



## Botanical Alternatives for the Management of Fall Armyworm: Efficacy of *Urtica dioica*-Derived Biopesticide

Kofi Frimpong-Anin<sup>1,2</sup>, Ernest Baafi<sup>1</sup>, Kwesi Atta Snr. Aidoo<sup>1</sup>, Ernestina N. Awarikabey<sup>1</sup>, Agbesi K. Keteku<sup>1</sup>, Franklin Bosompem<sup>1</sup>, Richard Y. Owusu<sup>1</sup> and Douglas Antwi<sup>1</sup>

<sup>1</sup>SIR-Crops Research Institute, P. O. Box 3785, Kumasi, Ghana

<sup>2</sup>Department of Plant Resources Development, Faculty of Natural Sciences and Environmental Management, CSIR-College of Science and Technology, Ghana

Corresponding Author: Email: [nanakofy@yahoo.com](mailto:nanakofy@yahoo.com)

Submitted 02/03/2026, Published online on 31/05/2026 in the <https://www.m.elewa.org/journals/journal-of-applied-biosciences-about-jab/> <https://doi.org/10.35759/JABs.220.3>

### ABSTRACT

**Objectives:** To evaluate the field efficacy of *Urtica dioica*-based botanical insecticide, *Adamfo Pa*, for managing fall armyworm (FAW) across the Forest and Transitional Ecological zones of Ghana, with the broader goal of expanding biopesticide options within integrated pest management strategies.

**Methodology and Results:** Maize plots were treated with three doses of *Adamfo Pa* – 300, 400, 500 mL/100L water), Bypel® (*Bacillus thuringiensis*) and water as controls, at weekly and bi-weekly intervals. FAW larval survival, incidence, maize leaf damage and yield were evaluated. The 500 mL/100 *Adamfo Pa* performed comparably to Bypel®, with both treatments showing significantly lower larval survival rates, FAW incidence, and leaf damage scores than the lower doses of *Adamfo Pa* and the untreated control. Weekly application intervals provided superior pest suppression compared to bi-weekly applications across all measured parameters. Highest cob weight and grain yield were recorded in plots treated with the high-dose *Adamfo Pa* and Bypel® applied weekly.

**Conclusion and Application of Results:** This study demonstrated that *Adamfo Pa*, a *Urtica dioica*-based biopesticide, is effective for fall armyworm (FAW) management in maize, particularly at the high dose of 500 mL/100 L applied weekly. Its efficacy was comparable to the commercial Bt-based insecticide, Bypel®. The findings highlight *Adamfo Pa* as a potent botanical alternative within integrated pest management (IPM) programmes. This offers farmers an eco-friendly option that reduces reliance on synthetic insecticides for the management of the pest. It also diversifies biopesticide choices beyond neem extracts. Its adoption can enhance sustainable maize production among smallholder farmers, mitigate insecticide footprint in agricultural landscapes, and slow resistance development in FAW populations. Further multi-season trials could strengthen evidence of its yield-enhancing potential and guide broader commercialization.

**Key words:** Bio-efficacy, botanical, fall armyworm, leaf damage, Maize, pest incidence,

## INTRODUCTION

The turbulence created by the Fall Armyworm (FAW) [*Spodoptera frugiperda* (J.E. Smith)] invasion in Africa having somehow subsided had evolved management approaches. The initial invasion was so severe that food security was threatened across the continent, particularly based in FAW effect on maize (Day *et al.*, 2017; Prassana, 2018). Maize is an important staple in Africa and any escalation in production constraints have profound effect on food security in Africa (Galani *et al.*, 2022). The environmental and weather conditions across most parts of Africa are highly favourable for short reproduction cycle of the pest (Kenis *et al.*, 2022; Togola *et al.*, 2025). Unavailability of natural enemies to counter the population explosion of the pest in its new environment (Tendeng *et al.*, 2019; Constantine *et al.*, 2023), and poor knowledge of the pest and management practices against the pest under the complex African farming systems (Asare-Nuamah, 2022) favoured its escalation. There was therefore urgent need to swiftly reduce the devastation that was being caused to maize and other food crops by the pest. Several unverified control strategies were therefore forced into the pest management space across the continent (Harrison *et al.*, 2019). Several indigenous and naturalized predators and parasitoids over the past few years have been found to attack different stages of the FAW (Sisay *et al.*, 2018; Tendeng *et al.*, 2019; Abbas *et al.*, 2022). However, with so many uncertainties, the best bet was to resort to synthetic insecticides (Tambo *et al.*, 2020; Togola *et al.*, 2025). These insecticides are broad spectrum, which efficiently kill pests and but also untargeted organisms including natural enemies (El-Wakeil *et al.*, 2013; Schmidt-Jeffris, 2023). There have been reports of non-usage of personal protective equipment (PPE), insecticide residues especially in fresh corn, pollution of aquatic systems with the excessive use of the insecticides and also the fear of wide scale of

