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Effects of Cropping Systems and Fruit Maturity on Infestation and Internal Population of Coffee Berry Borer in Arabica Coffee

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Abstract

The coffee berry borer (CBB), *Hypothenemus hampei*, remains the most destructive pest affecting Arabica coffee production in Indonesia. While its general biology is well-known, there is a significant knowledge gap regarding how different agro-ecosystems and host maturity stages influence the pest's internal population dynamics and reproductive fitness. This study aims to evaluate the interplay between three cropping systems (monoculture, coffee-orange intercropping, and coffee-vegetable intercropping) and fruit maturity stages (green, yellow, and red) on CBB infestation levels and its internal life stages. The research was conducted from December 2021 to Februari 2022 in Karo Regency, North Sumatra, Indonesia. A total of 1 kg of coffee berries per replicate was collected and all bored berries were dissected under a stereomicroscope to quantify eggs, larvae, pupae, and adults. Data were analyzed using Generalized Linear Models (GLM) and Tukey's HSD test. Results indicated that the monoculture system recorded the highest infestation levels, while the coffee-orange intercropping significantly reduced borer pressure, which may be associated with increased habitat complexity and possible olfactory interference. Green berries appeared less suitable for larval development, characterized by high adult penetration but failed larval development due to insufficient endosperm hardness. These findings underscore the importance of habitat complexity and timely harvesting as critical components of site-specific Integrated Pest Management (IPM) strategies to disrupt the CBB life cycle in the Indonesian highlands.

Keywords: *Hypothenemus hampei*, cropping systems, fruit maturity, internal population, North Sumatra

INTRODUCTION

Indonesia is recognized as one of the world's top five coffee-producing nations, with Arabica and Robusta serving as the primary cultivated varieties. Around 90% of Indonesia's coffee production is exported, while domestic consumption has shown a consistent upward trend, further increasing overall demand (Ramadhillah & Masjud, 2024). Despite this strong production capacity, the sustainability of coffee production is threatened by insect pest infestations. Among the most destructive pests is the Coffee Berry Borer (CBB), *Hypothenemus hampei* (Ferrari), which infests Arabica coffee (*Coffea arabica*) (Johnson *et al.,* 2020a).

The coffee berry borer (CBB) is a cryptic pest that spends most of its life cycle inside the coffee berry, where it bores into the fruit, feeds on the endosperm, and reproduces. This behavior causes significant economic losses by reducing both yield and the physical quality of the beans (Moreno-Ramírez *et al.*, 2026).

Effective management of this pest requires a deep understanding of its ecological preferences, particularly how it responds to the surrounding environment and the physiological state of its host. The severity of *H. hampei* infestation is often first evaluated through overall infestation rates, which provide a baseline for the pest pressure within a specific region. These broad metrics are heavily influenced by the cropping system and the surrounding agro-ecosystem (Tejada *et al.*, 2025). Variations in land management from intensive monocultures to complex shaded polycultures significantly alter the microclimate (Scordia *et al.*, 2023). Factors such as shade-driven temperature reductions and increased humidity play a critical role in the dispersal and survival rates of the borer (Abewoy, 2022). Understanding the overall infestation across different land types is the first step in identifying high-risk areas within a plantation (Mahob *et al.*, 2022). However, a comprehensive understanding of CBB ecology requires looking beyond general infestation levels to the interplay between the environment and host phenology. The physiological state of the coffee berry, specifically its maturity stage, is a primary driver for CBB host selection. This selection process is largely governed by the developmental regulation of Volatile Organic Compounds (VOCs) that act as potent olfactory cues. While classic attractants such as methanol and ethanol have been widely studied, recent evidence highlights the critical role of specific terpenes, particularly limonene and pinene, in host recognition. The biosynthesis of these compounds is developmentally regulated, with limonene synthase expression reaching its peak in ripe (red) fruits—a stage that correlates directly with maximum CBB attraction (Figueroa-Varela *et al.*, 2025). Consequently, the transition from green to red berries does not only offer a visual signal but also an intensified chemical 'map' that guides the borer toward the most suitable hosts for reproductive success (Figueroa-Varela *et al.*, 2025).

Despite these biochemical insights from laboratory settings, a significant knowledge gap persists regarding how sensory-driven preferences translate into internal population dynamics—specifically the ratio of larvae to imago—and overall borer fitness across diverse Indonesian agro-ecosystems. Beyond surface-level infestation, these internal dynamics (comprising eggs, larvae, pupae, and adults) offer a more profound metric of pest fitness. Relying solely on the percentage of infested berries (external infestation) fails to capture the true potential for future outbreaks. Thus, identifying the specific life stages within berries of varying maturity is vital to distinguish whether a fruit serves merely as a temporary refuge or as a productive 'nursery' for a succeeding generation. Therefore, this study aims to evaluate the combined influence of cropping systems and fruit maturity stages on both the overall infestation levels and the internal population dynamics of *H. hampei*. By analyzing the ratio of larvae to imago across various land types and berry ripeness, this research seeks to bridge the gap between landscape ecology and pest biology. The findings are expected to provide a scientific basis for developing site-specific Integrated Pest Management (IPM) strategies to disrupt the borer's life cycle in Arabica coffee plantations.

