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Research Article

The Influence of Climate Factors on the Incidence Area of *Fusarium* spp. in Shallots on Java Island during the Triple-Dip La Niña (2020-2022)

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ABSTRACT

Shallots are a strategic horticultural commodity that contributes to inflation in Indonesia. The productivity of shallots is vulnerable to pests and diseases. Based on the incidence area during the La Niña period (2020 – 2022), *Fusarium* spp. is among the top five main pests and diseases reported to attack shallot crops in Java. Climate factors are suspected to have an effect on diseases incidence in the field. So far, there has been no research on the influence of climate factors on *Fusarium* twisted disease in Java. This study aims to analyze the influence of climate factors on the monthly incidence area of *Fusarium* spp. in Java during the La Niña period (2020 – 2022). The analysis used correlation and simple linear regression tests. Based on the correlation test, humidity and precipitation had a strong positive correlation with the incidence area of *Fusarium* spp. in shallots. Conversely, the sunshine duration had a strong negative correlation, while the temperature showed no correlation. From the simple linear regression test, humidity, precipitation and sunshine duration was found to strongly influence *Fusarium* spp. incidence, accounting for 47%, 48% and 40%, respectively ($p<0.05$). Temperature had no effect because it had the lowest fluctuation among other climate factors, ranging between 26 - 27.5°C, which was ideal for the development of *Fusarium* spp. To manage *Fusarium* spp. on shallots, it is recommended to select resistant varieties, optimize plant spacing, use fertilizers judiciously, and utilize healthy seeds. Additionally, the application of biological agents can suppress the growth of pathogenic fungi and increase plant resistance.

Keywords: disease-climate interaction, ENSO, shallot twisted disease, tropical climate

INTRODUCTION

Shallot (*Allium ascalonicum* L.) stands as a significant commodity in Indonesia, playing a crucial role in the nation's food security and economy (JICA, 2018). By 2022, Indonesia had produced 1,982,360 tons of shallots, amounting to an annual economic value of IDR 14.47 trillion. The Java provinces, particularly Central Java and East Java, accounted for 63.15% of this production (BPS, 2022; Harti *et al.*, 2022). Nevertheless, various factors, including climate and fungal diseases, exert considerable influence on its production. Among these pathogens, *Fusarium* spp. pose a significant threat, leading to substantial yield losses.

Moreover, climate factors are suggested to exacerbate the occurrence and severity of diseases caused by *Fusarium* spp. (Basuki, 2014; Okungbowa & Shittu, 2014).

Climate plays a pivotal role in the dissemination of plant diseases by affecting temperature, humidity, rainfall patterns, and other environmental factors pivotal for the growth and proliferation of fungal pathogens. Fluctuations in temperature and humidity foster optimal conditions for fungal spore production, thriving in warm and moist environments, consequently escalating disease occurrence and severity (Ajmal *et al.*, 2022). Alterations in rainfall patterns further impact soil moisture levels, thereby affecting the survival and proliferation of fungal pathogens in the soil (Alkhalifah *et al.*, 2023; Timmusk *et al.*, 2020).

Fusarium thrives in warm soil conditions, with studies indicating optimal temperatures for fungal growth and infection ranging between 24°C to 32°C (Sharma *et al.*, 2024; Marianah *et al.*, 2024; Le *et al.*, 2021). This underscores the significance of warm climates with moist soils, which provide an ideal environment for *Fusarium* development and disease progression in allium species, including shallots.

The Indonesian Agency for Meteorological, Climatological, and Geophysics (BMKG) has warned about the Triple-Dip La Niña phenomenon anticipated between 2020 and 2022, highlighting the necessity for vigilance against extreme weather events and hydro-meteorological disasters triggered by excessive rainfall (Seta *et al.*, 2022). Excessive soil water content resulting from La Niña can lead to crop and bulb rotting, disrupting production and driving up shallot prices (Fitriana *et al.*, 2022). Price fluctuations of shallots have a significant impact on inflation rates (BPS, 2020), underscoring the importance of understanding factors affecting shallot production, including climate and fungal diseases, to ensure production stability and price control.

A Triple-Dip La Niña event characterized by three consecutive years of La Niña conditions can bring about stronger winds, increased humidity, and substantially higher rainfall to various parts of Indonesia (Alhadid & Nugroho, 2024). Indonesia recently endured such a prolonged La Niña episode from mid-2020 to late 2022, resulting in significantly elevated rainfall (up to 54% to 90% increases) and more frequent rainy days (up to 11% to 70% increases) compared to average conditions (Harahap *et al.*, 2023).

