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Spatial Temporal Pattern of Chili Virus Disease in Bogor and Its Relation with Yield Loss

Pola Spasial Temporal Penyakit Virus Tanaman Cabai di Bogor dan Hubungannya dengan Kehilangan Hasil

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ABSTRACT

Diseases caused by viruses are a major constraint in the production and productivity of chili peppers (*Capsicum annuum*) in Indonesia. Several viruses infect chili peppers, making viral infections complex. Viral infections in plants are systemic and potentially cause total yield loss. The spatial and temporal patterns of viral disease development in the field need to be studied to determine disease control decisions and estimate crop losses. The study was conducted in two chili pepper production fields owned by farmers in Bogor, treated with and without mulch. Observations and analysis were based on the incidence and severity of disease, as well as crop yields. The temporal development of viral diseases in chili peppers showed a sigmoid curve for both incidence and severity of disease in the two types of fields. The level of disease in fields without mulch was relatively higher than in mulched fields. The spatial development of viral diseases based on heatmap analysis showed that the virus spread evenly in both unmulched and mulched fields. The severity of viral diseases significantly affects the quality and quantity of harvested fruit, as indicated by a negative correlation between the level of disease and the harvest yield and the harvest price obtained per plant. The higher the disease severity, the greater the yield loss. In seven harvests, the unmulched plot yielded 5.3 kg of chilies, while the mulched plot yielded 6.7 kg of chilies (grades A–C). Thus, the use of mulch resulted in lower disease intensity and better yields compared to the unmulched plot.

Keywords: correlation, disease curve, disease intensity, heatmap, mulch

ABSTRAK

Masalah penyakit yang disebabkan oleh virus merupakan salah satu kendala utama dalam produksi dan produktivitas tanaman cabai (*Capsicum annuum*) di Indonesia. Terdapat beberapa jenis virus yang menginfeksi tanaman cabai sehingga infeksi virus bersifat kompleks. Infeksi virus dalam tanaman bersifat sistemik, dan berpotensi menyebabkan kehilangan hasil total. Pola perkembangan penyakit virus di lapangan secara spasial dan temporal perlu dipelajari untuk menentukan pengambilan keputusan tindakan pengendalian penyakit dan pendugaan kehilangan hasil panen. Penelitian dilakukan di dua lahan produksi cabai milik petani di Bogor dengan perlakuan mulsa dan tanpa mulsa. Pengamatan dan analisis didasarkan pada insidensi dan keparahan penyakit serta hasil panen. Perkembangan temporal penyakit virus pada tanaman cabai menunjukkan kurva sigmoid baik untuk insidensi maupun keparahan penyakit di dua jenis lahan. Tingkat penyakit pada lahan tanpa mulsa relatif lebih tinggi dibandingkan dengan lahan bermulsa. Perkembangan penyakit virus secara spasial berdasarkan analisis *heatmap* menunjukkan bahwa virus menyebar secara merata di lahan baik lahan tanpa mulsa maupun dengan mulsa. Tingkat keparahan penyakit virus sangat memengaruhi kualitas dan kuantitas buah yang dipanen yang ditunjukkan dengan korelasi negatif antara tingkat penyakit dengan hasil panen dan harga jual panen yang diperoleh per tanaman. Semakin tinggi keparahan penyakit maka semakin besar kehilangan hasil. Dalam tujuh kali panen, lahan tanpa mulsa mulsa dapat menghasilkan 5.3 kg buah cabai, sedangkan pada lahan mulsa menghasilkan 6.7 kg buah cabai (kelas A–C). Dengan demikian, penggunaan mulsa menunjukkan intensitas penyakit yang lebih rendah dan hasil panen yang lebih baik dibandingkan lahan tanpa mulsa.

Kata kunci: *heatmap*, intensitas penyakit, korelasi, kurva penyakit, mulsa

INTRODUCTION

Chili (*Capsicum annuum*) is an important horticultural crop in Indonesia, widely used both for daily consumption and as a raw material in the food industry. The demand for chili is high and continues to grow alongside population growth, creating a need for a continuous, year-round supply. As a result, chili cultivation is an attractive venture for farmers. However, production and productivity are often threatened by plant pests and diseases, particularly viral infections, which pose significant challenges to chili farming.