MATERIALS AND METHODS

Study Site and Experimental Design

The research was conducted from December 2021 to February 2022 within Arabica coffee (*Coffea arabica*) plantations located in Karo Regency, North Sumatra, Indonesia (02°50' – 03°19' North Latitude and 97°55' – 98°38' East Longitude. The study sites were situated in the highlands, with elevations ranging from approximately 1,100 to 1,450 m above sea level (asl.), a region characterized by a cool tropical climate ideal for Arabica cultivation (Figure 1). To evaluate the impact of land management on pest dynamics, the study utilized a structured design involving three distinct cropping systems:

1. Monoculture coffee (intensive management with minimal shade).
2. Coffee intercropped with orange (Citrus sp.).
3. Coffee intercropped with seasonal vegetables.

The experiment followed a randomized block design with three treatments each replicated three times across the designated sites.

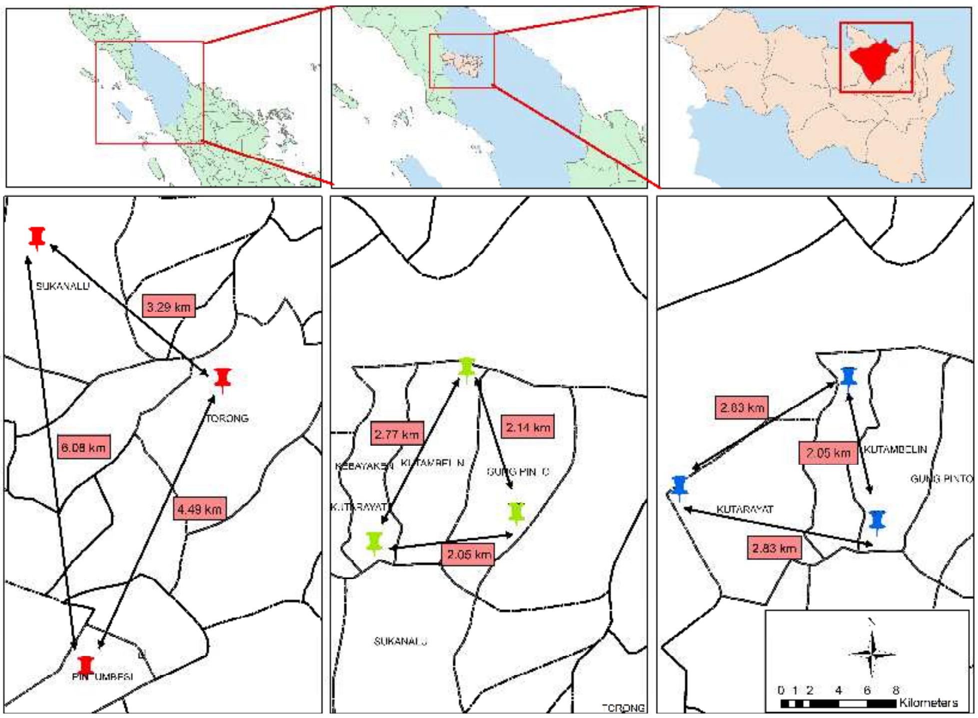

Figure 1. Spatial distribution of sampling locations

Sampling Procedure and Fruit Categorization

Sampling was conducted during the non-peak harvesting season to minimize bias associated with the excessive abundance of ripe berries during peak harvest and to allow clearer observation of host selection by the coffee berry borer, *Hypothenemus hampei*.

Three cropping systems were evaluated: (1) monoculture coffee, (2) coffee intercropped with orange (Citrus sp.), and (3) coffee intercropped with seasonal vegetables. Each cropping system was represented by three farmer-managed fields as replicates, resulting in a total of nine sampling sites. To ensure comparability among sites, selected fields met the following criteria: a minimum area of 0.5 ha, coffee plant age above five years, and a minimum population of 500 coffee trees per field. These criteria were established to reduce variation associated with field size, plant age, and stand density.

In each replicate field, a composite sample of 1 kg of freshly harvested Arabica coffee berries (approximately 350–450 berries) was randomly subsampled from the total harvest collected by farmers during routine harvesting activities. Farmers were instructed to harvest berries following their normal practices without prior selection based on visible pest damage, in order to minimize sampling bias and better represent field infestation conditions.

The collected berry samples were transported to the laboratory and sorted according to fruit maturity stage based on pericarp color: (1) Green (immature fruits) (2) Yellow (semi-ripe fruits), and (3) Red (fully ripe fruits).

Laboratory Analysis and Internal Population Assessment

To assess overall infestation levels, the percentage of bored berries was calculated for each sample using the following formula:

Infestation (%) =

(number of bored berries/total number of observed berries) × 100

Only berries showing visible entry holes caused by Hypothenemus hampei were selected for dissection. Each bored berry was carefully opened under a stereomicroscope to examine the internal population. Detailed observations were conducted to quantify all developmental stages present within each infested berry, including eggs, larvae (all instars), pupae, and adults (imago). The total number of individuals per developmental stage was recorded for each berry and subsequently pooled at the sample level for analysis. In addition, the larvae-to-adult ratio was calculated as a proxy for reproductive success and to evaluate the suitability of berries at different maturity stages as reproductive sites for the development of subsequent generations.

Statistical Analysis

All gathered data regarding infestation levels and internal pest populations were analyzed using Generalized Linear Models (GLM) to account for the interplay between cropping systems and maturity stages. The analysis was performed using RStudio software. To determine significant differences between treatment means, Tukey's Honestly Significant Difference (HSD) post-hoc test was applied at a 5% significance level (± = 0.05).

