone camera, stationery, and SPSS software for data analysis.

Edamame was planted in beds at 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 collected using spore traps installed within the crop area and were subsequently observed and counted under a compound microscope.

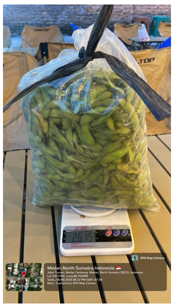
Leaf rust development was assessed using a severity scale from 0 to 4. A score of 0 indicated no symptoms; score 1 indicated symptoms on approximately 25% of the leaf area; score 2 indicated infection on more than 25% to 50% of the leaf area; score 3 indicated infection on more than 50% to 75% of the leaf area; and score 4 indicated infection on more than 75% of the leaf surface. Disease severity was calculated from the proportion of leaves in each severity category.


(a) Edamame plants in an immature oil palm plantation


(b) Spore trap for conidial monitoring


(c) Leaf rust symptoms observed in the field


(d) Symptom severity on sampled leaves


(e) Pod weight, *P. pachyrhizi*-infected plot

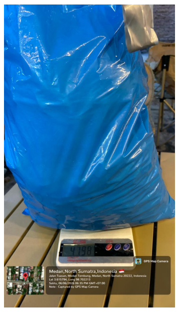

(f) Pod weight, control plot

Figure 1. Research documentation: (a) edamame plants in an immature oil palm plantation; (b) installation of a spore trap for conidial monitoring; (c) leaf rust symptoms observed in the field; (d) symptom severity levels on sampled leaves; (e) pod weight in the *Phakopsora pachyrhizi*-infected plot; and (f) pod weight in the control plot.

Source: Research documentation, 2026; interpretation of symptoms and spore dynamics adapted from Hossain et al. (2024), Murithi et al. (2021), Tapia et al. (2025), Krah & Bässler (2021), and Yu et al. (2023).

Figure 1 presents the field conditions used to examine the relationships among sunlight intensity, conidial density, and leaf rust severity. The edamame crop in the immature oil palm plantation was exposed to microclimatic variation caused by shading; therefore, sunlight intensity needed to be measured periodically. Spore traps were used to capture airborne conidia because spore density represents the principal inoculum source in leaf rust development. Leaf symptoms, including chlorosis, brown spots, necrosis, and marginal drying, reflected disease progression that could reduce photosynthetic capacity. These observations are consistent with reports that *Phakopsora pachyrhizi* relies on spores as its primary inoculum, while humidity and light influence infection success (Hossain et al., 2024; Murithi et al., 2021; Tapia et al., 2025).

Data were analyzed using multiple linear regression. The dependent variable was log-transformed leaf rust severity (Y), while the independent variables were sunlight intensity (X1) and conidial density (X2). Before regression analysis, the data were evaluated using classical assumption tests, including the Kolmogorov-Smirnov normality test, multicollinearity analysis based on Tolerance and Variance Inflation Factor (VIF) values, and a residual scatterplot for heteroscedasticity. Partial effects were tested using the t-test, simultaneous effects using the F-test, and the explanatory power of the model 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 analysis. Disease severity was analyzed after log transformation because the initial data did not meet the normality assumption. After transformation, all variables had significance values greater than 0.05.

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

		Sunlight Intensity	Conidial Density	Disease Severity (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

As shown in Table 1, the Asymp. Sig. values for sunlight intensity, conidial density, and log-transformed disease severity were all 0.200. Because these values were greater than 0.05, the data were considered normally distributed and met the requirements for multiple linear regression analysis.

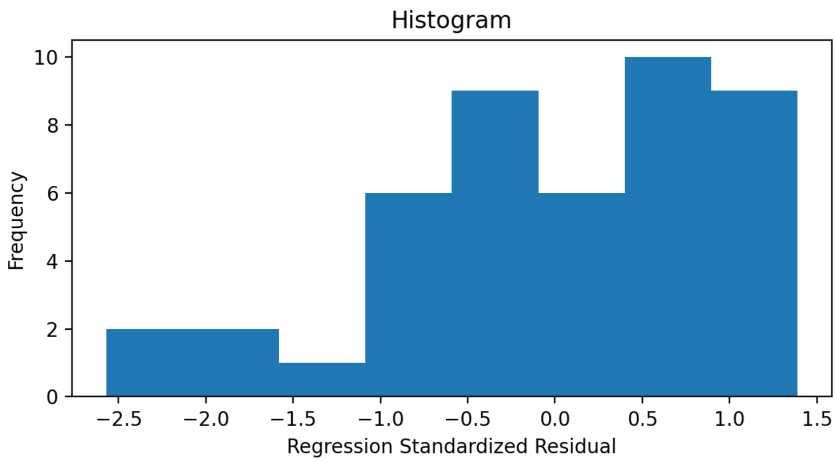


Figure 2. Histogram of Regression Standardized Residuals

Table 2. Multicollinearity Test Results

Variable	Tolerance	VIF	Interpretation
Conidial Density	0.904	1.106	No multicollinearity
Sunlight Intensity	0.904	1.106	No multicollinearity

The Tolerance value for both independent variables was 0.904, which was greater than 0.10, while the VIF value was 1.106, which was less than 10. Therefore, no multicollinearity was detected between sunlight intensity and conidial density in the regression model.