Viruses, as obligate pathogens, are difficult to control because there are no chemical pesticides effective against them. Therefore, appropriate cultural practices are essential to promote plant health and suppress disease development. One such practice is the use of mulch in cultivation, which can create more favorable soil conditions by maintaining stable soil temperatures and suppressing weeds that may serve as disease reservoirs (Wickramarathre *et al.* 2021). Mulch can also reduce the presence of insects, as some pests are less attracted to mulched environments, and its reflective properties can interfere with the activity of insect vectors of viruses (Nasruddin *et al*. 2020).

The occurrence and spread of viral diseases in the field-both from one plant to another and across locations (spatial patterns), as well as over time (temporal patterns)-are influenced by the mode of virus transmission, such as seed-borne, insect-mediated, or mechanical, and by environmental factors affecting both the disease and the host plant. Understanding the spatial and temporal patterns of plant diseases is crucial for disease forecasting, informed management decisions, and estimating potential yield losses (Heck *et al*. 2021; Huang *et al.* 2022). The objectives of this study are to: (1) observe the spatial and temporal patterns of viral disease development in chili plants in Bogor, West Java using census plots, (2) compare different minimum sample sizes for monitoring disease development, and (3) describe the relationship between disease levels and chili fruit yield losses.

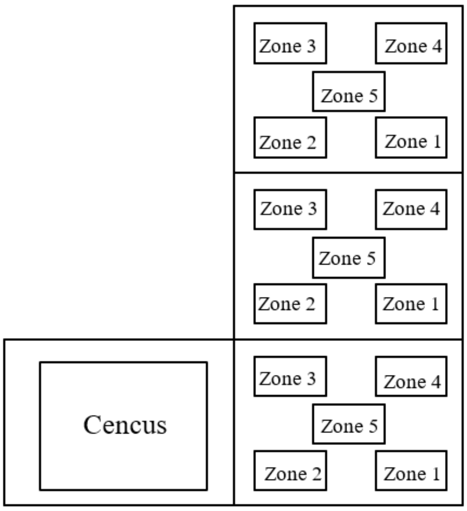
MATERIALS AND METHODS

Observation of Spatial and Temporal Disease Patterns

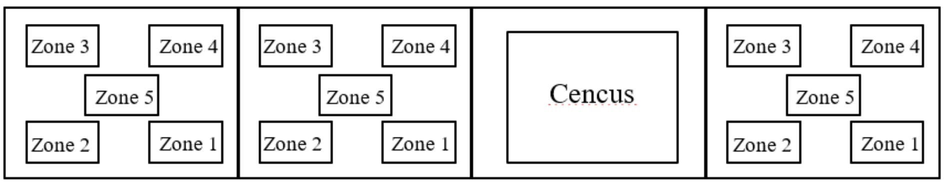
The observation of viral disease patterns was conducted in a red chili (‘Darmis F1’) cultivation area owned by a farmer in Bantarsari Village, Rancabungur District, Bogor Regency, West Java Province. The study utilized two plots: an unmulched plot of 7700 m² and a mulched plot of 4500 m². From each plot, a census plot measuring 20 × 20 plants (400 plants) was established. Additionally, observations were conducted using a zonation approach in both the unmulched and mulched plots with varying sample sizes of 200, 100, 50, and 25 plants, divided into five observation zones. Each observation was replicated three times per plot (Figure 1).

Disease Intensity Observation

Weekly observations of viral disease intensity, including both incidence and severity, were conducted



a



b

Figure 1 Design of research plots for chili plant cultivation. a, unmulched and b, mulched.

11 times, beginning when the plants were 4 weeks old. Disease incidence (DI) was calculated using the following formula

$$DI = \frac{n}{N} \times 100\%, \text{ with}$$

DI, disease incidence (%); n, number of symptomatic plants; and N, number of plants observed in the observation.

Disease severity (DS) was calculated as follows

$$DS = \frac{\sum(n_i \times v_i)}{N \times V} \times 100\%, \text{ with}$$

DS, disease severity (%); n_i, number of plants infected in the i-th category; v_i, symptom score of the i-th category; N, number of plants observed; and V, highest infection value. The scoring system and visualization of the disease levels used are presented in Table 1.

