Borneo Journal of Resource Science and Technology (2026), 16(1): 128-146
DOI: https:doi.org/10.33736/bjrst.10079.2026

Outbreak of *Opisina arenosella* Walker (Lepidoptera: Xyloryctidae): New Defoliator on Kopyor Coconut (*Cocos nucifera* L. var. Kopyor) Plantation in Bogor, Indonesia

MUHAMMAD FAIZ MUZHAFFAR[1], DEWI SARTIAMI*[1], NINA MARYANA[1] & CIPTADI ACHMAD YUSUP[2]

[1]Department of Plant Protection, Faculty of Agriculture, IPB University. Jl. Kamper IPB Dramaga Campus, Bogor, 16680 West Java, Indonesia; [2]Indonesian Oil Palm Research Institute (IOPRI) Unit Bogor, Jl. Taman Kencana No 1, Bogor, 16128 West Java, Indonesia
*Corresponding author: dsartiami@apps.ipb.ac.id

Received: 30 June 2025 Accepted: 08 January 2026 Published: 30 June 2026

ABSTRACT

Kopyor coconut (*Cocos nucifera* L. var. *Kopyor*) represents a distinct coconut form compared to common coconut which shows its uniqueness in Indonesia. The Kopyor coconut is characterised by its soft, crumbly endosperm that separates from the shell, commanding a market value ten times higher than regular coconuts. However, Kopyor coconut cultivation faces significant threats caused by the Black Headed Caterpillar (BHC), *Opisina arenosella* Walker, a defoliating pest capable of causing substantial economic losses. This study aimed to identify characteristic symptoms of BHC infestation, measure the infestation rate and infestation intensity inKopyor coconut plantations and analyse the influence of weather factors. Observations were conducted from August to November 2024 at the Ciampea plantation in Bogor, Indonesia. BHC symptoms of attacks are characterised as dried fronds, tunnel structures composed of fecal matter and chewed leaf remnants and the attachment of one leaf to another. BHC damages both young and old leaves. Field infestation levels varied depending on inter-plot proximity and planting patterns, with overall BHC infestation classified as severe to extremely severe. Outbreaks of BHC were strongly driven by weather factors: decreased rainfall and increased temperatures during the study period created optimal microhabitat conditions for pest development.

Keywords: BHC, climate, damage severity, infestation rate, infestation intensity, IPM

INTRODUCTION

Kopyor Coconut (*Cocos nucifera* L. var. Kopyor) is one of Indonesia's unique coconut varieties. Its cultivation holds significant economic appeal for farmers and entrepreneurs. Kopyor coconuts are priced up to ten times higher than common coconuts (Faramitha *et al.,* 2024). Kopyor coconuts are characterised by distinct traits, including endosperm that separates from the endocarp, a soft and crumbly texture and features more flesh volume compared to the water volume found in ordinary coconuts. This makes them a delightful treat for consumers (Maskromo *et al.,* 2013; Sukendah & Priyadarshini, 2023; Yunindanova *et al.,* 2024). These abnormal features arise from the absence of α-galactosidase enzyme production (Mujer *et al.,* 1984). The growing popularity of Kopyor coconuts is further driven by their diversification into value added products such as beverages, ice cream, baked goods, virgin coconut oil (VCO) and as one of the cosmetic base ingredients (Liwu *et al.,* 2022; Mahbub *et al.,* 2022; Dimawarnita *et al.,* 2025). Kopyor coconuts are cultivated in several regions across Indonesia, such as Bogor, Kebumen, Banjarnegara, Jepara, Pati, Rembang, Sumenep, Tulungagung and South Lampung (Mashud & Manaroinsong, 2007; Sukendah *et al.,* 2011; Novarianto *et al.,* 2014).

The Kopyor coconut industry in Indonesia is currently facing significant threats from infestations of the coconut black-headed caterpillar (BHC), *Opisina arenosella* Walker 1864 (Lepidoptera: Xyloryctidae). However, in 1905, Meyrick named this species as *Nephantis serenopa* and it was found in Sri Lanka (Meyrick, 1908), which was then synonymised as a junior name to *O. arenosella* by Becker (1981). The first sight of this pest in Indonesia was shown on a Kopyor coconut plantation in Ciomas, Bogor. At the end of 2020, approximately 60% of the total Kopyor coconut trees had been infested by this BHC (Yusup, 2021). The earliest observation of BHC was reported by Green in 1898 in Sri Lanka (Green, 1898). In India, the primary host of this pest was the palmyrah palm (*Borassus flabellifer* Linn.) in 1907 (Rao *et al.,* 1948). This pest has also been able to attack other than *Palmae* species, such as bananas, corn, jackfruit, sugarcane and others (Lever, 1969; Manjunath, 1985; Cammell *et al.,* 1990; Muralimohan & Srinivasa, 2005; Sukhirun *et al.,* 2015; Shameer *et al.,* 2018). Moreover, Josephrajkumar *et al.* (2018) state that the initial symptoms can be recognised by the drying and gray spotting of leaflets on its fronds. The niche of BHC larvae was a complex microhabitat structure. They form galleries composed of silk webs interwoven with frass and remnants of leaves. The defoliation pattern shows that this pest begins its infestation as circular damage from the outer edge of leaves and then it moves inward as an irregular configuration. A heavily infested BHC can cause canopies of coconut trees to exhibit scorching symptoms that resemble the effect of burning.

On a common coconut tree, BHC could consume more than 90% of its leaves in a single frond (Nirula, 1956). Outbreaks of this pest species on common coconut plantations in India reached 45% yield loss (Chandrika *et al.,* 2010). Coconut plants which have been infested by BHC could recover but on slow response of its appearance and it was taking approximately four years to return as new healthy trees (Kumara *et al.,* 2015). Recently, Mahadi *et al.* (2019) declared that *O. arenosella* could cause yield losses of up to 60% in oil palm plantations in Malaysia. This significant impact is reinforced by the fact that *O. arenosella* feeding behaviour on Kopyor coconut plants occurs at all stages of the coconut tree continuously throughout the year. The presence and fluctuation of infestation depended on ecological conditions, especially related to climate (Josephrajhkumar *et al.,* 2018; Shameer *et al.,* 2018). Field observations in China have shown that BHC populations are inhibited and slowed by low temperatures (Lin *et al.,* 2019).

The geographical distribution of the BHC has expanded to several countries, particularly in Southeast Asia, including Myanmar, Thailand, Malaysia and Vietnam (Ghosh & Abdurahiman, 1985; IPPC, 2017; Mahadi & Yusof, 2018; Le *et al.,* 2022). Furthermore, the BHC often undergoes population outbreaks, establishing the most economically damaging pests in coconut plantations across regions, including India, China and Thailand (Borse, 2014). Information regarding the BHC in Indonesia is limited and no studies have been done to describe the pattern of attack on the coconut leaves var. Kopyor on the field or even the environmental conditions that influence the pest. Since its emergence in 2020, the presence of BHC has been detected in various plantation locations. This necessitates greater attention to this threat and the development of an integrated pest management (IPM) program. This effort should begin with initial information regarding monitoring infestation intensity in the field. This basis demonstrates a strong relevance in realizing sustainable agriculture. Therefore, this study aims to describe BHC infestations on damage symptoms, investigate the infestation rates and infestation intensities in the Kopyor coconut tree and observe the influence of weather factors on the presence of BHC in the plantation.

MATERIALS AND METHODS

Data Collection

The research was conducted at the 10 year-old Kopyor coconut plantation in Ciampea, Ciaruteun Ilir Village, Cibungbulang District, Bogor Regency, West Java Province, Indonesia, situated at coordinates 6°32'46"S, 106°40'08"E, with an elevation ranging between 155–165 meters above mean sea level (msl). This research was conducted from August to November 2024, a period chosen to capture the late dry season through to the beginning of the rainy season. This timing is critical as it aligns with known fluctuations in temperature and rainfall, which are key drivers for pest development in tropical ecosystems. The research was sampled using a systematic diagonal pattern as subplots on four plots of cultivation. Observations were made on 6 trees on each subplot (Figure 1). Table 1 shows the different characteristics of each plot, including population or number of Kopyor coconut trees in the sampling plot.

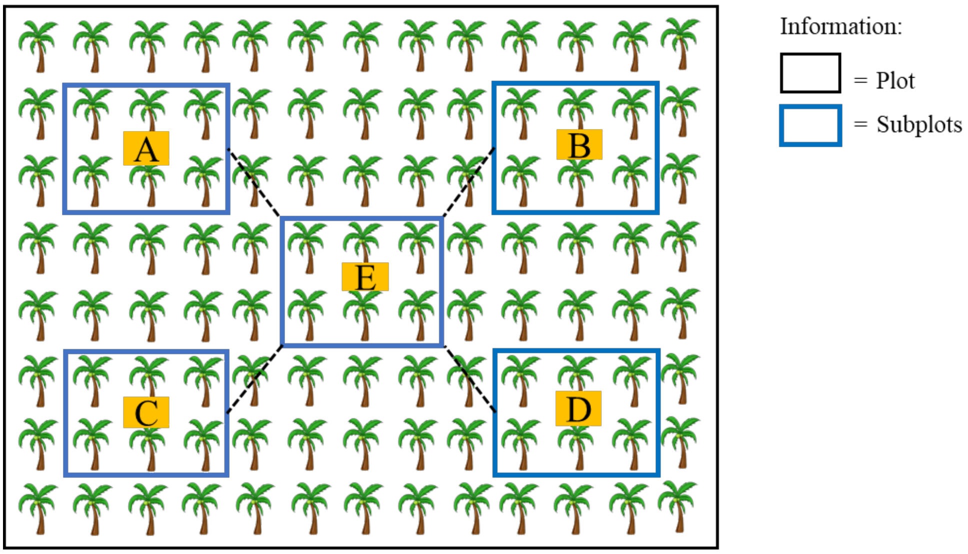


Figure 1. Schematic of Kopyor coconut tree sampling

Table 1. Characteristics of the sampling plot

Sampling plot	Land area (m^2)	Number of trees on the plot	Plant spacing (m)	Variety	Cropping Pattern
A2	12.420	115	12 × 9	Tall	Monoculture
A9	11.772	109	12 × 9	Tall	Polyculture*
A11	11.988	111	12 × 9	Tall	Monoculture
B2	8.040	134	6 ×10	Dwarf	Monoculture

*Polyculture with cacao plants

Observation on the Symptoms of Damage and Feeding Behaviour

The observation of *O. arenosella* infestation symptoms and feeding behavior was conducted by randomly selecting sample of Kopyor coconut plants. Visual assessments were performed on the leaflets of palm fronds, particularly on older fronds in the lower canopy. All symptoms from the early stage to final damage were recorded. Documentation was also carried out using digital cameras to obtain data on the site.

