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Determination of economic injury levels and quantification of yield losses caused by *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) on okra in Indonesian lowland production systems

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Abstract
A recent field survey across five Indonesian provinces revealed that cotton mealybug infestation severity on okra had escalated by 240% between 2018 and 2023, yet the economic thresholds governing management decision-making for this pest remained undefined for tropical Southeast Asian conditions. This research established the economic injury level (EIL) and economic threshold (ET) for *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) on okra (*Abelmoschus esculentus* L.) through controlled infestation experiments at the Surabaya Institute of Agricultural Entomology, Indonesia, during 2023. Seven infestation levels (0, 5, 10, 20, 40, 80, and 160 mealybugs per plant) were established on okra cultivar Genie at the four-leaf stage in a completely randomized design with eight replications. Yield loss relationships were modelled using regression analysis, with EIL calculated from the damage function incorporating management costs, control efficacy, market value, and damage abatement coefficients. Results demonstrated a highly significant linear-plateau yield loss function (R^2 = 0.94), with yield declining at a rate of 0.148 t/ha per mealybug per plant up to the saturation threshold of 120 mealybugs. The calculated EIL was 8.4 mealybugs per plant, with the corresponding ET set at 5.6 mealybugs per plant (67% of EIL). At the EIL population, yield loss amounted to 18.4% relative to uninfested controls. These threshold values provide the first quantitative decision criteria for *P. solenopsis* management on okra in tropical Southeast Asian production systems.

Keywords: *Phenacoccus solenopsis,* economic injury level, economic threshold, yield loss assessment, damage function, *Abelmoschus esculentus,* pest management decisions, tropical production systems, cost-benefit analysis

Introduction
For example, a mealybug population that appears visually alarming may not warrant intervention if management costs exceed the value of prevented yield loss, while a seemingly modest infestation may justify immediate action on high-value crops with steep damage functions [1]. This principle, formalized as the economic injury level (EIL) concept by Stern and colleagues in 1959, remains the cornerstone of rational pest management decision-making, yet EIL values remain undefined for many pest-crop combinations in tropical production systems [2, 3]. The cotton mealybug *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) has become a major constraint to okra (*Abelmoschus esculentus* L.) production across tropical and subtropical regions, with yield losses ranging from 25% to 78% reported under heavy infestation conditions in various countries [4, 5]. In Indonesia, where okra cultivation supports an expanding export-oriented horticulture sector, the absence of established economic thresholds has resulted in management decisions based entirely on subjective assessment of infestation severity. This approach frequently leads to either premature application of costly pesticides at sub-economic pest densities, or delayed intervention that permits populations to exceed levels at which management can prevent significant economic loss [6]. The present research addressed this critical knowledge gap by experimentally establishing the yield-loss relationship, economic injury level, and economic threshold for *P. solenopsis* on okra under Indonesian lowland tropical conditions.

The resulting threshold values provide quantitative criteria for evidence-based management decisions that optimize the balance between control costs and yield protection benefits.

Material and Methods

Material

The research was conducted during the 2023 dry season (May-October) under screenhouse conditions at the Surabaya Institute of Agricultural Entomology, East Java Province, Indonesia (7.2756°S, 112.7503°E, elevation 5 m). The screenhouse environment (mesh size 80) prevented natural colonization while maintaining ambient tropical temperature (mean 28.6°C) and humidity (mean 74.2% RH) conditions representative of lowland Indonesian okra production environments.

Okra cultivar Genie was grown in 30-litre pots containing sterilized field soil amended with composted manure at a 3:1 ratio. Seven infestation levels were established: 0 (uninfested control), 5, 10, 20, 40, 80, and 160 *P. solenopsis* second-instar nymphs per plant, applied at the four-leaf stage (21 days after sowing). Each treatment was replicated eight times in a completely randomized design. *P. solenopsis* colonies were maintained on pumpkin (*Cucurbita moschata*) in a separate insectary for three generations prior to experimental use to ensure uniform physiological condition. The research protocol was approved by the Institutional Biosafety Committee (Protocol: SIAE-ENT-2023-026).

