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Analysis of the Effect of Sunlight Intensity and Number of Conidia on the Intensity of Leaf Spots (*Cercosporsa sp*) of Edamame (*Glycine max* L. Merr) in Immature Oil Palm Areas

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Abstract

Leaf spot disease caused by *Cercospora sp*. is a major constraint in edamame (*Glycine max* L. Merr.) cultivation, particularly in intercropping systems under immature oil palm stands. This study aimed to analyze the effects of sunlight intensity and conidial density on the severity of *Cercospora sp*. leaf spot disease in edamame plants. The research was conducted at the Practice Garden of the Indonesian Institute of Palm Technology, Medan, from March to May 2026. We measured sunlight intensity using a digital lux meter in the morning, at noon, and in the afternoon. Conidial density was monitored using modified spore traps, while disease severity was assessed visually through symptom scoring. The data were analyzed using normality and multicollinearity tests, multiple linear regression, the F-test, and the coefficient of determination with SPSS. The results showed that sunlight intensity and conidial density simultaneously had a significant effect on disease severity. However, these two variables explained only 13.8% of the variation in disease severity, with the remaining 86.2% attributable to other factors not included in the model. Sunlight intensity contributed more than conidial density. This study provides initial quantitative evidence of the combined relationship between microclimatic conditions, inoculum density, and disease severity in edamame cultivated under immature oil palm stands. These findings can support more targeted disease management by encouraging growers to monitor sunlight conditions, optimize canopy and planting arrangements where necessary, and reduce potential inoculum sources. Further research incorporating additional environmental and plant-related variables is recommended to improve the model's explanatory power and to develop more effective disease management strategies and inoculum control in edamame cultivation systems under oil palm stands.

Keywords: Canopy, Inoculum, Intercropping, Microclimate, Phytopathology

1. Introduction

Edamame (*Glycine max* L. Merr.) is a horticultural commodity with high economic value because it has a high protein content, ranging from 30-40%, and has market demand that continues to increase both in the domestic and export markets, especially to Japan and East Asian countries (Badan Pusat Statistik BPS-Statistics Indonesia, 2024)

Despite its promising economic prospects, edamame cultivation still faces several fundamental challenges, including limited cultivation land, the need for suitable environmental conditions, and the risk of pest infestation, which can reduce productivity and yield quality. These challenges become more important in intercropping systems because conditions beneath the main crop can limit edamame growth and influence disease development.

Edamame can be developed as an intercrop in immature oil palm areas (TBM) because it can improve land-use efficiency and provide added economic value for farmers (Batubara, 2022). Intercrop selection should consider the relatively short harvest period, economic value, and the plant's ability to grow without inhibiting the

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main crop (Ilvira et al., 2023). However, success in this system depends not only on yield potential and economic value, but also on the farmer's ability to manage microclimate conditions and disease disturbances that arise during plant growth.

This plant also has the potential to be developed as an intercrop in immature oil palm areas (TBM) because it can increase land use efficiency and provide added economic value for farmers (Batubara, 2022). Plants used as intercrops must be selected with fast yields, and they must not compete with or hinder the growth of the main crop (Ilvira et al., 2023)

However, intercropping under oil palm stands creates different microclimatic conditions, especially in light intensity, temperature, and humidity, which can affect plant growth and the development of plant diseases (Hidayat, 2022)

One major constraint in edamame cultivation is leaf diseases caused by pathogenic fungi such as Cercospora spp., Peronospora spp., and *Colletotrichum* spp. Among these pathogens, Cercospora sp. is known to cause leaf spot disease (Cercospora leaf spot), which reduces leaf and pod quality and inhibits the plant's photosynthesis. According to Sitompul et al. (2024), Cercospora leaf spot disease can decrease yield by up to 30% if infection occurs during pod formation. Infection during pod formation can decrease yield by up to 30%. Initial symptoms are characterized by the appearance of small, purplish-brown spots on the leaf surface, which then spread and cause necrosis.

Research by Smith (2017) shows that High-Intensity sunlight increases the activity of the photoactive toxin cercosporin (Cercospora sp.), speeds up plant cell damage, and accelerates lesion formation and sporulation.

Previous research has shown that light plays a role in the development of diseases caused by *Cercospora* spp. Daub and Chung (2007), in their article *"Cercosporin: A Photoactivated Toxin in Plant Disease*," explain that cercosporin is a light-sensitive toxin that produces reactive oxygen species when exposed to light. These compounds can cause membrane lipid peroxidation, cell membrane damage, and plant cell death, thus contributing to the development of disease symptoms.

Furthermore, Zivanovic et al. (2021), through a study entitled *Elucidation of Factors Contributing to the Onset of Cercospora Leaf Blight During Later Reproductive Development of Soybean*, found that the content of simple sugars in soybean leaves, especially fructose, is associated with increased cercosporin production by *Cercospora cf. flagellaris*. The study focused on plant physiological factors and endophytic bacteria related to disease emergence, rather than on direct measurements of sunlight intensity and conidium density in the field.

In addition to toxin mechanisms and plant physiological factors, environmental conditions also influence the development of leaf spot disease in soybeans. Moseley et al. (2026), in the article *Identifying and Managing Cercospora Leaf Blight in Soybean: From Scouting to Best Management Practices, explain the importance of environmental factors, including humidity and temperature, as well as inoculum presence, in the development and spread of Cercospora* disease in soybeans. The article also discusses disease monitoring methods and management strategies.