Assessment of Infestation Rate

The infestation rate was assessed by observing all plants within the subplots on the plots. Kopyor coconut plants with symptoms of BHC were included in the following formula, Eq. (1):

$$I = \frac{n}{N} \times 100\% \qquad \text{Eq. (1)}$$

Description:
I = Infestation rate, n = Number of plants infested and N = Number of plants observed.

Assessment of Infestation Intensity

Assessment of infestation intensity was carried out by observing all trees in the subplot of each plot. Considering the limitations of existing field methods, the methodology for assessing severity categories was developed and customised based on the BHC feeding behavior and pattern of infestation, thereby yielding more accurate and representative measurements. The preliminary assessment for infestation intensity observation has been done to ensure results are consistent and carried out by a single observer. The infestation intensity was determined using a specific scoring for damage severities (Table 2). The percentage of severity was visually evaluated based on the proportion of the leaf area affected. Each Kopyor coconut tree has a different number of fronds and leaflets, depending on its variety. In general, the tall type has about 25 – 30 fronds, each bearing approximately 100 – 150 leaflets, whereas the dwarf type has around 20 – 25 fronds, each with about 150 – 200 leaflets.

The intensity of infestation is evaluated using the formula below, Eq. (2). The formula used for infestation intensity (K) is a standard formula widely adopted in similar studies (Priwiratama *et al.*, 2019) and has been modified for this research to suit the specific feeding patterns of BHC, as explained in the methodology section.

$$K = \frac{\sum(v_i \times n_i)}{Z \times N} \times 100\% \qquad \text{Eq. (2)}$$

Description:
K = Infestation intensity (%), *vi* = Damage score of the i-th frond category, *ni* = Number of fronds with damage score vi, N = Total number of fronds observed, Z = Maximum damage score.

Table 2. Criteria for category of BHC damage severity of each frond

Score	Infestation intensity (%)	Damage severity
0	0	Normal, no infestation
1	$0 < x \leq 10$	Light, 1-10% of leaflets per frond infested
2	$10 < x \leq 25$	Moderate, 11-25% of leaflets per frond infested
3	$25 < x \leq 50$	Severe, 25-50% of leaflets per frond infested
4	$x > 50$	Very Severe, > 50% of leaflets per frond infested

Data Analysis

The symptom and feeding behaviour were present on descriptive analysis. The intensity rate and infestation intensity were processed and tabulated using Microsoft Excel 2021 and they were analysed using analysis of variance (ANOVA). If the results were significantly different, Tukey's post hoc test was performed at a significance level of 5%. All statistical analyses were conducted using R software version 4.4.3 and the analysis results were visualised using the *ggplot* package. Supporting data related to weather factors, such as rainfall, temperature and humidity, were obtained from NASA Power (https:// power.larc.nasa.gov/) and supporting data related to air pollutants have also been obtained from OpenWeather (https://openweathermap. org/). The correlation between climate and infestation of *O. arenosella* is presented in a graph and description.

RESULTS

Damage Symptoms and Feeding Behavior

Kopyor coconut leaves are defoliated by BHC and a heavy attack caused severe damage to the canopy of the tree. The damage symptoms are indicated by drying leaves, thinning and sparse appearance, with leaflets drooping downwards and appearing scorched as if it was burned (Figure 2a). Further observation of the leaflets of fronds showed shriveled and turned to brownish (Figure 2b). Most of the feeding behaviour of BHC initially by eating from the underside of the leaflet and leaving the upperside epidermis of those leaflets and he could also move to the nearest leaflet to continue eating (Figure 2c). Injury leaves could disrupt photosynthesis, leading to inhibited energy flow and nutrient absorption.

Further symptoms of damaged leaves were characterised by the presence of meandering and irregular tunnels composed of frass and uneaten leaf fragments left behind by the BHC (Figure 2d). The presence of frass and leaf debris indicates active infestation, providing further visual evidence of this pest's activity. These tunnels are held together by thin silk produced by the larvae from their mouths through salivary glands. The larvae feed on the leaflets from inside the tunnels and the number of larvae found on these tunnels are up to three individual BHC larvae. The number of larvae per tunnel was calculated by carefully dissecting infested fronds, with an average of three larvae observed per tunnel. When the BHC reaches the pupal phase, it will remain inside the tunnels. Actually, these tunnels are highly beneficial for larvae and pupae stages, serving as a habitat and protection from natural enemies and unfavourable ecological conditions for their survival. This confirms Yusup (2021) statement that these tunnels are both a niche and a shelter for *O. arenosella* during the larval to pupal stages. This tunneling process begins on the lower part leaflets before advancing to the upper part toward the midrib and it leads to further damage severity.

The next stage of infestation manifests as the adhesion between adjacent leaflets (Figure 2e). Two or three leaflets sticked and attached are caused by some larvae of BHC, which also construct silk-reinforced tunnels between these leaflets. Actually, the tunnels function as a bridge that connects one leaflet to others. Further damage indicated the developing tunnel towards the upper side of the leaflets and the damage of the symptom visible from the upper side of the leaflets on the frond. Field observations reveal that affected leaves gradually lose functionality before eventually undergoing defoliation. As a result, the subsequent symptom appears as dried leaflet remnants where only the pale brown to grayish midribs and veins remain (Figure 2f). When this symptom spreads to all leaflets across the frond, complete damage of the necrotic frond will occur and finally cause the frond to detach from the trees and fall.

Figure 2. Damage symptoms of BHC on Kopyor coconuts. (a) Dried fronds appearing burned, (b) leaflets shriveled and turning brown, (c) BHC feeding marks leaving only the leaflet epidermis, (d) tunnels formed from frass and leaf fragments, (e) silk-webbing between adjacent leaflets, (f) dried midribs with grayish-brown discolouration

Infestation Rate

BHC was found to infest almost all trees on the plots. The damages showed differences in the infestation rate among plant plots (Figure 3). Plots B2 and A2 had the highest infestation rate, with a proportion of 100%, followed by plot A9 with a proportion of 89% and plot A11 with a proportion of 79.3%.

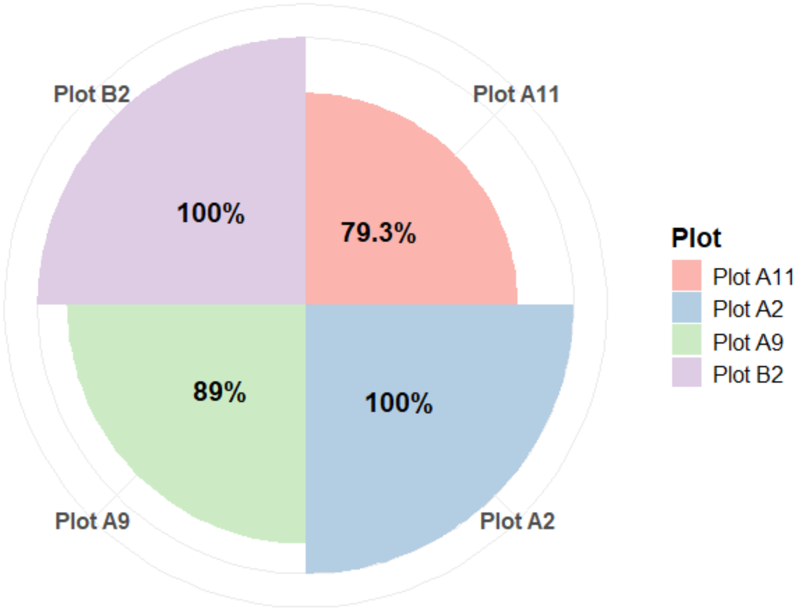


Figure 3. Infestation rates among plant plots

Infestation Intensity

Pest infestations revealed variations in the infestation scores of BHC on leaflets fronds across the plantation (Figure 4a). Surveys recorded a score of 0 as the highest, with a proportion of 27.2%, followed by score of 4 with 21.6%, score of 1 with 19.3%, score of 2 with 17.4% and score of 3 with 14.6%. This is because older leaf fronds located lower on the plant showed more damage compared to younger fronds at the top. This damage indicates a typical infestation pattern on older leaf fronds, as BHCs usually start feeding on older fronds at the bottom and move upward to feed on younger fronds when the availability of older leaf fronds decreases.

On the other hand, the variation in infestation scores for each frond provides a different justification between plants due to the varying number of fronds per plant. Consequently, each plant occupies a different position in the damage severity category. Field observations at Cimpea plantation showed only two categories of plant assessment: Severe and very Severe (Figure 4b). Proportional analysis revealed that most plants were concentrated in the severe category, with a proportion of 68.3%, followed by the very severe category with 31.7%. This indicates a significant tendency towards a fairly severe level of infestation at the Ciampea plantation.

