

ANTIFEEDANT ACTIVITY OF SELECTED BIOPESTICIDES AGAINST THE COCOA MIRID, *SAHLBERGELLA SINGULARIS* HAGL 1895 (HEMIPTERA: MIRIDAE)

AWE O. O¹, ABUBAKAR A. M² AND ADELEKE S. O.³

Department of Biology, Adeyemi Federal University of Education, Ondo.

omolarawe15@gmail.com

ABSTRACT

Cocoa mirids remain one of the most destructive insect pests affecting cocoa production in West Africa, causing substantial economic losses through feeding damage on developing pods. Conventional management relies heavily on synthetic insecticides, which often lead to environmental contamination, pest resistance, and adverse effects on non-target organisms. This study evaluated the antifeedant activity of three commercially available biopesticides; Bioneem EC (azadirachtin-based botanical insecticide), Biocatch WP (*Lecanicillium lecanii*), and Biomagic WP (*Metarhizium anisopliae*), against the cocoa mirid *Sahlbergella singularis* under laboratory conditions. Fresh unripe cocoa pods were collected from cocoa farms in Orimolade and Igba villages in Ondo State, Nigeria. Pods were treated with different concentrations (0.5%, 1.0%, and 2.0%) of the biopesticides and subjected to paired-choice feeding tests using starved mirids. Ten mirids were introduced into each experimental unit containing both treated and untreated pods, and feeding lesions were counted after 24 hours using a magnifying lens. The experiment followed a completely randomized block design with four replicates. Data were analyzed using analysis of variance (ANOVA), Pearson correlation coefficient, and Duncan's Multiple Range Test at 5% probability. Results showed significant reductions in feeding damage on treated pods compared with untreated controls. Pods treated with the biopesticides recorded an average of 6–9 feeding lesions, whereas untreated pods recorded approximately 91–97 lesions per ten mirids. Pyrinex 48EC, used as a synthetic reference insecticide, recorded an average of 17 lesions. No significant difference ($p > 0.05$) was observed among the three biopesticides, but all treatments differed significantly from untreated controls ($p < 0.05$). The findings demonstrate strong antifeedant and repellent properties of the tested biopesticides, highlighting their potential as environmentally sustainable alternatives for integrated management of cocoa mirids.

KEYWORDS: Antifeedant Activity, Biological Control, Biopesticides, Cocoa Mirids, *Sahlbergella singularis*, Sustainable Pest Management.

I. INTRODUCTION

Insect pests continue to pose a major constraint to agricultural productivity worldwide, necessitating the development of effective and environmentally sustainable pest management strategies. The indiscriminate use of synthetic chemical insecticides has led to issues such as pest resistance, resurgence, environmental contamination, and adverse effects on non-target organisms. Consequently, increased attention has been directed toward botanicals and microbial-based pesticides that are compatible with integrated pest management (IPM) programs (Pavela Roman *et al*, 2025)). Antifeedants play a crucial role in pest management by disrupting insect feeding behavior without necessarily causing immediate mortality (Sharma *et al*, 2019). Such compounds reduce crop damage

by deterring feeding, suppressing growth, and impairing insect development. Among botanical insecticides, neem-based formulations containing azadirachtin are widely reported to exhibit strong antifeedant, growth-regulating, and oviposition-deterrent properties against a broad range of insect pests. Azadirachtin acts primarily by interfering with insect chemoreceptors and endocrine systems, resulting in reduced feeding and abnormal development. (Moubarak *et al*, 2022). In contrast to plant-derived antifeedants, microbial biopesticides such as entomopathogenic fungi are primarily used for biological control through infection and colonization of insect hosts. Products based on *Lecanicillium lecanii* and *Metarhizium anisopliae* are commercially formulated as wettable powders and have demonstrated efficacy against sucking and chewing insect pests. Although these microbial agents do not function as classical antifeedants, infection-induced physiological stress may lead to reduced feeding activity prior to mortality. (Lengai *et al*, 2019).

This study was undertaken to evaluate and compare the antifeedant and feeding-related effects of three commercially available biopesticides; BIONEEM EC (azadirachtin-based), BIOCATCH WP (*Lecanicillium lecanii*), and BIOMAGIC WP (*Metarhizium anisopliae*) against target insect pests under laboratory conditions. The study aims to distinguish between direct antifeedant action and indirect feeding reduction resulting from microbial infection, thereby providing insights into their potential role in integrated pest management strategies. The control of the menace of cocoa mirids has predominantly been achieved by the use of synthetic pesticides. However, pesticides are known to be toxic to humans, animals, water, the soil, crops, air and non-target organisms. Pesticide applications sometimes drift beyond the pest infested areas and contaminate the air, soils, crops, water, humans and animals, thereby leaving some residue in them (Mahob *et al*, 2021). There have also been cases of pest becoming tolerant to insecticides, resulting in the use of double and triple application rates (Stoll, 2000). Also, due to additional problems such as health hazards, undesirable side effects and environmental pollution caused by the continuous use of synthetic pesticides (Nas *et al*, 2017), there is renewed interest in the application of botanical pesticides for crop protection. Scientists are now experimenting and working to protect insect infestation by indigenous plant materials. However, the use of such plants extracts to control pests is not a new innovation, as it has been widely used by small-scale subsistence farmers (Roy *et al*, 2005).