Positive rainfall anomalies of up to 200 mm/month were observed across much of Indonesia during these La Niña events (Hidayat *et al.*, 2018). Coinciding with these climatic shifts, the study on avocado plants by Ramírez-Gil & Morales-Osorio (2018) revealed that during El Niño-Southern Oscillation (ENSO) events, notably La Niña, disrupt the balance of soil microbes. Beneficial microbe populations decline, while harmful ones associated with avocado wilt complex thrive. This contributes to a heightened incidence of sick and dying trees.

Furthermore, research in Brazil also link ENSO to a higher risk of soybean rust during off-seasons (Minchio *et al.* 2016). Interestingly, studies suggest that the global-mean yields of major crops like maize, wheat, rice, and soybeans tend to be below normal (−4.5 to 0.0%) during La Niña years (Izumi *et al.* 2014). This highlights the potential for widespread agricultural disruptions associated with ENSO events.

In Indonesia, numerous studies have explored the distribution of diseases in shallots (Harti *et al.*, 2022), identified various *Fusarium* strains in shallots within Java's production centers, and examined the cultivation practices employed by shallot farmers affecting diseases (Herlina *et al.*, 2021; Poromarto, 2021). Widono *et al.* (2023) further showed that rainy seasons promote the progression of *Fusarium* twisted disease compared to dry seasons.

However, specific information regarding the influence of climate factors on *Fusarium* twisted disease in shallots on Java Island during Triple-Dip La Niña remains lacking. Further research is needed to enhance our understanding in this area. Therefore, this paper aims to provide an overview of the current understanding of the influence of climate factors on the incidence of *Fusarium* spp. on shallots in Java Island during the La Niña period (2020 – 2022).

MATERIALS AND METHODS

Variables and Study Sites

The monthly data on the incidence area (unit: hectare) were obtained from the internal data compilation of the Directorate of Horticulture Protection, Directorate General of Horticulture, Ministry of Agriculture (Indonesia). The data are reported by local officials in a hierarchical process involving pest observers at different levels, leading to the compilation of a unified database at the Directorate of Horticulture Protection. The data for this study represent the average area affected by *Fusarium* spp. on shallots in four Java provinces (Central Java, East Java, Yogyakarta, and Banten) over the La Niña period from 2020 to 2022.

Monthly climate data were obtained from the Ministry of Agriculture's database in collaboration with the Indonesian Agency for Meteorological, Climatological and Geophysics (Ministry of Agriculture, 2023a). The data used include four climate factors: average temperature (°C), relative humidity (%), average precipitation (mm), and average sunshine duration (hours) during the La Niña period.

Data Selection

Regencies or cities are selected based on major shallot production centers in Java (Ministry of Agriculture, 2023b). Subsequently, these areas undergo a selection process based on their consistent reporting of *Fusarium* incidence area data on a monthly basis. This process identified 18 regencies/cities that meet those criteria.

Following this initial selection, weather stations are identified within these regencies or cities that possess comprehensive climate data. In instances where such data is unavailable, information from the nearest regency or city is utilized. Consequently, a total of 13 weather stations meeting these criteria are identified (**Fig. 1**). It is important to note that the number of climate stations in Indonesia is limited and therefore, covering every regency/city may not be feasible.

