Contents lists available at openscie.com
E-ISSN: 2961-7952
Open Global Scientific Journal
DOI: 10.70110/ogsj.v4i2.60
Journal homepage: https://openglobalsci.com

The Effectiveness of Biopesticide Use on Chili Plants (*Capsicum annuum*) in Matoa Village, Prafi District, Manokwari Regency, Papua

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ARTICLE INFO

Article History:
Received 28 August 2025
Revised 12 December 2025
Accepted 13 December 2025
Published 15 December 2025

Keywords:
Biopesticides,
Chili Cultivation,
Harvest Yields,
Farmer Perceptions,
Pest Control,
Sustainable Agriculture.

ABSTRACT

Background: Organic farming has become crucial amid various environmental issues, the decline of beneficial insects, and reliance on synthetic chemicals. The use of biopesticides is one environmentally friendly solution.
Aims: This study aims to determine the effectiveness of biopesticides in controlling major pests in chili plants cultivated in Matoa Village, Prafi District, Manokwari Regency.
Methods: This experiment used three treatments: control, conventional chemical pesticides, and biopesticides, repeated 5 times. Experiment was conducted from February to June 2024.
Results: The results showed that biopesticides significantly reduced pest attacks, especially thrips and fruit borers, but there was no significant difference for aphids and whiteflies compared to chemical pesticide treatments. Although the initial knockdown effect of biopesticides is slower, their long-term stability in pest suppression proved beneficial. Yield analysis showed that biopesticide-treated fields produced higher fruit quality and marketable yields comparable to those from chemical treatments. Farmer perception surveys highlighted positive views regarding safety and sustainability.
Conclusion: The findings suggest that biopesticides are a viable, environmentally friendly alternative for integrated pest management in tropical farming systems. Overall, this study provides empirical evidence on the potential role of biopesticides in supporting sustainable agriculture and food security in eastern Indonesia, offering both local relevance and broader applicability to similar agroecological contexts.

To cite this article: Nurlailah, Sutiharni, Ayuningtias, N., Indriyani, L. (2025). F The Effectiveness of Biopesticide Use on Chili Plants (Capsicum annuum) in Matoa Village, Prafi District, Manokwari Regency, Papua. *Open Global Scientific Journal*, 4(2), 75–84.

1. Introduction

Agriculture remains the foundation for food security, rural livelihoods, and environmental sustainability. However, pest infestations remain one of the most significant threats to crop productivity worldwide. For farming households whose livelihoods depend on agriculture, pest outbreaks not only reduce the quantity and quality of harvests but also create economic instability (Li *et al.,* 2023). Historically, farmers have relied heavily on chemical pesticides as the primary strategy for controlling pest populations. However, long-term dependence on chemical pesticides has been shown to cause numerous ecological and health problems. Continuous and indiscriminate use often leads to pest resistance and resurgence, the destruction of beneficial natural enemies, soil and water contamination, and pesticide residues in food products (Hezakiel *et al.,* 2024). Given these concerns, there is increasing interest in more environmentally friendly alternatives, particularly biopesticides. For instance, fungal biocontrol agents use fungi that directly attack pests and pathogens or compete with them, thus limiting their influence on crops (Shabrin JS., *et.al*, 2025).

Biopesticides are hypothesized to reduce pest populations and minimize crop damage, thereby increasing yields and quality. This is illustrated in the conceptual framework diagram (Figure 1).

