Agricultural Sciences, 2023, 14, 1535-1546
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

# Bio-Efficacy of Plant-Derived Pesticides against Fall Armyworm (*Spodoptera frugiperda*) and Their Interactive Effects on Maize Agronomic Performance under Field Conditions

**Junias Sogra[1], Lux Jimmy[2,3], Kenndy Kamik[4], Alex Galus[4*]**

[1]Department of Agriculture, Papua New Guinea University of Technology, Lae, Papua New Guinea
[2]Department of Agriculture, Sonoma Adventist College, Kokopo, Papua New Guinea
[3]Coconut Product Limited, Rabaul, Papua New Guinea
[4]National Agricultural Research Institute, Kokopo, Papua New Guinea
Email: *alex.galus@nari.gov.pg

**How to cite this paper:** Sogra, J., Jimmy, L., Kamik, K. and Galus, A. (2023) Bio-Efficacy of Plant-Derived Pesticides against Fall Armyworm (*Spodoptera frugiperda*) and Their Interactive Effects on Maize Agronomic Performance under Field Conditions. *Agricultural Sciences*, **14**, 1535-1546.
https://doi.org/10.4236/as.2023.1411099

**Received:** August 15, 2023
**Accepted:** November 7, 2023
**Published:** November 10, 2023



## Abstract

Maize is widely cultivated in Papua New Guinea (PNG) and provides farmers with nutrition and income. However, the fall armyworm (FAW) (*Spodoptera frugiperda*) (J.E. Smith) (Lepidoptera: Noctuidae) invasion is a threat to its production and supply. Hence, this field experiment was conducted to assess the bio-efficacy of plant-derived pesticides (PDPs) against FAW and their interactive effects on maize agronomic performance under field conditions. The treatments studied were turmeric rhizome extract (TRE), neem leaf ash solution (NLAS), neem bark extract (NBE), and untreated plots (control) and were replicated 5 times using the randomized complete block design. The data were subjected to analysis of variance and means were separated by Fisher's protected least significant difference test. The result showed that the application of PDPs significantly reduced FAW infestation during the period of peak infestation. At 33 DAS, NBE significantly had the lowest number of FAW larvae (0.6) [$F(4, 15) = 5.11$, $p = 0.02$] and FAW attack intensity (29.8%) [$F(4, 15) = 8.69$, $p < 0.001$] compared to the control. Apart from the control, it also had the lowest FAW attack intensity (0 %) [$F(4, 15) = 3.58$, $p = 0.04$] and had the highest number of harvested ears (5.0) [$F(4, 15) = 3.72$, $p = 0.04$] and fresh ear weights (447 g) [$F(4, 15) = 4.65$, $p = 0.02$] compared to NLAS. The TRE and NLAS had performed poorly relative to the control. Hence, NBE can be used to control FAW infestation at a period of high attack intensity (33 DAS). Moreover, this study will provide basic information for future studies on biopesticidal plant extracts as a control of FAW infestation under field conditions in PNG.