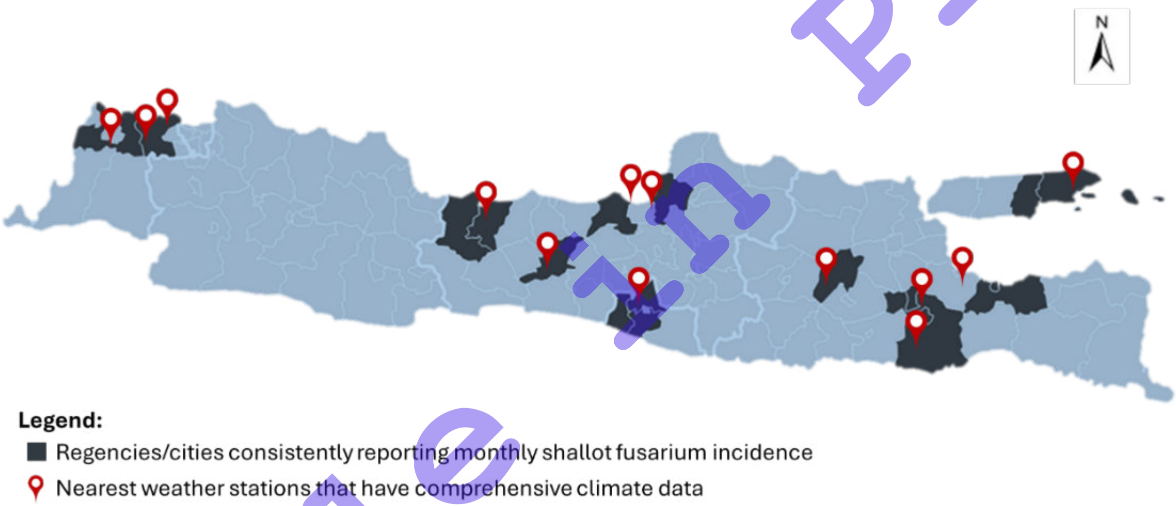

Figure 1. Study sites on Java island with nearest weather stations

Statistical Analysis

The incidence area is visualized in the form of diagrams and graphs. The influence of climate factors on the incidence area of *Fusarium* spp. on shallots is analyzed using Pearson correlation and simple linear regression tests, with a confidence level of 95%. The regression formula is shown below (Hartmann *et al.*, 2023):

$$y = \alpha + \beta x$$

where:
y – dependent variable
x – independent variable
α – intercept
β – regression coefficient

The independent variables are the climate factors, which include temperature, relative humidity, precipitation, and sunshine duration. The dependent variable is the incidence area of *Fusarium* spp. on shallots. Data analysis and visualization are conducted using *Microsoft Excel Analysis ToolPak & PivotChart.*

RESULTS & DISCUSSION

Data visualization (**Fig. 2**) indicates that *Fusarium* spp. was the main pest and disease affecting shallots in Java, with a reported cumulative of incidence area of 838.14 hectares during the La Niña period (2020 – 2022). The provinces reporting the highest incidence of *Fusarium* spp. attacks were Central Java and East Java (**Fig. 3**), consistent with BPS data (2022), which identified Central Java and East Java as Indonesia's leading shallot-producing provinces.

When analyzed by regency/city, Brebes reported the highest incidence of *Fusarium* spp. affecting shallots (**Fig. 4**). Additionally, BPS data (2022) shows that Brebes Regency contributes 18.5% to the national shallot production. The prevalence of *Fusarium* spp. in this area is suspected to be linked to abiotic factors such as temperature, relative humidity, precipitation, and sunshine duration.

Figure 2. Cumulative of incidence area of *Fusarium* spp. compared to other main pests and diseases on shallots in Java during the La Niña period (2020 – 2022).

Fusarium spp. are soilborne pathogens that infect plants through the roots, obstructing the vascular system and causing symptoms like yellowing leaves, stunted growth, twisting, and plant death (Herlina *et al.*, 2021). These pathogens persist in the soil for extended periods and survive on plant debris (Volesky *et al.*, 2022). Unfortunately, wet conditions like frequent rain and high humidity during La Niña, which are ideal for fungal growth (Velásquez *et al.*, 2018), also create favorable environment for *Fusarium* to infect shallot roots.

This becomes especially problematic because different *Fusarium* species cause diverse symptoms on shallots. For instance, wilting is caused by *F. solani* and *F. acutatum*, while bulb rot can be caused by any of *F. solani, F. acutatum*, or even *F. oxysporum*. Additionally, these same *Fusarium* species (*F. solani* and *F. acutatum*) can cause *moler*, a condition characterized by twisted leaves (Lestiyani *et al.*, 2014).