the pest becoming resistance to the insecticides (Gebreziher, 2020; Tambo *et al.*, 2020; Safo *et al.*, 2023; Togola *et al.*, 2025). These led to the current focus of developing sustainable and eco-friendly management practices using botanical extracts as one of the effective components of Integrated Pest Management (IPM) systems for the control of the FAW. Botanical extracts have the advantages of low toxicity, non-persistence, environmentally friendly and low affinity of pest developing resistance to it. The complex compounds in these botanical insecticides sustain their efficacy over long period compared to the synthetics (Bateman *et al.*, 2018); Lengai *et al.*, 2020; Ruikar *et al.*, 2025). Several plants are known to have insecticidal effect on pests of which some have been exploited but quite a number are yet to be harnessed, especially for commercial use (Amason *et al.*, 2012; Ruikar *et al.*, 2025). Some of the commonly used plant products including nicotine, rotenone, sabdilla and ryania are being phased out due to high risks such as high toxicity to non-targets (fishes and pollinators), and links to some human diseases (Isman, 2014; Ruikar *et al.*, 2025). This necessitates the continuous exploitation of safer botanical insecticides, especially against the fall armyworm which has now become naturalized pest in Africa. The most widely used or commercialized botanical insecticides are the neem (*Azadirachtin*) and pyrethrum (*Pyrethrin*) extracts (Chaudhary *et al.*, 2024). In Ghana, the key botanical insecticide is the neem (Babendreier *et al.*, 2020). There is therefore the need to widen the scope of developing other plants that have shown good insecticidal properties for wider usage options. This creates good practice of alternating insecticides to confound pest and resistance development (Madgwick and Kanitz, 2024). The stinging nettle, *Urtica dioica* (Family Urticaceae) is a perennial plant widely distributed in humid environments and well known for their

therapeutic uses in traditional medicines and culinary (Dhouibi *et al.*, 2020). Its insecticidal properties are being exploited for commercial botanical insecticide formulation (Al-Chalabi *et al.*, 2023; Eldesouky *et al.*, 2024). One of such biopesticide formulations, *Adamfo Pa*,

have been developed from the plant for agricultural use. A field study was thus conducted on efficacy of *Adamfo Pa* and also determine the effective dosage for the management of FAW in maize.

## MATERIALS AND METHODS

**Study locations:** This study was conducted in two maize producing areas in two agro-ecological zones namely Fumesua (Coordinates: 6.715297, -1.532023) in the semi-deciduous rainforest and Ejura (7.403591, -1.346156) in the Forest-Savannah Transitional zone in 2025. Ejura is one of the commercial maize growing hubs in Ghana with farm architecture ranging from smallholdings of about 2 acres to over 100 acres. Farms are usually mechanized but rainfed and maize is usually rotated with cowpea. The area has two rainfall seasons, the major being in April – August and minor September – November, with dry season from December to February. Mean annual rainfall is 1200 – 1500 mm and mean annual temperature of 21- 31°C. The soils are forest savanna ochrosols ((Cudjoe *et al.*, 2021; Obour *et al.*, 2022). Fumesua is peri-urban with small holdings averaging 1.9 acres (Mensah and Yankson, 2013). It also experiences two rainy seasons, but with mean annual rainfall and temperature of 1,250 – 1,700 mm and 22 – 31°C, respectively (MOFA). Fumesua has ferric acrisol soil, which is mainly sandy loam to clayey loam (Adjei-Gyapong and Asiamah, 2000).

**Field set up and experimental design:** Experimental fields were ploughed and harrowed to loosen soil. Maize was planted at 2 seeds per hill at distance of 80 cm between rows and 30 cm within rows on 456 m<sup>2</sup> plot. Weeds were cleared twice manually at 3 and 7 weeks after planting. The recommended rate of 100:60:60 NPK/ha and 400kg urea was employed by applying NPK 15:15:15 2 weeks after planting and 87kg urea top dress 4 weeks

after planting. Field was laid out in a split-split plot design to allow the assessment of treatments, application intervals and dosage rate. The main plot factor was location, subplot factor application interval at two levels - weekly and bi-weekly, and the sub-subplot comprised of five treatments as *Adamfo Pa* at 300 ml/100 L (Low dose), *Adamfo Pa* at 400 ml/100 L (Mid dose), *Adamfo Pa* at 500 ml/100 L (High dose), Bypel® (active ingredients: *Bacillus thuringiensis* and Granulovirus) as reference biopesticide, and Control at 0 ml/100 L of water. There were three replications of each treatment. Spraying of the maize commenced at 40% FAW infestation threshold and these were repeated at weekly and bi-weekly, depending on the plot. Thus, there were four sprayings for weekly and 2 for bi-weekly spraying regimes. All sprayings were done prior to tasselling using a calibrated manually-operated knapsack sprayers equipped with a single nozzle.

### Data collection

**Effect on fall armyworm larvae:** Five maize plants with fresh frass, indicative of live FAW larvae were selected randomly from each plot. Maize whorls were carefully opened (to ensure minimal damage to maize plant) to ensure FAW larvae was present. Larvae of about 5<sup>th</sup> and 6<sup>th</sup> instars were excluded, to ensure larvae will still be present at least three days before dropping to the soil to pupate. Selected maize plants harbouring the live FAW larvae were tagged. All plots were sprayed with the three different concentrations of *Adamfo Pa* [ Low = 300 ml/100 L, mid = 400 ml/100 L, and high = 500 ml/100 L), Bypel® and the control. All tagged plants were sampled 72 hrs after the

spraying for live FAW larvae. Percent FAW larvae alive after the 72 hrs were calculated.