Natural pesticides (Bio-insecticides) are active principles derived from plants and animal for the management of human and animal pest organisms or it can be said to be biologically active ingredients, for the management of human and animal pest organisms (Ivbijaro,1990). With the growing global demand for environmentally sound pest management strategies; there is a need to develop alternative pesticides with minimal or non-ecological hazards. Bio- pesticides are easily biodegradable (Delvin & Zettel, 1999) and their use in crop protection is a practically sustainable alternative. It maintains biological diversity of predators (Grange & Ahmed 1988) and reduces environmental contamination and human health hazards. In recent times, considerable effort has been put into the development and promotion of bio-insecticides for the control of pests (Stoll, 2000). This has resulted in the development of a science-based approach that uses a formal set of steps to discover and determine their efficacy and attempts to either produce the bio-insecticides on a commercial scale or synthesize it for broader use in commercial agriculture (Philogene & Lambert, 1993). Biomagic WP is a talc based product containing spores and mycelial fragments of a naturally occurring entomopathogenic fungus, *Metarhizium anisopliae*. The spores of this fungus, when in contact with the cuticle of target insects, germinate and grow directly through the cuticle to the inner body of their host. The fungus proliferates throughout the insect's body draining the insect of nutrients and eventually killing it. Like Bioneem EC and Biocatch

WP, it does not create resistance, resurgence and residues problem and have been certified for use in organic agriculture and integrated pest management programme (BICCO, 2009, Stanes 2025)

Biocatch WP is a talc based product containing spores and mycelial fragments of a naturally occurring entomopathogenic fungus, *Verticillium lecani*. The spores of this fungus, when in contact with the cuticle of target insects, germinate and grow directly through the cuticle to the inner body of their host. The fungus proliferates throughout the insect's body draining the insect of nutrients and eventually killing it. Like Bioneem EC, it does not create resistance, resurgence and residues problem (BICCO, 2009, Stanes 2025). Bioneem EC is Neem-oil based botanical insecticide containing Azadirachtin and other Limonoids like Meliantriol, Salanin, Nimbin and other Terpinoids in the ratio as it occurs in nature. It acts as an antifeedant, repellent, insect growth regulator, oviposition deterrent and sterilant. Bioneem EC is compatible with most agricultural crop protection chemicals. It is eco-friendly and maintains ecological balance. It does not create resistance, resurgence and residue problem. Bioneem EC does not affect natural enemies of insect pests and is very useful in Integrated Pest Management (IPM) programme (BICCO, 2009, Stanes 2025).

II. MATERIALS AND METHODS

Fresh unripe cocoa pods were collected from cocoa farms located at Orimolade and Igba villages in Ondo State. The pods were soaked separately in the various treatments (0.5%, 1.0% and 2.0%) of the bio-insecticides for one (1) minute before being removed and allowed to drain off; these pods were labeled "Treated Pods". The remaining pods were labeled "Untreated Pods". Pods treated with reference standard miridicide (Pyrinex 48EC) were used for Positive control, while untreated pods were used as Negative control. One bio-insecticide treated pod together with one untreated pod each were placed separately inside a transparent plastic bucket with perforated lid. 10 Mirids each, previously collected from infected cocoa plots were starved overnight to encourage feeding and were introduced into the plastic buckets containing cocoa pods. Each of the treatments was replicated four times using completely randomized block design (CRBD). The antifeedant response of mirids to the tested bio-insecticides was measured using "paired choice" tests according to (Bomford, 1959) modified by (Pavela Roman *et al*, 2025). In a paired choice test, mirids were given a choice between bio-insecticide treated pods and untreated pods. The number of feeding lesions on each cocoa pod (treated and untreated) were counted with the aid of a magnifying hand lens and recorded after 24 hours.

III. RESULTS

The effect of Bioneem EC, Biocatch WP and Biomagic WP on the feeding activities of the cocoa mirid, *Sahlbergella singularis* was pronounced. Bioneem EC, Biocatch WP and Biomagic WP exhibited strong antifeedant and repellent properties. Cocoa pods treated with 0.5% concentration of the bio-insecticides recorded an average of 9 lesions per 10 mirids per pod, while untreated pods recorded an average of 93 lesions per 10 mirids per pod. Cocoa pods treated with 1.0% and 2.0% concentrations of the bio-insecticides recorded an average of 6 lesions per 10 mirids per pod while untreated pods recorded an average of 91 lesions per 10 mirids per pod. Cocoa pods treated with Pyrinex 48 EC recorded an average of 17 lesions per 10 mirids per pod. For the control, between 95 and 97 lesions were recorded per 10 mirids per pod. (Table 1). There was no significant difference ($p>0.05$) between the treated pods for all the tested bio-insecticides. Significant differences existed between Pyrinex 48 EC treated pods and bio-insecticide treated pods ($p<0.05$). Untreated pods were significantly different from treated pods ($p<0.05$)