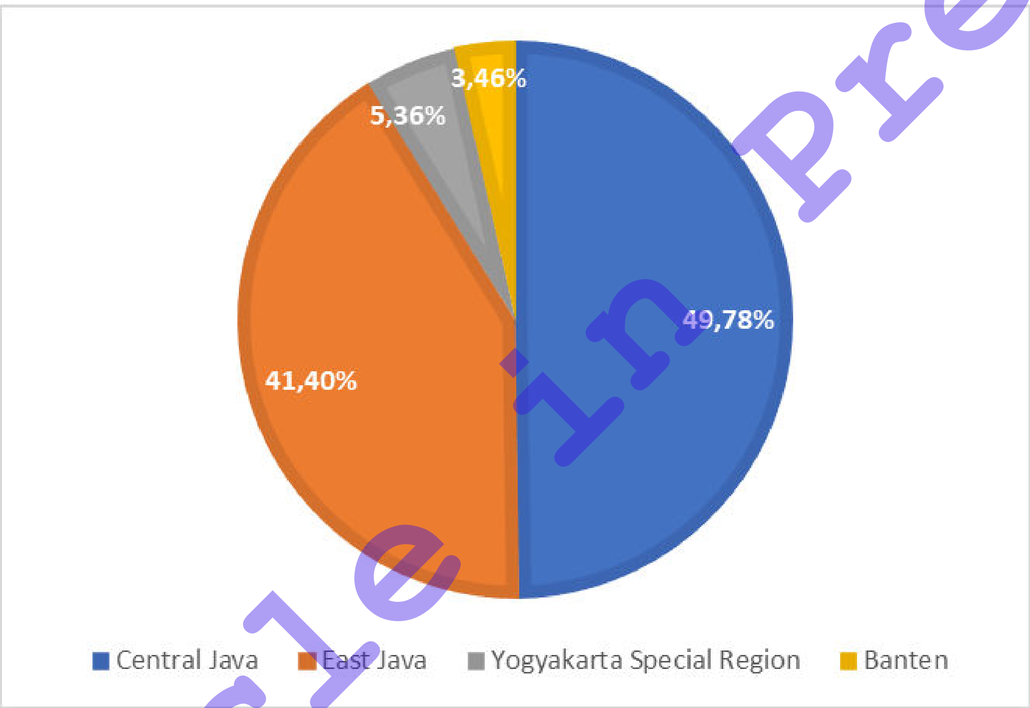

Figure 3. The percentage of incidence area of *Fusarium* spp. on shallots in Java during the La Niña period (2020 – 2022). Central Java is the highest province reporting the incidence area of *Fusarium* spp. on shallots (49.78%), followed by East Java (41.40%), Yogyakarta Special Region (5.36%), and Banten (3.46%). West Java and DKI Jakarta did not report any *Fusarium* twisted disease incidence on shallots.