Observations in the plantations showed a significant difference ($p<0.05$) in the intensity of BHC infestation among the observed plant plots (Figure 5). Plot B2 showed the highest pest infestation intensity, significantly higher than the other plant plots. The BHC infestation intensity in plot B2 reached 61.72%, followed by plot A2 at 45.96%, then plot A9 at 40.48% and the lowest BHC infestation intensity was in plot A11 at 37.22%. This situation reveals that the proximity of each plant plot plays a role in the proportion of BHC pest infestation intensity in the plantation. Plot B2 is situated near an industrial area, a poultry farm and this strongly contributes to their highest BHC infestation intensity in the plantation. This situation is exacerbated by the fact that this plot is a dwarf variety with a closer planting distance than other plots. Plot A2 was found to be in second place, due to the plot's proximity to an industrial area, but it benefited from the fact that the planting distance for this crop was not closer than that of plot B2. Meanwhile, plot A11 ranked lowest due to the complex weeds on this plot, which provided nectar and shelter for natural enemies to thrive and contributed to higher parasitism and predation on this plot. Moreover, the planting pattern in each plant plot also stands out. Plot A9, intercropped with cacao, ranked third in BHC infestation intensity among the field sampling plots. This supports the concept that polyculture or mixed-planting patterns are unfavourable for pests in the plantation.

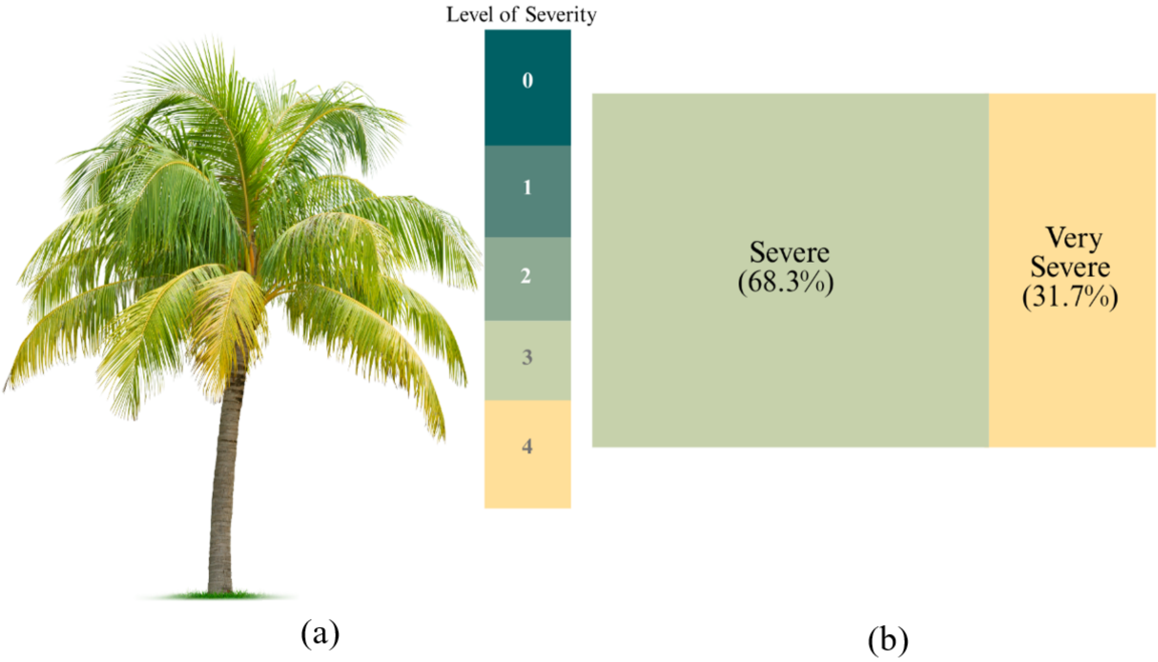


Figure 4. Assessment of infestation intensity. (a) Classification of severity for each frond attack by BHC on all sampling plots (0 = 27.2%; 1 = 19.3%; 2 = 17.4%; 3 = 14.6%; 4 = 21.6%), (b) Proportion severity of plant categories on the Ciampea plantation

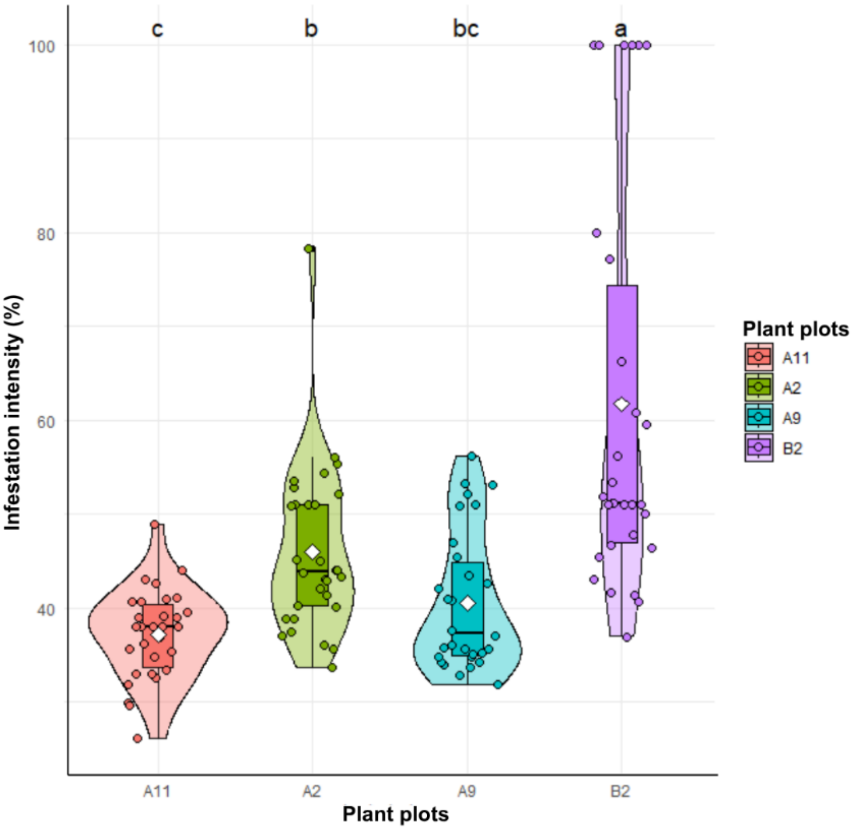


Figure 5. Infestation intensity for each plot. Different letters above the violin plots indicate significant differences as shown by Tukey's HSD, p<0.05

Distribution Map of BHC

This map illustrates the distribution of BHC in Ciampea plantation (Figure 6). Based on the map legend, the distribution of infestation intensity at the Ciampea plantation shows the highest very severe infestation intensity, represented by the orange colour in plot B2, followed by plot A2, plot A9 and the lowest in plot A11. This condition indicates that the pest infestation in plot B2 is spreading rapidly, suggesting that the BHC infestation in the Ciampea plantation likely began within or near this plot. It can thus be inferred that *O. arenosella* initially emerged in the western section of the plantation area.