Table 1: Mean Post Treatment Lesion Count for Treated and Untreated Pods

Treatments	Mean±SE	
	Treated pods	Untreated pods
Bioneem EC	7.00 ^a ±1.00	81.33 ^a ±5.90
Biocatch WP	8.67 ^a ±0.38	78.00 ^a ±6.02
Biomagic WP	8.33 ^a ±1.20	91.33 ^a ±0.33
Pyrinex 48EC	17.00 ^b ±0.00	91.00 ^a ±0.57
Control	95.67 ^c ±0.67	95.67 ^a ±0.67

*Means with different superscript in the same column are significantly different (P<0.05) by DMRT

Table 1 presents the mean number of feeding lesions (± SE) recorded on cocoa pods after 24 hours of exposure to *Sahlbergella singularis*. The lesions represent feeding damage caused by the cocoa mirid, and therefore serve as a direct indicator of feeding activity and antifeedant effectiveness. The results show that pods treated with the three biopesticides; Bioneem EC, Biocatch WP, and Biomagic WP recorded very low lesion counts compared with untreated pods. These values indicate that the feeding activity of the cocoa mirid was greatly suppressed when exposed to pods treated with the biopesticides. The lesion counts remained below 10 lesions per pod, which represents more than 90% reduction compared with untreated controls (≈95 lesions). This strong reduction suggests that the tested biopesticides possess significant antifeedant and/or repellent properties, discouraging mirids from probing or feeding on treated pods.

Pods treated with the synthetic insecticide Pyrinex 48EC recorded 17 lesions, which is significantly higher than the lesion counts recorded for the biopesticide treatments. This finding suggests that the biopesticides were more effective at deterring feeding than the synthetic chemical used as a standard. Pyrinex may function more as a toxic insecticide rather than a feeding deterrent, that is, insects may still probe or feed before being affected by the insecticide. Thus, the results highlight the behavior-modifying advantage of botanical and microbial pesticides, which can prevent feeding damage even before mortality occurs. These values also indicate intense feeding activity in the absence of any treatment. The high lesion count on untreated pods confirms that the experimental mirids were highly active and capable of causing severe feeding damage within 24 hours, validating the experimental setup and reinforcing the effectiveness of the treatments.

The superscript letters in Table 1 represent Duncan’s Multiple Range Test (DMRT) results. Bioneem EC, Biocatch WP, and Biomagic WP share the same superscript (a) which indicates no significant difference (P > 0.05) among the three biopesticides. Pyrinex 48EC with a different superscript (b) indicates significantly higher lesion counts than the biopesticides (P < 0.05). The control treatment has superscript (c) which confirms that untreated pods experienced significantly higher feeding damage than all treated pods. Overall, the statistical results demonstrate that all treatments significantly reduced mirid feeding compared with untreated controls, but the biopesticides performed better than the synthetic insecticide in terms of feeding deterrence.

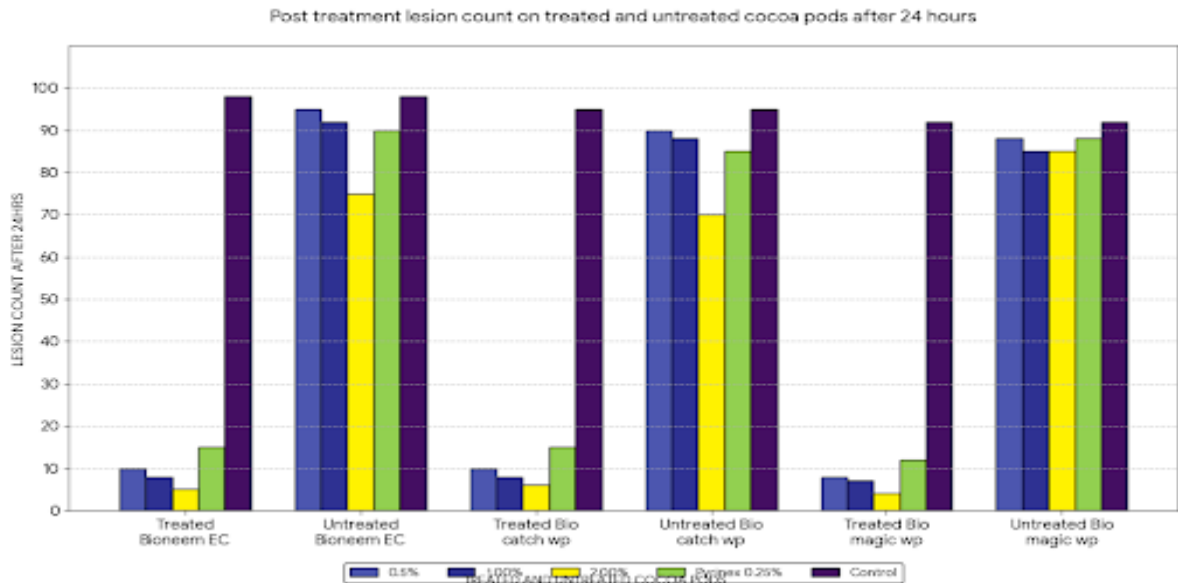


Figure 1: Post Treatment Lesion Count on Treated and Untreated Cocoa Pods after 24hours