Previous research on Cercospora disease has examined light-induced toxin mechanisms, plant physiological factors, and environmental conditions that support disease development. However, this study takes a different focus: analysing the relationship between sunlight intensity and conidium density, along with the severity of *Cercospora* sp. leaf spot disease in edamame cultivated as an intercrop under immature oil palm stands. Measuring light intensity in the morning, afternoon, and evening and observing conidium density using a modified spore trap are approaches to studying these two variables under field conditions. Thus, this study's novelty lies in its cultivation system and its approach to analyzing both factors simultaneously, which is expected to provide quantitative information to support disease management based on microclimate conditions in the intercropping system.

Apart from light, the number of conidia or spores also plays a major role in determining infection severity. The higher the conidial concentration on the leaf surface, the greater the chance of infection.

Therefore, this study was conducted to analyze the effect of sunlight intensity and conidial number on the development of Cercospora sp. leaf spot disease in edamame plants, so the results can serve as a basis for a more effective and sustainable disease-control strategy in edamame cultivation.

2. Research Methods

The research was conducted at the Indonesian Palm Oil Technology Institute's Practice Garden, Medan, at approximately 3.616702° N and 98.709846° E, at an altitude of 27 meters above sea level, from March to May 2026. The research location was in an immature oil palm area. The main research material was edamame plants planted in research beds. Tools included a digital lux meter, modified spore trap, object glass, cover glass, compound microscope, stationery, SPSS software, and other secondary tools and materials.

We observed sunlight intensity daily at three times: morning, noon, and evening. We calculated light data in lux and averaged them as a daily value. Conidium density was observed using modified spore traps installed at observation points in the field. Captured conidia were observed under a microscope.

The intensity of the attack or severity of leaf spot disease is calculated using the formula:

$$Disease\ Intensity = \frac{\sum(n \times V)}{z \times N} \times 100\%$$

Where:
I = Disease Intensity/Severity
n = Severity score
V = Leaf severity score on observation
Z = Highest value of observation score
N = Total leaves observed

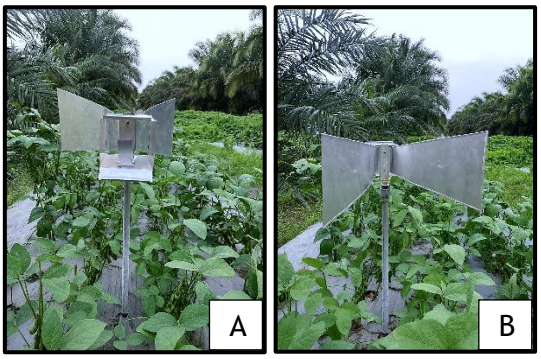

Figure 1. (A) Spore trap front view, (B) Spore trap back view

To find out the scale/scoring of the severity of the disease, you can see the following scale:

- Scale 0 = no symptoms of disease
- Scale 1 = 25% of leaf area causes disease symptoms (mild criteria)
- Scale 2 = >25%-50% of leaves are attacked / cause symptoms (moderate criteria)
- Scale 3 = >50%-75% of leaf area causes symptoms (severe criteria)
- Scale 4 = >75% of leaf area causes symptoms (severe symptoms) (Guntoro et al., 2025).

Disease incidence describes the percentage of infected plants compared to the total observed plant population. This parameter indicates how widely the disease has spread within the plant population. The following formula is used:

$$KP = \frac{n}{N} \times 100\%$$

Where:

- KP = Event Disease
- n = The number of plants that were attacked
- N = Total number of plants observed
  (Guntoro et al., 2025)

Data obtained from observations of leaf spot disease development under different sunlight intensities and the number of Cercospora sp. conidia were processed and analyzed. Statistical analysis was carried out to ensure objective and scientifically accountable results. The analysis used quantitative descriptive methods and was processed using SPSS Version 26, including normality, multicollinearity, heteroscedasticity, multiple linear regression, F, and R2 tests.

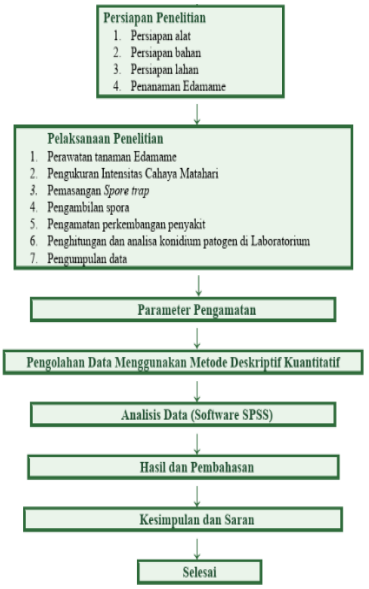

Figure 2. Research flow diagram

3. Results and Discussion

3.1. The Effect of Sunlight Intensity on Leaf Spot Disease (Cercospora sp)

Observations showed significant fluctuations in light intensity in the study area. Observations were conducted over 45 days, from April 16 to May 30, 2026, at three observation times: 6:30 a.m., 12:00 p.m., and 6:00 p.m.

The highest light intensity consistently occurs at 12:00 PM. The average light intensity at 12:00 PM reaches 95,880.73 lux, significantly higher than the 1,136.78 lux at 6:30 AM and the 2,137.09 lux at 6:00 PM. Therefore, the daily average is more influenced by daytime light intensity.

Cercospora sp. leaf spot disease in edamame. Light intensity can influence the disease through two pathways. First, light influences the microclimate conditions around the plant. Second, light can be linked to the activity of certain pathogens, particularly those in the *Cercospora group* that produce photosensitive toxins.