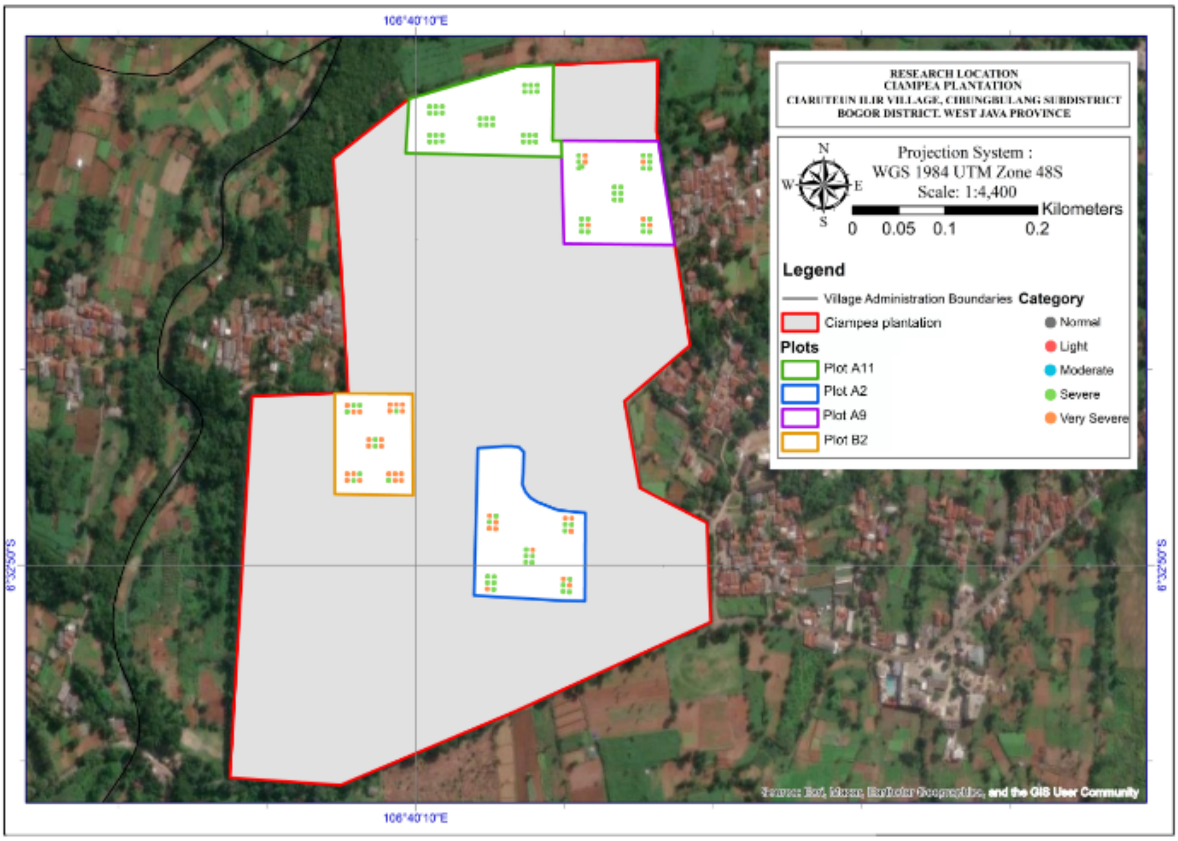


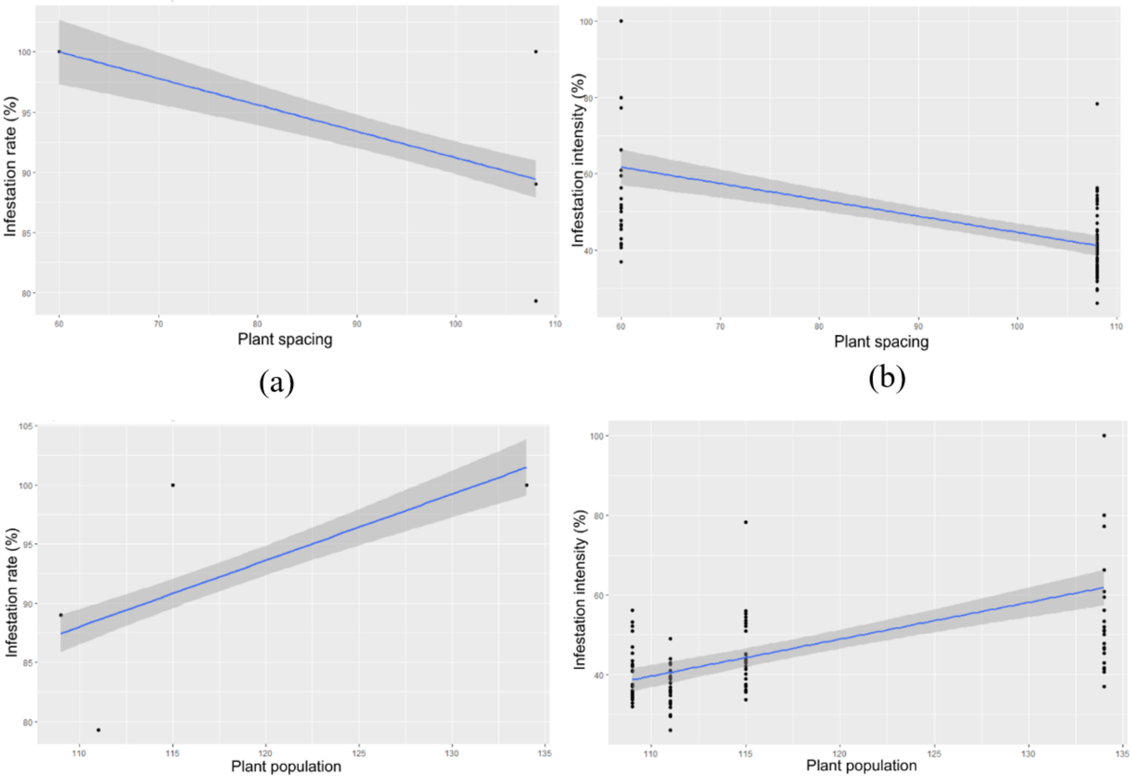
Figure 6. Distribution map of BHC infestation intensity on Kopyor coconut

Influence of Plant Plot Characteristics on BHC Infestation

The variation in infestation rate and infestation intensity in the field is influenced by factors such as plant spacing and Kopyor coconut population on each plot. Linear regression analysis showed a significant correlation between plant spacing and infestation rate ($R^2 = 0.2808$; $P < 4.87 \times 10^{-10}$). This indicates that wider plant spacing leads to a reduction in the infested area (Figure 7a). Similarly, a significant correlation was also observed between plant spacing and infestation intensity ($R^2 = 0.3297$; $P < 7.091 \times 10^{-12}$), indicating that wider plant spacing effectively lowers the infestation intensity (Figure 7b). Linear regression analysis showed a significant positive correlation between population and infestation rate ($R^2 = 0.4087$; $P < 2.36 \times 10^{-15}$), indicating that an increase in population correlates with an increase in infestation rate (Figure 7c). Linear regression analysis also demonstrated a significant positive correlation between plant population and infestation intensity ($R^2 = 0.347$; $P < 8.91 \times 10^{-13}$), indicating that an increase in tree population correlates with an increase in infestation intensity (Figure 7d). These results reinforce that narrower plant spacing and larger plant populations provide greater opportunities for increased BHC population density, leading to more severe infestation intensity.

Influence of Climate Variables on BHC Infestation

Pest infestation outbreaks in agricultural fields demonstrate substantial dependence on prevailing weather conditions, with rainfall levels and ambient temperatures exhibiting the most pronounced effects. Rainfall and temperature conditions in the study area during 2024 are shown in the graph below (Figure 8). Generally, rainfall in the research area showed a declining trend during the study period, from early August to early November 2024. The decrease in rainfall began in May (3.09 mm) and continued until October (2.57 mm), before starting to rise again in November (11.3 mm). Meanwhile, temperatures in the research area began to increase in August (25.01 °C), peaked in October (26.3 °C) and then started to decrease in November (25.79 °C). This condition suggests an argument that low rainfall and rising temperatures impact the existence of BHC infestation in the field. Overall, the observed fluctuations in temperature and rainfall support the justification that the development of BHC pests in the field begins when the dry season approaches.



(a) (b)

(c) (d)

Figure 7. Influence of plant spacing and a number of tree coconut Kopyor population on infestation rate and infestation intensity. (a) between plant spacing and infestation rate, (b) between plant spacing and infestation intensity, (c) between plant population and infestation rate, (b) between plant population and infestation intensity

Correlation analysis of various climatic variables with both infestation rate and infestation intensity provides insights into the relationships between variables contributing to the development of *O. arenosella* in the field (Figure 9). Rainfall exhibited a moderately strong negative correlation with the infestation rate (r = -0.428; p<0.001). This indicates that an increase in rainfall is likely to result in a smaller affected area. Conversely, rainfall showed a negligible correlation with infestation intensity (r = -0.022; p<0.001), while statistically significant, the extremely weak coefficient suggests that rainfall is practically irrelevant in influencing whether the infestation becomes more or less severe in already affected locations. Temperature displayed a weak positive correlation with the infestation rate (r = 0.195; p<0.001). This indicates a tendency for the infested area to expand as the temperature rises. Meanwhile, temperature also demonstrated a weak negative correlation with infestation intensity (r = -0.138; p<0.001), suggesting that an increase in temperature might lead to a slight decrease in infestation intensity. Humidity showed a weak negative correlation with the infestation rate (r = -0.152; p<0.001), indicating that increased humidity might contribute to a reduction in the affected area. Conversely, humidity also exhibited a weak positive correlation with infestation intensity ($r = 0.132$; $p<0.001$), implying that increased humidity could potentially lead to a slight rise in infestation intensity, although this relationship is not statistically significant. Overall, the correlation results for the observed climatic factors indicate that rainfall plays the most prominent role in reducing the infestation rate.

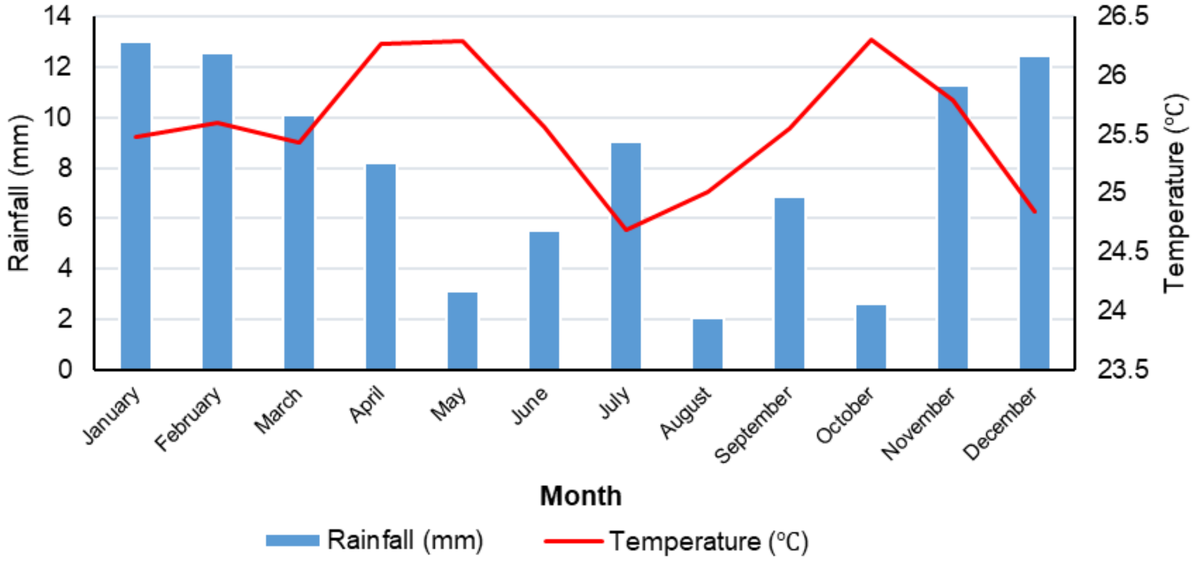


Figure 8. Rainfall (mm) and temperature (°C) during 2024. (Raw data from Nasa Power, 2024)

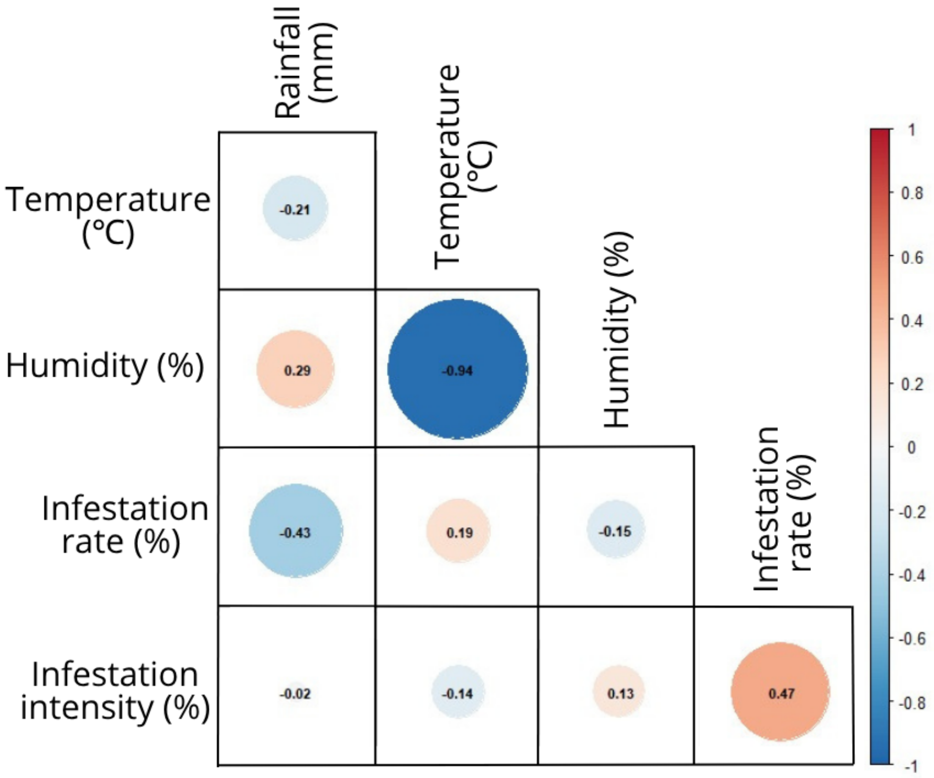


Figure 9. Correlation between climatic variables and the infestation rate and infestation intensity