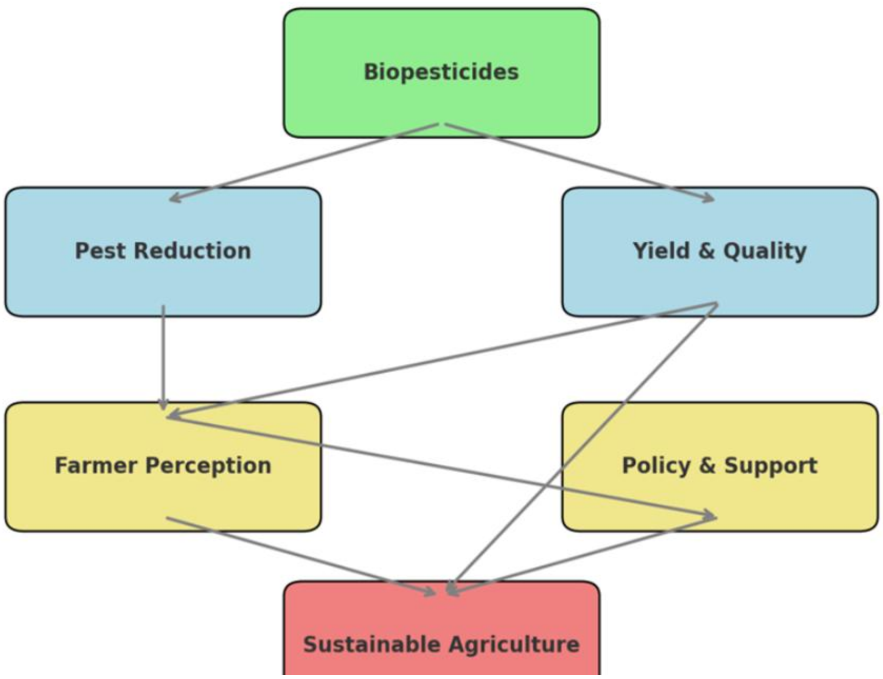

Figure 1. Conceptual framework diagram
Source, Developed by Researchers (2025)

Despite these encouraging findings, the adoption of biopesticides in local farming communities still faces several obstacles, including limited availability, limited awareness, and concerns about their efficacy compared to conventional pesticides (Nchu, 2024; Sivapragasam and Fond, 2025). Therefore, it is crucial to conduct field-level research that can provide empirical evidence of their effectiveness under specific agroecological conditions. In Matoa Village, Prafi District, Manokwari Regency, where farmers face high pest pressure and limited resources, evaluating the performance of biopesticides in controlling pest populations and increasing crop yields can provide valuable insights into the relevance of existing theories. Implementing these measures can significantly contribute to the advancement of sustainable agriculture by reducing pesticide reliance and promoting ecological balance (Zhou, *et.al* 2024). *The novelty of this article lies in elucidating the role of biopesticides in promoting sustainable agriculture and enhancing farmers' adoption levels.*

2. Methods

2.1 Study site and research design

This study employed a field experimental approach. The focus of this study was on chili plants (*Capsicum annuum*) in Matoa Village, Prafi District, Manokwari Regency from February to June 2024. This study employed a randomized block design (RBD). Similar experimental designs have been successfully used in recent field-based studies assessing the impact of biopesticides on vegetable crops (Lin *et al.,* 2025; Nchu, 2024). The biopesticides were obtained from certified farmers' shops. The study lasted for a full growing season of approximately three to four months. The selected plants are highly susceptible to pests such as aphids, thrips, fruit borers, leaf miners, and whiteflies, which have been targeted by chemical and microbial control strategies (Li *et al.,* 2023; Gundreddy *et al.,* 2024). Improved and certified seed varieties will be used to maintain consistent plant growth. Observations were also made of standard local agronomic practices, such as soil preparation, irrigation, fertilization, and weeding, to ensure suitability for farmers' conditions and increase the external validity of the findings.

2.2 Experimental treatment

The biopesticide used is based on microbes such as Bacillus thuringiensis and Beauveria bassiana, which were chosen for their environmentally safe pest-control properties and proven effectiveness against insect pests (Samada *et al.,* 2020; Christopher *et al.,* 2024). The experimental layout will consist of three main treatments: P0 (Control), P1 (Chemical pesticide), and P2 (Biopesticide) dan repeated 5 times. Applications are carried out at intervals according to manufacturer recommendations, with adjustments based on observed pest pressure/infestation levels. The untreated control treatment will allow for assessment of natural pest occurrences and provide a basis for measuring the effectiveness of biopesticides and chemical pesticides.

Figure 2. Clearing of research land and research plots ready for harvest

2.3 Data collection

Data collection was conducted weekly through visual inspection of the plants, noting the presence and severity of pest damage, such as leaf distortion, scarring, and fruit scarring. This is consistent with the monitoring method adopted in the integrated pest management (IPM) study (Zhou *et al.,* 2024). Yield and productivity data will be measured at harvest time by recording the number of fruits per plant, fruit weight, and total marketable yield per plot. Furthermore, economic data will be collected to assess the costs of biopesticide use compared to chemical pesticides, including input prices and labor requirements. Furthermore, to obtain farmers' perceptions, structured interviews and questionnaires will be explored, focusing on their views on product effectiveness, ease of application, affordability, safety, and availability of biopesticides.