The value of the area under disease progress curve (AUDPC) based on the incidence and severity of the disease is calculated as follows (Cooke 2006)

$$AUDPC = \sum_{i=1}^{n=1} \left[\frac{(X_{i+1} + X_i)}{2} \right] \times (t_{i+1} - t_i), \text{ with}$$

n, number of observations; X_i, disease intensity at baseline (previous) observation; X_{i+1}, disease intensity at next observation; t_i, previous observation time; and t_{i+1}, next observation time.

Yield Recording

When the plants reached harvest age, chili plants showed different levels of viral disease (scores 0 to 6) in each plot both unmulched and mulched were identified. For each disease level, 10 sample plants were selected to observe and evaluate the harvest yield. Chili fruit harvesting was carried out 7 times from each plant. The first fruit harvest was carried out in the fifth week. The harvested fruits were grouped based on the length and weight of the fruit into grade A (length > 12 cm, weight > 12 g), grade B (length 7–12 cm, weight 5–12 g), and grade C (length < 7 cm, weight < 5 g). The relationship between viral disease levels in plants (independent variable) and chili yield (dependent variable) was assessed using correlation analysis and visualized with scatter plots in Microsoft Excel. Differences in data were further analyzed using Tukey's test (α 0.05) in SPSS.

Table 1 Scoring system for determining the severity of viral diseases in the field

Score	Level of symptom coverage (v)	Visualization in grayscale
0	v = 0%	
1	v < 5%	
2	5% ≤ v ≤ 15%	
3	15% < v ≤ 30%	
4	30% < v ≤ 50%	
5	50% < v ≤ 80%	
6	80% < v ≤ 100%	

RESULTS

Symptomatology of Viral Diseases

The dominant viral disease symptoms observed in the field were those associated with yellowing virus infection. These symptoms are characterized by leaf narrowing, yellowing, curling, and overall plant stunting (Figure 2). This virus infection also causes leaves to become smaller and stunted due to the disruption of photosynthesis. As a result, the green color on the leaves appears uneven or imperfect.

Spatial and Temporal Development of Viral Diseases

The increasing levels of viral infection in plants are represented in grayscale, from white to dark gray (Table 1; Figure 3). Between 1 and 3 weeks of age, viral infection was observed at low and random incidence. It likely originated from seed-borne viruses, but systematic observations were not conducted during this period. From the 4th week onward, over an 8-week period, the spatial distribution of viral disease in the field initially showed a random pattern with low intensity. Disease intensity then progressively increased over time, reaching near-saturation levels by the final observation weeks (weeks 10–11).

The temporal development of viral disease levels in chili plants over 8 weeks in the census plots of unmulched and mulched treatments is shown in Figure 4a. Disease incidence was similarly low in the 4th week, then increased sharply in the 5th week and plateaued from week 6 through week 11. Incidence was higher in the mulched plot than in the unmulched plot, as confirmed by the AUDPC values, i.e. 638 for

Figure 2 Yellowing of chili leaf is a predominant viral infection found in the observation field.