**FAW incidence and damage on maize:** The number of maize plants (excluding boundary rows) for each plot were counted. The number of maize plants showing signs of FAW damage on the leaves were also counted and the level of damage scored using Davis scale (1 – 9) (Prasana *et al.*, 2018). The different *Adamfo Pa* concentrations (low, mid and high), Bypel® and control were applied to maize plants three weeks after emergence. Spraying was repeated at weekly and bi-weekly intervals and on each occasion the FAW incidence and leave damage were assessed until tasselling. Percent FAW

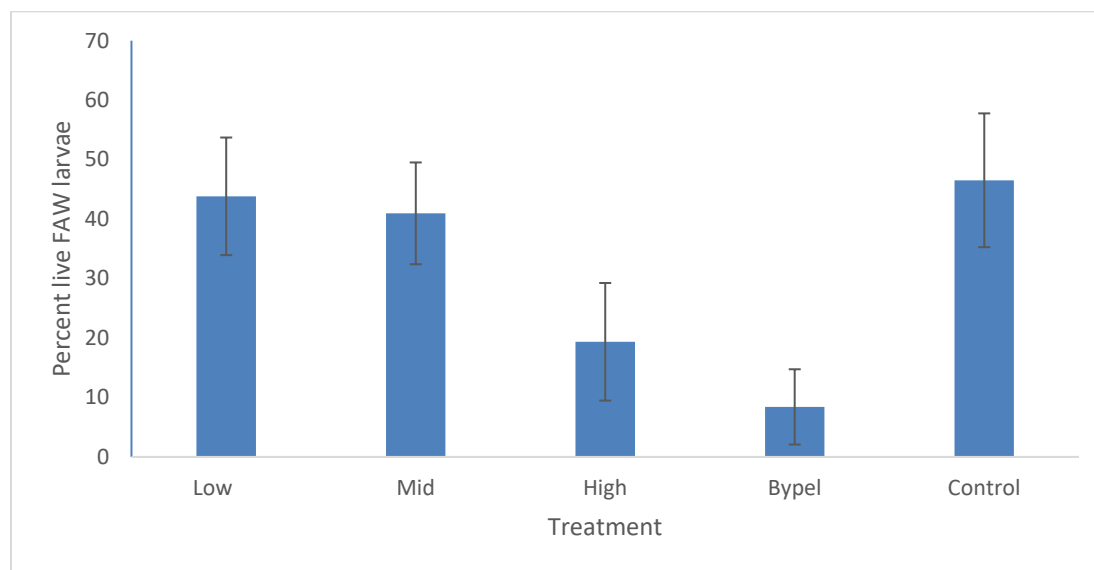
incidence and leave damage on maize were calculated.

**Data analysis:** Data collected on the effect of the treatments on FAW larvae, incidence, leaf damage and yield of maize were analysed using Analysis of Variance (ANOVA). The FAW larvae, incidence and leaf damage were square root  $(x + 0.5)^{1/2}$  transformed after Shapiro-Wilk test on normality was conducted. Least significance difference (LSD) was used to separate means at  $p \leq 0.05$  when significant differences exist. Statistix version 8 was used to run all the analysis, while MS Excell was used to draw graphs.

## RESULTS

**Effect on fall armyworm larvae:** The lowest FAW larvae was observed on Bypel® (8.41%) sprayed plots followed by high *Adamfo Pa* (19.36%). The mid and low *Adamfo Pa* were not significantly different from the control

(Fig. 1). Although the positive check, Bypel® caused the highest mortality of the FAW larvae, the *Adamfo Pa* at high dosage (500ml/L) also caused appreciable mortality to the FAW larvae.



**Fig. 1:** Mean±SE of live fall armyworm larvae 48 hours after treatment with different dosages of *Adamfo Pa* bioinsecticide

**FAW incidence and damage on maize:** There were significant differences in FAW incidence and leaf damage among insecticide treatments, application intervals and at the two different locations (Table 1). There were also

significant interactions between insecticide treatment and location as well as application interval location. The least FAW incidence was recorded by Bypel® at Fumesua, followed by high *Adamfo Pa*. At Ejura, however, the

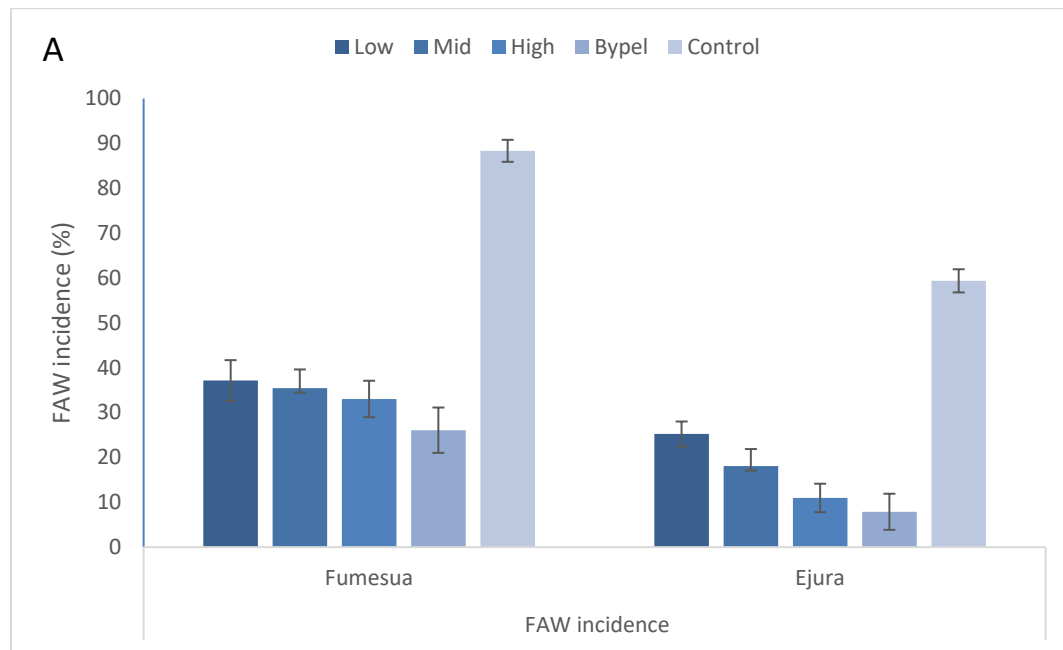
Bypel® and high *Adamfo Pa* were similar. Mid and Low *Adamfo Pa* were similar statistically and were lower than control (Fig. 2A). The weekly spraying had lower FAW incidence than the biweekly (Fig. 2B). The leaf damage followed the FAW incidence pattern. Bypel® had least leaf damage at Fumesua compared to