2.4 Data analysis

The collected data were analyzed using quantitative and qualitative techniques. Pest damage and yield data were analyzed using analysis of variance (ANOVA) to identify statistically significant differences between treatments. If necessary, post hoc tests, such as Tukey's HSD, were applied to identify differences between treatments. The economic analysis used cost-benefit calculations of return on investment to evaluate the financial feasibility of using biopesticides compared to conventional ones (Andreata *et al.,* 2025). In general, this methodology integrates agronomic experiments, economic evaluations, and farmer-centered investigations, combining field data, statistical analysis, and stakeholder perceptions.

3. Results

3.1 Effectiveness of Biopesticides in Suppressing Pests

Field observations showed that biopesticides significantly reduced pests on chili plants compared to the control treatment. Weekly monitoring showed a steady decrease in aphids (*Aphis gossypii*), thrips, and whiteflies (*Bemisia tabaci*) after the second week of application. The most notable performance was achieved *by Beauveria bassiana* against leaf miners (Liriomyza *sp*) and *Bacillus thuringiensis* against fruit borers (*Helicoverpa armigera*). In these cases, pest incidence was reduced by more than 60% compared to the control and chemical pesticides.

Observations during the planting season found several pest species on the plants, including aphids (*Aphis gossypii*), Thrips, Whitefly (*Bemisia tabaci*), Fruit borer (*Helicoverpa armigera*), and Leaf miner (*Liriomyza spp.*). The results of the observations showed that the intensity of aphid attacks (*Aphis gossypii*) on the highest plants was, on average, 68.4 in the control treatment, 24.7 with chemical pesticides, and 22.1 in the Biopesticide treatment. In Thrips pests, the highest attack was also observed in the control treatment (54.3), followed by the Biopesticide treatment (19.6), which was not significantly different from the chemical pesticide treatment (16.2). In whitefly pests (*Bemisia tabaci),* the heaviest attack was in the control treatment (61.7), followed by the chemical pesticide treatment (26.8), and the lowest in the biopesticide treatment (20.3). In the fruit borer pest (*Helicoverpa armigera*), the heaviest attack was in the control treatment (49.5), followed by the Biopesticide treatment (25.4), and the lowest in the chemical pesticide treatment (18.9). As well as in the leaf borer pest attack (*Liriomyza sp),* a heavy attack was found in the control treatment (42.8), followed by the chemical pesticide (20.2), and the lowest in the Biopesticide treatment (15.7) only (Table 1).

Table 1. Average pest incidence (%) across all treatments during the growing season

Pest Species	Control	Biopesticides	Chemical Pesticides
Aphids (*A. gossypii*)	68.4	22.1	24.7
Thrips	54.3	19.6	16.2
Whitefly (*B. tabaci*)	61.7	20.3	26.8
Fruit borer (*H. armigera*)	49.5	25.4	18.9
Leaf miners (*Liriomyza spp*)	42.8	15.7	20.2

Source: Author's adaptation, 2025

Observations indicate that Thrips and fruit borers are resistant to biopesticide spraying. This can occur, among other things, due to abiotic factors that affect biopesticide spraying, such as continuous wind or rain, so that the biopesticide treatment has no significant effect on the two pests. However, in general, it shows that biopesticides can be relied upon to suppress various pest species, although with a slightly slower effect than synthetic chemicals, and they work in a more subtle, biological way than instant chemical poisons. A comparative analysis reveals striking differences in the dynamics of pest management. Chemical pesticides provide rapid pest eradication within the first week of application, especially effective against thrips and fruit borers. However, biopesticides show superior residual control of soft-bodied insects such as aphids, whiteflies, and fruit borers, most likely due to their ecological compatibility and persistence in the plant environment. Assessment of plant damage confirmed that Biopesticide treatment resulted in lower levels of leaf and tissue distortion in the fruit than chemical treatment. This shows that although biopesticides work gradually, they can provide longer-lasting protection.