Air Pollutant Conditions during the Observation period

Supporting data on air pollutants were obtained from the OpenWeather platform for the study area during the observation period from August to November 2024. The parameters analysed included ozone (O_3), particulate matter with aerodynamic diameter ≤2.5 µm ($PM_{2,5}$) and particulate matter with aerodynamic diameter ≤10 µm (PM_{10}). Air pollutant concentrations exhibited clear temporal variation during the observation period (Table 3). Ozone (O_3) concentrations ranged from 18.23 to 68.61 µg m^{-3}, with the highest value recorded in August 2024, followed by a gradual decline towards November 2024. Particulate matter showed a similar temporal pattern. $PM_{2,5}$ concentrations decreased from 94.70 µg/m^3 in August to 61.80 µg/m^3 in October, before increasing again in November (73.08 µg/m^3). Likewise, PM_{10} concentrations declined from 126.83 µg/m^3 in August to 89.55 µg m^{-3} in October, followed by an increase to 104.97 µg/m^3 in November.

Overall, O_3 concentrations demonstrated a gradual decreasing trend throughout the study period, whereas particulate matter exhibited greater short-term variability, particularly during the transition from the dry season to the early rainy season. These data provide an environmental context for understanding pest dynamics during the observation period.

Table 3. Temporal variation of air pollutant concentrations

Month (2024)	O_3(µg/m^3)	$PM_{2,5}$ (µg/m^3)	PM_{10}(µg/m^3)
August	68.61	94.70	126.83
September	67.57	83.63	116.67
October	64.12	61.80	89.55
November	18.23	73.08	104.97

DISCUSSION

The research findings have revealed distinct symptoms that confirm the presence of an active BHC infestation in the field. Observations of BHC in this study align with the findings of Mahadi & Yusof (2018) and Yusup (2021), who reported that BHC larvae damage ordinary coconut leaves by scraping the leaflets and then creating tunnels with silk threads as shelter for the pest until pupation. These tunnels are then reused by the adult insects for oviposition. As a result of this scraping activity, young leaves appear dis coloured, turning brown and drying out. In addition, young leaves also become curved outwards and stick together due to the silk threads produced by the pest. The behavior of BHC in the field also indicates a positive correlation between body size and the intensity of damage to leaflets. This means that as the larval instar stage increases, the potential for damage area on the leaves also increases. Furthermore, the amount of BHC larval consumption also increases with the larval stage. Interestingly, the BHC exhibits the behavior of feeding on both old and young leaves, although it prioritises older leaves in the field. This represents a significant difference from the symptoms of the Coconut Leaf Beetle (CLB), *Brontispa longissima* (Gestro), which primarily infests young leaves or unopened fronds (spears) and whose infestation pattern is even influenced by the age of the coconut palm. Coconut trees that have not yet fruited (non-bearing) are preferred by CLB over those that have already fruited (bearing) (Galicia *et al.,* 2023). This comparison confirms that BHC infestation, with its widespread and intense characteristics, poses a distinct and potentially more destructive threat to photosynthetic capacity and plant health, ultimately leading to reduced production. As a result, this context requires a different control strategy, given that this pest is among the most destructive and commonly encountered in Kopyor coconut plantations.

The infestation rate and infestation intensity vary in the plantation. This condition has also occurred in a region of India where continuous infestations of BHC have taken place. Investigations by Gurav *et al.* (2018) found that BHC infestations occurred throughout the year, with the lowest proportion being 18.79% and the highest proportion being 54.92% in five different locations in the Navsari District, India. Interestingly, the summer season (April–May) was the period of the highest infestation rate, followed by a decrease in infestation rate in September and reaching its lowest point in the winter (November–December). Inspections conducted by Gurav *et al.* (2018) for over two years found that the intensity of BHC infestation fluctuated throughout the year in five different locations in the Navsari District, India. The records showed an overall highest proportion of 52.95% (April) and the lowest proportion of

8.61% (January). These conditions suggest that BHC intensity peaks in the summer and decreases in the winter. A different location in India also recorded an infestation intensity of 54.16% (Gurav *et al.,* 2014).

This research revealed that the proximity between plants in the plots holds a crucial role in pest presence in the plantations. Industrial activities surrounding plantation areas are known to release various air pollutants that can adversely affect plant physiological processes. Air pollution has been reported to disrupt nutrient allocation, reduce the production of secondary metabolites and weaken plant defence mechanisms, thereby increasing host plant susceptibility to herbivorous insects. Furthermore, polluted environments may indirectly reduce the effectiveness of natural enemies by affecting the abundance and activity of predators and parasitoids (Hijii *et al*., 1995). Exposure to moderate levels of ozone (O_3) over extended periods has been widely reported to inhibit photosynthesis, reduce plant biomass and alter the diversity and composition of soil microbial communities (Calatayud *et al*., 2004; Zhang *et al*., 2012; Chen *et al*., 2014; Feng *et al*., 2014; Wang *et al*., 2015). Similarly, particulate matter (PM_{25} and PM_{10}) can reduce light penetration, decrease chlorophyll content and cause physical damage to leaf tissues, ultimately lowering plant vigor (Giri *et al*., 2013; Popek *et al*., 2018; Setsungnern *et al*., 2018). In this context, air pollutants are more likely to act as chronic environmental stressors that gradually weaken host plant condition and create a more favourable environment for pest development, rather than serving as direct triggers of population outbreaks. This phenomenon has been confirmed by Zvereva & Kozlov (2010), who conducted a meta-analysis to substantiate the observed increase in pest insect abundance near industrial pollution sources.

Furthermore, the pattern planting of the trees also plays a significant role in disrupting pest existence in the plantation. This is supported by field observations conducted in the Sukabumi area, Indonesia, where soybeans and coconuts were planted as a mixture crop on the same land. The results showed that cultivating both plants was effective and beneficial for farmers (Manoppo *et al.,* 2021). This approach is useful in improving overall soil health, both physical and chemical properties, ultimately proving economically advantageous. This is supported by Selva Rani *et al.* (2024), who suggest that coconut intercropping is highly compatible with several crops, such as pepper, bananas and cacao. Intercropping is a plant protection mechanism that contributes to preventing pest attacks in the field, both through visual and physical effects, as well as through the disruption of the sense of smell in the form of volatile compounds. This directly or indirectly impacts pest biological activity, such as reducing feeding activity, inhibiting pest dispersal, disrupting egg-laying activity and attracting more pollinators (Magnin *et al.,* 2025). Intercropping also has a positive effect on the abundance of natural enemies, meaning it directly increases predation and parasitism on pests (Miranda *et al.,* 2025; Yuya *et al.,* 2025). Additionally, intercropping contributes to suppressing weed vegetation abundance, thereby maximising crop productivity (Leskovšek *et al.,* 2025).

Generally, the visualization of the infestation mapping in this Kopyor coconut plantation shows a distribution pattern that is nearly similar among sub-plot sampling points, where BHC infestations tend to be distributed in clusters according to the damage severity scale. This occurs because the female adults lay eggs in clusters on Kopyor coconut leaves, so that when the larvae hatch, they congregate in the same area. In contrast, the bagworm *Pteroma pendula*, a major oil palm pest, has a relatively slow distribution because adult female bagworms cannot fly and remain inside their bags until they lay eggs and die, thus limiting their distribution to the area around the initial infestation site (Priwiratama *et al.,* 2019).

The distribution pattern of BHC is further reinforced by the fact that the BHC migrates from infested Kopyor coconut trees to other Kopyor coconut trees via leaves connected by the silk threads they produce. This explanation aligns with the analysis results of this study, which reveal that a larger plant population correlates with an increase in the infestation rate and infestation intensity of BHC. Concurrently, it confirms that smaller planting distances facilitate the easy movement of this pest in the field (Kareiva, 1982). The relevance of these results also underpins the positive effect of pest insect movement responses on host plant density (Bach, 1988; Kang *et al.,* 2008).

Pest dispersal is influenced by vectors, animals and humans (Hosang, 2010). This study assesses that the pest dispersal occurred via vehicles carrying Kopyor coconut fruit that originated from the initial outbreak site of this pest in Indonesia, specifically in the Ciomas plantation, Bogor (Yusup, 2021). One of the factors contributing to the spread of BHC is planting spacing. This study revealed that the plant plots with the heaviest BHC distribution were planted with dwarf varieties, resulting in closer spacing between Kopyor coconut trees. This facilitates the movement of BHC from one leaf frond to another, both within the same tree and between different trees. BHC can create tunnels from frass and leftover leaf debris by sticking leaflets together, enabling rapid dispersal. This is further supported by the findings in this study, which show that denser plant populations also correlate with higher BHC infestation rates. This condition further facilitates BHC migration. A study by Manurung & Anwar, (2023) found that the dispersal of bagworm *Clania tertia* in oil palm plantations was triggered by the proximity of observation sites to operational plantation roads. This proximity is suspected to facilitate the movement of *C. tertia* from one location to another.