RESULTS AND DISCUSSION

Evaluation of Habitat Heterogeneity and Precipitation on Overall CBB Infestation Levels

The analysis of overall infestation rates reveals a significant disparity between the three evaluated agro-ecosystems, demonstrating that habitat complexity is a primary driver of *H. hampei* population pressure. Our findings indicate that the monoculture system consistently exhibited the highest percentage of bored berries. This phenomenon can be explained through the *'Resource Concentration Hypothesis'* where a simplified landscape with high host density (*C. arabica*) minimizes the energetic 'searching cost' for female borers (Figure 2.) (Gonzalez & Grezz, 1995; (Lanta *et al*., 2025). In such environments, the continuous availability of host plants and a more stable microclimate favor rapid colonization and high dispersal efficiency, as the beetles do not need to navigate through non-host vegetation(Vázquez & Jacques, 2019). Furthermore, the lack of shade in monocultures leads to increased canopy temperatures and lower relative humidity—conditions known to accelerate the metabolic rates and flight initiation of the CBB, which typically prefers temperatures between 20°C and 30°C for optimal activity (Mariño *et al*., 2016).

The environmental context of the Karo highlands plays a critical role in sustaining these populations. Based on the historical rainfall data from 2013 to 2022 (Figure 3.), the region has consistently experienced high annual precipitation, with 2022 recording approximately 3,000 mm. This high rainfall regime, despite showing a slight fluctuation from the peak in 2019 (approx. 4,500 mm), maintains a consistently high relative humidity (>80%) within the coffee canopy. Such micro-humid conditions are essential for CBB survival, as they prevent the desiccation of eggs and larvae inside the galleries (Jaramillo *et al*., 2009). However, high precipitation also plays a dual role; while it favors internal development, heavy rain events can physically wash away dispersing females or promote the growth of entomopathogenic fungi, such as *Beauveria bassiana*, which naturally regulates CBB populations (Melissa A. & Manoukis, 2020). In contrast, the marked reduction in infestation within the Coffee-Orange intercropping system suggests a potent 'masking effect' or olfactory interference (Castro *et al*., 2017). Orange trees emit a diverse and intense profile of volatile organic compounds (VOCs), including limonene, citral, and various terpenes (Góngora *et al*., 2020). These compounds

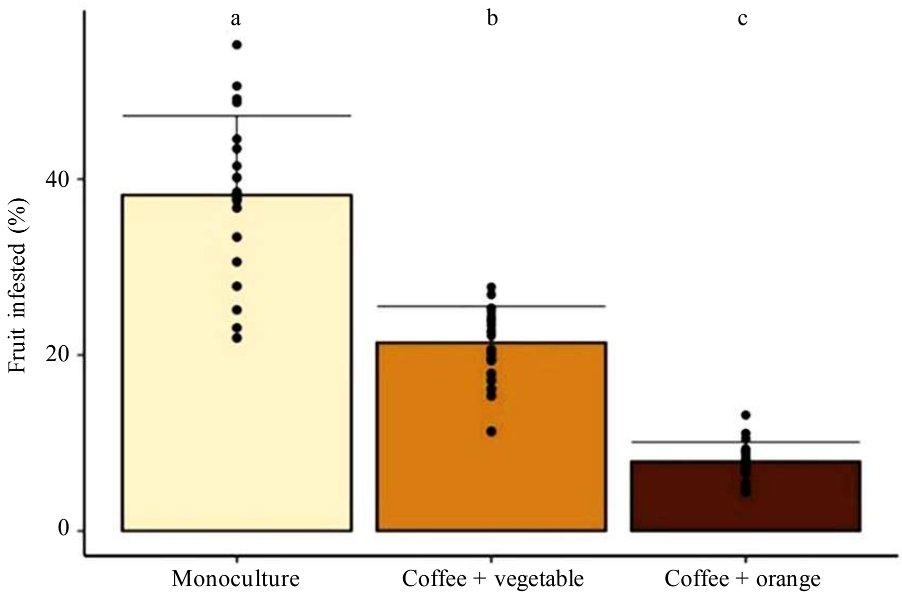

Figure 2. Comparison of fruit infestation among cropping systems

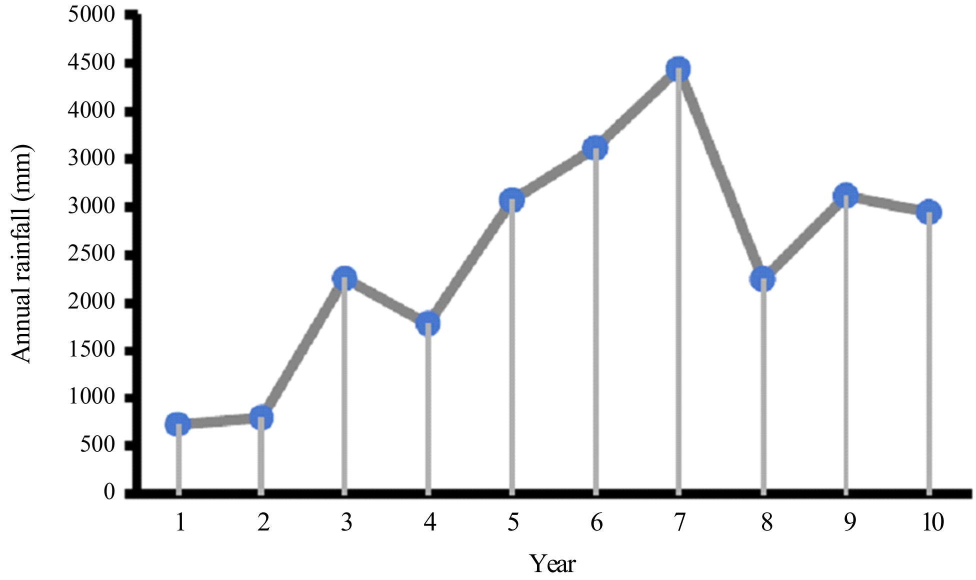

Figure 3. Annual rainfall variation in Karo Regency (2013–2022)