Observations showed that sunlight intensity during the study period ranged from 3,575–196,327 lux, with an average value of 99,154.60 lux. This range indicates a significant variation in lighting conditions in the edamame plantation area intercropped with immature oil palms (IMP). Variations in light intensity are thought to be related to changes in daily weather conditions, the apparent movement of the sun, and the degree of shading of the oil palm canopy. In an intercropping system, the main plant canopy can cause uneven light distribution, both temporally and spatially. These conditions can create different microenvironments for edamame plants and influence interactions between the host plant and the pathogen that causes leaf spot disease.

Table 1. Sunlight Intensity Data

NO	Day	LUX METER			Amount	Average (X)
		06.30	12.00	18.00		
1	April 16, 2020	838	142400	2410	145648	48549
2	April 17, 2020	713	42390	457	43560	14520
3	April 18, 2020	978	120500	2452	123930	41310
4	April 19, 2020	1152	1767	656	3575	1192
5	April 20, 2020	1172	118400	2541	122113	40704
6	April 21, 2020	762	67380	2609	70751	23584
7	April 22, 2020	894	64060	2457	67411	22470
8	April 23, 2020	1199	162600	1641	165440	55147
9	April 24, 2020	1140	49080	1107	51327	17109
10	April 25, 2020	647	130500	1261	132408	44136
11	April 26, 2020	862	94120	1683	96665	32222
12	April 27, 2020	1179	130900	1680	133759	44586
13	April 28, 2020	790	108600	1266	110656	36885
14	April 29, 2020	1199	43770	1143	46112	15371
15	April 30, 2020	2100	43560	1488	47148	15716
16	01-May-26	2154	23890	2521	28565	9522
17	02-May-26	2584	64060	2674	69318	23106
18	03-May-26	1401	30940	1779	34120	11373
19	04-May-26	719	3576	2228	6523	2174
20	05-May-26	1064	133500	4566	139130	46377
21	06-May-26	1059	21920	2890	25869	8623
22	07-May-26	1464	81550	1145	84159	28053
23	08-May-26	1170	85210	2990	89370	29790
24	09-May-26	188	83120	1743	85051	28350
25	10-May-26	1182	64340	1890	67412	22471
26	11-May-26	794	142300	1746	144840	48280
27	12-May-26	1740	168500	1985	172225	57408
28	13-May-26	758	89270	2228	92256	30752
29	14-May-26	925	8290	2762	11977	3992
30	15-May-26	668	118400	1449	120517	40172
31	16-May-26	270	82170	4294	86734	28911
32	17-May-26	535	153200	1904	155639	51880
33	18-May-26	1589	192300	2438	196327	65442
34	19-May-26	1374	192300	1993	195667	65222
35	20-May-26	1577	63590	1896	67063	22354
36	21-May-26	427	80380	1518	82325	27442
37	22-May-26	1336	132100	1451	134887	44962
38	23-May-26	593	160800	4369	165762	55254
39	24-May-26	1590	185700	2177	189467	63156
40	25-May-26	1676	80380	1367	83423	27808
41	26-May-26	853	126800	4644	132297	44099
42	27-May-26	150	75120	1518	76788	25596
43	28-May-26	2867	100400	1997	105264	35088
44	29-May-26	1509	132100	3287	136896	45632
45	30-May-26	1314	118400	1869	121583	40528

Pearson correlation analysis showed a positive relationship between sunlight intensity and disease severity (r = 0.326). This value indicates a positive relationship of relatively weak to moderate strength, so increasing light intensity in the observational data tends to be followed by increasing disease severity, but the relationship is not considered strong. The results of multiple linear regression also showed that sunlight intensity had a statistically significant partial effect on disease severity ((p=0.031); (\beta) standardized (=0.320)), after conidium density was included in the model. This finding indicates that light intensity contributes more to the model than conidium density. However, these results should be interpreted as a statistical relationship, not evidence that increased light directly causes increased disease severity.

Biologically, the relationship between light and Cercospora disease can be explained by light's role in activating the cercosporin toxin produced by several Cercospora species. Daub and Ehrenshaft (2000) explained that cercosporin is a light-activated toxin that can produce reactive oxygen species, particularly singlet oxygen, which damage plant cell membranes. Daub and Chung (2007) also described the role of light in cercosporin toxicity. This mechanism provides a biological basis for light's role in pathogenesis, especially when the pathogen produces the toxin. However, this study did not directly measure

cercosporin concentration, toxin production, or cell membrane damage. Therefore, this mechanism is used as a biological explanation that may support the statistical results, not as a mechanism that has been proven in edamame crops in this study.

The results of this study also need to be understood in the context that disease responses to light are not always linear or independent. Light can influence toxin activity, but disease progression still depends on inoculum presence, humidity, duration of leaf wetness, temperature, and host plant susceptibility. Therefore, the positive relationship between light intensity and disease severity in this study suggests a link that should be examined alongside other environmental factors. Further observations measuring light intensity at different canopy positions, relative humidity, temperature, and duration of leaf wetness are needed to elucidate further the role of light in leaf spot disease development in TBM oil palm intercropping systems.

Thus, days with low light intensity, such as April 19, 2026, May 4, 2026, and May 14, 2026, may create microclimatic conditions more conducive to disease development, especially if high humidity and high conidium density occur simultaneously. Low light intensity does not necessarily indicate a high disease rate. However, low light intensity can indicate shadier, more humid conditions with poor air circulation.