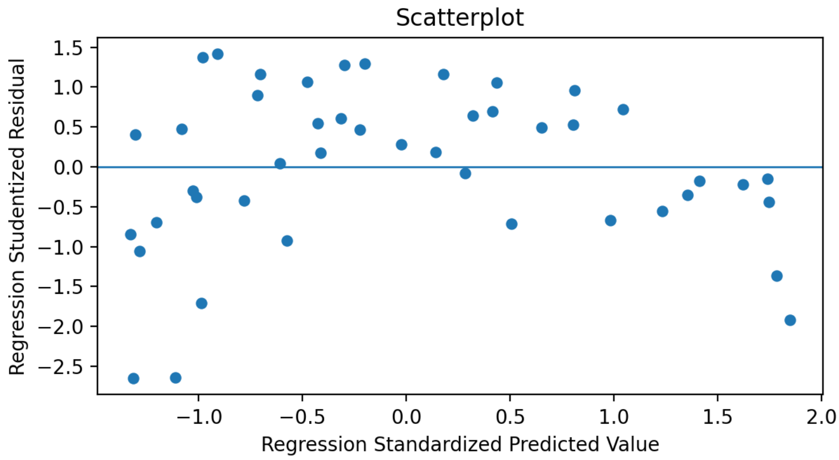


Figure 3. Scatterplot of Regression Studentized Residuals by Regression Standardized Predicted Values

As shown in Figure 3, the residual points were dispersed around the zero line and did not form a distinct pattern. This distribution indicates that the regression model did not exhibit heteroscedasticity and was therefore 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 severity. The R Square value of 0.954 indicates that 95.4% of the variation in leaf rust severity was explained by sunlight intensity and conidial density, while the remaining 4.6% was explained by factors outside the 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 value of 440.049 with a significance value of 0.000. Because the significance value was less than 0.05, sunlight intensity and conidial density simultaneously had a significant effect on edamame leaf rust severity.

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		
Conidial 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 was Y = 0.830 + 0.000000039X1 + 0.033X2. In this equation, Y represents log-transformed leaf rust severity, X1 represents sunlight intensity, and X2 represents conidial density.

The regression coefficient for sunlight intensity was 0.000000039, indicating a positive direction of association. However, the t value was 0.626 and the significance value was 0.535, which was greater than 0.05.

Thus, sunlight intensity did not have a significant partial effect on leaf rust severity. This finding indicates that the observed variation in sunlight intensity was not sufficiently strong to explain disease severity independently.

Conidial density had a regression coefficient of 0.033, a t value of 28.008, and a significance value of 0.000. These values indicate that conidial density had a positive and significant effect on leaf rust severity. A one-unit increase in conidial density increased log-transformed disease severity by 0.033 units, assuming that the other variable remained constant.

Table 6. Regression Residual Statistics

Residual Statistic	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 was close to zero (0.000), indicating that the model's prediction errors were relatively balanced. The maximum Cook's Distance value was 0.164, which remained below the level indicating an excessively influential observation in the overall model.

Table 7. Edamame Pod Weight

Infected with *Phakopsora pachyrhizi*	Control
2,615 g	4,798 g

The measurements showed that pod weight in the plot infected with *Phakopsora pachyrhizi* was 2,615 g, whereas pod weight in the control plot was 4,798 g. Thus, the control plot produced a higher pod weight than the infected plot.

Discussion

The results indicate that conidial density was the principal factor explaining the increase in leaf rust severity. Biologically, a higher number of conidia increases the likelihood that spores will land on the leaf surface, germinate, and penetrate host tissue. This process supports the development of rust pustules, which subsequently produce new spores and accelerate the infection cycle. This pattern is consistent with the biology of *Phakopsora pachyrhizi*, a rust pathogen that relies on spores as the primary inoculum in its infection cycle (Hossain et al., 2024; Mwelasi et al., 2025).

Sunlight intensity did not show a significant partial effect in the present model. This result may be attributable to insufficient variation in sunlight intensity, the influence 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 disease severity. Light remains environmentally relevant because it may affect fungal metabolism and the leaf-surface microclimate; however, its contribution in this model was weaker than that of conidial density (Krah & Bässler, 2021; Yu et al., 2023; Tapia et al., 2025).