likely create 'chemical noise' that overlaps with or antagonizes the specific olfactory plume (e.g., ethanol and methanol) emitted by ripening coffee berries (Figueroa-Varela *et al*., 2025). From a neuroethological perspective, this interference disrupts the borer's highly specialized antennal receptors, significantly hindering its ability to discriminate and locate suitable hosts amidst a heterogenic chemical background (Kumar *et al*., 2024). Despite the high rainfall in 2022 which generally favors pest development, the chemical and physical barriers in intercropped systems remained effective in suppressing colonization.

Additionally, the Coffee-Vegetable system showed intermediate infestation levels, providing a degree of 'associational resistance' The concept of intermediate infestation in Coffee–Vegetable systems is well-supported in agroecology: such systems typically provide partial (not maximal) associational resistance. This occurs because added plant diversity begins to interfere with pest behavior and supports some natural enemies, but does not yet reach the structural and functional complexity of full agroforestry systems. As a result, pest suppression is measurable but incomplete, which is exactly what "intermediate infestation" implies (Venzon, 2021). Although seasonal vegetables provide limited volatile-mediated interference compared to citrus, their contribution to habitat heterogeneity and microclimate regulation—particularly through reduced light intensity and increased humidity—likely impairs Hypothenemus hampei flight and host-location efficiency, resulting in lower infestation than in open monocultures (Moreno-Ramirez *et al*., 2024). The presence of non-host barriers increases the 'environmental grain', forcing the borer to spend more time in flight and increasing its exposure to mortality factors, such as the heavy rainfall typical of the Karo Regency. Collectively, these results underscore that maintaining landscape complexity in the Karo highlands serves as a fundamental ecological strategy to dampen the initial pressure of CBB outbreaks by disrupting both the sensory cues and the physical dispersal of the pest.

Host Preference and Fruit Maturity

The physiological state of the coffee berry, specifically its maturity stage, serves as a primary driver for *H. hampei* host selection and reproductive success (Gongora *et al*, 2026). Our findings demonstrate a significant preference for red (fully ripe) berries across all cropping systems, followed by yellow (semi-ripe) and green (immature) fruits. This hierarchy is likely associated with changes in volatile organic compound (VOC) emissions during fruit development, which may enhance the olfactory attractiveness of ripe berries, although VOCs were not directly measured in this study (Rodríguez *et al.*, 2013). While classic attractants such as methanol and ethanol are present in ripening fruits, emerging evidence suggests that specific terpenes, including limonene and pinene, may play a key role, as their emissions tend to increase and peak in fully ripe (red) fruits. This transition from green to red berries may creates an intensified chemical 'map' that guides the female borer toward the most suitable hosts for offspring survival (Figueroa-Varela *et al.*, 2025).

Interestingly, the presence of adults in green berries (Figure 5.), despite the low overall infestation, may indicate exploratory behavior consistent with a "test-boring" phenomenon (Johnson *et al.*, 2020b). In these immature fruits, the high number of adults coupled with the near absence of eggs and larvae suggests that, although females can penetrate the pericarp, the internal conditions may not be conducive to successful colonization and reproduction (Aristizábal *et al.*, 2023). The apparent resistance of green berries is likely associated with both chemical and physical barriers. Immature fruits often contain higher concentrations of secondary metabolites, such as chlorogenic acids and caffeine, which function as anti-feedants or toxic deterrents, particularly affecting early larval development, consistent with ontogenetic defense theory (Boege & Marquis, 2005; (Barton & Koricheva, 2010); (Al-Khayri *et al.*, 2023). Physically, the milky or soft-paste endosperm of green fruits likely lacks the structural integrity required for stable gallery construction. In the absence of a sufficiently hardened substrate, galleries

