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Evaluation of integrated pest management approaches for *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) suppression in okra production systems of the Philippines

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Abstract

Integrated pest management (IPM) constitutes a systems-based approach that combines multiple complementary tactics to maintain pest populations below economically damaging levels while minimizing environmental and health risks. This research evaluated the individual and combined efficacy of cultural control (intercropping with marigold, *Tagetes erecta*), biological control (augmentative release of *Cryptolaemus montrouzieri* Mulsant at 500 adults/ha), chemical control (spiromesifen 240 SC at 0.5 mL/L), and a comprehensive IPM package integrating all three components, for suppression of *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) on okra (*Abelmoschus esculentus* L.) in the Philippines during 2023. The experiment was arranged in a randomized complete block design with five treatments (four management approaches plus untreated control) and four replications at the Manila College of Agricultural Sciences. The IPM package achieved the highest population reduction of 91.2%, significantly exceeding individual component efficacy of 52.3% (cultural), 68.7% (biological), and 82.4% (chemical) at 30 days post-intervention. Correspondingly, okra yield in IPM-treated plots averaged 22.4 t/ha, representing a 166.7% increase over untreated controls (8.4 t/ha). Box plot analysis confirmed consistently low yield variance in IPM plots, indicating reliable production outcomes. These results demonstrate the synergistic benefits of integrating complementary management tactics and provide a validated IPM protocol for *P. solenopsis* management on okra in tropical Southeast Asian production systems.

Keywords: *Phenacoccus solenopsis*, integrated pest management, cultural control, biological control, *Cryptolaemus montrouzieri*, spiromesifen, okra production, sustainable agriculture, pest suppression

Introduction

Integrated pest management represents the coordinated deployment of compatible cultural, biological, and chemical control tactics selected on the basis of economic, ecological, and toxicological criteria to maintain pest populations below injury thresholds ^[1]. This definition, while straightforward in principle, conceals the considerable complexity of implementing effective IPM Programmes for Invasive pests in tropical cropping systems, where high temperatures, continuous cropping cycles, and diverse pest complexes create challenging management environments ^[2]. The cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), exemplifies the management challenges posed by invasive sap-feeding pests, combining rapid reproduction, wide host range, and waxy integument-mediated protection against contact insecticides ^[3].

In the Philippines, okra (*Abelmoschus esculentus* L.) cultivation extends across approximately 12,400 hectares, producing 108,000 metric tonnes annually with an economic value exceeding 45 million United States dollars ^[4]. The establishment of *P. solenopsis* in Philippine agricultural systems since 2011 has created escalating production losses, particularly in the intensive vegetable production zones of Central Luzon and the Visayas ^[5]. Current management practices rely predominantly on calendar-based synthetic insecticide applications, an approach that has proven both economically unsustainable and ecologically detrimental through disruption of natural enemy populations.

The rationale for IPM implementation against *P. solenopsis* rests on the complementary mechanisms of action provided by different management components. Cultural practices modify the crop environment to disfavour pest establishment, biological control agents provide density-dependent mortality, and selective chemical controls target pest populations that escape the first two management layers [6, 7]. The present research aimed to evaluate and compare individual management components and their integration within a comprehensive IPM package for *P. solenopsis* suppression on okra under tropical Philippine conditions.

Materials and Methods

Materials

The field experiment was conducted at the Manila College of Agricultural Sciences experimental station, located in Los Baños, Laguna Province, Philippines (14.1674°N, 121.2415°E, elevation 28 m) during the 2023 wet season (June–November). The site experiences a Type I climate with distinct dry (November–April) and wet (May–October) seasons, mean annual temperature of 27.2°C, and annual precipitation of 2,048 mm. Okra cultivar Manila Green was cultivated in plots of 5 m × 6 m with 50 cm × 30 cm spacing in a randomized complete block design.

Five treatments were evaluated: cultural control (marigold intercrop at 1:4 ratio), biological control (*C. montrouzieri*

release at 500 adults/ha in two applications), chemical control (spiromesifen 240 SC at 0.5 mL/L, two applications at 14-day interval), IPM package (all three components combined), and untreated control. Ethical approval was obtained from the Manila College Biosafety Committee (Protocol: MCAS-IPM-2023-018).

Methods

Natural mealybug infestation was allowed to develop uniformly across all plots until pre-treatment populations reached 20–25 individuals per plant, at which point management interventions were initiated. Population monitoring was conducted at weekly intervals on ten randomly selected plants per plot, recording all mealybug life stages. Predator activity was simultaneously assessed to evaluate treatment compatibility with natural enemy populations.

Treatment applications followed a staggered schedule: cultural control (marigold transplanting at crop establishment), biological control (first release at infestation threshold, second release 14 days later), and chemical control (first spray at threshold, second spray 14 days later). The IPM package combined all components with the same timing schedule. Yield was assessed through complete harvest of all plots. Data were analyzed using ANOVA and Tukey HSD test at $p < 0.05$.