3.2. Severity of Leaf Spot Disease

Observations of symptom appearance at 37 days after planting indicate that the disease begins to develop in the late vegetative phase and progresses into the early generative phase. During this phase, the edamame plant canopy thickens, increasing humidity around the leaves. To clarify the differences in disease severity, visual observations were made between healthy edamame plants and those infected with Cercospora sp., as shown in Figure 2.

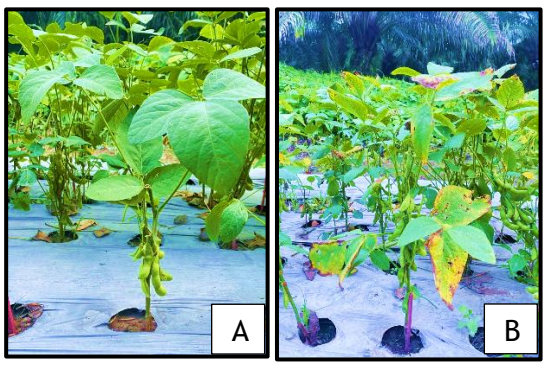

Figure 2. (A) Healthy Edamame Plants, (B) Edamame Plants Infected with *Cercospora sp. Disease*

Conidium density during the observation period ranged from 16–42 conidia, with an average of 30.11 conidia. The highest number was found on May 10, 2026, with 42 conidia, while the lowest number was found on April 16, 2026, with 16 conidia. This variation indicates that *Cercospora inoculum* around the plants changed during the study period. Changes in the number of conidia captured may reflect conidium formation and release from the pathogen's reproductive structures, environmental conditions, and differences in spore-dispersal intensity on each observation day. Thus, conidium density can indicate inoculum presence in the planting environment. However, the number of conidia captured does not always reflect the number of viable spores that successfully infect plant tissue.

Based on Pearson correlation analysis, conidium density has a weak positive relationship with disease severity ($r = 0.189$). This means that an increase in conidia tends to be followed by an increase in disease severity, but the relationship is relatively weak. Multiple linear regression results indicate that conidium density does not have a significant partial effect on disease severity ($p = 0.219$; standardised $\beta = 0.179$). A significance value greater than 0.05 indicates that the statistical evidence in this study is not sufficient to state that conidium density makes a significant partial contribution to variations in disease severity after sunlight intensity is accounted for in the model. These results do not mean that conidia do not play a role in the infection process; rather, they indicate that the number of conidia measured in this study cannot significantly explain variation in disease severity.

Epidemiologically, conidia are a crucial component of disease development because they act as inoculum that can spread and initiate infection in host plants. However, infection success is not determined solely by inoculum amount. Schuh (1991), in his study of *Cercospora kikuchii* in soybeans, demonstrated that relative humidity and duration of leaf wetness play a significant role in conidia germination and disease development. Under the reported experimental conditions, conidia did not germinate at relative humidity levels below 92%, while disease severity increased with longer leaf-wetness duration. This study shows that conidia require appropriate environmental conditions for germination, penetration, and infection. Therefore, a high conidia count does not necessarily lead to increased disease severity if environmental conditions do not support successful infection.

Comparison with Ploper et al.'s (2001) study of frogeye leaf spot disease caused by *Cercospora sojina* on soybeans in Argentina also shows that disease severity can vary by season and location. In the 1997–1998 growing season, disease severity was reported to be less than 1%, while in the 1998–1999 season, severity reached approximately 10% in some locations with highly susceptible varieties. These differences indicate that Cercospora disease development is influenced by a combination of pathogen, host, and environmental factors, rather than solely by the presence of inoculum. Although the pathogen species and conditions of Ploper et al.'s study differ from these, these results support the importance of

considering environmental factors and host susceptibility when interpreting the relationship between conidial density and disease severity.

The insignificant partial effect of conidial density in this study may also reflect limitations in inoculum measurements. The spore traps represent conidia captured at a given time and location but do not directly reflect viability, germination, or the number of conidia that reach the leaf surface. Furthermore, an infection occurring on one day may produce symptoms that do not appear until several days later. Therefore, the relationship between conidium density and disease severity may not always be apparent on the same day of observation. Further testing, accounting for the time lag between conidium release and symptom appearance, as well as measurements of conidium viability and leaf wetness, is needed better to characterize inoculum's role in edamame leaf spot development.

To assess leaf spot severity, sample leaves are observed, taking into account the surface area showing symptoms of infection. This assessment aims to obtain a representative value of the disease condition in plants in the field.

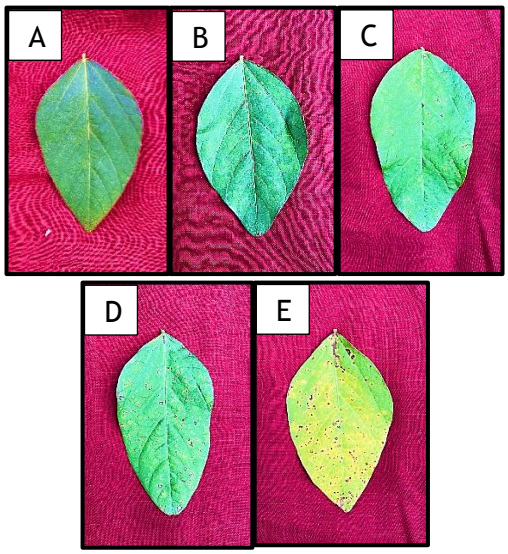

Figure 3. Scale of disease attack on edamame leaves: (A) Scale 0, (B) Scale 1, (C) Scale 2, (D) Scale 3, (E) Scale 4