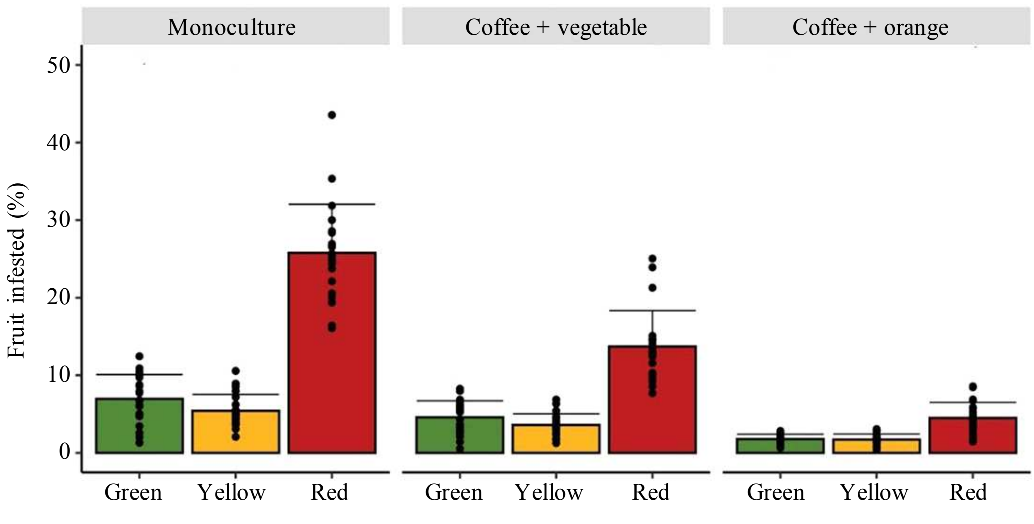

Figure 4. Fruit infestation across cropping systems and fruit maturity stages

may be unstable or difficult to maintain, and the high moisture content of immature beans may further compromise larval survival (Vega *et al.*, 2019; Johnson *et al.*, 2020b;).

In contrast, the red berries provide the optimal balance of nutritional quality and physical stability. The hardening of the endosperm (dry matter >20%) provides a solid foundation for the borer to expand its maternal gallery and protect its brood from environmental fluctuations (Baker *et al.*, 1992; Damon, 2000;Jaramillo *et al.*, 2006; Aristizábal *et al.*, 2023). Our data indicates that the transition to the ripe stage triggers a shift in borer behavior from host-seeking (sampling) to reproductive investment (oviposition) (Aristizábal *et al.*, 2023). Thus, while green and yellow berries may serve as temporary refuges or demographic sinks due to limited reproductive success, red berries function as the primary source of population growth, as oviposition and brood development occur only after sufficient endosperm maturation (Johnson *et al.*, 2020b). This distinction is vital for management strategies, as it underscores that the presence of holes in green berries does not necessarily equate to a productive breeding site, whereas every infested red berry represents a potential launchpad for the next generation.

Internal Population Dynamic

The internal population dynamics across different maturity stages reveal that red berries serve as the primary biochemical nursery for *H. hampei*. As illustrated in Figure 5, there is a significant "population explosion" exclusively within the red berries, where the numbers of eggs, larvae, and imago are dramatically higher compared to the green and yellow stages. This confirms that once a female colonizes a ripe fruit, it shifts from dispersal and host-seeking to reproductive investment, initiating oviposition within the endosperm where population growth occurs (Johnson *et al.*, 2020b;Mariño *et al.*, 2016; (Aristizábal *et al.*, 2016). The hardened endosperm of red fruits likely provides a more suitable physical substrate for gallery expansion, while also offering nutritional conditions that can support the development of a larger brood (Strong *et al.*, 2023)

A critical observation from the data is the high density of eggs and larvae in red berries compared to their near-absence in green fruits. This disparity reinforces the 'test-boring' hypothesis discussed in Section 3.2; while imago counts are present in green berries, the failure to produce a significant number of offspring (eggs/larvae) indicates a lack of host acceptance or high larval mortality due to the chemical deterrents (chlorogenic acids) and high moisture content of immature beans (Damon, 2000). In red berries, however, the successful transition from egg to larvae identifies these fruits as a potent ecological 'source' for the next generation of CBB (Mariño *et al.*, 2021)

Furthermore, the data shows a consistently lower population of pupae across all stages, including red berries, when compared to larvae and imago. This phenomenon points toward a rapid generation turnover or a highly synchronized developmental transition (Azrag *et al.*, 2020). In the tropical highland climate of Karo, the pupal stage likely represents a brief physiological 'bridge,' allowing for the rapid emergence of new adults to exploit the remaining ripe harvest. The high count of imago in red berries, often exceeding 100-200 individuals per sample in some cases (as shown by the data points), underscores the massive capacity of a single fruit to act as an inoculum source.

From a management perspective, these results highlight the necessity of sanitation (*lelesan*) and timely harvesting. Since red berries function as the "reproductive engine"

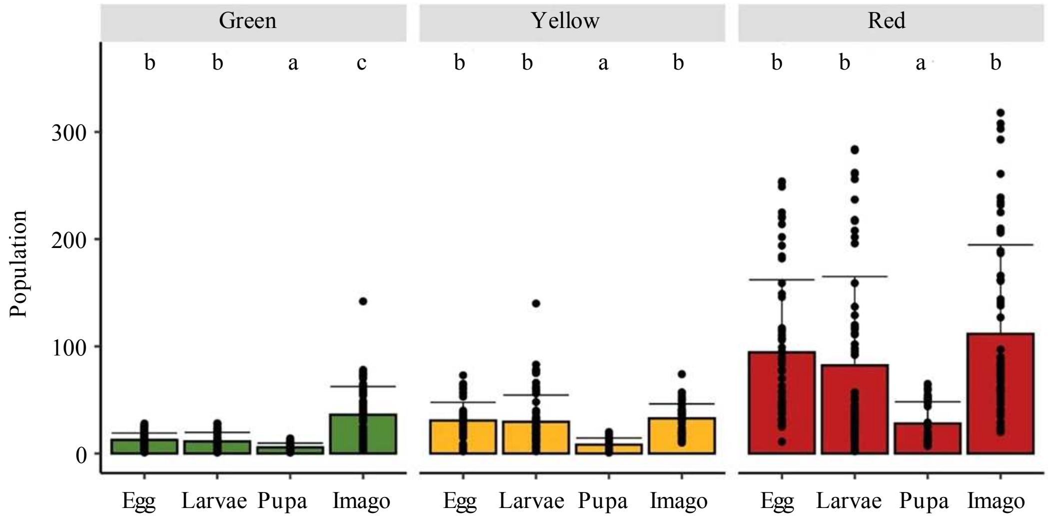

Figure 5. Population distribution across developmental stages and fruit maturity levels