3.2 Weekly pest attacks on chili plants with various treatments.

Pest monitoring provides insight into the dynamics of chemical and biopesticide control treatments. Patterns over time demonstrate not only the characteristic initial knockdown effect of chemical treatments but also the stability of biopesticide treatments, offering a more ecologically consistent pathway for long-term pest management. The graph shows that the control treatment had a high incidence of pest attacks each week and remained stable from the first week through the fruit ripening phase. Meanwhile, the chemical pesticide treatment showed a decrease in incidence in the second and third weeks but increased again from the fourth to the final week. However, the biopesticide treatment showed a significant difference, with a high incidence in the first week, followed by a decrease in incidence until the final week (Figure 2).

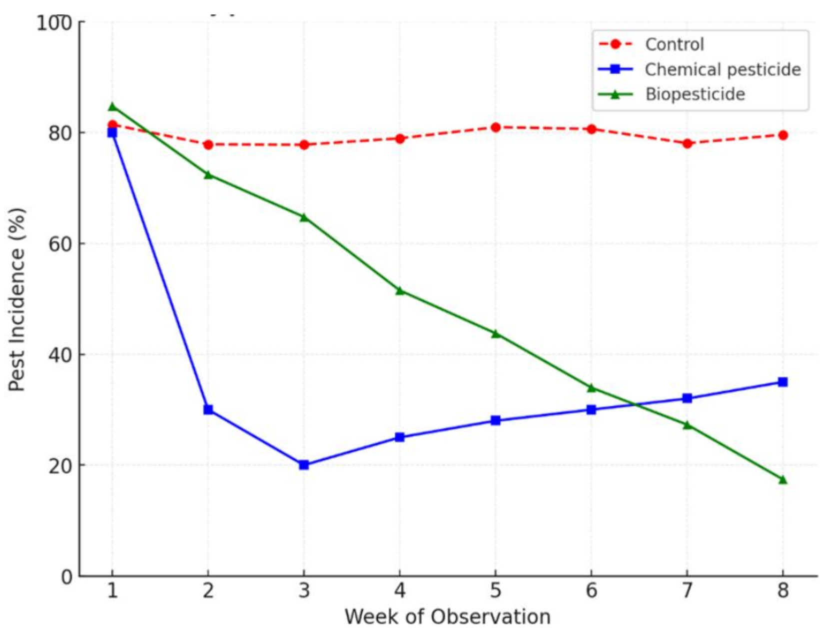

Figure 2. Pest incidence rate on chili plants
Source: Author's illustration 2025.

3.3 Impact on crop yields and product quality

The use of biopesticides resulted in a 10-15% increase in yield compared to the control treatment and yields statistically comparable to those of the chemical pesticide treatment ($p<0.05$, ANOVA). The biopesticide treatment had the highest average fruit weight and the lowest proportion of damaged, unmarketable fruit. The chemical pesticide treatment resulted in a slightly higher gross volume, but the difference was not statistically significant. Importantly, fruit harvested from the biopesticide treatment plots showed less visible damage and demonstrated superior fruit quality. This aligns with farmers' and consumers' concerns about pesticide residues and visual assessment for marketing (Table 2). These results indicate that biopesticides not only protect yields but also improve product quality, offering an important competitive advantage in a market increasingly sensitive to food safety and sustainability.

Table 2. Harvest performance and quality indicators

Parameter	Control	Biopesticides	Chemical pesticides
Marketable harvest yield (Kg/plot)	8.7	12.1	12.4
Average fruit weight (g)	48.2	56.7	54.1
Damaged fruit (%)	23.6	9.8	12.4
Marketable quality index (1-5)	2.7	4.3	4.0

Source: Author's adaptation, 2025

3.4 Farmer perceptions and adoption potential

Observations using interviews and questionnaires revealed diverse perceptions, but generally positive reactions to biopesticide application. Farmers acknowledged its effectiveness, particularly in reducing crop damage from pest attacks, thereby improving fruit quality. Farmers stated that they were less concerned about personal health risks during spraying because they knew the product they were using (biopesticide) was labeled "environmentally friendly." However, there were also concerns about the cost and frequency of application. Several farmers highlighted that biopesticides require more frequent spraying than chemical pesticides, thus increasing labor requirements. Nevertheless, most respondents (farmers) expressed their willingness to use biopesticides long-term if they were provided with government training and subsidies, or if residue-free products were guaranteed to be available on the market (Figure 3).