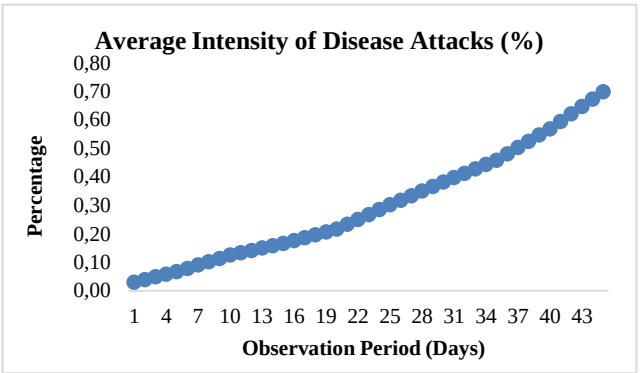

Figure 4. Graph of Disease Attack Intensity

3.3. Conidium Density

Based on the microscopic photograph, the structure, which appears to resemble a *Cercospora* sp. conidium, is elongated, needle-like or thread-like, slender, hyaline to slightly brownish, and septate. However, the exact size cannot be determined from the photograph because it lacks a micrometre scale or magnification information. In the literature, conidia *Cercospora sojina* in soybeans generally measure around 40–70 µm long and 6–8 µm wide, are cylindrical to fusiform, and can have up to 10 septa. Meanwhile, *Cercospora kikuchii* has longer conidia, measuring around 70–164 µm × 4–5 µm, with varying numbers of septa. Therefore, for this research, Cercospora sp. conidia can be described as 40–164 µm × 4–8 µm, depending on the species and observation conditions.

Based on Table 2, observations over 45 days showed daily variations in the number of Cercospora sp. conidia captured using spore traps, ranging from 16 to 42 conidia. The average number of conidia captured was 30.11 conidia per day. The lowest number of conidia was found on April 16, 2026, with 16 conidia, when the disease intensity was still low at 0.03. The highest number of conidia was found on May 10, 2026, with 42 conidia, with a disease intensity of 0.30. This indicates that conidia were present from the start of the observation and served as an inoculum source for leaf spot disease development in edamame plants.

Based on the observation period, the average number of conidia from April 16–30 was 28.07 conidia, then increased to 32.00 conidia from May 1–15, and decreased slightly to 30.27 conidia from May 16–30. The increase in conidia from early to mid-May corresponded to an increase in disease intensity from 0.18 to 0.38. This indicates that more conidia captured meant a greater chance of infection in edamame leaves.

Based on observations, the average number of conidia increased from 28.07 conidia on April 16–30 to 32.00 conidia on May 1–15, then decreased slightly to 30.27 conidia on May 16–30. The increase in conidia in early to mid-May aligned with the increase in disease intensity from 0.18 to 0.38. This indicates that inoculum availability can support the development of leaf spot disease in edamame plants. *Cercospora* sp. conidia can be spread by wind and rainwater splashes, then infect susceptible leaf tissue if environmental conditions are favorable.

These results align with those of Dalla Lana et al. (2023), who explained that *Cercospora sojina conidia* can spread through wind and water splashes and cause repeated infections throughout the growing season. Germination and infection are favored by warm conditions and high humidity. However, in this study, conidia decreased slightly at the end of the observation period, while disease intensity continued to increase to 0.70. This difference is thought to be related to the time lag between infection and symptom onset, as well as the influence of environmental factors and host plant susceptibility.

Table 2. Data on Sun Intensity, Number of Conidia, and Disease Intensity

NO	Day	Sunlight Intensity	Disease Intensity	Conidium
1	April 16, 2020	145648	0.03	16
2	April 17, 2020	43560	0.04	24
3	April 18, 2020	123930	0.05	27
4	April 19, 2020	3575	0.06	20
5	April 20, 2020	122113	0.07	29
6	April 21, 2020	70751	0.08	33
7	April 22, 2020	67411	0.09	22
8	April 23, 2020	165440	0.10	29
9	April 24, 2020	51327	0.11	28
10	April 25, 2020	132408	0.12	25
11	April 26, 2020	96665	0.13	36
12	April 27, 2020	133759	0.14	36
13	April 28, 2020	110656	0.15	28
14	April 29, 2020	46112	0.16	33
15	April 30, 2020	47148	0.17	35
16	01-May-26	28565	0.18	22
17	02-May-26	69318	0.19	34
18	03-May-26	34120	0.20	31
19	04-May-26	6523	0.21	26
20	05-May-26	139130	0.22	34
21	06-May-26	25869	0.23	36
22	07-May-26	84159	0.25	36
23	08-May-26	89370	0.27	27
24	09-May-26	85051	0.28	41
25	10-May-26	67412	0.30	42
26	11-May-26	144840	0.32	33
27	12-May-26	172225	0.33	27
28	13-May-26	92256	0.35	33
29	14-May-26	11977	0.37	29
30	15-May-26	120517	0.38	29
31	16-May-26	86734	0.40	30
32	17-May-26	155639	0.41	31
33	18-May-26	196327	0.43	28
34	19-May-26	195667	0.44	33
35	20-May-26	67063	0.46	29
36	21-May-26	82325	0.48	32
37	22-May-26	134887	0.50	26
38	23-May-26	165762	0.52	31
39	24-May-26	189467	0.55	36
40	25-May-26	83423	0.57	33
41	26-May-26	132297	0.59	27
42	27-May-26	76788	0.62	34
43	28-May-26	105264	0.65	30
44	29-May-26	136896	0.67	28
45	30-May-26	121583	0.70	26



Figure 5. Cercospora conidium at 400x magnification

The statistical analysis results showed that conidium density had a weak positive correlation with disease intensity (r=0.189) and had no partial significant effect (p=0.219). This indicates that the number of conidia captured is not sufficient to explain the increase in disease severity independently. The success of infection is determined not only by the amount of inoculum, but also by conidium viability, temperature, humidity, and duration of leaf wetness. Thus, edamame leaf spot disease results from interactions among the pathogen, the host plant, and environmental conditions.