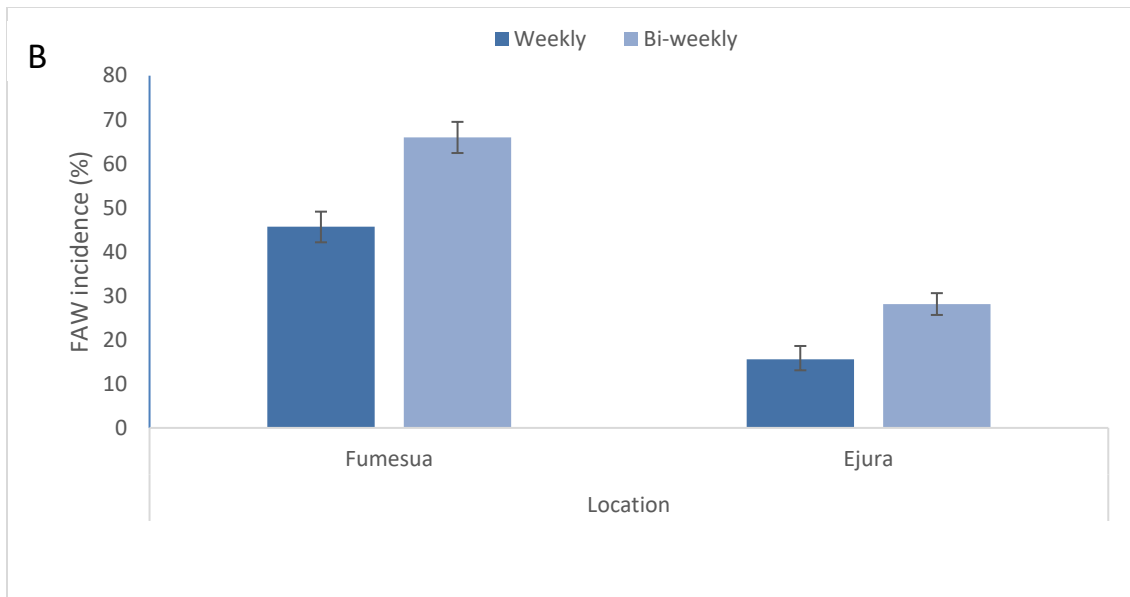
all the concentrations of *Adamfo Pa* (Fig. 3A). However, the leaf damage recorded for Bypel® and high *Adamfo Pa* were similar at Ejura. The control had the highest leaf damage. The biweekly also recorded higher leaf damage compared to weekly spraying of *Adamfo Pa* (Fig. 3B).

**Table 1:** Mean squares of FAW incidence and maize leaf damage for treatment at different spraying intervals across different locations

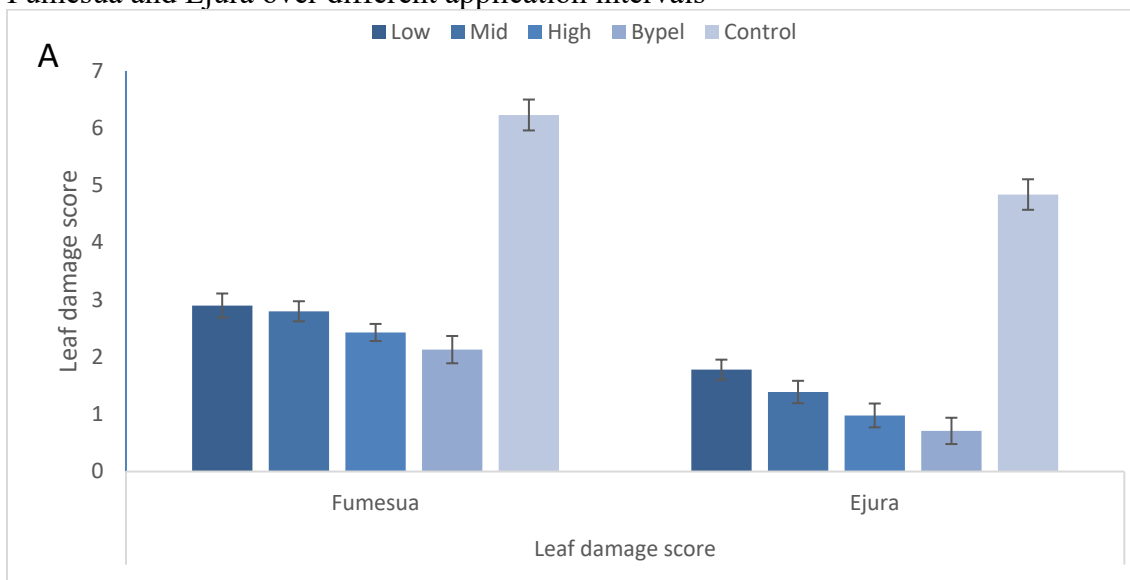
Source of variation	Degree of freedom	FAW Incidence	Maize leaf damage
Rep	2	0.16	8.53
Treatment	4	308.09*	295.76*
Application interval	1	36.81*	20.65*
Location	1	570.23*	1970.93*
Treatment*Application interval	4	11.44 <sup>ns</sup>	3.54 <sup>ns</sup>
Treatment*Location	4	136.34*	110.21*
Application interval*Location	1	29.65*	6.12*
Treatment*Application interval*Location	4	13.28 <sup>ns</sup>	2.47 <sup>ns</sup>
Error	278	533.69	497.63
Total	299		