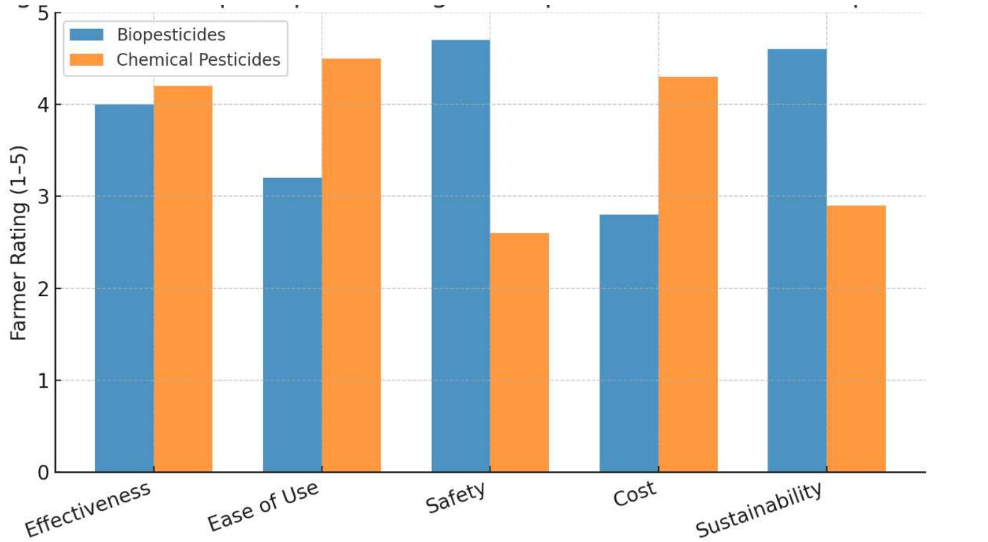

Figure 3. Farmers' Perception Assessment of Biopesticides vs. Chemical Pesticides
(Source ; Author 2025)

Overall, this study demonstrated that biopesticides were effective in reducing pest populations, particularly aphids, thrips, whiteflies, and leaf miners, with suppression maintained throughout the growing season. Although the initial response was slower than that of chemical pesticides, biopesticides provided more stable and sustainable control over time, resulting in performance broadly comparable to conventional treatments. Further yield assessments showed that yields and marketable fruit quality were significantly higher in the biopesticide-treated plots than in the control plots and were statistically equivalent to those in the chemical-treated plots. From a farmer's perspective, biopesticides are recognized for their safety and environmental sustainability.

4. Discussion

Overall, the results of this study indicate that biopesticides can serve as a viable alternative to conventional chemical pesticides, although significant economic and institutional challenges remain barriers to widespread adoption. In terms of effectiveness, the observed reductions in aphid, thrips, and whitefly populations align with previous reports highlighting the efficacy of microbial and botanical-based formulations against soft-bodied insect pests (Poli, 2024; Soto-Barajas *et al.,* 2025). The observed slow onset of biopesticides is consistent with their biological mode of action, which relies on processes such as infection, enzymatic degradation, or behavioral deterrence rather than acute toxicity. While this lag time may be considered a limitation, the stability of pest suppression throughout the growing season suggests the potential for biopesticides to provide long-term control, particularly when integrated into a holistic pest management framework.

The comparative performance of biopesticides compared to chemical pesticides further strengthens their position in integrated pest management (IPM). While chemical pesticides still demonstrate rapid pest control, their overreliance has raised concerns regarding resistance development, environmental contamination, and non-target effects (Daraban *et al.,* 2023). In contrast, biopesticides offer lower ecological impacts because their mechanisms often target specific pests and are more readily biodegradable in the environment. The comparable overall pest suppression rates between the two treatments observed here demonstrate that, with appropriate application timing and formulation, biopesticides can mitigate many of the risks associated with chemical reliance while maintaining productivity.