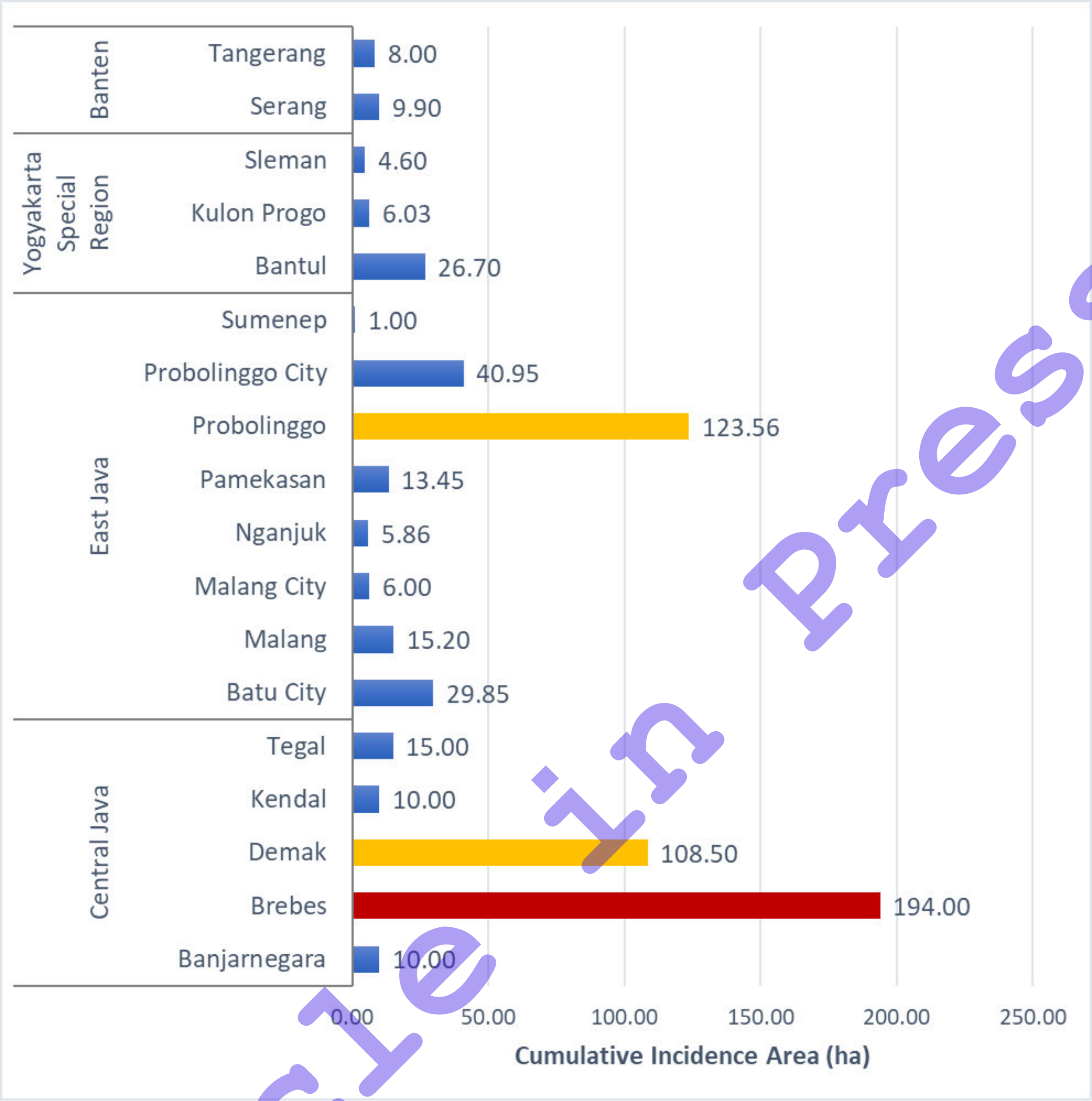

Figure 4. The cumulative incidence area of *Fusarium* spp. on shallots by selected regency/city in Java (2020-2022). During the La Niña period (2020 – 2022), Brebes Regency reported the highest cumulative of incidence area of *Fusarium* spp. on shallots, which was 194 hectares, followed by Probolinggo Regency (123.56 hectares) and Demak Regency (108.5 hectares).

Figure 5. Plots of incidence area of *Fusarium* spp. on shallots in Java Island during the La Niña period (2020 – 2022), which was associated with four climate factors: (A) temperature, (B) humidity, (C) precipitation, and (D) sunshine duration. Throughout the years 2020 – 2022, the trend analysis of incidence area of *Fusarium* spp. on shallots reported in Java appeared to be directly proportional to the climate factors of humidity (B) and precipitation (C). Conversely, for the climate factor of sunshine duration (D), it appeared to be inversely proportional to the incidence area value, while for the temperature factor (A), it did not show a clear trend. Temperature had the lowest fluctuation (more stable) among other climate factors, ranging between 26 - 27.5°C.