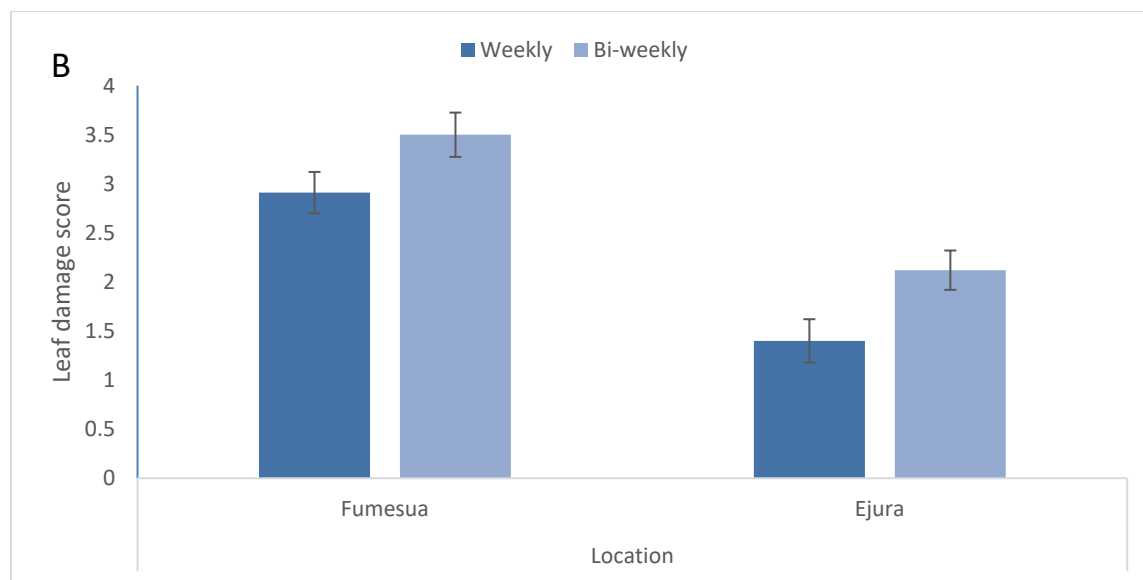
\* =significant; ns = not significant;  $\alpha = 0.05$





**Fig. 2:** Mean±SE fall armyworm incidence on maize treated with *Adamfo Pa* biopesticide at Fumesua and Ejura over different application intervals





**Fig. 3:** Mean±SE leaf damage to maize by fall armyworm treated with *Adamfo Pa* at different intervals at Fumesua and Ejura (Leaf damage score: 1= no damage, 9 = severe damage).

**Maize yield:** The effect of *Adamfo Pa* on maize cob weight and grain yield is shown in Table 3. Significant differences were observed in the dosage and application intervals. Maize cob weight and grain yield varied significantly among treatments at Fumesua with the highest recorded for the Bypel® and *Adamfo Pa* high

dose. At Ejura, however, all the three doses of *Adamfo Pa* resulted in grain yield similar to the reference biopesticide, and were higher than the control. Weekly applications resulted in higher cob weight and grain yield, compared to biweekly, the only exception being grain yield at Fumesua.

**Table 2:** Effect of *Adamfo Pa* on maize productivity

	Cob weight (kg/ha)		Grain yield (kg/ha)	
	Fumesua	Ejura	Fumesua	Ejura
<b>Application Dose</b>				
Control (water)	4088.00 <sup>c</sup>	3668.00 <sup>b</sup>	2745.00 <sup>d</sup>	3103.00 <sup>b</sup>
<i>Adamfo Pa</i> Low: 300 ml/100 L	5406.00 <sup>d</sup>	4625.00 <sup>a</sup>	3955.00 <sup>c</sup>	3724.00 <sup>a</sup>
<i>Adamfo Pa</i> Mid: 400 ml/100 L	7317.00 <sup>c</sup>	4653.00 <sup>a</sup>	5773.00 <sup>b</sup>	3603.00 <sup>a</sup>
<i>Adamfo Pa</i> High: 500 ml/100 L	8440.00 <sup>b</sup>	4769.00 <sup>a</sup>	7235.00 <sup>a</sup>	3733.00 <sup>a</sup>
Bypel® (reference)	9525.00 <sup>a</sup>	4774.00 <sup>a</sup>	7646.00 <sup>a</sup>	3691.00 <sup>a</sup>
P-value (5%)	<.001	<.001	<.001	<.001
LSD (5%)	451.50	451.50	473.60	473.60
<b>Application Interval</b>				
Weekly	7118.00 <sup>a</sup>	4853.00 <sup>a</sup>	5537.00 <sup>a</sup>	3976.00 <sup>a</sup>
Biweekly	6793.00 <sup>b</sup>	4142.00 <sup>b</sup>	5405.00 <sup>a</sup>	3166.00 <sup>b</sup>
P-value (5%)	0.043	0.043	0.054	0.004
LSD (5%)	381.1	381.1	293.10	293.10

Figures with the same alphabets in a column are significantly different at  $\alpha = 0.05$ .