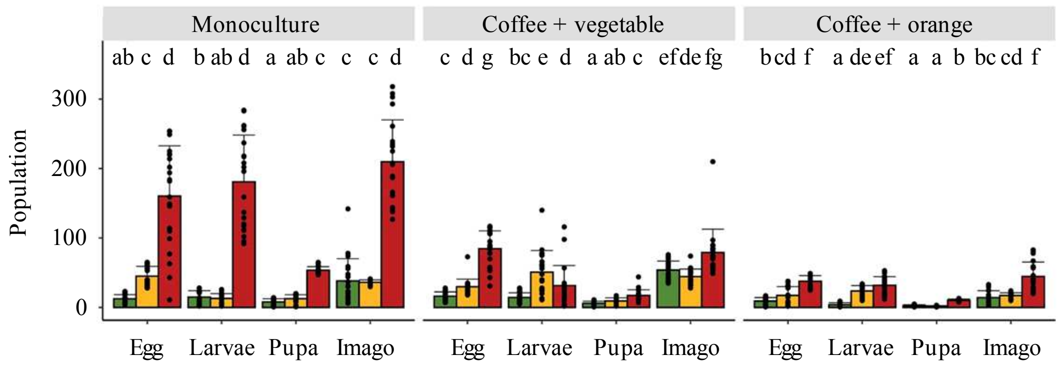

Figure 6. Developmental stage composition of *Hypothenemus hampei* in coffee berries across cropping systems and fruit maturity stages

of the infestation, leaving them on the tree or ground provides a continuous supply of new adults. By targeting the removal of these high-capacity nurseries, farmers in North Sumatra can effectively break the borer's life cycle and dampen future outbreak pressures.

Practical Implications for Integrated Pest Management (IPM)

The findings of this study offer a robust scientific framework for refining Integrated Pest Management (IPM) strategies specifically tailored for the Arabica coffee landscapes of the Karo highlands. Our results underscore that habitat diversification, particularly through Coffee-Orange intercropping, serves as a non-chemical primary defense. By leveraging the potential "masking effect" of non-coffee plant VOCs (volatile organic compounds), farmers can naturally reduce the colonization rate of *H. hampei* without sole reliance on synthetic insecticides, as habitat complexity and intercropping systems are known to disrupt pest host-location behavior and enhance ecological control (Bhattacharyya *et al.*, 2026). This ecological approach is particularly vital given the high annual precipitation in the region (approx. 3,000 mm), which often reduces the persistence and effectiveness of foliar-applied chemical treatments, making biological and structural barriers more cost-effective and sustainable (Haider *et al*., 2026; Góngora *et al.*, 2023).

Furthermore, the clear identification of red berries as the critical "reproductive engine" (as shown by the high larvae-to-imago ratio in Section 3.3) dictates the timing and intensity of field interventions. Management efforts must prioritize sanitation (lelasan) and rapid harvesting cycles to remove these high-capacity nurseries from the field before the next generation of adults emerges, as IPM programs consistently highlight the importance of targeting reproductive sites within mature berries (Góngora *et al*., 2023). Since green berries primarily serve as temporary "sinks" or early colonization sites, the presence of borer holes in immature fruits should not trigger immediate chemical intervention, but rather serve as an early warning for an impending surge in the red berry population.

Lastly, the high rainfall patterns observed from 2013 to 2022 suggest that IPM programs in North Sumatra must account for micro-humid stability. In high-moisture environments, the application of entomopathogenic fungi such as *Beauveria bassiana* may be highly effective, as consistent humidity enhances fungal infection, sporulation, and persistence in the field (Bhattacharyya *et al*., 2026; Góngora *et al*., 2023). By integrating habitat complexity, rigorous sanitation of ripe fruits, and climate-adaptive biological controls, a more resilient coffee production system can be established—ensuring both the yield and the quality of North Sumatran Arabica for the international market.

REFERENCES

Abewoy, D. (2022). Impact of Coffee berry borer on Global Coffee Industry: Review. *International Journal of Novel Research in Engineering and Science*, 9(8). www.noveltyjournals.com.

Al-Khayri, J.M.; R. Rashmi; V. Toppo; P.B. Chole; A. Banadka; W.N. Sudheer; P. Nagella; W.F. Shehata; M.Q. Al-Mssallem; F.M. Alessa; M.I Almaghasla & A.A.S. Rezk (2023). Plant Secondary Metabolites: The Weapons for Biotic Stress Management. *Metabolites,* 13(6). MDPI. https://doi.org/10.3390/metabo13060716.

Aristizábal, L.F.; A.E. Bustillo & S.P Arthurs. (2016). Integrated pest management of coffee berry borer: Strategies from latin america that could be useful for coffee farmers in Hawaii. *Insects*, 7(1). MDPI AG. https://doi.org/10.3390/insects7010006.