Conidia are the asexual reproductive structures *of Cercospora* sp., which can be spread by wind and water

splashes, then infect susceptible leaf tissue when environmental conditions are favorable. In soybean leaf spot disease caused by *Cercospora sojina*, conidia landing on susceptible tissue can initiate infection, and symptoms appear several days after infection.

3.4. Disease Incidence

Table 3 shows that leaf spot disease incidence is closely related to disease severity in edamame plants. At the first observation on April 16, all sample plants showed signs of disease, but with low severity. Therefore, each observation date through the last observation showed that all sample plants were infected, and disease severity increased to a scale of 4.

Table 3. *Cercospora* sp. Leaf Spot Disease

Observation Date	Number of Attacked Plants	Number of Sample Plants	Disease Event (%)
16/04/2026	60	60	100
20/04/2026	60	60	100
25/04/2026	60	60	100
30/04/2026	60	60	100
05/05/2026	60	60	100
10/05/2026	60	60	100
15/05/2026	60	60	100
20/05/2026	60	60	100
25/05/2026	60	60	100
30/05/2026	60	60	100

Cercospora sp. leaf spot disease reached 100% from the first observation on April 16, 2026, to the last observation. This indicates that all sampled plants were infected from the start of the observation, although symptom severity remained low. Furthermore, the increase in disease severity to a scale of 4 indicates that symptoms progressed over the observation period. This indicates that disease incidence has reached its maximum level, while further disease progression is more evident in the increasing severity of attacks.

These results align with a study by Dalla Lana et al. (2023) on frogeye leaf spot disease in soybeans caused by *Cercospora sojina*. The study explained that infection can develop into secondary infections during the growing season, allowing disease symptoms to spread and worsen. Therefore, the results indicate that disease incidence and disease severity are distinct parameters: incidence reflects the percentage of infected plants, while severity indicates the extent of tissue damage in infected plants.

3.5. Pod Weight

Pod weight serves as a yield indicator to assess the impact of leaf spot disease on edamame productivity. High disease prevalence can reduce the plant's photosynthetic capacity, thus inhibiting pod formation and filling.

Higher disease severity increases the potential for pod weight loss because less leaf area is available for photosynthesis. Control and research beds served as a comparison of edamame productivity. In the control beds, pod weight reached 4.7 kg, while in the research beds, pod weight was only 2.35 kg. This indicates that Cercospora sp. leaf spot disease severity significantly reduces edamame productivity.

3.6. Analysis of the Effect of Sunlight Intensity and Number of Conidia on the Intensity of Disease Attacks

3.6.1. Normality Test

From the combined observation data, the data were processed using a normality test, and the results are shown below.

Table 4. Normality Test of the Effect of Sunlight Intensity, Number of Conidia on Disease Intensity

Data	Kolmogorov-Smirnov	Asym. Sig
	α	
Sunlight (X1)	0.05	0.200
Number of Conidia (X2)		0.200
Disease Intensity (Y)		0.200
Condition	If Asymp.Sig > 0.05, then it is normally distributed	
Conclusion	The normality test results indicate that the research variables are normally distributed.	

Based on the Kolmogorov-Smirnov normality test results, all research variables had an Asymp. Sig. value of 0.200. These variables include Sunlight (X1), Number of Conidia (X2), and Disease Intensity (Y).

The Asymp. Sig. value is greater than the significance level of $\alpha = 0.05$. Thus, the data for all three variables are normally distributed. This means that the distribution of the research data does not deviate significantly from the normal distribution. Because the data are normally distributed, the analysis can proceed to the next stage, such as the multicollinearity test, multiple linear regression test, F test, and coefficient of determination.

3.6.2. Multicollinearity Test

From the combined observation data, the data were processed using a multicollinearity test, and the results are shown below.

Table 5. Multicollinearity test of the effect of sunlight intensity and number of conidia on disease intensity

Data	Tolerance	VIF
Sunlight (X1)	0.999	1,001
Number of Conidia (X2)	0.999	1,001
Condition	If the tolerance value > 0.10 and VIF < 10, then it is free from symptoms of multicollinearity.	
Conclusion	The multicollinearity test results show no symptoms of multicollinearity.	

A multicollinearity test was conducted to determine

whether the independent variables in the regression model had a strong linear relationship. In this study, the independent variables tested were Sunlight (X1) and Conidium Count (X2). The analysis results showed that both variables had a Tolerance value of 0.999 and a VIF value of 1.001.

These values meet the multicollinearity test criteria, namely Tolerance > 0.10 and VIF < 10. This means that the Sunlight and Conidium Count variables do not have a strong linear correlation with each other. A VIF value close to 1 also indicates little variance inflation in the regression coefficient. Thus, both independent variables can be used together in a multiple linear regression model.