One of the triggers for pest outbreaks in the plantation is climate change and weather disturbances in a region (Liu *et al.,* 2024). Recent climate change has increased the frequency of severe dry seasons, which create ideal conditions for the emergence and spread of infestations, leading to outbreaks (Singh *et al.,* 2024). This aspect includes several components that directly and indirectly contribute to the situation in the field. The BHC outbreaks in the field coincided with a decrease in rainfall during 2024. This confirms field observations reported by Lin *et al.* (2019), who found that BHC reached its highest population density between July and November (summer). Meanwhile, Muralimohan *et al.* (2013) found that the pre-oviposition period was longer, ranging from 3–4 days in January (low temperature). This is also supported by the laboratory findings of Lu *et al.,* (2016), which can represent field conditions. The life cycle duration of BHC will continuously increase with the applied temperature treatments. This also has implications for other biological activities, such as increased fecundity, increased net reproductive rate, shorter generation time and other biological activities.

The implications of decreased rainfall in the study area are consistent with its effects on other weather components, such as increased average temperature and decreased relative humidity. Increased average and extreme temperatures directly accelerate pest metabolism, development and reproduction, increasing the likelihood of pest outbreaks (Sandra *et al.,* 2021; Skendžić *et al.,* 2021; Zhou *et al.,* 2024). Changing rainfall patterns, which tend to decrease, can affect the survival of natural enemies and induce physiological stress in host plants, increasing plant susceptibility to pest infestations (Sivakumar, 2020; van Huis & Gasco, 2023). Changes in relative humidity directly affect pest physiology (e.g., egg survival) and can influence the effectiveness of pest pathogens (Heeb *et al.,* 2019; Desprez-Loustau *et al.,* 2021). The interaction of rainfall and temperature also affects plant phenology (flowering time, growth), influencing the availability and quality of resources for pests, as well as affecting pest behavior and activity, such as flight, oviposition and foraging, which collectively create conditions that are more conducive to exponential and widespread pest infestation (Harvey *et al.,* 2022; Li *et al.,* 2023; Wei *et al.,* 2023).

The occurrence of invasive BHC outbreaks in Kopyor coconut plantations makes pest control a fundamental necessity. Environmentally friendly approaches are highly recommended to maintain beneficial ecological conditions for beneficial organisms, such as parasitoids, predators and pollinators (Sánchez-Bayo, 2021). This principle is embodied in the IP strategy, which is an innovative method to reduce pest populations below the economic threshold using ecological, biological, physical and chemical approaches judiciously (Parveen & Rashtrapal, 2024). The use of natural enemies, including parasitoids, predators and entomopathogens, in other regions has been reported to reduce BHC populations. Several parasitoids have been reported to be effective in reducing BHC populations in South India, such as *Antrocephalus hakonensis*, *Brachymeria nephantidis*, *Kriechbaumerella* sp., *Apanteles* sp., *Goniozus nephantidis* and *Xanthopimpla punctata* (Nivetha *et al.,* 2025). The parasitoid *Trichospilus pupivorus* has been developed to control BHC pupae in Malaysia (Mahadi *et al.,* 2019). The parasitoid *Chouioia cunea* has also been reported to effectively control BHC larvae and pupae. Potential predators of BHC include the anthocorid bug *Cardiastethus exiguus*, the coccinellid beetle *Jauravia* sp. and the ground beetle *Parena nigrolineata* (Velasco-Hernandez *et al.,* 2021). In addition, the use of the entomopathogen *Metarhizium* spp. is also recommended for application due to its large and readily available population in nature. It has been widely reported to successfully infect several pests, such as Lepidoptera (Pathan & Deshpande, 2019), Orthoptera (Zhao *et al.,* 2019), Blattodea (Syazwan *et al.,* 2021), Hemiptera (Wahyuni *et al.,* 2025) and Coleoptera (Saciloto-de-Oliveira *et al.,* 2023). These biological approaches should also be supported by routine monitoring, removing infested leaves and clearing weeds to limit BHC development. Furthermore, intercropping is a viable recommendation for Kopyor coconut plantations to inhibit BHC biological activity. Combining these control activities enhances the resilience of Kopyor coconut plantations to outbreaks and minimises the potential negative effects of BHC.

CONCLUSION

BHC exhibits characteristic damage symptoms, including dried fronds, tunnel pathways composed of frass and chewed leaf debris and webbing between leaflets. BHC infestations both young and older leaves of Kopyor coconut palms. The observed infestation levels in the field varied due to factors such as proximity between plant plots and differing cropping patterns; however, overall, BHC infestations were predominantly categorised as severe to very severe. Outbreaks of BHC were significantly driven by climatic factors, specifically decreased rainfall and increased temperatures.

ACKNOWLEDGEMENTS

This research is part of the first author's master's thesis. The authors thank the technician of the Insect Biosystematics Laboratory, Department of Plant Protection, IPB University, Bogor, Indonesia, for assistance in this research. The authors also thanks to Indonesian Oil Palm Research Institute (IOPRI) Unit Bogor for providing permission and facilities in this research.

REFERENCES

Bach, C.E. (1988). Effects of host plant patch size on herbivore density: Underlying mechanisms. *Ecology,* 69 (4): 1103-1117. DOI: 10.2307/1941265.

Becker, V.O. (1981). Identities and provenance of the gelechioid moths originally described by Francis Walker from 'unknown countries'. *Systematic Entomology*, 6: 137-141.

Borse, R.D. (2014). Control of coconut black headed caterpillar (*Opisina arenosella* Walker). *Indian Journal of Applied Research*, 11: 73-74.

Calatayud, A., Iglesias, D.J., Talón, M. & Barreno, E. (2004). Response of spinach leaves (*Spinacia oleracea* L.) to ozone measured by gas exchange, chlorophyll a fluorescence, antioxidant systems and lipid peroxidation. *Photosynthetica*, 42:23-29. DOI: 10.1023/b:phot.0000040565.53844.c6.

Cammell, M.E., Perera, P.A.C.R., Way, M.J. & Jeganathan, M. (1990). Host plant nutrition and outbreaks of the coconut caterpillar, *Opisina arenosella* Walker in Sri Lanka. *Cocos*, 8: 4050. DOI: 10.4038/cocos.v8i0.2122.

Chandrika, M., Radhakrishnan, N.C.P., Kesavan, N.C. & Rajan, P. (2010). Leaf eating caterpillar (*Opisina arenosella*) induced yield loss in coconut palm. *International Journal of Tropical Insect Science*, 30: 132-137. DOI: 10.1017/S174275841000024X.

Chen, Z., Wang, X.K. & Shang, H. (2014). Using 13C isotope to investigate O_3 effects on C fixation and translocation of rice. *Chinese Journal of Ecology*, 33: 1983-1988.

Desprez-Loustau, M.L., Ramirez-Valiente, J.A.C. & Robin, C. (2021). The fungal dimension of biological invasions. *Trends in Ecology & Evolution*, 31 (2021): 327-328.

Dimawarnita, F., Aisyah, A., Mawardanti, A.S.S., Faramitha, Y., Sinta, M.M., Saptari, R.T. & Riyadi, I. (2025). Physicochemical characteristics of virgin coconut oil (VCO) from Kopyor coconut (*Cocos nucifera* L.). *IOP Conference Series: Earth and Environmental Science*, 1482 (2025): 012033. DOI: 10.1088/1755-1315/1482/1/012033.

Faramitha, Y., Dimawarnita, F., Sinta, M.M., Saptari R.T., Riyadi, I. & Sumaryono, S. (2024). Observations on Kopyor coconut (*Cocos nucifera* var. Kopyor) characteristics during distribution.

*BIO Web of Conferen*ces, 99: 02018. DOI: 10.1051/bioconf/20249902018.

Feng, Z., Sun, J., Wan, W., Hu, E. & Calatayud, V. (2014). Evidence of widespread ozone-induced visible injury on plants in Beijing, China. *Environmental Pollution*, 193: 296-301. DOI: 10.1016/j.envpol.2014.06.004.

Galicia, G.L., Medina, d.R., Velasco, L.R.I, Ceballo, F.A. & Rebancos, C.M. (2023). Patterns in the distribution and abundance of the post outbreak population of the coconut leaf beetle, *Brontispa longissima* (Gestro) (Coleoptera: Chrysomelidae) in Albay, Philippines. *IOP Conference Series: Earth and Environmental Science*, 1235 (2023): 012007. DOI: 10.1088/1755-1315/1235/1/012007.

Ghosh, S.M. & Abdurahiman, U.C. (1985). Bioethology and evaluation of comparative efficiency of *Apanteles taragamae*, a larval parasitoid of coconut caterpillar, *Opisina arenosella*. *The Philippine Journal of Coconut Studies*, 10 (2): 4-8.

Giri, S., Shrivastava, D., Deshmukh, K. & Dubey, P. (2013). Effect of air pollution on chlorophyll content of leaves. *Current Agriculture Research Journal*, 1: 93-98. DOI: 10.12944/CARJ.1.2.04.

Green, E.E. (1898). A coconut palm caterpillar. *Tropical Agriculture*, 26: 298-308.

Gurav, S.S, Khandekar, R.G., Sawant, V.S. & Narangalkar, A.L. (2014). Impact of olfactory conditioned parasitoid *Goniozus nephantidis* in suppression of *Opisina arenosella* Walker under field conditions in konkan region of Maharashtra. Book of abstract of Placrosym XXI organised at Kozhikode, Kerala, 2014. pp. 133-134.

Gurav, S.S., Radadia, G.G. & Shinde, C.U. (2018). Status of coconut black headed caterpillar, *Opisina arenosella* (Walker) and it's associated larval parasitoid, *Goniozus nephantidis* (Muesebeck) under south Gujarat conditions. *International Journal of Chemical Studies*, 6 (2): 2713-2718.