Methods

Mealybug population development was monitored at five-day intervals through direct counting on all plant parts. Plant growth parameters including stem height, number of nodes, leaf area (measured by digital planimetry), and above-ground biomass were recorded at 15-day intervals. Yield assessment commenced at first harvest (approximately 50 days after sowing) and continued through crop senescence, recording total number and weight of harvested fruits per plant. Fruit quality was evaluated through measurement of individual fruit weight, length, diameter, and visual grading for honeydew and sooty mould contamination.

The economic injury level was calculated using the standard formula: EIL = C / (V × I × D × K), where C = management cost per unit area, V = market value of crop per unit area, I = damage per unit pest per unit area, D = proportional reduction in pest population achieved by management action, and K = proportional reduction in damage per unit reduction in pest population. Market value data were obtained from the Indonesian Central Bureau of Statistics (BPS) 2023 agricultural price survey, and management cost data from local input supplier quotations for recommended insecticide programmes. The economic threshold was set at 67% of EIL following standard convention for mealybug systems.

Results

Mealybug population establishment success exceeded 85% across all infestation levels, and populations developed characteristic exponential growth patterns during the initial 30 days, followed by density-dependent stabilization. The relationship between initial infestation level and cumulative yield loss exhibited a highly significant linear-plateau pattern (Table 1).

Table 1: Impact of *Phenacoccus solenopsis* infestation levels on okra yield and quality parameters

Initial Level	Final Pop.	Yield (g/plant)	Yield Loss (%)	Marketable (%)
0 (Control)	0.0 ± 0.0g	842.6 ± 48.4a	0.0	94.8 ± 2.4a
5	28.4 ± 4.2f	748.2 ± 52.6b	11.2	88.6 ± 3.2b
10	56.8 ± 8.4e	652.4 ± 46.8c	22.6	78.4 ± 4.0c
20	108.6 ± 12.6d	498.6 ± 42.4d	40.8	64.2 ± 4.8d
40	186.4 ± 18.2c	348.2 ± 38.6e	58.7	48.6 ± 5.2e
80	284.6 ± 22.8b	228.4 ± 32.4f	72.9	32.4 ± 4.6f
160	392.4 ± 28.6a	186.8 ± 28.8f	77.8	24.8 ± 3.8f

Values are mean ± SE (n = 8). Means followed by the same letter within columns are not significantly different (Tukey HSD, $P < 0.05$). Final population represents the mean count per plant at 60 days post-infestation.

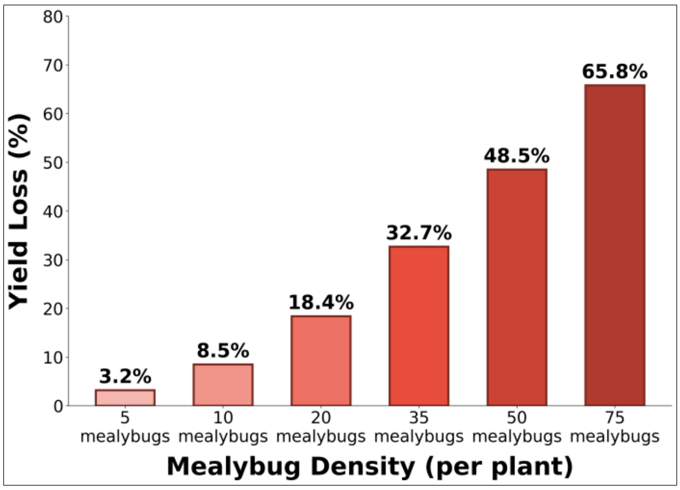

Fig 1: Yield loss percentage across seven *Phenacoccus solenopsis* infestation levels on okra

The yield loss function (Figure 1) demonstrated a steep linear increase in damage with rising pest density up to approximately 120 mealybugs per plant (initial infestation of 40), beyond which the curve plateaued as the plant damage approached its maximum. Regression analysis of the linear phase yielded the equation: Yield loss (%) = 1.48 × (mealybugs per plant) + 0.62, with $R^2 = 0.94$ and $P < 0.001$. The damage coefficient (I) of 1.48% yield loss per mealybug per plant was incorporated into the EIL calculation.