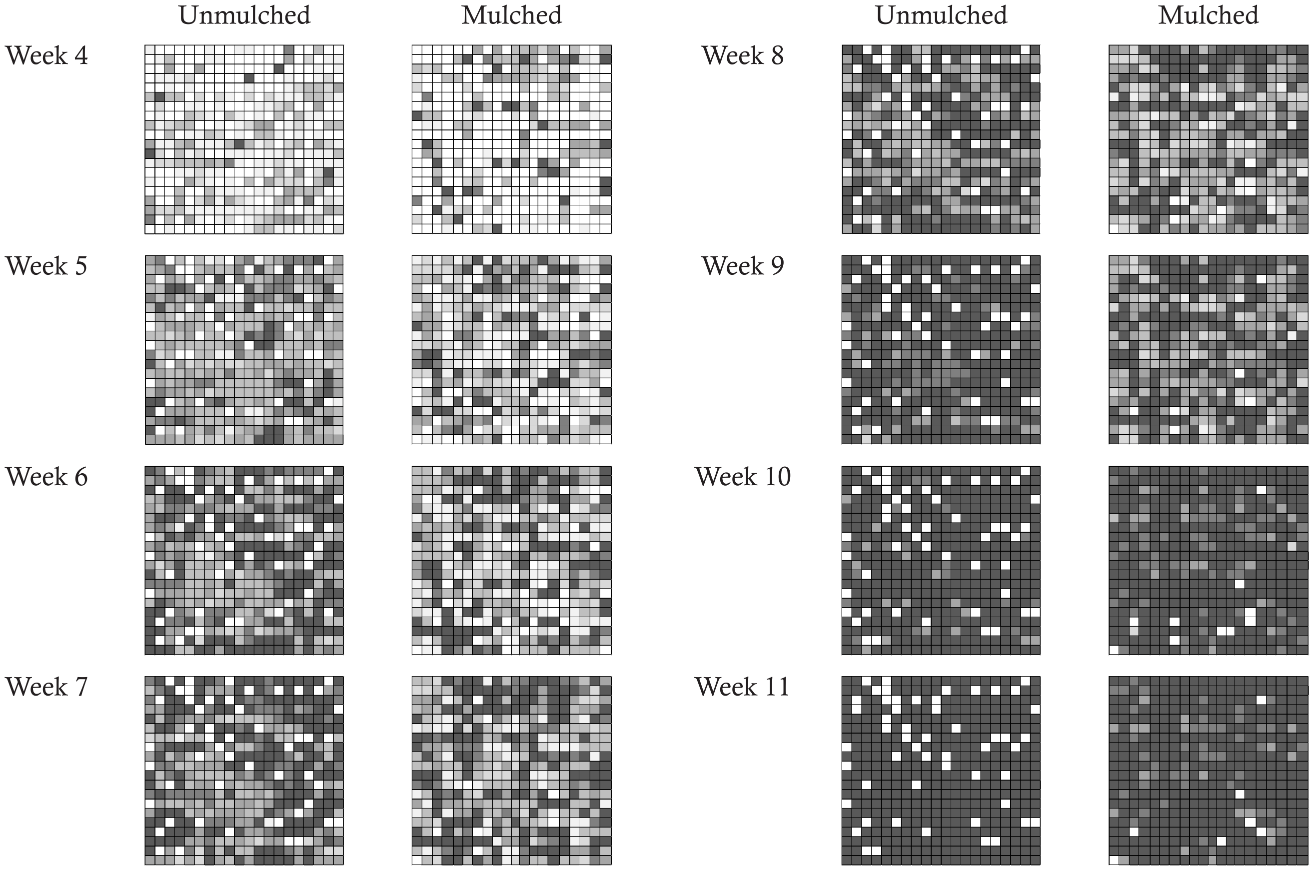


Figure 3 Spatial pattern of yellow disease in chili plants cultivated using mulch and without mulch during 8 weeks of observation (from week 4 to week 11).

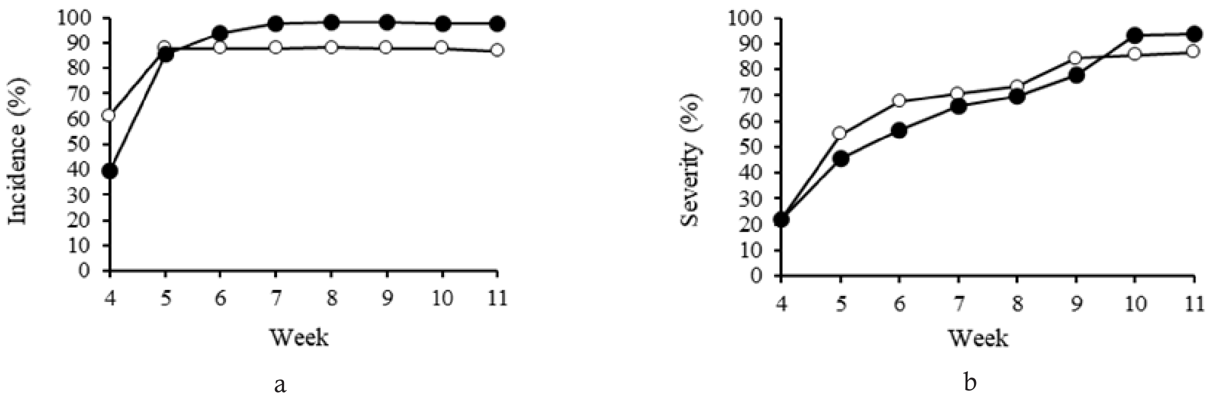


Figure 4 Temporal pattern of yellow disease in chili plants cultivated using mulch and without mulch during 8 weeks of observation (from week 4 to week 11) based on a, disease incidence (—○—, unmulched. AUDPC = 601; —●—, mulched. AUDPC = 638) and b, severity (—○—, unmulched. AUDPC = 491; —●—, mulched, AUDPC = 467).

the mulched plot compared to 601 for the unmulched plot.