Figure 1 illustrates the general comparison between treated and untreated pods after 24 hours. The graphical representation shows a clear contrast between treatments and controls, treated pods show minimal lesion counts while untreated pods show very high feeding damage. Figure 1 reinforces the statistical results presented in Table 1 by demonstrating that mirids strongly avoided or reduced feeding on treated pods as well as feeding damage being suppressed by biopesticide application. The large gap between treated and untreated pods suggests that the treatments possess strong repellent and antifeedant effects.

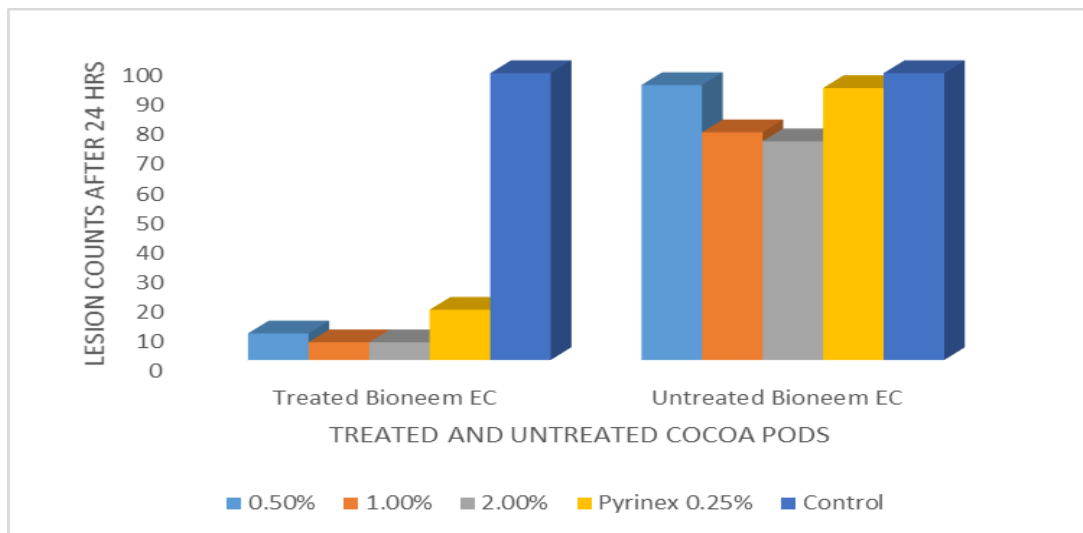


Figure 2: Post Treatment Lesion Count on Treated and Untreated Cocoa Pods after 24hours (BIONEEM WC)

Figure 2 specifically compares treated and untreated pods exposed to Bioneem EC. The treated pods show very low lesion counts (~7 lesions) compared with untreated pods (~80+ lesions). The strong reduction in feeding damage can be attributed to azadirachtin, the active ingredient in neem-based insecticides. Azadirachtin is known to disrupt insect chemoreceptors, because mirids rely heavily on stylet probing and sap feeding, interference with chemoreception likely caused feeding inhibition and avoidance behavior. Azadirachtin also interfere with taste perception, prevent probing and feeding behavior and act as a feeding deterrent, thus the low lesion count recorded indicate excellent antifeedant activity by Bioneem EC against *S. singularis*.