3.6.3. Heteroscedasticity Test

From the combined observation data, the data were processed using a heteroscedasticity test, and the results are shown below.

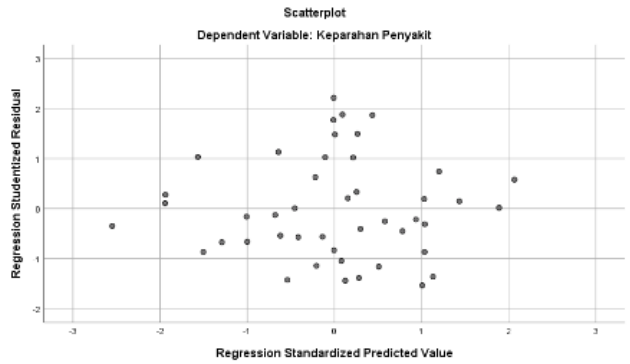

Figure 6. Heteroscedasticity test of the effect of sunlight intensity and number of conidia on disease intensity

The image shows that the points are randomly distributed above and below 0 on the Y-axis, and the residual distribution is irregular and shows no pattern. The scatterplot suggests no heteroscedasticity and meets the classical assumption test requirements.

Based on the scatterplot of the heteroscedasticity test results on the Disease Severity regression model, it can be seen that the residual points are randomly spread above and below the horizontal line at 0 on the Y-axis. These points do not form a specific pattern, such as a funnel, widening, wavy, or other regular pattern. The points also appear relatively evenly distributed across the entire range of predicted values.

This condition indicates that residual variance is constant and does not change systematically with the predicted value. In other words, the regression model does not exhibit symptoms of heteroscedasticity.

These results indicate that the independent variables, namely Sunlight (X1) and Number of Conidia (X2), have a stable relationship with the dependent variable Disease Severity. Hence, the regression model used fulfils one of the classical assumptions in multiple linear regression analysis.

The test results show that the residual distribution does not form a specific pattern and is randomly distributed both above and below zero. This condition indicates that the regression model does not exhibit heteroscedasticity and has relatively constant residual variance. These results align with the regression testing principles proposed by Ghozali (2018), which state that a model is free of heteroscedasticity if the points on the scatterplot are randomly distributed without forming a clear pattern. Thus, the regression model testing the relationship between sunlight intensity and the number of conidia on disease severity meets the assumption of homoscedasticity. However, this result indicates only that one classical assumption is met and does not guarantee that all regression assumptions are met.

3.6.4. Multiple Regression Test

Using the combined observation data, the data were processed using multiple regression tests, and the results are shown below.

Table 5. Multiple Regression Test of the Effect of Sunlight Intensity and Number of Conidia on Disease Intensity

Variable Y	Parameter	Unstandardized Coefficients		Standardized Coefficients
		B	Std. error	Beta
Disease Intensity	(Constant)	-0.021	0.171	
	Sunlight	1.207E-6	0,000	0.320
	Number of Conidia	0.007	0.005	0.179

The equation values used are those in column B (coefficients). From the multiple linear regression equation formula:

$$\mathbf{Y = a + b_1 X_1 + b_2 X_2}$$

The multiple linear regression results indicate that sunlight and conidium count have a positive relationship with disease intensity. The regression coefficient for sunlight is 1.207E-6, or 0.000001207. This means that each one-unit increase in sunlight will increase disease intensity by 0.000001207, assuming the number of conidia remains constant.

Based on the Standardized Beta Coefficients, sunlight has a beta value of 0.320, while the number of conidia is 0.179. This indicates that sunlight contributes more to changes in disease intensity than the number of conidia in this model. However, conclusions about each variable's significance still require a Sig. value or p-value from the t-test results.

Based on the results of the multiple linear regression test, the following equation was obtained:

$$\mathbf{Y = -0.021 + 0.000001207X1 + 0.007X2}$$

In general, sunlight and conidium count are positively related to disease intensity. Based on the beta values,

sunlight has a greater influence than conidium count. This model suggests that increasing sunlight and conidium count tend to be followed by increased disease intensity, although statistical significance data are needed to confirm the strength of the effect.

The standardised beta coefficient for sunlight intensity is 0.320, higher than that for conidial count (0.179). This indicates that sunlight intensity has a relatively stronger relationship with disease severity than the number of conidia in the regression model. This result aligns with Daub and Chung (2007), who explain that light activates the cercosporin toxin, which can produce reactive oxygen species and damage plant cells. Meanwhile, a lower beta value indicates that inoculum presence does not always lead to a direct increase in disease because infection success is also influenced by humidity, temperature, and leaf wetness. This is supported by Schuh (1991), who explained the importance of environmental conditions, especially temperature and duration of leaf wetness, on conidia germination and *Cercospora kikuchii infection* in soybeans. Thus, the results indicate that light intensity has a stronger relationship in the model, but disease development is still influenced by interactions among various environmental factors and pathogens.

3.6.5. PP Normal Test Plot of Regression Standardized Residual

From the combined observation data, the data were processed using the Normal PP Plot of Regression Standardised Residual test, and the results are shown below.