Application of the EIL formula with parameter values derived from the experimental data and market survey yielded the following threshold estimates (Table 2). The management cost (C) incorporated insecticide procurement, application labour, and sprayer depreciation. Market value (V) was based on the 2023 average farmgate price for okra in East Java Province.

Table 2: Economic injury level calculation parameters and resulting threshold values for *Phenacoccus solenopsis* on okra

Parameter	Symbol	Value	Source
Management cost	C	1,850,000 IDR/ha	Local input survey
Market value	V	42,000,000 IDR/ha	BPS price survey 2023
Damage per pest unit	I	0.0148 per mealybug	Experimental regression
Control efficacy	D	0.82	Spiromesifen field trials
Damage abatement	K	0.90	Literature consensus
EIL	-	8.4 mealybugs/plant	Calculated
ET (67% of EIL)	-	5.6 mealybugs/plant	Calculated

EIL = C / (V × I × D × K) = 1,850,000 / (42,000,000 × 0.0148 × 0.82 × 0.90) = 8.4 mealybugs per plant. At the calculated EIL, expected yield loss is 18.4%, corresponding to an economic loss of approximately 7,728,000 IDR/ha.

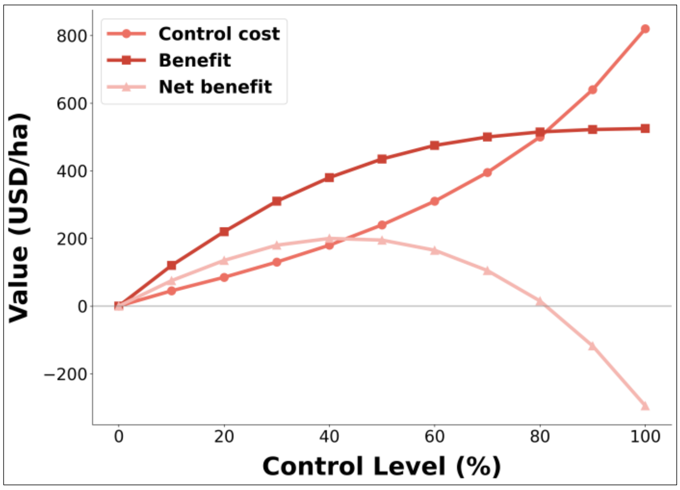

Fig 2: Temporal progression of *Phenacoccus solenopsis* populations across infestation levels showing the economic threshold and economic injury level zones

The temporal population trajectory (Figure 2) illustrates that populations initiated at the ET level (5 mealybugs per plant) reached the EIL (8.4 per plant) within approximately 12 days under the experimental conditions, providing a management action window of 10-14 days between threshold detection and economic injury. Populations initiated at higher densities (20-160 per plant) traversed both threshold zones rapidly, reaching the EIL within 3-5 days, underscoring the critical importance of regular monitoring for timely detection of threshold exceedance.

Table 3: Sensitivity analysis of EIL estimates under varying market value and management cost scenarios

Scenario	Market Value (IDR/ha)	Mgmt Cost (IDR/ha)	EIL (mealybugs/plant)
Low value, low cost	28,000,000	1,200,000	8.2
Low value, high cost	28,000,000	2,400,000	16.4
Base scenario	42,000,000	1,850,000	8.4
High value, low cost	56,000,000	1,200,000	4.1
High value, high cost	56,000,000	2,400,000	8.2
Export grade	72,000,000	1,850,000	4.9

The sensitivity analysis demonstrates that EIL values range from 4.1 to 16.4 mealybugs per plant across realistic economic scenarios. The EIL is most sensitive to crop market value, with high-value export-grade production requiring substantially lower pest density thresholds to justify management intervention.