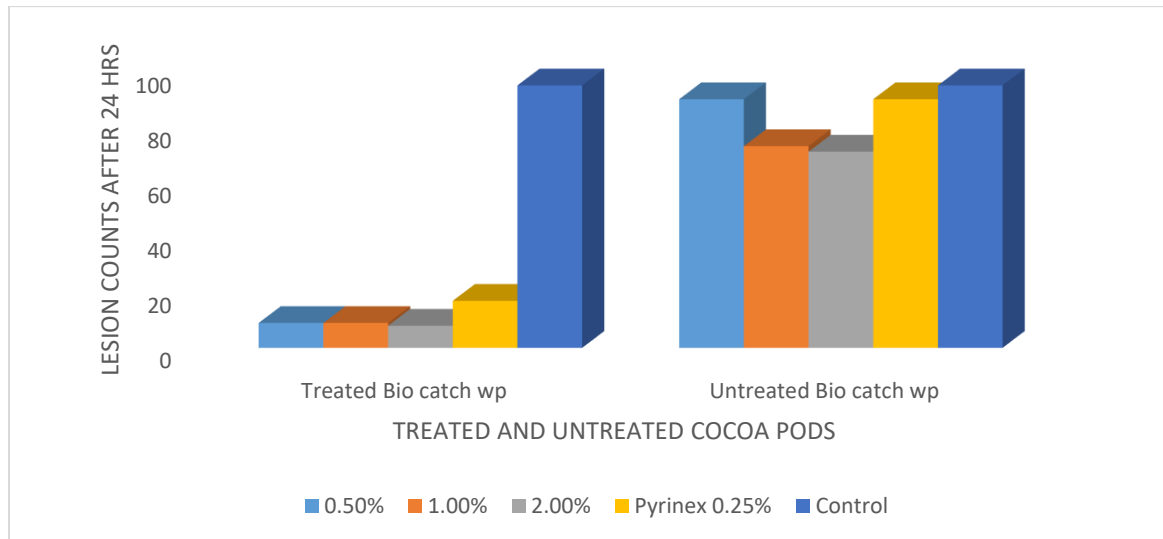


Figure 3: Post Treatment Lesion Count on Treated and Untreated Cocoa Pods after 24hours (BIOCATCH WP)

Figure 3 shows the feeding response of mirids to pods treated with Biocatch WP, which contains the entomopathogenic fungus *Lecanicillium lecanii*. The lesion counts on treated pods remained very low (~8 lesions), whereas untreated pods showed extensive feeding damage. Unlike neem, microbial insecticides do not function primarily as antifeedants., rather, they act by attaching to the insect cuticle, germinating and penetrating the insect body thus colonizing internal tissues. Even before infection progresses, insects may experience physiological stress, reduced movement and altered feeding behavior. Therefore, the reduction in lesion counts observed in this study suggests that early infection or fungal metabolites may have disrupted normal feeding behavior, demonstrating that microbial biopesticides can indirectly reduce feeding damage.

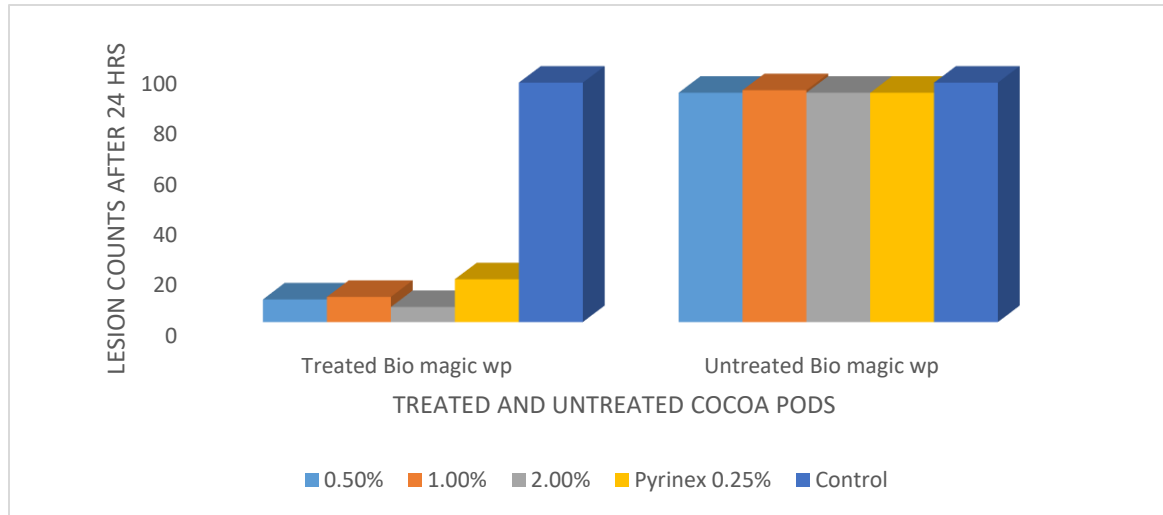


Figure 4: Post Treatment Lesion Count on Treated and Untreated Cocoa Pods after 24hours (BIOMAGIC WP)

Figure 4 illustrates the antifeedant effect of Biomagic WP, the active ingredients being *Metarhizium anisopliae*, an entomopathogenic fungus. This fungus infects insects through cuticle penetration, internal proliferation and nutrient depletion. Prior to mortality, infected insects often exhibit reduced feeding, impaired coordination and weak probing behavior. Therefore, the reduction in feeding lesions may be attributed to early physiological stress caused by fungal infection. This indicates that entomopathogenic fungus can provide dual protection by immediate reduction in feeding activity and eventual insect mortality. From Figures 1-4, findings revealed that all the tested biopesticides significantly reduced feeding activities of mirids. The three tested biopesticides consistently reduced feeding damage to less than 10 lesions per pod, compared with over 90 lesions in untreated controls. This confirms their strong antifeedant and repellent effects. Statistical analysis shows that Bioneem EC, Biocatch WP, and Biomagic WP were not significantly different in their efficacy as feeding deterrent agents. This suggests that both botanical and microbial pesticides can be effective against cocoa mirids, affording farmers multiple environmentally safe options for pest control. The performance of the biopesticides is far better than the synthetic insecticide. Result shows Pyrinex 48EC allowed more feeding damage (17 lesions) than the biopesticides. This indicates that synthetic insecticides may not prevent initial feeding damage of mirids but biopesticides may act more effectively as behavioural deterrents