**Keywords**

FAW Larvae, Attack Intensity, Plant Height, Harvested Ear, Ear Fresh Weight

## 1. Introduction

Maize, *Zea mays* L., of the annual grass family Poaceae is an important cereal crop in the world. It is one of the four world's major crops along with sugar cane, rice, and wheat that accounted for half the global production of primary crops in 2020 with a production of more than 2 billion tonnes [1]. It provides producers and consumers with health, nutritional, and economic benefits [2]. It is a source of protein, carbohydrates, sugar, minerals, dietary fibers, vitamins, oils, and natural antioxidants [3]. Despite its numerous benefits, it is under threat of transboundary pests such as fall armyworm (FAW) (*Spodoptera frugiperda*) (J.E. Smith) (Lepidoptera: Noctuidae). FAW introduction to Africa has resulted in estimated national mean losses of maize yield from 40% in Zambia to 45% in Ghana [4]. In Zimbabwe, the severe infestation of FAW has reduced income per capita for each household by 44% and increased their likelihood of experiencing hunger by 17% [5]. These problems have warranted effective control of this pest by African maize farmers. However, chemical control of FAW in Africa has raised major concerns as to farmers' health risks to hazardous pesticides that have been recommended and used in America, and FAW developing resistance to the same mode of action by cheapest and most widely used pesticides [4]. While Africa has gone through the issue of controlling this pest, it rapidly spread to other tropical countries and was confirmed in Yemen and India in July 2018, and by early 2019, it was reported in China including other five Asian countries [6]. It was again confirmed in Indonesia and Australia in March 2019 and January 2020 respectively [7] [8]. In February 2020, it was detected in Western Province [9], and its invasion posed a threat to maize cultivation, food security, and income generation for producers and consumers in Papua New Guinea (PNG). Maize is cultivated by 94% of the rural population in PNG and its cultivation spreads from sea level up to an altitude of 2450 meters [10]. It has been grown commercially for more than 30 years in the Markham and Ramu valleys for stock feed production [10]. Furthermore, it is a crop that is normally used in emergence response [9], and it is a source of food during seasonal dry climates in some parts of PNG [10]. The larvae of *S. frugiperda* feed on the whorl, shoot, tassel, and ears of maize causing yield reduction and quality deterioration. Thus, the provision of information on its control is necessary to protect against such problems. In PNG information on chemical control of this pest is unknown by most of the farmers, there is a lack of government intervention, and chemical pesticides are very expensive for a resource-poor farmer to afford.

This necessitates the need to identify locally available biopesticidal plants for controlling this pest. Biopesticidal plants such as neem (*Azadirachta indica* A. Juss.), chili (*Capsicum frutescens* L.), derris (*Derris elliptica* (Wall.) Benth.) and pyrethrum (*Tanacetum cinerariifolium* Sch. Bip.) are widely available in PNG and their pesticidal extracts are cost-effective and significant control for leaf chewing pests [11]. There are several studies conducted to assess the effects of biopesticidal plant extracts against FAW larvae. The ethanolic extracts of *A. indica* and *Piper nigrum* seeds, and *Calotropis procera* leaf powder had been shown to have insecticidal effects on FAW larvae [12]. According to [13] the aqueous crude extracts of tobacco leaves had antifeedant activity against FAW larvae, with the highest concentration (50%) exhibiting the highest mortality. In a study by [14] the ethanolic extracts of the dehydrated leaves of *Cedrela odorata* and *Piper auritum* presented insecticidal activity as high (100% mortality at a concentration of 92 mg/cm$^2$) as that obtained with the positive control, *Melia azedarach* L. (Sapindales: Meliaceae). Furthermore, seed oil and leaf extracts from *A. indica* and plant oil from turmeric (*Curcuma longa* L.) have shown to be promising in controlling FAW larvae under laboratory conditions [15] [16]. Apart from these pesticidal plants, farmers in some parts of the world use soil, sand, wood ash, lime, oils, and soaps to control FAW [6]. Since FAW is new to PNG and limited or no study has been done in PNG on its control using biopesticidal plant extracts and their interactive effects on maize agronomic performance, this field experiment was conducted to evaluate the bio-efficacy of plant-derived pesticides (PDPs) against FAW and their interactive effects on maize agronomic performance under field conditions.

## 2. Materials and Methods

### 2.1. Experimental Site Description

The field experiment was conducted at the National Agricultural Research Institute (NARI) in Keravat (4˚20'0.50"S, 152˚1'51.22"E; 21 masl) from December 2022 to February 2023. Keravat is situated in the Gazelle Peninsula and its climate is described as humid lowland because of its hill and alluvium lowland forest setting [17]. The monthly mean temperature, precipitation, and relative humidity of the trial period are 26.7˚C, 283.4 mm, and 89.3% respectively. The soil is characterized as andosol [18] and has a sandy loam texture. The site used for this experiment was planted with velvet beans (*Mucuna pruriens*) as a fallow strategy for a year before the field experiment.