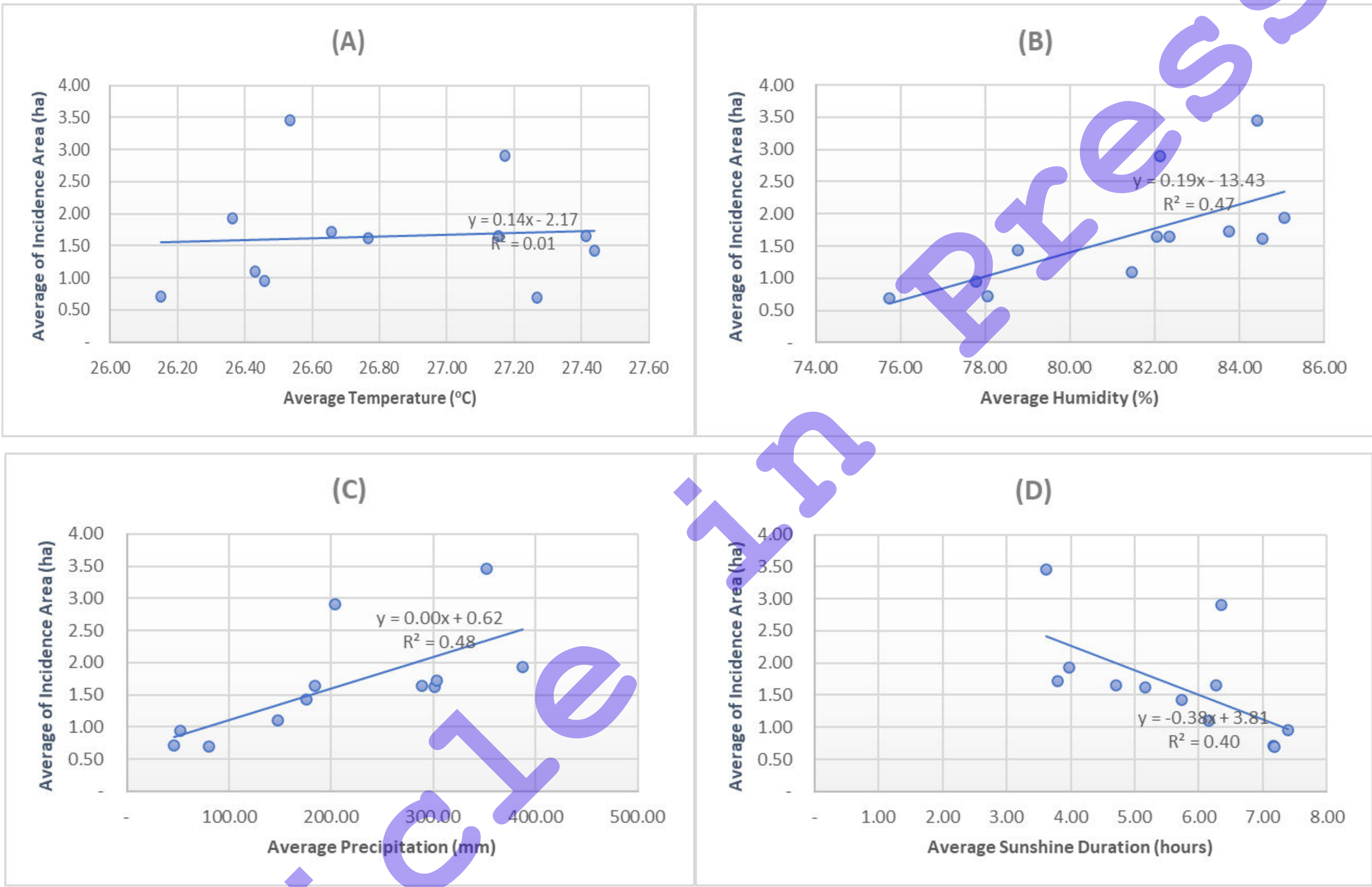

Figure 6. Simple regression analysis of the influence of climate factors on the incidence area of *Fusarium* spp. on shallots in Java Island during the La Niña period (2020 – 2022): (A) temperature, (B) humidity, (C) precipitation, and (D) sunshine duration. Temperature (A) had no significant effect on the incidence area of *Fusarium* spp. on shallots in Java, R^2 = 1% (p = 0.81). Humidity (B), precipitation (C) and sunshine duration (D) had strong influences, R^2 = 47% (p = 0.01), R^2 = 48% (p = 0.01) and R^2 = 40% (p = 0.02), respectively. The confidence level was set at 95%.

Table 1. Correlation test of the incidence area of *Fusarium* spp. on shallots in Java with four climate factors during the La Niña period (2020 – 2022)

Climate factors	***Correlation coefficient (r)****	***p-value***
temperature (°C)	+0.08	0.81
humidity (%)	+0.68	0.01*
preciptation (mm)	+0.69	0.01*
sunshine duration (hours)	-0.63	0.03*

The asterisk symbol (*) indicated statistically signficant at *p<0.05*.

Based on Pearson correlation test, the incidence of *Fusarium* spp. in shallots in Java shows a strong positive correlation with humidity (+0.68) and precipitation (+0.69) (**Table 1**). Conversely, sunshine duration exhibits a strong negative correlation (-0.63), while temperature shows no significant correlation. Monthly data visualization (**Fig. 5**) demonstrates that humidity and precipitation positively correlate with *Fusarium* spp. incidence in shallots, while sunshine duration shows an inverse correlation. Temperature, however, shows no clear trend.

Simple linear regression analysis (**Fig. 6**) reveals that humidity, precipitation, and sunshine duration strongly influence *Fusarium* spp. incidence, explaining 47%, 48%, and 40% of the variance, respectively. While sunshine duration itself may not directly affect *Fusarium* incidence, it has a strong correlation with precipitation and humidity. This is because increased sunshine can lead to higher evaporation rates, impacting soil moisture levels. Higher humidity caused by increased precipitation often associated with La Niña events, reduces water evaporation from the soil (Zeng *et al.*, 2023), potentially creating a more favorable environment for the fungus.

Most plant diseases thrive under conditions of rain, high humidity, and elevated soil moisture. *Fusarium* disease in shallots particularly flourishes in environments conducive to fungal growth and root infection (Velásquez *et al.*, 2018). Especially during high humidity events like La Niña, rapid spore germination can occur, leading to the development of fungal mycelium capable of infiltrating shallot roots. Furthermore, moist soil, aided by water percolation, facilitates the movement of fungal threads, increasing the likelihood of root infection (Gracia-Garza & Fravel, 1998; Ramírez-Gil & Morales-Osorio, 2018).