The results of this study have important implications for sustainable cocoa production. Biopesticides are biodegradable, less toxic to humans and safer for beneficial organisms, this makes them suitable for integrated pest management (IPM) programs. There is also reduced resistance risk and protection of cocoa yield. The combined evidence from Table 1 and Figures 1–4 clearly demonstrates that the tested biopesticides possess strong antifeedant and repellent properties against *Sahlbergella singularis*. The treatments significantly reduced feeding lesions on cocoa pods compared with untreated controls. Furthermore, the absence of significant differences among the three biopesticides indicates that both botanical and microbial formulations are effective alternatives to conventional insecticides. These findings support the integration of biopesticides into sustainable cocoa pest management strategies.

Discussion

A. Effect of biopesticides on feeding activity of *Sahlbergella singularis*

The feeding activity of the cocoa mirid, *Sahlbergella singularis*, was significantly affected by the application of the tested biopesticides. Cocoa pods treated with Bioneem EC, Biocatch WP, and Biomagic WP recorded substantially lower feeding lesion counts compared with untreated pods. Mean lesion counts on treated pods ranged from 7.00 to 8.67 lesions per pod, whereas untreated pods recorded between 78.00 and 91.33 lesions. The untreated control recorded the highest feeding damage with 95.67 lesions per pod. The dramatic reduction in feeding lesions on treated pods clearly indicates that the tested biopesticides possess strong antifeedant and repellent properties against the cocoa mirid. The paired-choice test used in the study allowed insects to choose between treated and untreated pods, and the strong preference for untreated pods demonstrates that the treatments effectively deterred feeding. Antifeedants function by interfering with insect feeding behaviour, often by affecting gustatory receptors or by producing deterrent compounds that inhibit probing and ingestion of plant tissues (Grange & Ahmed, 1988; Philogene & Lambert, 1993; BICCO, 2009; Stanes & Company, 2025; Asogwa, *et al*, 2009; Akhtar & Isman, 2004). The results further revealed no significant difference ($P > 0.05$) among the three tested biopesticides in terms of lesion counts on treated pods. This suggests that all three formulations possess comparable efficacy in suppressing mirid feeding activity. However, significant differences were observed between the biopesticide treatments and the synthetic insecticide Pyrinex 48EC, which recorded 17 lesions per pod, indicating comparatively weaker feeding deterrence. Gbadegesin *et al*, (2023). This observation suggests that although synthetic insecticides may cause insect mortality, they may not immediately prevent feeding activity, allowing insects to cause damage before succumbing to toxic effects. In contrast, botanical and microbial biopesticides can influence insect behaviour by preventing feeding and colonization of host plants. Pavel, (2015, 2016, 2023)

B. Antifeedant Effect of Bioneem EC (Azadirachtin-based biopesticide)

Among the tested products, Bioneem EC recorded the lowest mean lesion count (7.00 lesions per pod), demonstrating strong antifeedant activity. Neem-based insecticides are widely recognized for their potent feeding deterrent properties, primarily due to the presence of azadirachtin and related limonoids. These compounds disrupt insect chemoreceptors and interfere with the perception of plant tissues, thereby inhibiting feeding behaviour (Pavela *et al.*, 2025). Azadirachtin is also known to function as an insect growth regulator, oviposition deterrent, and repellent, affecting multiple physiological pathways in insects. Previous studies have reported similar findings in cocoa pest management. For example, Padi *et al.* (2000) demonstrated that neem-based products significantly reduced feeding damage caused by cocoa capsids under field conditions. Similarly, Adu-Acheampong (2000) reported up to 80.3% mortality of mirids following treatment with crude neem extracts. The strong feeding deterrence observed in the present study is consistent with earlier research showing that neem formulations can significantly reduce insect feeding lesions compared with untreated plants. Padi *et al.* (2000) reported that neem-treated cocoa pods recorded 23–48 lesions per 10 capsids, compared with 157 lesions in untreated controls, confirming the antifeedant potential of neem-based products.

C. Feeding Suppression by Microbial Biopesticides

The microbial biopesticides Biocatch WP (*Lecanicillium lecanii*) and Biomagic WP (*Metarhizium anisopliae*) also significantly reduced feeding damage, recording 8.67 and 8.33 lesions per pod, respectively. These results indicate that microbial biopesticides can effectively suppress feeding activity in addition to causing insect mortality.

Unlike botanical insecticides, entomopathogenic fungi do not typically act as classical antifeedants. Instead, they infect insects through contact with the cuticle, penetrate the insect body, and proliferate internally, eventually leading to death (Lengai et al., 2019). However, infection often causes physiological stress and behavioural changes, including reduced feeding activity prior to mortality. The reduction in feeding lesions observed in the present study suggests that early stages of fungal infection may impair the normal feeding behaviour of *S. singularis*. Similar findings have been reported in other insect species exposed to fungal pathogens, where infected insects show reduced movement, decreased feeding activity, and eventual mortality due to nutrient depletion. Microbial biopesticides such as *Metarhizium anisopliae* and *Lecanicillium lecanii* have been widely studied for their effectiveness against sap-sucking pests, including aphids, whiteflies, and mirids. According to Ayilara et al. (2023), microbial biopesticides represent a promising alternative to synthetic pesticides due to their high specificity, environmental safety, and reduced risk of resistance development.