Figure 4b showed the temporal development of viral disease severity in chili plants over 8 weeks in both unmulched and mulched plots. Unlike disease incidence, severity increased steadily each week, reaching its peak in weeks 10 and 11. Disease severity was higher in the unmulched plot than in the mulched plot, as reflected by the AUDPC values (491 for unmulched vs. 467 for mulched).

Development of Viral Diseases Based on Observations with Different Sample Sizes

The development of viral diseases in chili plants over 8 weeks in the unmulched plot, based on observations with different sample sizes, showed that sample sizes of 200, 100, and 50 produced overlapping graphs with no noticeable differences. In contrast, the graph for a sample size of 25 was lower and clearly separated from the others (Figures 5a and 5b). This indicates that a sample size of 25 is too small and inadequate for reliably estimating disease intensity, both in terms of incidence and severity. Analysis of variance for AUDPC values confirmed this, showing that the AUDPC for a sample size of 25 was significantly lower than for the larger sample sizes (Table 2). In the unmulched plot, the planting environment was less homogeneous due to the continual emergence of weeds between scheduled weeding activities, despite regular weed control.

In contrast, mulching created a more homogeneous planting environment. In the mulched plot, the development of disease-measured by both incidence and severity-produced similar graphs across all sample sizes. Even a sample size of 25 was sufficient to estimate disease levels (Figures 5c and 5d). This was further supported by analysis of variance of AUDPC values, which showed no significant differences among sample sizes of 200, 100, 50, or 25 in the mulched plot (Table 2).

Relationship between Severity of Virus Disease and Yield Loss

The weight of high (grade A) and medium (grade B) quality fruits (Figure 6) harvested per plant decreased with increasing disease severity in both unmulched and mulched plots, whereas the weight of low-quality fruits (Grade C) (Figure 6) showed relatively minor fluctuations (Figures 7a and 7b). Disease severity had a significant impact on the decline in fruit quality.

The market selling price of chili fruit per kg is determined by its grade, with lower grades commanding lower prices. The weight of fruit produced per plant at different levels of infection, converted to monetary value, is presented in Figure 7c. Chili plants grown in mulched plots achieved higher harvest values than those in unmulched plots, both for individual infection levels and on average per plant. On average, plants in mulched plots produced a harvest value of IDR 40 242 per plant, compared to IDR 33 107 per plant in unmulched