The temperature had minimal impact because it had the lowest fluctuation among other climate factors, ranging between 26 - 27.5°C, which was ideal for the development of *Fusarium* spp. (**Fig. 5: A**). *Fusarium* spp. thrives within a temperature range of 20 – 30 °C, with optimal growth at 25 °C (Hibar *et al.*, 2006; Quintana *et al.*, 2017). Humidity, precipitation, and sunshine duration fluctuations were higher, influencing *Fusarium* spp. incidence more significantly (**Fig. 6: B, C, D**). Studies demonstrate that high humidity levels promote *Fusarium* spp. growth and sporulation, potentially leading to crop damage (Pempee *et al.*, 2020; Fatima *et al.*, 2020).

Table 2. Correlation test between climate factors in Java during the La Niña period (2020 – 2022)

Correlation coefficient (r)	*Average Temperature (°C)*	*Average Humidity (%)*	*Average Precipitation (mm)*	*Sunshine Duration (hours)*
Average Temperature (°C)	+1 *			
Average Humidity (%)	-0.18	+1 *		
Average Precipitation (mm)	-0.04	+0.91 *	+1 *	
Sunshine Duration (hours)	+0.13	-0.84 *	-0.95 *	+1 *

The asterisk symbol (*) indicated statistically signficant at $p<0.05$.

Report of the incidence area of *Fusarium* spp. was always higher in the rainy season than in the dry season during Triple-Dip La Niña in selected regencies/cities in Java (**Fig. 7**). The rainy season in Indonesia generally occurs from November to April, and the dry season from May to October (Yanto *et al.*, 2016). According to Basuki (2014), *Fusarium* twisted disease was identified as the main disease that affected shallot plants during the rainy season.

The excessive precipitation led to the infection of shallots by *Fusarium* spp. Precipitation and sunshine duration also have a strong inverse relationship (-0.95). On the other hand, precipitation and humidity had a strong positive correlation (+0.91) (**Table 2.**). During the La Niña period, characterized by increased precipitation and humidity but reduced sunshine duration, shallots may experience heightened stress, rendering them more susceptible to diseases.

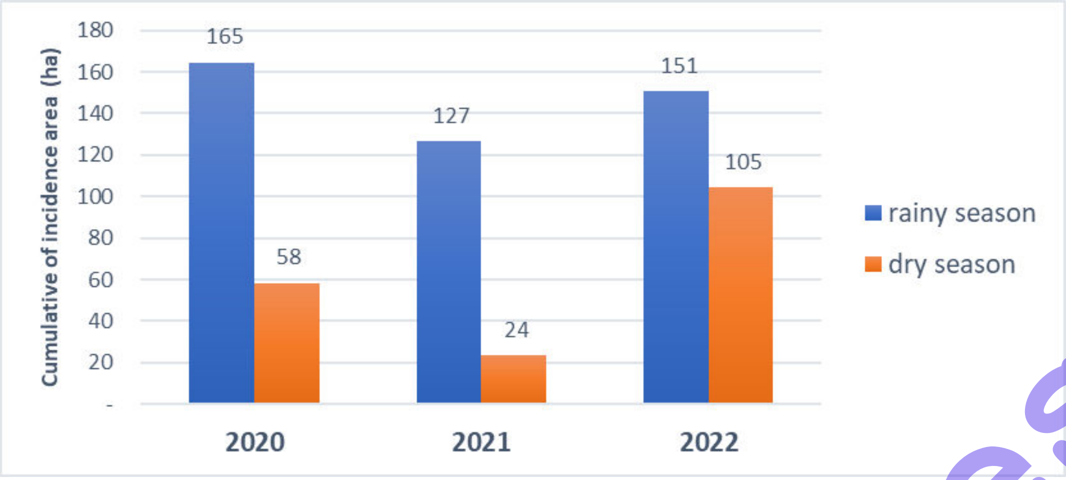

Figure 7. The cumulative incidence area of *Fusarium* spp. on shallots by seasons. The incidence area of *Fusarium* spp. was always higher in the rainy season than in the dry season between 2020 – 2022 (La Niña period).

Fusarium spp. infection in shallots may have seen a rise in affected areas during the 2022 dry season due to unusual weather patterns (**Fig. 7**). Rainfall data from July to September 2022 indicated levels exceeding the thirty-year average, coinciding with the persistence of La Niña. This early rainfall likely contributed to higher than normal precipitation across southern Indonesia, potentially creating a more favorable environment for the fungus to thrive during what is typically a drier period (WFP, 2022).