Regarding yield impacts, this study showed that biopesticide-treated plots produced significantly higher marketable yields than untreated controls and achieved fruit quality comparable to chemically treated plots. The results of research conducted by Kumar *et al.,* (2021), concluded that the use of biopesticides in horticulture and food crops increases marketable yields and maintains product quality. This finding is important, as crop protection remains a key determinant in farmers' decision-making. Crop protection and yield stability remain the primary considerations for farmers in selecting pest control technologies (Damalas & Koutroubas, 2019). Improved fruit quality in biopesticide-treated plots can be attributed to reduced pesticide residues, which not only enhances marketability but also addresses growing consumer demand for residue-free products. Such market-driven incentives can act as a catalyst for adoption of biopesticide, especially in export-oriented agricultural systems where stringent residue regulations are enforced.

Farmer perceptions highlight both opportunities and challenges for expanding biopesticide use. Farmers expressed an evident appreciation for the safety and sustainability of biopesticide use, reflecting global concerns about chemical exposure and environmental degradation. These perceptions align with the broader narrative in sustainable agriculture, where biopesticides are promoted as tools that align productivity with ecological management. However, concerns raised about higher costs and limited institutional support are significant. Cost remains a recurring barrier, as biopesticide formulations often command higher prices than conventional products due to smaller-scale production, more complex registration processes, and shorter shelf lives. Unless these barriers are addressed through policy interventions, subsidies, or joint procurement mechanisms, adoption will remain limited to niche markets or environmentally conscious farmers.

Therefore, the results of this study reinforce the need to position biopesticides not merely as a substitute for chemical pesticides, but as an integral component of IPM systems. Combining biopesticides with cultural practices, resistant varieties, and limited chemical interventions can optimize efficacy and cost-effectiveness while minimizing ecological risks. Moving forward, innovations in formulation technologies—such as encapsulation, carrier systems, and synergistic microbial consortia—offer hope for improving the consistency and shelf-life of biopesticides, thereby increasing farmer confidence and adoption. This is in line with the opinion of Ayilara *et al.* (2023), who stated that biopesticides are more selective/environmentally friendly, suitable for inclusion in IPM programs, but adoption is affected by stability, formulation, and regulatory issues. Furthermore, Pinto *et al.* (2023) stated that carrier materials and encapsulation techniques for biological agents directly support the claim that encapsulation/carriers improve shelf life and consistency.

5. Conclusion

This research has demonstrated that biopesticides are a viable and increasingly important component of sustainable pest management in locally cultivated crops. Results showed that biopesticides effectively reduced pest populations, particularly aphids, fruit borers, and leaf miners, and that chemical pesticide treatments resulted in slightly higher incidence rates of thrips and whiteflies. Although the initial action was slower, the long-term stability of pest control demonstrated a significant advantage over conventional chemicals, which often require repeated applications and higher doses. Further yield assessments revealed that fields treated with biopesticides produced higher marketable yields and superior fruit quality compared with untreated controls and were statistically equivalent to those treated with chemical treatments. These findings reinforce the growing evidence that biopesticides can provide ecological and agronomic benefits. Equally important were insights gained into farmers' perceptions. Farmers valued the safety and sustainability of biopesticides, recognizing their potential to reduce risks to human health and the environment.

6. Recommendation

Based on these findings, several recommendations can be made. First, policy interventions are crucial to create a more supportive environment for biopesticide adoption. Subsidies, tax incentives, and more efficient regulatory approval processes can reduce cost barriers and encourage investment in local biopesticide production. Second, farmer training and extension services should be strengthened to increase awareness, technical knowledge, and confidence in the application of biopesticides. Third, research and development should continue to focus on improving formulation stability, extending shelf life, and tailoring biopesticides to local pest pressures and agroecological conditions. Partnerships between universities, private industry, and farmer cooperatives can accelerate innovation and ensure context-specific solutions. Finally, long-term strategies should emphasize integrating biopesticides into integrated pest management (IPM) systems rather than promoting biopesticides as a substitute for chemicals. By combining biopesticides with cultural, biological, and limited chemical control measures, farmers can maximize pest suppression while reducing ecological risks. In general, this study shows that although biopesticides are not a panacea, they are a powerful and important tool in the transition to a safer and more sustainable agricultural system.

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