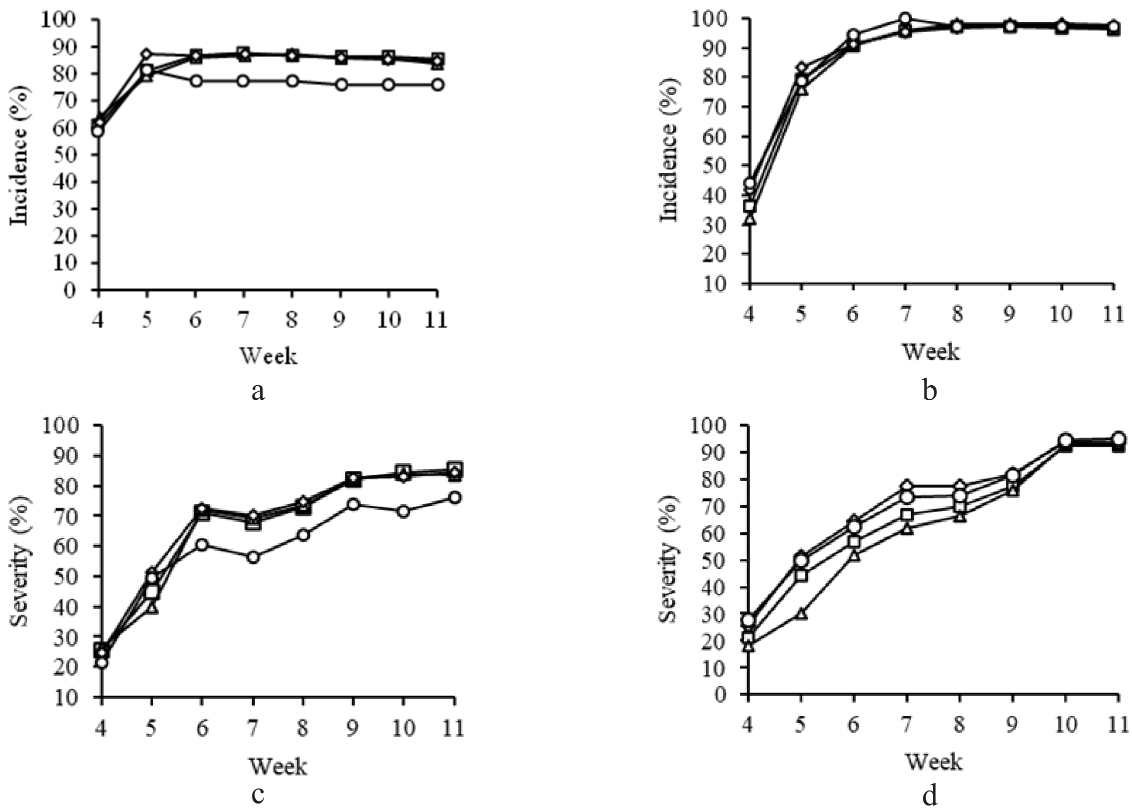


Figure 5 Temporal pattern of viral disease based on a and c, disease incidence; b and d, severity on chili plants cultivated in unmulched and mulched plots, respectively using different sample sizes —○—, 25; —◇—, 50; —△—, 100; and —□—, 200).

Table 2 AUDPC values for the development of viral diseases based on observations with different sample sizes for incidence and severity for chili plants planted in unmulched and mulched fields

Sample size	Incidence AUDPC		Severity AUDPC	
	Unmulched	Mulched	Unmulched	Mulched
200	588.00 b*	624.25 a	479.43 ab	465.73 a
100	584.33 b	622.33 a	475.66 ab	434.72 a
50	592.66 b	631.33 a	488.88 b	505.38 a
25	532.66 a	636.00 a	424.22 a	497.01 a

*Values in the same column followed by the same letter are not significantly different based on the Tukey test at the 5% level.

plots, based on March 2025 Bogor market prices (Grade A = IDR 47 500 kg^{-1}, Grade B = IDR 40 000 kg^{-1}, Grade C = IDR 30 000 kg^{-1}).

Correlation analysis between harvest components and chili selling price (Figure 8) revealed a negative relationship, indicating that higher yield losses corresponded to lower market prices. A simple correlation analysis between disease severity (independent variable) and harvest value per plant in unmulched and mulched plots is also presented in Figure 8.

DISCUSSION

Yellow type symptoms on chili plants infected by virus initially show yellowing, typically starting at the shoots or young leaves (Selangga and Listihani 2021; Tricahyati *et al.* 2021). As the infection progresses,

Figure 6 Grade of chili fruit. a, grade A; b, grade B; and c, grade C.