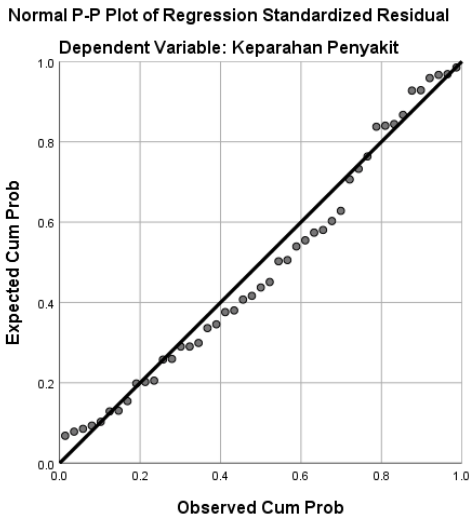

Figure 7. Normal PP Plot of Regression Standardized Residual Test of the Effect of Sunlight Intensity and Number of Conidia on Disease Intensity

Based on the Normal PP Plot of Regression Standardized Residual graph:

- In this graph, the X-axis represents the Observed Cumulative Probability, while the Y-axis represents the Expected Cumulative Probability.
- The points on the graph represent the regression model's standardised residuals. If the points follow the diagonal line (normal line), the residuals are normally distributed.
- Visually, the points are close to the diagonal line, indicating that the residual assumption is met.
- Some points are slightly off, but these deviations do not seem significant.

Based on Figure 7, the residual points on the Normal PP Plot generally follow and cluster around the diagonal line, although there are some small deviations. This pattern indicates that the regression residuals tend to be normally distributed, so the assumption of normality is visually acceptable. This result is in accordance with the explanation of Ghozali (2018), who stated that the residuals are said to be normally distributed if the points on the Normal PP Plot graph are spread around the diagonal line and follow the direction of the line. Thus, based on visual inspection, the regression model analysing the relationship between sunlight intensity and the number of conidia on disease severity meets the assumption of normality. However, to strengthen the conclusion, the test can be supplemented with the Shapiro-Wilk statistical test, especially since this study had 45 observations.

3.6.6. Simultaneous Test (F Test)

From the combined observation data, the data were processed using a simultaneous test (F test), and the results are shown below.

Table 6. Simultaneous Test (F Test) Effect of Sunlight Intensity, Number of Conidia on Disease Intensity

Parameter	Analysis
	X → Y
Sig	0.044
A	0.05
F count	3,364
F table	3.22
Condition	Sig. < α, then Ho is rejected, Ha is accepted F count > F table then Ho is rejected Ha is accepted
Conclusion	The F test results show that multiple linear regression is suitable; sunlight and the number of conidia simultaneously have a significant effect on disease intensity. H0 is rejected; Ha is accepted. Sunlight and the number of conidia simultaneously have a significant effect on disease intensity.

3.7. The Relationship Between Sunlight and Conidia and Disease Development

R = 0.372 This indicates a fairly weak relationship between the predictor variables (sunlight and conidium count) and the dependent variable (disease intensity). The R value ranges from -1 to 1, and the closer it is to zero, the

weaker the relationship between the variables.

Model Summary [b]

Model	R	R Square	Adjusted R Square	Standard Error of the Estimate
1	.372 [a]	.138	.097	.18396

a. Predictors: (Constant), Number of Conidia, Intensity
b. Dependent Variable: Disease Severity

R Square = 0.138. This means that only 13.8% of the variability in disease intensity variables can be explained by the model (sunlight and conidium count). The remaining 86.2% is explained by factors outside the model, such as environmental conditions, humidity, temperature, plant variety resistance, or other factors not analyzed in this study.

Adjusted R Square = 0.097 or 9.7% indicates that after adjusting for the number of independent variables in the model, the ability of the disease intensity and conidium count variables to explain variation in disease severity decreased slightly. This indicates that the model has relatively low predictive ability.

The simultaneous test yielded an F value of 3.364, greater than the F table value of 3.22, with a significance value of 0.044, which is smaller than 0.05. This indicates that sunlight intensity and conidia number are significantly related to the severity of *Cercospora* sp. leaf spot disease in edamame plants. However, the R-squared value of 0.138 indicates that these two variables explain only 13.8% of the variation in disease severity, while the remaining 86.2% is due to factors outside the model. After adjustment, the Adjusted R-squared value of 0.097 indicates the model explains 9.7% of the variation, so its explanatory power is relatively low.

These results align with Schuh's (1991) study, which explains that the development of *Cercospora disease* in soybeans is influenced not only by the presence of conidia, but also by temperature and the duration of leaf wetness. Daub and Chung (2007) also explain that light affects the activity of the cercosporin toxin, which can support plant tissue damage. Both studies reinforce that Cercospora disease development involves interactions among various pathogenic and environmental factors. Therefore, the low coefficient of determination indicates that light intensity and conidium count do not fully capture the complexity of leaf spot disease development in edamame. Therefore, factors such as humidity, temperature, leaf wetness, and plant resistance need to be considered in further research.

4. Conclusion

This study shows that sunlight intensity and conidium count are simultaneously significantly associated with the development of *Cercospora* sp. leaf spot disease in edamame planted in immature oil palm areas. Observations over 45 days recorded a conidium count ranging from 16–42 conidia per day, with an average of 30.11 conidia. The research model explains 13.8% of the variation in disease intensity, so environmental factors and other plant conditions also need to be considered.

This study's strength lies in simultaneously observing light intensity and conidium density in an edamame intercropping system in an immature oil palm area. The results also showed a difference in pod weight between the control bed (4.7 kg) and the experimental bed (2.35 kg), indicating a potential yield reduction in diseased plants.

Based on these results, farmers are advised to monitor the disease from the initial symptoms, reduce inoculum sources, and pay attention to microclimate conditions, especially humidity and leaf wetness, as part of efforts to manage leaf spot disease in edamame.

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