D. Comparison between Biopesticides and Synthetic Insecticide

An important finding of this study is the superior antifeedant performance of the biopesticides compared with the synthetic insecticide Pyrinex 48EC. Although Pyrinex-treated pods recorded fewer lesions than untreated pods, the lesion count was significantly higher than those recorded for the biopesticide treatments. This suggests that the primary mode of action of Pyrinex may be toxic rather than behavioural, meaning insects may continue feeding until toxic effects occur. In contrast, the tested biopesticides appear to function primarily as feeding deterrents and repellents, preventing insects from initiating feeding. These findings support earlier studies indicating that botanical pesticides can provide effective protection against crop pests while minimizing environmental contamination. According to Sharma et al. (2019), excessive reliance on synthetic pesticides has resulted in problems such as pest resistance, environmental pollution, and toxicity to non-target organisms. Consequently, there has been increasing interest in developing environmentally friendly pest management strategies based on botanical and microbial pesticides.

E. Implications for Sustainable Cocoa Pest Management

The results of this study highlight the potential role of biopesticides in integrated pest management (IPM) programmes for cocoa production. The strong antifeedant and repellent properties of Bioneem EC, Biocatch WP, and Biomagic WP suggest that these products can effectively protect cocoa pods from mirid attack. Biopesticides offer several advantages over conventional chemical insecticides, including: biodegradability and environmental safety, low toxicity to humans and non-target organisms, reduced risk of pest resistance development and compatibility with integrated pest management strategies. According to Gahukar (2016), plant-derived and microbial pesticides are increasingly recognized as viable alternatives to synthetic pesticides due to their ecological compatibility and effectiveness in reducing pest populations. Furthermore, botanical pesticides such as neem extracts have been used traditionally by farmers in many tropical regions for pest control. Roy *et al.* (2005) reported that plant extracts have been successfully applied as natural insecticides against several agricultural pests, demonstrating their potential for sustainable crop protection. Overall, the present study demonstrates that the tested biopesticides possess significant antifeedant and repellent activity against *Sahlbergella singularis*. All three products effectively reduced feeding damage on cocoa pods compared with untreated controls. The absence of significant differences among the biopesticides suggests that both botanical and microbial formulations can serve as effective alternatives to synthetic insecticides in cocoa pest management.

These findings support the increasing adoption of biopesticide-based pest control strategies in cocoa production systems and highlight the importance of further research into the development and commercialization of environmentally sustainable pest management tools.

IV. CONCLUSION

The results of the present study demonstrate that the tested biopesticides possess strong antifeedant and feeding-suppressive effects against the cocoa mirid *Sahlbergella singularis*. Cocoa pods treated with Bioneem EC, Biocatch WP, and Biomagic WP experienced significantly lower feeding damage compared with untreated controls, confirming the potential of these products for sustainable cocoa pest management. The neem-based formulation exhibited particularly strong feeding deterrence, consistent with the well-known antifeedant properties of azadirachtin. The microbial biopesticides also significantly reduced feeding activity, likely due to physiological stress associated with fungal infection. These findings support the growing body of evidence that botanical and microbial biopesticides can serve as effective alternatives to synthetic insecticides. By reducing feeding damage, minimizing environmental contamination, and supporting integrated pest management strategies, biopesticides represent a promising approach to sustainable cocoa production. There is a need for collaboration within cocoa growing regions and for sharing knowledge of pest management practices because pest problems are often common to adjacent countries. The need for strategic cocoa pesticides that can be used for specific important pests and their life stages should be met. These insecticides must however show acceptable levels of low mammalian toxicity and environmental impact. Cocoa growing regions need pesticide scientists with up to date training, capable of foreseeing issues before they arise.