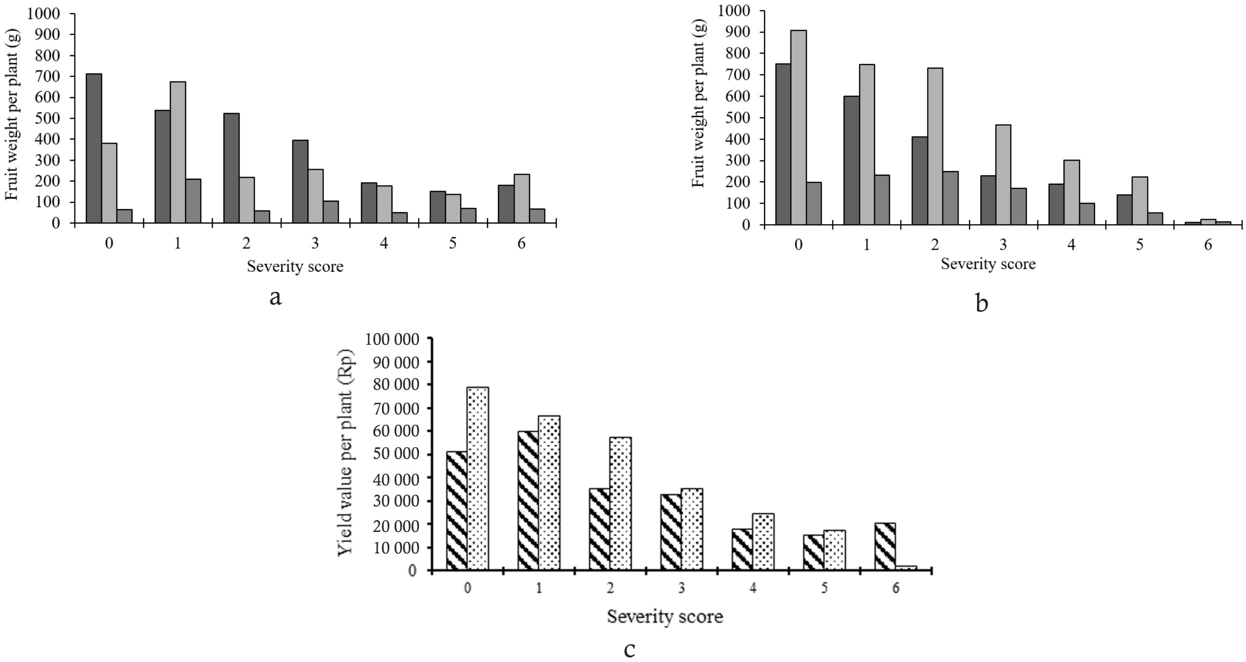


Figure 7 Weight of graded fruit per plant with different severity levels at 7 harvesting times. a, unmulched; b, mulched; and c, total yield per plant. ■, grade A; ■, grade B; ■, grade C; ◪, unmulched, Rp 33 107 per plant; ⊡, mulched, Rp 40 242 per plant.

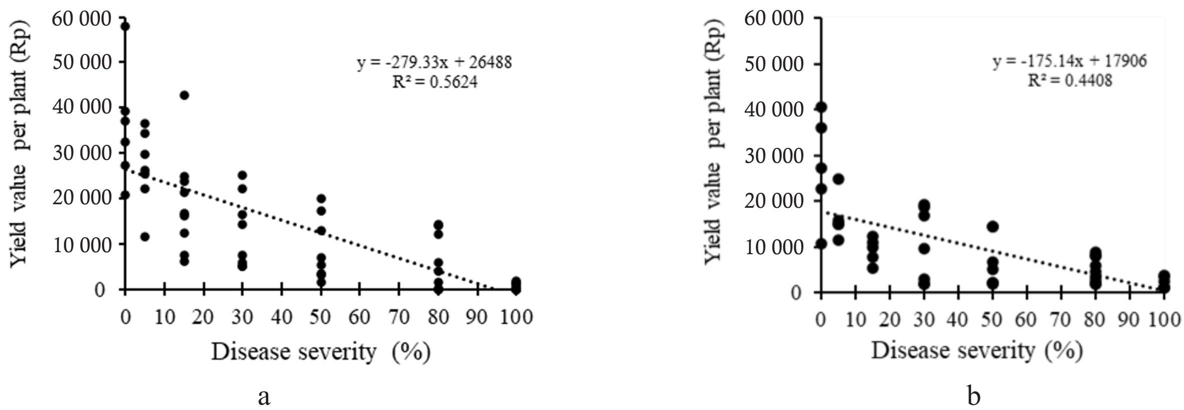


Figure 8 Correlation between disease severity and chili fruit yield per plant. a, unmulched plot; and b, mulched plot.

leaf veins thicken, and only older, lower leaves remain relatively unaffected. Virus-infected plants produce fewer and smaller fruits due to disruptions in physiological functions, particularly the inhibition of photosynthesis (Taufik *et al.* 2024; Tricahyati *et al.* 2021).