## DISCUSSION

The use of biorational insecticides is considered one of the sustainable means of managing the Fall Armyworm in Africa, including Ghana (Sissay *et al.*, 2018; Tepa-Yotto *et al.*, 2023). This study sought to expand botanical based insecticide alternative to control FAW, particularly among smallholder farmers. Among the commonest botanical insecticide formulations include extracts from neem (*Azadirachta indica*), Senoria, chili pepper (Dougoud *et al.*, 1993). The insecticide used in this trial is an extract from *Urtica dioica*, a plant known for its insecticidal, fungicidal and bactericidal properties (Dhouibi *et al.*, 2020; Al-Chalabi *et al.*, 2023). It is also known to stimulate plant growth leading to improved yield (Maričić *et al.*, 2021). This study shows the extract used to formulate *Adamfo Pa* is potent against FAW at appropriate dosage. The FAW larval stage causes the plant damage and suppression of their numbers reduce damage and subsequently sustain yield. The high dose of *Adamfo Pa* was able to reduce the live FAW larvae although was lower than the reference insecticide. The about 50% FAW larval reduction on control plots could be attributed to high number of natural enemies observed on all plots throughout the experiment. Among the predators were the wasp, and reduviid in addition to egg predators like ladybird beetles, and lacewings. These predators might have influenced the FAW population (Clarkson *et al.*, 2022) as was evident in pest reaching 40% threshold at six weeks after germination. All the doses of *Adamfo Pa* were able to reduce FAW infestation on the maize when compared to the control. However, only the high dose (500ml/100L water) showed efficacy comparable to the reference biopesticide, Bypel®. This suggests the high dose should be the recommended dosage of the *Adamfo Pa* for the management of FAW albeit the producer's suggested dose of 300ml/100L water. Bypel® has consistently recommended as one of the

most effective bioinsecticide against the FAW in Ghana. Its efficacy has also been found to be comparable to most evaluated synthetic insecticides since the outbreak of the FAW in Ghana (Agboyi *et al.*, 2023; Fiaboe *et al.*, 2024). This *Urtica dioica* based bioinsecticide add up to neem-based products available on the Ghanaian market. It will also serve as alternative bioinsecticide for the smallholder farmers to prevent continuous use of the neem-based insecticides. Besides the dosage, frequency of application influences the success of an insecticide against target pests. Results from this study show that it is more efficacious to apply the *Adamfo Pa* at weekly intervals if FAW is the target pest. Higher incidence of FAW resulted in high leaf damage score and this trend has been reported across areas where the pest has been reported (Thejaswini *et al.*, 2025). Thus, all *Adamfo Pa* doses resulted in low leaf damage. However, only the high dosage reduced the damage to the same level as the reference biopesticide, Bypel®, which is similar to the recorded observation for the FAW incidence. The *Adamfo Pa* have been suggested to enhance plant growth hence boost crop productivity due to natural nutrients made available to crops upon application (Maričić *et al.*, 2021). The current study showed inconsistent results with respect to *Adamfo Pa* boosting yield of maize. Yield increased as dosages increased from low to high at the forest ecozone but not at transition ecozone. Although all *Adamfo Pa* dosages yielded higher maize than the control, there were no differences across the three dosages. This could be attributed to differences in FAW infestation and damage levels. This could be attributed to differences in FAW infestation and damage levels. Treatments in this study generally had fewer FAW infestations compared to the control, showing strong influence of *Adamfo Pa* on FAW than yield of maize. This inference is affirmed by the greater yields under weekly applications than

biweekly, where consistently lesser FAW infestation and leaf damage were observed on the former. A repeat of the experiment over

seasons will ascertain the extra nutritional properties that enhance plant growth.

## CONCLUSION AND APPLICATION OF RESULTS

The *Adamfo Pa* biopesticide at the application rate of 500ml/L is effective in reducing FAW larval survival, incidence and leaf damage in maize. The weekly application of the biopesticide proved more effective against the

FAW and therefore recommended. Its incorporation into the current FAW management strategies will offer a good alternative to neem-based insecticide.

## ACKNOWLEDGEMENT

We acknowledge the support of Naturnova Solutions, Zhengzhou Lubing Maoyi Co Ltd. P. O. Box 450000, Zhengzhou City, China and

EcoEmpower Alliance, Kanvili Tunayili, TM493 NR, Tamale, Ghana for the supply of the *Adamfo Pa*.

## REFERENCES

- Dougoud, J., Toepfer, S., Bateman, M., & Jenner, W. H. 2019. Efficacy of homemade botanical insecticides based on traditional knowledge. A review: Efficacy of homemade botanical insecticides based on traditional knowledge. A review. *Agronomy for sustainable development*, 39(4), 37.
- Maričić, B., Radman, S., Romić, M., Perković, J., Major, N., Urlić, B., Palčić, I., Ban, D., Zorić, Z., & Ban, S. G. 2021.. Stinging Nettle (*Urtica dioica* L.) as an Aqueous Plant-Based Extract Fertilizer in Green Bean (*Phaseolus vulgaris* L.) Sustainable Agriculture. *Sustainability*, 13(7), 4042. <https://doi.org/10.3390/su13074042>
- Clarkson J, Borah JR, Baudron F and Sunderland TCH 2022. Forest Proximity Positively Affects Natural Enemy Mediated Control of Fall Armyworm in Southern Africa. *Frontiers in Forests and Global Change* 5:781574. doi: 10.3389/ffgc.2022.781574
- Day R, Abrahams P, Bateman M, Beale T, Clotey V, Cock M, Cock M, Colmenarez Y, Corniani Natalia, Early R, Godwin J, Gomez J, Moreno PG, Murphy ST Oppong-Mensah B, Phiri N, Pratt C, Silvestri S, Witt, A 2017. Fall armyworm: impacts and implications for Africa. *Outlooks Pest Manage.* 28, 196–201. doi: 10.1564/v28\_oct\_02
- Prasanna, B.M., Huesing, J.E., Eddy, R. and Peschke, V.M. 2018. Fall Armyworm in Africa: A Guide for Integrated Pest Management. CIMMYT. USAID. Mexico. 109p
- Galani YJH, Orfila C, Gong YY 2022. A review of micronutrient deficiencies and analysis of maize contribution to nutrient requirements of women and children in Eastern and Southern Africa. *Critical Reviews in Food Science and Nutrition*,. 62, 1568–1591. doi: 10.1080/10408398.2020.1844636
- Kenis M, Benelli G, Biondi A, Calatayud PA. Day R, Desneux NR, Harrison, D Criticos, I Rwomushana, J van den Berg, F Verheggen, Y-J Zhang, LK Agboyi, RB Ahissou, MN Ba, J Bernal, A de Freitas Bueno, Y Carrière, GA Carvalho, X-X Chen, L Cicero, H du Plessis, R Early, P Fallet, KKM Fiaboe, DM Firake, G Goergen, AT Groot, RNC Guedes, A Gupta, G Hu, FN Huang, LR Jaber, EA Malo, CB McCarthy, RL Meagher, S Mohamed,