Aristizábal, L.F.; M.A. Johnson; Y.A. Mariño; P. Bayman & M.G. Wright (2023). Establishing an Integrated Pest Management Program for Coffee Berry Borer (*Hypothenemus hampei*) in Hawaii and Puerto Rico Coffee Agroecosystems: Achievements and Challenges. *Insects*, 14(7). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/insects14070603.

Azrag, A.G.A.; A.A. Yusuf; C.W.W. Pirk; S. Niassy; K.K. Mbugua & R. Babin (2020). *Temperature-dependent development and survival of immature stages of the coffee berry borer Hypothenemus hampei (Coleoptera: Curculionidae)*.

Barton, K.E. & J. Koricheva (2010). The ontogeny of plant defense and herbivory: Characterizing general patterns using meta-analysis. *American Naturalist*, 175(4), 481–493. https://doi.org/10.1086/650722.

Bhattacharyya, P.N.; B.C. Nath; P. Sarma; J.F. Hussain; B. Sarma & D.J. Borgohain (2026). *Recent Advances in Entomo-pathogenic Fungi as Biocontrol Agents in the Management of Insect Pests in Agriculture*.

Castro, A.M.; J. Tapias; A. Ortiz; P. Benavides & C.E. Góngora (2017). Identification of attractant and repellent plants to coffee berry borer, Hypothenemus hampei. *Entomologia Experimentalis et Applicata*, 164(2), 120–130. https://doi.org/10.1111/eea.12604.

Damon, A. (2000). A review of the biology and control of the coffee berry borer, Hypothenemus hampei (Coleoptera: Scolytidae). *Bulletin of Entomological Research*, 90.

Figueroa-Varela, P.A.; C.P. Martínez; J. Tapias; A. Ortiz; B.E. Mira-Rada; D. Villanueva-Mejía & C.E. Góngora (2025). Identification of two monoterpenes and their coding genes in *Coffea arabica* L. associated with the attraction of the coffee berry borer (*Hypothenemus hampei*). *Journal of Plant Interactions*, 20(1). https://doi.org/10.1080/17429145.2025.2591468.

Góngora, C.E.; Z.N. Gil; L.M. Constantino & P. Benavides (2023). Sustainable Strategies for the Control of Pests in Coffee Crops. *Agronomy*, 13(12). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/agronomy13122940.

Góngora, C.E.; J. Tapias; J. Jaramillo; R. Medina; S. Gonzalez; H. Casanova; A. Ortiz & P. Benavides (2020). Evaluation of Terpene-Volatile Compounds Repellent to the Coffee Berry Borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae). *Journal of Chemical Ecology*, 46(9), 881–890. https://doi.org/10.1007/s10886-020-01202-5.

Góngora, C.E.; C.P. Martinez; P.A. Figueroa-Varela & R. Medina-Rivera (2026). Preference of Hypothenemus hampei for coffee fruits according to state of maturation and infestation. *International Journal of Pest Management*, 72(2), 224-233.

Haider, K.; Abbas D.; Ullah F. *et al.* (2026). Climate-driven insect pest outbreaks and food security risks: A review of adaptive strategies for resilient agriculture. *J. Pest. Sci.* 99(12). https://doi.org/10.1007/s10340-025-01985-0.

Jaramillo, J.; C. Borgemeister & P. Baker (2006). Coffee berry borer *Hypothenemus hampei* (Coleoptera: Curculionidae): searching for sustainable control strategies. *Bulletin of Entomological Research*, 96(3), 223–233. https://doi.org/10.1079/ber2006434.

Jaramillo, J.; A. Chabi-Olaye; H.M. Poehling; C. Kamonjo & C. Borgemeister (2009). Development of an improved laboratory production technique for the coffee berry borer *Hypothenemus hampei*, using fresh coffee berries. *Entomologia Experimentalis et Applicata*, 130(3), 275–281. https://doi.org/10.1111/j.1570-7458.2008.00820.x.

Johnson, M.A.; C.P. Ruiz-Diaz; N.C. Manoukis & J.C.V. Rodrigues (2020a). Coffee berry borer (Hypothenemus hampei), a global pest of coffee: Perspectives from historical and recent invasions, and future priorities. *Insects*, 11(12), 1–35. https://doi.org/10.3390/insects11120882.

Johnson, M.A.; C.P. Ruiz-Diaz; N.C. Manoukis & J.C.V. Rodrigues (2020b). Coffee berry borer (*Hypothenemus hampei*), a global pest of coffee: Perspectives from historical and recent invasions, and future priorities. *Insects*, 11(12), 1–35. https://doi.org/10.3390/insects11120882.

Kumar, A.; M. Kumar & V. Verma (2024). *New Entomology System*. Book Saga Publications.

Lanta, V.; P. Sebek; P. Kozel; J. Altman; R. Bače; Z. Chlumská; T. Černý; M. Dvorský; D. Hauck; K. Korznikov; J. Miklín; Š. Vodka; J. Doležal & L. Čížek (2025). Plant and saproxylic beetle dynamics during succession in lowland temperate broadleaf forests reveal only short periods of increased diversity. *Biological Conservation*, 308. https://doi.org/10.1016/j.biocon.2025.111258.

Mahob, R.J.; L. Baleba; P. Nwane; S.E. Enama; K. Mang'dobara; C. Félix Bilong Bilong & R. Hanna (2022). Spatio-temporal Patterns in Coffee Berry Borer Infestations in Robusta Coffee Plantations Across an Elevation Gradient in Cameroon, Central Africa. *International Journal* *of Agricultural Science. http://Iaras. Org/Iaras/Journals/Ijas*, 7, 6–18. http://iaras.org/iaras/journals/ijas.