REFERENCES

1. Adu-Acheampong, R. (2000). Field trials on the control of cocoa capsids with aqueous Neem (*Azadirachta indica* A. Juss) seed extract. Proc. Efficacy and Commercialization of Neem Products in Ghana, 1, 12–16.
2. Akhtar, Y., & Isman, M. B. (2004). Comparative growth inhibitory and antifeedant effects of plant extracts and pure allelochemicals on four phytophagous insect species. *Journal of Applied Entomology*, 128, 32–38.
3. Asogwa, E. U., Ndubuaku, T. C. N., Ugwu, J. A., Mokuwunye, I. U., & Awe, O. O. (2009). Evaluation of Ethanol plant extract for protection of *Cola nitida* against *Kola Weevils* (*Balanogastriis kolae* and *Sophrorhinus* spp) (Coleoptera: curculionidae) in storage. *African Journal of Agricultural Research*, 4(5), 484–490.
4. Ayilara, M. S., Adeleke, B. S., Akinola, S. A., Fayose, C. A., Adeyemi, U. T., Gbadegesin, L. A., Omole, R. K., Johnson, R. M., Uthman, Q. O., & Babalola, O. O. (2023). Biopesticides as a promising alternative to synthetic pesticides: A case for microbial pesticides, phytopesticides, and nanobiopesticides. *Microbiology*, 14, 1040901.
5. BICCO. (2009). Biopesticides. “<http://www.bicco.com/html>
6. Bomford, M. (1959). Neem as an antifeedant. <http://www.sfu.ca/bisc/bisc-842>
7. Devlin, J. F., & Zettel, T. (1999). *Ecoagriculture: Initiatives in Eastern and Southern Africa*. Weaver Press.
8. Gahukar, R. T. (2016). Plant-derived products in crop protection: Effects of various application methods on pests and diseases. *Phytoparasitica*, 44, 379–391.
9. Gbadegesin, L.A., Omole, R.K., Johnson, R.M., Uthman, Q.O & Babalola, O.O. (2023). Biopesticides as a promising alternative to synthetic pesticides: A case for microbial pesticides, 446

- and nanobiopesticides. *Front Microbiol* doi:10.3389/fmicb.2023
10. Grange, N., & Ahmed, S. (1988). *Handbook of plants with pest control properties*. John Wiles & Sons.
 11. Ivbijaro, M. F. (1990). *Natural Pesticides: Role and Production Potential in Nigeria*. National workshop on the pesticide Industry in Nigeria, University of Ibadan, 24.
 12. Lengai, G. M. W., Muthomi, J. W., & Mbega, E. (2019). Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. *Scientific African*, 7.
 13. Mahob, R. J., Taliedje, D. M., Mahot, H. C., Mama Ngah, I., Eteme Enama, S., Cilas, C., Fotso Toguem, Y. G., Hanna, R., & Bilong Bilong, C. F. (2021). Biocontrol of the brown cocoa mirids using neem oil and an ethanolic extract from neem under laboratory conditions. *African Entomology*, 29(2), 507–521.
 14. Moubarak, K., Seth, N. W., Adiginou, A. K., Exonam, A. K., Pana, K., & Adolé, G. I. (2022). Analysis of aspects of the conventional and organic cocoa production system and producers' perception of the use of botanical pesticides for the management of cocoa mirids in Togo. *International Journal of Advanced Research*, 10(10), 67–77.
 15. Nas, F. S., Zage, A. U., & All, M. (2017). Phytochemical screening and Antibacterial activity of *Garcinia kola* seed extract against pathogenic methicillin resistant *Staphylococcus aureus*. *Bayero Journal of pure and Applied Sciences*, 10(2), 198–203.
 16. Padi, B., Adu-Acheampong, R., & Nkansah, A. (2000). Botanical pesticides for the control of cocoa capsids (Heteroptera: Miridae). *Proc. 13th Int. Cocoa Res. Conf*, 403–413.
 17. Pavela, R. (2015). Acute toxicity and synergistic and antagonistic effects of the aromatic compounds of some essential oils against *Culex quinquefasciatus* Say larvae. *Parasitology Research*, 114, 3835–3853.
 18. Pavela, R. (2016). History, presence and perspective of using plant extracts as commercial botanical insecticides and farm products for protection against insects—A review. *Plant Protection Science*, 52, 229–241.
 19. Pavela, R., Guedes, R. N. C., Maggi, F., Desneux, N., & Benelli, G. (2023). Essential oil antifeedants against armyworms: Promises and challenges. *Entomologia Generalis*, 43, 689–704.
 20. Pavela, R., Kovaříková, K., & Novák, M. (2025). Botanical Antifeedants: An Alternative Approach to Pest Control. *Insects*, 16(2), 136.
 21. Philogene, B. J. R., & Lambert, J. D. H. (1993). Botanical pesticides: Optimizing pest control and minimizing environmental impacts. In G. Forget, T. Goodman, & A. de Villiers (Eds.), *Impact of pesticide use on health in developing countries* (pp. 280–291). IDRC Ottawa.
 22. Roy, B., Amin, R., Uddin, M. N., Islam, A. T. M., Islam, M. J., & Halder, B. C. (2005). Leaf extracts of *Shiyalmutra* (*Blumea lacera* DC) as botanical insecticides against lesser grain borer and rice weevil. *Journal of Biological Sciences*, 5, 201–204.
 23. Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G. P. S., Handa, N., Kohli, S. K., Yadav, P., Bali, A. S., & Parihar, R. D. (2019). Worldwide pesticide usage and its impacts on ecosystem. *SN Applied Sciences*, 1, 1446.
 24. Stanes T & Company. (2025). *Biopesticides and Sustainable crop protection product*.
 25. Stoll, G. (2000). *Natural Crop protection in the tropics: Letting information come to life* (2nd ed.). Margraf Verlag.