- DM Sanchez, RN Nagoshi, N Nègre, S Niassy, N Ota, C Nyamukondiwa, C Omoto, SR Palli, R Pavela, R Ramirez-Romero, JC Rojas, S Subramanian, BE Tabashnik, WT Tay, EG Virla, S Wang, T Williams, L-S Zang, L-S Zhang, K Wu. 2022. Invasiveness, biology, ecology, and management of the fall armyworm, *Spodoptera frugiperda*. *Entomologia Generalis* 43 (2), 187–241. doi: 10.1127/entomologia/2022/1659
- Togola, A., Beyene, Y., Bocco, R., Tepa-Yotto, G., Gowda, M., Too, A., & Boddupalli, P. (2025). Fall armyworm (*Spodoptera frugiperda*) in Africa: Insights into biology, ecology and impact on staple crops, food systems and management approaches. *Frontiers in Agronomy*, 7, 1538198.
- Tendeng, E., Labou, B., Diatte, M., Djiba, S., & Diarra, K. (2019). The fall armyworm *Spodoptera frugiperda* (JE Smith), a new pest of maize in Africa: biology and first native natural enemies detected. *International Journal of Biological and Chemical Sciences*, 13(2), 1011-1026.
- Constantine, K., Makale, F., Mugambi, I., Rware, H., Chacha, D., Lowry, A., ... & Williams, F. 2023. Smallholder farmers' knowledge, attitudes and practices towards biological control of papaya mealybug in Kenya. *CABI Agriculture and Bioscience*, 4(1), 1-15.
- Asare-Nuamah, P. 2022. Smallholder farmers' adaptation strategies for the management of fall armyworm (*Spodoptera frugiperda*) in rural Ghana. *International Journal of Pest Management*, 68(1), 8–18. <https://doi.org/10.1080/09670874.2020.1787552>
- Harrison, R. D., Thierfelder, C., Baudron, F., Chinwada, P., Midega, C., Schaffner, U., & Van Den Berg, J. 2019. Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of environmental management*, 243, 318-330.
- Bariw, S. A., Kudadze, S., & Adzawla, W. 2020. Prevalence, effects and management of fall army worm in the Nkoranza South Municipality, Bono East region of Ghana. *Cogent Food & Agriculture*, 6(1), 1800239.
- Rwomushana, I., Bateman, M., Beale, T., Beseh, P., Cameron, K., Chiluba, M., Clotey, V., Davis, T., Day, R., Early, R., Godwin, J., Gonzalez-Moreno, P., Kansime, M., Kenis, M., Makale, F., Mugambi, I., Murphy, S., Nunda. W., Phiri, N., Pratt, C. and Tambo, J. 2018 Fall armyworm: impacts and implications for Africa. CABI Evidence Note Update, October 2018. CAB International, Wallingford, UK, 51 pp. DOI: <https://dx.doi.org/10.1079/CABICOMM-62-8184>
- Sisay, B., Simiyu, J., Malusi, P., Likhayo, P., Mendesil, E., Elibariki, N., & Tefera, T. 2018. First report of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), natural enemies from Africa. *Journal of Applied Entomology*, 142(8), 800-804.
- Abbas, A., Ullah, F., Hafeez, M., Han, X., Dara, M. Z. N., Gul, H., & Zhao, C. R. 2022. Biological control of fall armyworm, *Spodoptera frugiperda*. *Agronomy*, 12(11), 2704.
- Tambo, J.A., Day, R.K., Lamontagne-Godwin, J., Silvestri, S., Beseh, P.K., Oppong-Mensah, B., Phiri, N.A. and Matimelo, M., 2020. Tackling fall armyworm (*Spodoptera frugiperda*) outbreak in Africa: an analysis of farmers' control