Symptoms such as stunting, mosaic, or yellowing in chili plants in Indonesia can be caused by several phytopathogenic viruses, including *Pepper yellow leaf curl Indonesia virus* (PepYLCIV), *Pepper yellow leaf curl Aceh virus* (PepYLCAV), *Cucumber mosaic virus* (CMV), *Chilli veinal mottle virus* (ChiVMV), *Pepper vein yellows virus* (PeVYV), and *Pepper mild mottle virus* (PMMoV) (Sutrawati *et al.* 2012; Kesumawati et al. 2019; Trisno *et al.* 2021; Damayanti and Kurniawati 2022; Saputra *et al.* 2025). These viruses often infect chili plants simultaneously, resulting in a range of symptoms.

The initially random pattern and subsequent more uniform distribution of the disease can be attributed to two modes of virus transmission, i.e. seed-borne and vector-mediated. Lestari *et al.* (2021) reported that the primary vector for the pepper yellow leaf curl virus is the whitefly. The development of yellow leaf curl disease is closely associated with the population density of whiteflies in the planting area (Sudiono and Purnomo *et al.* 2009; Sujatha *et al.* 2025).

The temporal development of viral disease intensity in chili plants generally follows a sigmoid (S-shaped) curve for both incidence and severity in unmulched and mulched plots. The sigmoid curve consists of three phases, namely (1) an initial slow-increase phase, where disease incidence and severity rise gradually; (2) an exponential phase, marked by a rapid increase in disease intensity and severity; and (3) a stationary or saturation phase, in which disease levels gradually approach their maximum. Madden *et al.* (2007) explained that the sigmoid disease progression curve is part of the logistic model and indicates infection by a polycyclic pathogen, which undergoes multiple cycles during a single growing season. In this study, systematic observations began at phase 2, starting from the 4th week, when disease intensity increased sharply in an exponential manner, followed by phase 3, the saturation phase.

Observations with smaller sample sizes up to 50 plants still provided an accurate representation of disease intensity in the unmulched plot, while a sample size of 25 was sufficient for the mulched plot. These results suggest that even small sample sizes can reliably represent disease intensity at the population level. Using smaller, yet adequate, sample sizes can save both time and resources without compromising the accuracy of the observations.

Random disease patterns can occur when disease intensity is high and are influenced by the use of mulch. Silver mulch, in particular, can reduce the spread of viral diseases by altering vector behavior. Nasruddin *et al.* (2020) reported that mulched plots had fewer whitefly eggs, nymphs, and adults because ultraviolet rays reflected by the mulch prevented adults from landing and laying eggs. In contrast, vectors move freely in unmulched plots, resulting in more random disease distribution and higher severity. Additionally, silver mulch improves plant growth and yield by creating a favorable environment, leading to increased fruit number and weight per plant, per plot, and per hectare (Idaryani *et al.* 2021). Similarly, Arogundade *et al.* (2019) found that white plastic mulch reduced viral disease incidence by 18.9% and increased fruit weight compared to unmulched plots. These findings highlight mulching as an effective strategy for managing viral diseases while enhancing crop productivity.

Over seven harvests, the unmulched plot produced 5.3 kg of chili fruit, whereas the mulched plot produced 6.7 kg (Grades A–C). Despite exhibiting a higher final disease incidence, the mulched plot achieved greater productivity. This is likely associated with the slower rate of disease progression under mulched conditions, which allowed plants to maintain functional growth and fruit set for a longer period. Consequently, mulching helps sustain crop performance under disease pressure by delaying pathogen spread and preserving early-to mid-season yields. The negative correlation between viral disease severity and the market value of the harvest indicates that greater disease severity leads to higher yield losses. At mild to moderate disease levels, chili plants still produce marketable fruit, but higher severity reduces yield value and increases potential economic losses for farmers.

In conclusion, this study demonstrates that mulching can slow the progression of viral diseases in chili plants, thereby maintaining higher cumulative yields compared to unmulched plots. However, mulching alone is insufficient for comprehensive disease management and should be integrated with other control strategies. Regarding sampling efficiency, a sample size of 50 plants is adequate for accurately estimating disease intensity in unmulched plots, whereas 25 plants are sufficient in mulched plots to obtain reliable population-level estimates.

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