Recent research conducted in the Bantul District has revealed that disease occurrence and progression are more common during the rainy season compared to the dry season (Wibowo *et al.,* 2023). Additionally, the rainy season exhibits a shorter incubation period for diseases. Several farming practices can help manage *Fusarium* twisted disease. These practices include selecting resistant shallot varieties, optimizing plant spacing, using fertilizers judiciously, and potentially incorporating fungicides (Wibowo *et al.,* 2023).

Furthermore, using pathogen-free seeds (True Shallot Seeds or TSS) has been shown to improve plant health and reduce disease risk (Adin *et al.*, 2023). Similarly, applying mulch can create a more stable environment, potentially lowering disease risk (Ramírez-Gil *et al.*, 2020). Beyond these practices, broader disease management strategies exist. These preventive measures, as outlined by Volesky *et al.* (2022) and Okungbowa & Shittu (2014), include crop rotation, soil solarization, and ensuring well-drained soil to suppress pathogen populations.

Various biological agents, including *Bacillus velezensis* and *B. cereus* (Rahma *et al.*, 2020; Pratiwi *et al.*, 2024), *Rhizophagus intraradices*, and *Trichoderma asperellum*, have been shown to effectively reduce the incidence and severity of twisted disease in shallot (Artanti *et al.*, 2022; Abdullah *et al.*, 2023; Maharani *et al.*, 2024). These applications offer a promising approach to not only enhance crop yield and quality but also increase shallot tolerance towards twisted disease (Sundari *et al.*, 2023).

CONCLUSION

Shallots, a crucial horticultural crop in Indonesia are vulnerable to diseases like *Fusarium* spp., particularly during prolonged La Niña events. The study found humidity and precipitation positively correlated with *Fusarium* spp. incidence, while sunshine duration had a inverse relationship. Temperature showed no correlation. The simple linear regression test indicated that high humidity, high precipitation, and low sunshine duration significantly influence the incidence of *Fusarium* spp. during La Niña periods. These conditions promote fungal growth and root infection.

Based on these findings, farmers and government agencies can employ various strategies to mitigate disease risk. These include selecting resistant shallot varieties, optimizing plant spacing, using fertilizers judiciously, implementing pathogen-free seeds, and and incorporating biological agents that suppress fungal growth. By adopting these measures, shallot health can be improved, leading to a reduction in disease occurrence.

This study is limited to using data from the La Niña period (2020 – 2022) for climate factors and the incidence area of *Fusarium* spp. in Java. In addition, the data used is still dominated by reports from Central Java and East Java. Further research can be focused on the forecasting of *Fusarium* spp. attacks on shallot productivity in Indonesia based on climate factors.

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APPENDIX

The climate data used in this analysis was obtained from 13 weather stations situated across Java. These stations cover locations where *Fusarium* incidence in shallots has been reported, as follows:

Table 4. Weather station used for four climate factors data

No.	Weather Station Name	Regency/City	Province	Coordinate (Latitude, Longitude)
1	Serang Meteorological Station	Serang City	Banten	6°06'41.0"S 106°07'54.8"E
2	Budiarto Curug Meteorological Station	Tangerang	Banten	6°17'11.3"S 106°33'50.2"E
3	Soekarno-Hatta Meteorological Station	Tangerang City	Banten	6°07'31.2"S 106°39'32.5"E
4	Tegal Meteorological Station	Tegal	Central Java	6°52'05.9"S 109°07'16.4"E
5	Banjarnegara Geophysical Station	Banjarnegara	Central Java	7°19'57.7"S 109°42'34.3"E
6	Semarang Climatology Station	Semarang	Central Java	6°59'05.0"S 110°22'50.8"E
7	Maritime Meteorological Station	Semarang City	Central Java	6°57'01.7"S 110°25'05.7"E
8	Yogyakarta Climatology Station	Sleman	Special Region of Yogyakarta	7°43'52.7"S 110°21'15.5"E
9	Karang Ploso Climatology Station	Malang	East Java	7°54'02.3"S 112°35'52.1"E
10	Karangkates Geophysical Station	Malang	East Java	8°09'08.6"S 112°27'02.6"E
11	Saawahan-Nganjuk Geophysical Station	Nganjuk	East Java	7°44'04.6"S 111°45'59.9"E
12	Tretes Geophysical Station	Pasuruan	East Java	7°42'15.5"S 112°38'06.8"E
13	Kalianget Meteorological Station	Sumenep	East Java	7°02'27.7"S 113°54'57.0"E