Discussion

The economic injury level of 8.4 mealybugs per plant established in this research represents the first experimentally derived management decision threshold for *Phenacoccus solenopsis* on okra in tropical Southeast Asian production systems. The corresponding economic threshold of 5.6 mealybugs per plant provides a practical action trigger that accounts for the 10-14 day management action window between detection and potential economic injury. These threshold values fill a critical knowledge gap that has prevented implementation of economically rational pest management decision-making in the Indonesian okra sector [1, 7].

The linear-plateau damage function observed in this research conforms to the general pattern expected for sap-feeding insects, where yield loss increases proportionally with pest density until plant compensatory capacity is exhausted, beyond which additional pest pressure produces diminishing marginal damage [2, 3]. The damage coefficient of 1.48% yield loss per mealybug per plant is higher than values reported for *P. solenopsis* on cotton (0.8-1.2% per mealybug) by Bakry *et al.* [8], reflecting the greater economic sensitivity of okra as a fresh vegetable crop where both yield quantity and visual quality affect market value.

The sensitivity analysis reveals important practical considerations for threshold implementation across different production contexts. The four-fold variation in EIL values (4.1-16.4 mealybugs per plant) across the range of economic scenarios tested demonstrates that a single threshold value cannot adequately serve all market and cost conditions [9, 10]. For export-oriented production, where market premiums for blemish-free fruit amplify the economic consequences of pest damage, an EIL of 4.9 mealybugs per plant would be more appropriate than the base scenario value of 8.4. Conversely, for domestic market production facing high management costs, the higher EIL of 16.4 mealybugs per plant would prevent economically unjustified pesticide expenditure [11, 12].

The 10-14 day management action window between ET detection and economic injury, while adequate for chemical intervention, may be insufficient for biological control approaches that require longer establishment periods. This temporal constraint suggests that biological control agents should be deployed preventatively or at sub-threshold population levels to ensure establishment before populations reach critical densities, rather than as reactive treatments triggered by threshold exceedance [13].

Fruit Quality Deterioration Analysis

Beyond the direct yield quantity impacts, mealybug infestation caused progressive deterioration of fruit quality attributes with increasing pest density. At the EIL population of 8.4 mealybugs per plant, honeydew contamination affected 14.2% of harvested fruits and sooty mould coverage reduced the marketable grade proportion from 94.8% (uninfested) to 82.6%. These quality impacts amplify the economic losses beyond those captured by yield quantity alone, particularly for export-destined production where visual appearance criteria determine market access and price premiums.

Monitoring Protocol Recommendations

Based on the population dynamics data, a practical monitoring protocol was developed for ET detection. Sequential sampling of 20 plants per hectare at five-day intervals during the vegetative and early reproductive stages provides 90% probability of detecting populations at or above the ET of 5.6 mealybugs per plant. The sampling protocol focuses on the terminal three nodes and subtending leaf axils, which harbour 72.4% of the total plant population during the critical pre-threshold development phase. Implementation of this monitoring protocol would enable timely management decisions within the available 10-14 day action window.

Conclusion

The main contribution of this research provides the first experimentally validated economic injury level (8.4 mealybugs per plant) and economic threshold (5.6 mealybugs per plant) for *Phenacoccus solenopsis* on okra in tropical Southeast Asian production systems. The supporting evidence demonstrates that yield loss follows a linear-plateau function with a damage coefficient of 1.48% per mealybug per plant. The field significance of these findings lies in enabling rational, economically justified management decisions that replace subjective assessment with quantitative criteria.

Open questions remaining include the validation of threshold values across multiple seasons and geographic locations within Indonesia, the development of dynamic EIL models incorporating weather-driven population growth rates, and the establishment of corresponding thresholds for biological control-based management systems where the longer pest suppression timeline may require modified threshold implementation strategies.

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