Simultaneously, sunlight intensity and conidial density had a significant effect on disease severity. This finding demonstrates that the development of edamame leaf rust is influenced not only by inoculum availability but also by environmental conditions that regulate the success of the infection process. The high coefficient of determination indicates that the regression model had strong explanatory power for the observed variation.

The practical implication of these findings is that leaf rust management should prioritize reducing inoculum sources and monitoring spore density in the field. Microenvironmental management through appropriate plant spacing, crop sanitation, and routine monitoring may help reduce the likelihood of infection. In edamame intercropping systems within immature oil palm plantations, disease control should integrate the dynamics of light, humidity, and conidial density (Hossain et al., 2024; Tapia et al., 2025).

CONCLUSION

Based on the multiple linear regression analysis, the research model met the classical assumptions because the log-transformed data were normally distributed, no multicollinearity was detected, and no heteroscedasticity was observed. Sunlight intensity did not have a significant partial effect on edamame leaf rust severity, whereas conidial density had a positive and significant effect. Simultaneously, sunlight intensity and conidial density had a significant effect on leaf rust severity, with F = 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 severity was explained by the two variables. Conidial density was the most dominant variable in the model; therefore, monitoring and controlling inoculum sources should be prioritized in the management of edamame leaf rust in immature oil palm plantations.

REFERENCES

Brooks, K., Reiter, M., Zhang, B., & Mott, J. (2023). *Edamame yield and quality response to nitrogen and sulfur fertilizers. Agronomy, 13(7).* https://doi.org/10.3390/agronomy13071865

Campos, M. D., Patanita, M., Varanda, C., Materatski, P., & Félix, M. do R. (2021). *Plant-pathogen interaction. Biology, 10-11.*

Chen, D. V., Slowinski, S. P., Kido, A. K., & Bruns, E. L. (2024). *High temperatures reduce growth, infection, and transmission of a naturally occurring fungal plant pathogen. Ecology, 105(8), 1-12.*

Dhakal, K., Zhu, Q., Zhang, B., Li, M., & Li, S. (2021). *Analysis of shoot architecture traits in edamame reveals potential strategies to improve harvest efficiency. Frontiers in Plant Science, 12, 1-13.*

Gunawan, H., Isra, M., & Febrianto, E. B. (2025). *Intercropping growth response of edamame plants on oil palm land with the application of Biosaka. Journal of Agriculture, 1, 67-78.*

Hossain, M. M., Sultana, F., Yesmin, L., Rubayet, M. T., Abdullah, H. M., Siddique, S. S., Bhuiyan, M. A. B., & Yamanaka, N. (2024). *Understanding Phakopsora pachyrhizi in soybean: Comprehensive insights, threats, and management. Plant Pathology Journal.*

Krah, S., & Bässler, C. (2021). *Transcriptional response of mushrooms to artificial sun exposure. Ecology and Evolution*, 11, 10538-10546. https://doi.org/10.1002/ece3.7862

Meilinda, T. (2021). *Effectiveness of several Actinomycetes isolates as biological control agents against Phakopsora pachyrhizi, the causal agent of leaf rust, and for increasing soybean (Glycine max) production*.

Murithi, H. M., Soares, R. M., Mahuku, G., van Esse, H. P., & Joosten, M. H. A. J. (2021). *Diversity and distribution of pathotypes of the soybean rust fungus Phakopsora pachyrhizi in East Africa. Plant Pathology*.

Mwelasi, P., Laing, M., Ibaba, J., Rogers, R., Nemeth, M., & Yobo, K. (2025). *Ultrastructural examination of the fungus-fungus interactions of Lecanicillium uredinophilum and Phakopsora pachyrhizi.*

Naseri, B., & Jalilian, F. (2021). *Characterization of leaf rust progress in wheat cultivars with different resistance levels and sowing dates. European Journal of Plant Pathology, 159(3), 665-672.*

Simanjuntak, W. F., Kusuma, R. M., & Wiyatiningsih, S. (2025). *Pest and disease challenges in oil palm (Elaeis guineensis Jacq.) seedling in Sukamara, Central Borneo, Indonesia. February, 12-22.*

Tapia, L., Castillo-Novales, D., Riquelme, N., Valencia, A. L., Larach, A., Cautín, R., & Besoain, X. (2025). *Rainfall and high humidity influence the seasonal dynamics of spores of Glomerellaceae and Botryosphaeriaceae genera in avocado orchards and their fruit rot association. Agronomy, 15(6), 1-19.* https://doi.org/10.3390/agronomy15061453

Yu, W., Pei, R., Zhang, Y., Tu, Y., & He, B. (2023). *Light regulation of secondary metabolism in fungi. Journal of Biological Engineering, 17(1), 57. https://doi.org/10.1186/s13036-023-00374-4*