- actions. *International Journal of Pest Management*, 66(4), pp.298-310.
- El-Wakeil, N., Gaafar, N., Sallam, A., & Volkmar, C. 2013. Side effects of insecticides on natural enemies and possibility of their integration in plant protection strategies. In *Insecticides-development of safer and more effective technologies*. IntechOpen.
- Schmidt-Jeffris, R. A. 2023. Nontarget pesticide impacts on pest natural enemies: progress and gaps in current knowledge. *Current Opinion in Insect Science*, 58, 101056.
- Gebreziher H. G. 2020. Review on management methods of fall armyworm (*Spodoptera frugiperda* JE Smith) in Sub-Saharan Africa. *Int. J. Entomol. Res.* 5, 09–14.
- Safo, A., Avicor, S.W., Baidoo, P.K., Addo-Fordjour, P., Ainooson, M.K., Osae, M., Gyan, S.E. and Nboyine, J.A., 2023. Farmers' knowledge, experience and management of fall armyworm in a major maize producing municipality in Ghana. *Cogent Food & Agriculture*, 9(1), p.2184006.
- Bateman, M. L., Day, R. K., Luke, B., Edgington, S., Kuhlmann, U., Cock, M. J. 2018. Assessment of potential biopesticide options for managing fall armyworm (*Spodoptera frugiperda*) in Africa. *Journal of Applied Entomology*, 142(9), 805-819.
- Lengai, G. M., Muthomi, J. W., & Mbega, E. R. 2020. Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. *Scientific African*, 7, e00239.
- Ruikar, S. S., Mohapatra, S., Dhadde, S., Tandel, R., & Shrivastava, D. 2025. Evaluating the efficacy of new botanical insecticides under controlled conditions. *Journal of Entomological Research*, 49(3), 780-787.
- Fenibo, E. O., Christian, R., & Matambo, T. S. 2023. Biopesticide commercialization in African countries: successful case studies. In *Development and Commercialization of Biopesticides* (pp. 297-328). Academic Press.
- Isman, B. M. 2014. Botanical insecticides: A global perspective. In *Biopesticides: State of the art and future opportunities* (pp. 21–30). American Chemical Society. <https://doi.org/10.1021/bk-2014-1172.ch002>
- Babendreier D, Koku Agboyi L, Beseh P, Osae M, Nboyine J, Ofori SEK, Frimpong JO, Attuquaye Clotley V, Kenis M. The Efficacy of Alternative, Environmentally Friendly Plant Protection Measures for Control of Fall Armyworm, *Spodoptera Frugiperda*, in Maize. *Insects*. 2020 Apr 10;11(4):240. doi: 10.3390/insects11040240. PMID: 32290333; PMCID: PMC7240539.
- Chaudhary, S., Yadav, S. K., Verma, P., Sagar, S., & Lal, M. 2024. Botanical Insecticides for Crop Protection: Major Classes and Possible Mechanisms of Action.
- Madgwick, P. G., & Kanitz, R. 2024. What is the value of rotations to insecticide resistance management? *Pest Management Science*, 80(4), 1671-1680.
- Dhouibi, R., Affes, H., Salem, M. B., Hammami, S., Sahnoun, Z., Zeghal, K. M., & Ksouda, K. 2020. Screening of pharmacological uses of *Urtica dioica* and others benefits. *Progress in biophysics and molecular biology*, 150, 67-77.
- Al-Chalabi, B., Al-Sinjari, S., & Rasheed, M. 2023. The Effect of Ethanolic Extract of Stinging Nettle (*Urtica Dioica*) on the Larval Stages of Greater Wax Moth (*Galleria mellonella*) Lepidoptera. *New Valley Journal of Agricultural*

- Science*, 3(8), 869-876. doi: 10.21608/nvjas.2023.212480.1213
- Eldesouky, S. E., Tawfeek, M. E., & Salem, M. Z. M. 2024. The toxicity, repellent, and biochemical effects of four wild plant extracts against *Aphis gossypii* Glover and *Phenacoccus solenopsis* Tinsley: HPLC analysis of phenolic compounds. *Phytoparasitica*, 52, 98. <https://doi.org/10.1007/s12600-024-01212-z>
- Cudjoe, G. P., Antwi-Agyei, P., & Gyampoh, B. A. 2021. The Effect of Climate Variability on Maize Production in the Ejura-Sekyedumase Municipality, Ghana. *Climate*, 9(10), 145. <https://doi.org/10.3390/cli9100145>
- Obour, P. B., Arthur, I. K., & Owusu, K. 2022. The 2020 maize production failure in Ghana: A case study of Ejura-Sekyedumase municipality. *Sustainability*, 14(6), 3514.
- Mensah, S. O. and Yankson, D. A. 2013. The role of agriculture in the economic empowerment of women in the Ejisu Juaben Municipality in the Ashanti Region of Ghana. *Journal of Environment and Earth Science*, 3 (11).
- Adjei-Gyapong, T and Asiamah, R.D. (2000). The interim Ghana soil classification system and its relation with the world reference base for soil resources. Food Agric. Organ. <https://www.fao.org/4/y3948f/y3948f06.htm>
- Sisay, B., Tefera, T., Wakgari, M., Ayalew, G., & Mendesil, E. 2019. The efficacy of selected synthetic insecticides and botanicals against fall armyworm, *Spodoptera frugiperda*, in maize. *Insects*, 10(2), 45.
- Tepa-Yotto, G. T., Chinwada, P., & Rwomushana, I. 2023. Integrated pest management for fall armyworm in Africa: A review. *CABI Agriculture and Bioscience*, 4(1), 1-15
- Agboyi, L. K., Nboyine, J. A., Asamani, E., Beseh, P., Badii, B. K., Kenis, M., & Babendreier, D. 2023. Comparative effects of biopesticides on fall armyworm management and larval parasitism rates in northern Ghana. *Journal of Pest Science*, 96(4), 1417-1428.
- Fiaboe, K. R., Abalo, F., Abalo, K. M., Peter, E., Agnamba, A. O., & Abdoulaye, A. 2024. Ecological and financial efficiency of insecticidal control of fall armyworm. *Arthropod Anthropoces*, 1, aa00064.
- Thejaswini, S., Deshmukh, S. S., Hanumanthaswamy, B. C., Soumya, T. M., Mallikarjuna, H. B., & Reddy, G. V. 2025. Estimation of the level of economic injury of fall armyworm (*Spodoptera frugiperda*) on maize. *Southwestern Entomologist*, 50(3), 1-17.