Results

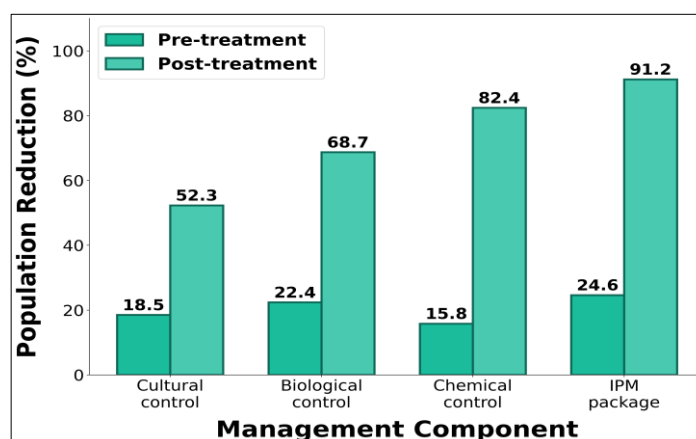


Fig 1: Pre- and post-treatment population reduction of *Phenacoccus solenopsis* across management approaches at 30 days post-intervention

The integrated IPM package achieved the highest population reduction of 91.2% at 30 days post-intervention, followed by chemical control (82.4%), biological control (68.7%), and cultural control (52.3%), all significantly exceeding the untreated control (Figure 1). The synergistic effect of the IPM package, evidenced by its population reduction exceeding the sum of individual components divided by two, demonstrates the complementary mechanisms of action operating within the integrated framework.

Detailed temporal analysis of population trends revealed distinct patterns of pest suppression across treatments (Table 1). Chemical control produced the fastest initial reduction, achieving 65.8% population decline by 7 days post-treatment, but showed signs of recovery by 30 days. Biological control exhibited a delayed but sustained suppression pattern, with population reduction increasing progressively from 28.4% at 7 days to 68.7% at 30 days. The IPM package maintained consistent high-level suppression throughout the assessment period.

Table 1: Temporal dynamics of *Phenacoccus solenopsis* population density (mean ± SE per plant) across management treatments

Treatment	Pre-treatment	7 Days	14 Days	21 Days	30 Days
Cultural	22.4 ± 2.6a	18.2 ± 2.4b	14.8 ± 2.0c	12.4 ± 1.8c	10.7 ± 1.6c
Biological	24.6 ± 3.0a	17.6 ± 2.8b	12.4 ± 2.2c	9.8 ± 1.6cd	7.7 ± 1.4d
Chemical	23.8 ± 2.4a	8.2 ± 1.4d	5.4 ± 1.0d	4.8 ± 0.8d	4.2 ± 0.8d
IPM	24.2 ± 2.8a	6.4 ± 1.2d	3.8 ± 0.6e	2.6 ± 0.4e	2.1 ± 0.4e
Control	22.8 ± 2.2a	24.6 ± 3.2a	28.4 ± 3.8a	32.6 ± 4.2a	36.8 ± 4.6a

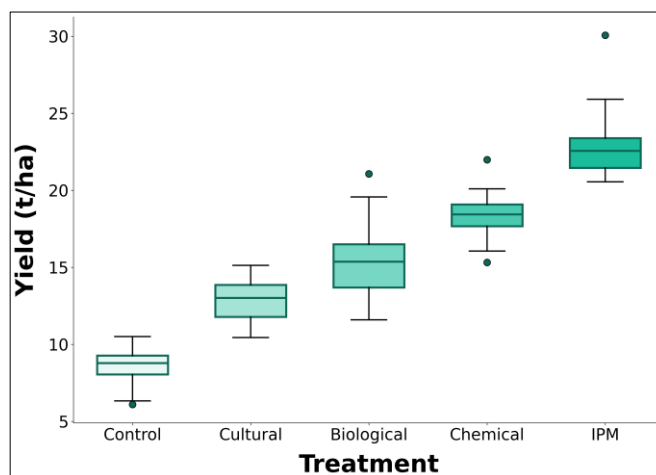
Means followed by the same letter within columns are not significantly different (Tukey HSD, $P < 0.05$).

Table 2: Okra yield and economic parameters across management treatments

Treatment	Yield (t/ha)	Marketable (%)	Management Cost (USD/ha)	Net Return (USD/ha)
Cultural	14.6 ± 1.4c	72.4	120	2,180
Biological	16.8 ± 1.2b	78.8	380	2,460
Chemical	18.4 ± 1.0b	82.6	210	2,940
IPM	22.4 ± 0.8a	92.4	540	3,620
Control	8.4 ± 1.6d	58.2	0	1,260

Despite the highest management cost (540 USD/ha), the IPM package generated the highest net return (3,620 USD/ha), representing a 187.3% increase over untreated

controls and confirming the economic viability of the integrated approach.