Mariño, Y.A.; P. Bayman & A.M. Sabat (2021). Demography and perturbation analyses of the coffee berry borer *Hypothenemus hampei* (Coleoptera: Curculionidae): Implications for management. *PLoS ONE*, 16 (12 December). https://doi.org/10.1371/journal.pone.0260499.

Mariño, Y.A.; M.E. Pérez; F. Gallardo; M. Trifilio; M. Cruz & P. Bayman (2016). Sun vs. shade affects infestation, total population and sex ratio of the coffee berry borer (*Hypothenemus hampei*) in Puerto Rico. *Agriculture, Ecosystems and Environment*, 222, 258–266. https://doi.org/10.1016/j.agee.2015.12.031.

Melissa, A.J. & N.C. Manoukis (2020). Influence of seasonal and climatic variables on coffee berry borer (Hypothenemus hampei Ferrari) flight activity in Hawaii. *Plos One*, 1–14. https://doi.org/101371/journal.pone.0257861.

Mexico, S.; P.S. Baker; J.F. Barrera & A. Rivas (1992). Life-history studies of the coffee berry borer (Hypothenemus hampei, Scolytidae) on coffee trees in southern Mexico. *Conditions Journal of Applied Ecology*, 29(3).

Moreno-Ramirez, N.; F.J.J.A. Bianchi; M.R. Manzano & M. Dicke (2024). Ecology and management of the coffee berry borer (*Hypothenemus hampei*): The potential of biological control. *BioControl*, 69(2), pp. 199–214. Springer Nature. https://doi.org/10.1007/s10526-024-10253-6.

Moreno-Ramírez, N.; F.J.J.A. Bianchi; M.R. Manzano; F. Martinez-Hofmans & M. Dicke (2026). Coffee berry borer infestations and natural enemy communities shaped by altitude, shade, and management practices. *Agriculture, Ecosystems and Environment*, 395. https://doi.org/10.1016/j.agee.2025.109944.

Ramadhillah, B. & Y.I. Masjud (2024). Climate change impacts on coffee production in Indonesia: A review. *Journal of Critical Ecology*, 1(1), 1–7. https://doi.org/10.61511/jcreco.v1i1.645.

Ramesha, N.M.; D. Mahanta; G.S. Sujatha; S. Hazarika; S. Parmar; B. Bala; C.K. Panigrahi; A.N. Warghat & K.S.S. Teja (2024). Understanding Insect Behavior and Physiology for Effective Pest Management. *Uttar Pradesh Journal of Zoology*, 45(14), 312–323. https://doi.org/10.56557/upjoz/2024/v45i144208.

Rodríguez, A.; B. Alquézar & L. Peña (2013). Fruit aromas in mature fleshy fruits as signals of readiness for predation and seed dispersal. *New Phytologist*, 197(1), pp. 36–48). https://doi.org/10.1111/j.1469-8137.2012.04382.x.

Scordia, D.; S.A. Corinzia; J. Coello; R. Vilaplana Ventura; D.E. Jiménez-De-Santiago; B. Singla Just; O. Castaño-Sánchez; C. Casas Arcarons; M. Tchamitchian; L. Garreau; M. Emran; S.Z. Mohamed; M. Khedr; M. Rashad; R.S. Lorilla; A. Parizel; G. Mancini; A. Iurato; S. Ponsá; … G. Testa (2023). Are agroforestry systems more productive than monocultures in Mediterranean countries? A meta-analysis. *Agronomy for Sustainable Development*, 43(6). https://doi.org/10.1007/s13593-023-00927-3.

Strong, W.B.; A.C. Mangini & J.N. Candau (2023). Insects of Reproductive Structures. *Forest Entomology and Pathology: Volume 1: Entomology*, 1, pp. 523–579). Springer International Publishing. https://doi.org/10.1007/978-3-031-11553-0_16.

Tejada, D.A.C.; J.L. Parra; I. Grass & F.M. Schurr (2025). Coffee berry borer control, but not coffee yield, is mediated by non-additive interaction between birds and ants across different cultivation systems. *Basic and Applied Ecology*, 90, 1–10. https://doi.org/https://doi.org/10.1016/j.baae.2025.11.002.

Vázquez, L.L. & G.C. Jacques (2019). Dispersion and increase of natural enemies in agroecosystems. In *Natural Enemies of Insect Pests in Neotropical Agroeco-*

systems: Biological Control and Functional Biodiversity (pp. 49–62). Springer International Publishing. https://doi.org/10.1007/978-3-030-24733-1_5.

Vega, F.E.; L.T. Smith; N.M.J. Davies; J. Moat; T. Góral; R. O'Sullivan & A.P. Davis (2019). Elucidation of Hosts, Native Distribution, and Habitat of the Coffee Berry Borer (*Hypothenemus hampei*) Using Herbaria and Other Museum Collections. *Frontiers in Plant Science*, 10. https://doi.org/10.3389/fpls.2019.01188.

Venzon, M. (2021). Agro-Ecological Management of Coffee Pests in Brazil. *Frontiers in Sustainable Food Systems*, 5. Frontiers Media S.A. https://doi.org/10.3389/fsufs.2021.721117.

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