Harvey, J.A., Tougeron, K., Gols, R., Heinen, R., Abarca, M., Abram, P.K., Basset, Y., Berg, M., Boggs, C., Brodeur, J., Cardoso, P., de Boer, J.G., De Snoo, G.R., Deacon, C., Dell, J.E., Desneux, N., Dillon, M.E., Duffy, G.A., Dyer, L.A., Ellers, J., Espíndola, A., Fordyce, J., Forister, M.L., Fukushima, C., Gage, M.J.G., García-Robledo, C., Gely, C., Gobbi, M., Hallmann, C., Hance, T., Harte, J., Hochkirch, A., Hof, C., Hoffmann, A.A., Kingsolver, J.G., Lamarre, G.P.A., Laurance, W.F., Lavandero, B., Leather, S.R., Lehmann, P., Le Lann, C., López-Uribe, M.M., Ma, C.-S., Ma, G., Moiroux, J., Monticelli, L., Nice, C., Ode, P.J., Pincebourde, S., Ripple, W.J., Rowe, M., Samways, M.J., Sentis, A., Shah, A.A., Stork, N., Terblanche, J.S., Thakur, M.P., Thomas, M.B., Tylianakis, J.M., Van Baaren, J., Van de Pol, M., Van der Putten, W.H., Van Dyck, H., Verberk, W.C.E.P., Wagner, D.L., Weisser, W.W., Wetzel, W.C., Woods, H.A., Wyckhuys, K.A.G. & Chown, S.L. (2022). Scientists' Warning on Climate Change and Insects. *Ecological Monograph*, 93 (1): 1-37. DOI: 10.1002/ ecm.1553.

Heeb, L.L., Jenner, E. & Cock, M.J.W. (2019). Climate-smart pest management: building resilience of farms and landscapes to changing pest threats. *Journal of Pest Science,* 35 (2019): 96-101. DOI: 10.1007/s10340-019-01083-y.

Hijii, N., Futai, K. & Kaneko, N. (1995). Effects of air pollution on population dynamics of phytophagous insects. *Japanese Journal of Ecology*, 45 (1): 19-31.

Hosang, M.L.A. (2010). Field resistance of four dwarf kopyor coconut accessions against *Oryctes rhinoceros*. *Buletin Palma*, 38: 34-42.

IPPC. (2017). Coconut black headed caterpillar. Available at: https://www.ippc.int/en/ countries/thailand/pestreports/2017/02/coconut-black-headed-caterpillar/ (Accessed 15 May 2025).

Josephrajkumar, A., Mohan, C., Prathibha, P.S., Rajkumar, R., Nalinakumari, T. & Nair C.P.R. (2018). Pest dynamics and supression strategies. In Nampoothiri, K.U.K., Krishnakumar, V., Thampan, P.k., Nair, M.A (editor). *The Coconut Palm (Cocos nucifera L.).* Research and Development Perspective. pp. 574-582. DOI: 10.1007/978-981-13-2754-4_12.

Kang, Y., Armbruster, D. & Kuang, Y. (2008). Dynamics of a plant–herbivore model. *Journal of Biological Dynamics*, 2 (2): 89-101. DOI: 10.1080/17513750801956313.

Kareiva, P. (1982). Experimental and mathematical analyses of herbivore movement: quantifying the influence of plant spacing and quality on foraging discrimination. *Ecological Monographs*. 52 (3): 261-282. DOI: 10.2307/2937331.

Kumara, A.D.N.T., Chandrashekharaiah, M., Subaharan, K. & Chakravarthy, A.K. (2015). Periodicity of adult emergence and sexual behaviour of coconut black headed caterpillar, *Opisina arenosella* Walker (Lepidoptera:

Oecophoridae). *Phytoparasitica*, 43:701-712. DOI: 10.1007/s12600-015-0481-2.

Le, H., Lu, N., Dat, L., Nhan, N., Xuan, L. & Quan, N.. (2022). Population fluctuation, damage status and some biological characteristics of coconut black-headed caterpillar (BHC), *Opisina arenosella* Walker (Lepidoptera: Xylorictidae) in Ben tre province. *Journal of Plant Protection Research*. 3: 23-31.

Leskovšek, R., Eler, K. & Zamljen, S.A. (2025). Weed suppression and maize yield influenced by cover crop mixture diversity and tillage. Weed suppression and maize yield influenced by cover crop mixture diversity and tillage. *Agriculture, Ecosystems and Environment*, 383: 109530. DOI: 10.1016/j.agee.2025.109530.

Lever, R.J.A.W. (1969). "*Pests of the coconut palm*," in FAO agricultural studies (Rome, Italy: FAO), 190. No. 77.

Li, Y., Schmid, B., Schuldt, A., Li, S., Wang, M.Q., Fornoff, F., Staab, M., Guo, P.F., Anttonen, P., Chesters, D., Bruelheide, H., Zhu, C.D., Ma, K., (2023). Multitrophic arthropod diversity mediates tree diversity effects on primary productivity. *Nature Ecology Evolution*, 7 (6): 832-840. DOI: 10.1038/s41559-024-02324-9.

Lin, Y.Y., Jin, T., Ma, G.C., Wen, H.B., Jin, Q.A. & Peng, Z.Q. (2019). Population reproduction characteristics of *Opisina arenosella* Walker. *Chinese Journal of Tropical Crops*, 40: 960-964. DOI: 10.3969/j.issn.1000-2561.2019.05.018.

Liu, M., Jiang, P., Chase, J.M. & Liu, X. (2024). Global insect herbivory and its response to climate change. *Current Biology*, 34: 2558–2569. DOI: 10.1016/j.cub.2024.04.062.

Liwu, S.L., Rindengan, B., Pradhana, A.Y., Wunkana, J. & Pasang, P. (2022). Effect of application edible coating on the quality of Kopyor coconut meat during storage. *IOP Conference Series: Earth and Environmental Science*, 974: 012125 DOI: 10.1088/17 551315/97 4/1/012125.

Lu, B., Tang, Z., Bellis, G., Li, Y., Peng, Z., Jin, Q. & Wen, H. (2016). Life table analysis under constant temperature for *Opisina arenosella* (Lepidoptera: Xyloryctidae), an invasive moth of palm plants. *Austral Entomology*, 55 (3): 334-339. DOI: 10.1111/aen.12195

Magnin, L., Hiltpold, I., Jullien, A. & Baux, A. (2025). Intercropping mitigates incidence of the oilseed rape insect pest complex. *Pest Management Science*. DOI: 10.1002/ps.8835.

Mahadi, N.A., Yusof, T.A.A. & Laboh, R. (2019). Searching and parasitism behaviour of *Trichospilus pupivorus* (Hymenoptera: Eulophidae), a potential parasitoid for coconut black-headed caterpillar, *Opisina arenosella* (Lepidoptera: Oecophoridae). *Serangga*, 24: 80-90.

Mahadi, N.A. & Yusof, T.A.A. (2018). The first record of incidence of the invasive moth *Opisina arenosella* (Walker) and its parasitoids on coconut palms in Malaysia. In Laboh, R., Annamalai, S., Lian, T.S., Jaafar, A.H., Hamid, M.A., Mamt, W.Z.W., Serin, T., Amzah B, editor. Proceedings National Coconut Conference 2018. Malaysian Agricultural Research and Development Institute. pp. 92-97.

Mahbub, K., Octaviani, I.D., Astuti, I.Y., Sisunandar, S. & Dhiani, B.A. (2022). Oil from Kopyor coconut (*Cocos nucifera var. Kopyor*) for cosmetic application. *Industrial Crops and Products*, 186 (10): 115221. DOI: 10.1016/ j.indcrop.2022.115221.

Manjunath, T.M. (1985). Coconut black-headed caterpillar on banana and coconuts. FAO. *Plant Protection Bulletin*, 33: 71–72.

Manoppo, C.N., Yusuf, Y. & Yusron, M. (2021). Farming analysis of soybean cultivation under coconut plantation in North Sulawesi. *IOP Conference Series: Earth and Environmental Science*, 807 (2021): 042016. DOI: 10.1088/ 1755-1315/807/4/042016.

Manurung, C.F.B. & Anwar, R. (2023). Population dynamics of the bagworm, *Clania tertia* Templeton (Lepidoptera: Psychidae) on immature oil palm at Pelalawan Regency, Riau. *IOP Conference Series: Earth and Environmental Science*, 1208 (2023): 012019. DOI: 10.1088/175 5-1315/1208/1/012019.

Mashud, N. & Manaroinsong, E. (2007). Teknik kultur embryo untuk pengembangan kelapa Kopyor. *Buletin Palma*, 33: 37-44.

Maskromo, I., Novarianto, H., Sukendah, S., Sukma, D. & Sudarsono, S. (2013). Productivity of three dwarf Kopyor coconut varieties from Pati, Central Java, Indonesia. *Coconut Research & Development*, 29 (2): 19–28. DOI: 10.37833/ cord. v29i2.86.

Meyrick, E. (1908). Description of Indian micro-lepidoptera. *Journal of the Bombay Natural History* Society, 16: 580-619.

Miranda, P.S., Barbosa, T.G., Lima, Z.C.M., Pérez-Maluf, R., Moreira, A.A. & Leite, S.A. (2025). Faunistic composition and seasonal occurrence of parasitoid and predatory wasps in maize intercropped with beans. *Journal of Ecology and Environment*, 49 (11): 1–8. DOI: 10.5141/jee.25.004.

Mujer, C.V., Ramírez, D.A. & Mendoza, E.M.T. (1984). Coconut α-galactosidase isoenzyme: isolation purification and characterization. *Phytochemistry*, 23 (6): 1251–1254. DOI: 10.1016/ S0031-9422(00)80435-5.

Muralimohan, K. & Srinivasa, Y.B. (2005). Black headed caterpillar on sugarcane leaves. *Insect Environment*, 11: 42–43.

Muralimohan, K., Srinivasa Y.B. & Sreekanth, P.N. (2013). Effect of temperature on developmental biology of *Opisina arenosella* (Walker). *Current Biotica*, 7: 228–232.

Nirula, K.K. (1956). Investigations on the pests of coconut palm-part III. *Indian Coconut Journal*. 9: 101-131.