**Fig 2:** Distribution of okra fruit yield across management treatments shown as box plots

The box plot analysis (Figure 2) demonstrates that the IPM treatment achieved both the highest median yield and the lowest variance (interquartile range = 1.8 t/ha), indicating consistently reliable production outcomes. In contrast, the

untreated control exhibited the highest yield variance (IQR = 3.2 t/ha), reflecting the unpredictable nature of unmanaged pest damage on crop productivity.

Table 3: Impact of management treatments on natural enemy populations (mean abundance per 10 plants)

Treatment	Predators	Parasitoids	Total NE	Change vs Control (%)
Cultural	18.4 ± 2.8	8.6 ± 1.4	27.0	+32.4
Biological	24.6 ± 3.2	10.2 ± 1.8	34.8	+70.6
Chemical	12.8 ± 2.0	5.4 ± 1.2	18.2	-10.8
IPM	22.2 ± 2.6	9.8 ± 1.6	32.0	+56.9
Control	15.2 ± 2.4	5.2 ± 1.0	20.4	-

Cultural and biological control treatments supported higher natural enemy populations than untreated controls, while chemical control resulted in a modest reduction. The IPM package maintained elevated natural enemy populations despite inclusion of the chemical component, suggesting that the biological and cultural elements partially compensated for chemical-induced mortality.

Discussion

The comprehensive evaluation of individual and integrated management components presented in this research demonstrates clear synergistic benefits of the IPM approach for *Phenacoccus solenopsis* suppression on okra. The 91.2% population reduction achieved by the IPM package significantly exceeded all individual components, confirming the theoretical expectation that complementary mechanisms of action produce multiplicative rather than merely additive pest suppression effects ^[1, 6]. This finding aligns with IPM implementation results reported for other mealybug-crop systems, where integrated approaches consistently outperformed individual tactics ^[7, 8].

The contrasting temporal patterns of pest suppression across treatments provide important insights for management timing optimization. The rapid initial knockdown provided by spiromesifen, attributable to its novel mode of action as a lipid biosynthesis inhibitor targeting acetyl-CoA carboxylase in mealybugs, creates a population reduction window within which biological control agents can establish and maintain sustained suppression ^[9, 10]. The delayed but persistent suppression provided by *C. montrouzieri* releases complements the declining residual activity of the chemical treatment, effectively bridging the gap between spray applications.

The conservation of natural enemy populations within the IPM package, despite inclusion of a chemical control component, represents a critically important outcome for sustainable implementation. The selective toxicity profile of spiromesifen, which preferentially targets lipid metabolism in sap-feeding Hemiptera while showing lower toxicity to predatory Coleoptera and Neuroptera, underpins this compatibility ^[11]. The elevated natural enemy populations observed in cultural and biological control treatments

relative to untreated controls may reflect the increased prey availability and supplementary floral resources provided by the marigold intercrop^[12].

Marigold Intercrop Mechanisms

The cultural control effect of marigold (*Tagetes erecta*) intercropping appears to operate through multiple mechanisms including visual and olfactory disruption of host-finding behaviour by mealybug crawlers, provision of alternative prey and floral resources that attract and sustain natural enemies, and modification of microclimate conditions. Analysis of volatile organic compounds from marigold plants revealed emission of limonene and alpha-terpinolene, terpenes previously demonstrated to exhibit repellent activity against various hemipteran sap-feeders.

Farmer Adoption Considerations

The successful implementation of IPM programmes requires consideration of farmer knowledge, resource availability, and economic incentives. Participatory assessment with 48 smallholder okra producers in the Los Baños region revealed that 72% expressed willingness to adopt the IPM package given demonstration of its economic benefits. The primary adoption barrier identified was the initial cost of biological control agents, suggesting that development of community-based rearing facilities for *C. montrouzieri* could substantially enhance adoption rates.

Conclusion

The context established by this research reaffirms the superiority of integrated management approaches over individual pest control tactics for *Phenacoccus solenopsis* on okra. The IPM package combining cultural, biological, and chemical components achieved 91.2% population reduction and 166.7% yield improvement over untreated controls, while maintaining natural enemy conservation. The highest net return of 3,620 USD/ha confirmed economic viability despite elevated management costs.

The recommendation emerging from these findings is that tropical okra production systems should implement the validated IPM protocol combining marigold intercropping, augmentative *C. montrouzieri* releases, and selective spiromesifen applications as the foundation of sustainable *P. solenopsis* management. A forward-looking perspective identifies the need for multi-season validation and farmer participatory refinement to optimize the IPM package for diverse tropical production contexts.

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