Nivetha, S., Arulprakash, R., Binoy, C. & Chitra, N. (2025). Hymenopteran parasitoids of black-headed caterpillar *Opisina arenosella* Walker (Lepidoptera: Xyloryctidae) in South India. *Plant Science Today*, 12 (sp1): 1–7. DOI: 10.14719/ pst.5978.

Novarianto, H., Maskromo, I., Dinarti, D. & Sudarsono, S. (2014). Production technology for Kopyor coconut seednuts and seedlings in Indonesia. *Internasional Journal on Coconut Research and Development*, 30 (2): 31–40. DOI: 10.9755/ejfa.2015-07-552.

Parveen, S.S. & Rashtrapal, P.S. (2024). Integrated pest management strategies using endophytic entomopathogenic fungi. *Plant Science Today*, 11 (1): 568–574. DOI: 10.14719/pst.2740.

Pathan, E.K. & Deshpande, M.V. (2019). The puzzle of highly virulent *Metarhizium anisopliae* strains from *Annona squamosa* fields against *Helicoverpa armigera*. *Journal of Basic Microbiology*, 59: 392–401. DOI: 10.1002/jobm.201800631.

Popek, R., Przybysz, A., Gawrońska, H., Klamkowski, K. & Gawroński, S.W. (2018). Impact of particulate matter accumulation on the photosynthetic apparatus of roadside woody plants growing in the urban conditions. *Ecotoxicology and Environmental Safety*, 163: 56–62. DOI: 10.1016/j.ecoenv.2018.07.051.

Priwiratama, H., Rozziansha, T.A.P., Prasetyo, A.E. & Susanto, A. (2019). Effect of bagworm *Pteroma pendula* Joannis attack on the decrease in oil palm productivity. *Jurnal Hama dan Penyakit Tumbuhan Tropika*, 19 (2): 101–108. DOI: 10.23960/j.hptt.219101-108.

Rao, Y.R., Cherian, M.C. & Ananthanarayan, K. P. (1948). Infestation of *Nephantis serinopa* Meyr. in South India and its control by biological methods. *Indian Journal of Entomology*, 10: 205–247.

Saciloto-de-Oliveira, L.R., Broetto, L., Alves, C.I., da Rosa, R.L., Calegari Alves, Y.P., da Silva, R.C., Berger, M., Macedo, A.J., Dalberto, P.F., Bizarro, C.V., Guimaraes, ˜ J.A., Yates, J.R., Santi, L. & Beys-da-Silva, W.O. (2023). *Metarhizium anisopliae* E6 secretome reveals molecular players in host specificity and toxicity linked to cattle tick infection. *Fungal Biology*, 127: 1136–1145. DOI: 10.1016/j. funbio.2023.0 6.006.

Sánchez-Bayo, F. (2021). Indirect effect of pesticides on insects and other orthropods. *Toxics*, 9: 177–199. DOI: 10.3390/toxics 9080177.

Sandra, R., Patel, N. & Kumar, A. (2021). Temperature effects on insect development and population dynamics. *Journal of Entomological Research*, 37 (2021): 145–158.

Selva Rani, A., Subbulakshmi, S., Sudha, R., Kavitha, K., Nazreen Hassan, S.H., Muthulakshmi, M., Sivagamy, K. & Suresh, S. (2024). Synergizing sustainability: Integrated nutrient management and intercropping for optimal coconut cultivation in South India. *Horticulturae*, 10 (6): 653. DOI: 10.3390/horti culturae10060653.

Setsungnern, A., Treesubsuntorn, C. & Thiravetyan, P. (2018). Chlorophytum comosum bacteria interactions for airborne benzene remediation: effect of native endophytic *Enterobacter* sp. EN2 inoculation and blue-red LED light. *Plant Physiology and Biochemistry*, 130: 181–191. DOI: 10.1016/j.plaphy.2018.06.042.

Shameer, K.S., Nasser, M., Mohan, C. & Hardy, I.C. (2018). Direct and indirect influences of intercrops on the coconut defoliator *Opisina arenosella*. *Journal of Pest Science*, 91: 259–275. DOI: 10.1007/s10340-017-0904-6.

Singh, V.V., Naseer, A., Mogilicherla, K., Trubin, A., Zabihi, K., Roy, A., Jakuš, R. & Erbilgin, N. (2024). Understanding bark beetle outbreaks: exploring the impact of changing temperature regimes, droughts, forest structure and prospects for future forest pest management. *Review in Environmental Science and Bio/Technology*, 23: 257–290. DOI: 10.1007/s11157-024-09692-5.

Sivakumar, M.V.K. (2020). Climate extremes and impacts on agriculture," *Agronomy Monographs*. (2020): 621–647.

Skendžić, S., Zovko, M., PajačŽivković, I., Lešić, V., Lemić, D. & Ivanović, V. (2021). The impact of climate change on agricultural insect pests. *Insects*, 12 (5): 440. DOI: 10.3390/insects12050 440.

Sukendah, S. & Priyadarshini, R. (2023). Morpoloical diversity Kopyor coconut in Indonesia. *Plant Diversity in Biocultural*, DOI: 10.1007/978-981-19-8649-9_10.

Sukendah, S., Abidin, Z., Wiyatiningsih, S. & Wijayanti, B.W. (2011). Morphological characters of Kopyor coconut grown in Sumenep, Madura, Indonesia. Isnar C2FS Proceeding (pp. 245–254). Surabaya, June 27-28, 2011. Faculty of agriculture, Universitas pembangunan nasional "Veteran" Jawa timur. ISBN: 9786028915939.

Sukhirun, N., Sakulmak, C. & Keaubunsong, P. (2015). Life cycle of the coconut black-headed caterpillar, *Opisina arenosella* Walker (Lepidoptera: Oecophoridae) cultured at room temperature. *Songklanakarin Journal of Science and Technology*, 2: 43–46.

Syazwan, S.A., Lee, S.Y., Sajap, A.S., Lau, W.H., Omar, D. & Mohamed, R. (2021). Interaction between *Metarhizium anisopliae* and its host, the subterranean termite *Coptotermes curvignathus* during the infection process. *Biology,* 10 (4): 263. DOI: 10.3390/biology10040263.

van Huis, A. & Gasco, L. (2023). Insects as feed for livestock production. *Science*, 379 (6628): 138–139. DOI:10.1126/science.adc9165.

Velasco-Hernandez, M.C., Shameer, K.S., Nasser, M., Moya, G. & Hardy, I.C.W. (2021). Contests between beneficial natural enemies: brood guarding parasitoids vs. foraging predators. *Entomologia Experimentalis et Applicata*, 169: 209–218. DOI: 10.1111/eea.12996.

Wahyuni, R.S., Triwidodo, H. & Anwar, R. (2025). The effectiveness of three entomopathogenic fungi against the brown planthopper, *Nilaparvata lugens* Stal (Hemiptera: Delphacidae) in rice nurseries. *IOP Conf. Ser.: Earth Environmental. Science,* 1494 (1): 012027. DOI:10.1088/1755-1315/1494/1/012027.

Wang, X., Qu, L., Mao, Q., Watanabe, M., Hoshika, Y., Koyoma, A., Kawaguchi, K., Tamai, Y. & Koike, T. (2015). Ectomycorrhizal colonization and growth of the hybrid larch F1 under elevated CO_2 and O_3. *Environmental Pollution*, 197: 116–126. DOI: 10.1016/j.envpol.2014.11.031.

Wei, B., Zhang, D., Wang, G., Liu, Y., Li, Q., Zheng, Z., Yang, G., Peng, Y., Niu, K. & Yang, Y. (2023). Experimental warming altered plant functional traits and their coordination in a permafrost ecosystem. *New Phytologist*, 240 (5): 1802–1816. DOI: 10.1111/nph.19115.

Yunindanova, M.B., Putri, S.P., Novarianto, H. & Fukusaki, E. (2024). Characteristics of Kopyor coconut (*Cocos nucifera* L.) using sensory analysis and metabolomics-based approach. *Journal of Bioscience and Bioengineering*, DOI: 10.1016/j.jbiosc.2024.02.008.

Yusup, C.A. (2021). The first record of the incidence of *Opisina arenosella* infestation on coconut plants in Indonesia and its potential for biotechnological control. In Kresnawaty, I., Prakoso, H.T., Saptari, R.T., Aziz, M.A., Fadila, H., editor. Sustainable Innovation in Improving the Quality of Human Life. Proceedings of the National Biotechnology Seminar II; October 13-14, 2021; Bogor, Indonesia. Center for Biotechnology and Bioindustry Research Indonesia. pp. 37–44.

Yuya, A.I., Degaga, E.G., Degefu, D.T. & Bekele, G.D. (2025). Impact of maize-legume intercropping systems on fall armyworm, *Spodoptera frugiperda (J.E. Smith)* infestation levels and natural enemy complex. *International Journal of Tropical Insect Science,* 45: 989–1005. DOI: 10.1007/s42690-02 5-01487-7.

Zhang, W., Feng, Z., Wang, X. & Niu, J. (2012). Responses of native broadleaved woody species to elevated ozone in subtropical China. *Environmental Pollution*, 163: 149–157. DOI: 10.1016/j.envpol.2011.12.035.

Zhao, T., Tian, H., Xia, Y. & Jin, K. (2019). MaPmt4, a protein O-mannosyltransferase, contributes to cell wall integrity, stress tolerance and virulence in *Metarhizium acridum. Current Genetics*, 65: 1025–1040. DOI: 10.1007/s00294-019-00957- z.

Zhou, J., Luo, W., Song, S., Wang, Z., Zhu, X., Gao, S., He, W. & Xu, J. (2024). The impact of high-temperature stress on the growth and development of *Tuta absoluta* (Meyrick). *Insects,* 15 (6): 423. DOI: 10.3390/insects 15060423.

Zvereva, E.L. & Kozlov, M.V. (2010). Responses of terrestrial arthropods to air pollution: A meta-analysis. *Environmental Science and Pollution Resource*, 17: 297–3.