### 2.2. Agronomic Activities

The land had been cleared by slashing and seedbed preparation done by a tractor with primary and secondary tillage. Ridges had been created at 1 m spacing and about 30 to 40 cm in height. Green manuring using *M. pruriens* was done by the tractor. The corn seeds of the variety called Yellow Seed Maize have sown 3 seeds per hole at a spacing of 60 cm between plants and 100 cm between rows.

Thinning was done after germination and 15 plants per treatment were selected and tagged for data collection. Weeds were maintained manually until harvesting.

### 2.3. Treatment, Design and Application

The experiment had four treatments which consisted of turmeric rhizome extract (TRE), neem leaf ash solution (NLAS), neem bark extract (NBE), and untreated plots (control). All these treatments were replicated 5 times using a randomized complete block design. Each plot had an area of 4.8 $m^2$ and had two guard rows. The extracts were prepared following a protocol modified from [19]; approximately 1 kg of neem bark was pounded using a pounder, put in a 5 liters (L) bucket, and mixed with 2 L of water. It was covered and fermented for 3 days. The solution was sieved using a cotton shopping bag as a strainer. The same was done for turmeric rhizomes. For NLAS, about 2 kg of neem leaves were oven-dried at 80˚C for 1 and a half days. The leaves were burnt and ash was collected. The ash was placed in a 5 L bucket and 2 L of water was added and the solution was stirred and sieved as the other extracts. Before application, approximately 8 g of laundry soap powder was added as a sticking agent to each treatment and mixed thoroughly. The application was done in the afternoon (4 to 6 p.m.) only to avoid pesticide degradation from direct sunlight. The nozzle of a hand sprayer was adjusted before spraying to avoid spray drift. The PDPs were applied by carefully spraying the plant stand in each treatment plot at 15 DAS when the plant was at the 3 to 4 leaf stage and through the shoot which then flowed down through the plant stem at 22, 29, and 36 DAS when the plant was at increased height to avoid contact with other treatment plots using a 2 L hand sprayer. The extracts were applied for 7 rounds before harvesting.

### 2.4. Data Collection

The identification of FAW infestation and larvae was conducted at 12 DAS. The larvae were collected and identified in the field using the Department of Primary Industry and Regional Development (DPIRD) FAW identification guide [20] to confirm the presence of FAW. The application of PDP and data collection commenced at 15 and 19 DAS respectively. The growth attribute measured was plant height which was taken from the soil surface to the shoot tip of each of the three data plants per plot using a 1 m ruler. The FAW infestations were measured by FAW attack intensity and the number of FAW larvae. The number of FAW larvae was determined by examining the plant and counting the larvae. The foliar damages were recorded using the modified rating scale [21] [22] and the extension of damages was measured using a 30 cm ruler (**Figure 1**). The FAW attack intensity was then computed (Equation (1)) for each treatment [22]. The measurements taken at the ripening stage were the number of FAW larvae, percentage of ear damage, number of harvested ears, and fresh ear weight (without sheath) according to the treatments. The number of FAW larvae was


**Figure 1.** Rating scale based on foliar damage by FAW on maize plant [21] [22].

determined by examining the ear and counting the larvae. The percentage of ear damage was determined by dividing the number of ears damaged by the total number of harvested ears for each treatment and multiplying by 100. The number of harvested ears was determined by counting and the fresh ear weight was taken by weighing the harvested ears (without sheath) using a table scale.

$$\text{FAW attack intensity}(\%) = \frac{\sum n \times v}{N \times Z} \times 100 \qquad (1)$$

where $n$ indicates the number of plants that have a "$v$" value (crop damage); $v$ indicates the value (score) of crop damage based on a scale of 1 - 9 (**Table 1**); $N$ indicates the number of plants assessed, and Z indicates highest score (9) on a scale of 1 - 9.

## 2.5. Statistical Analysis

The raw data were collated and the summary data (average values) generated for

**Table 1.** Foliar damage scale for fall armyworm infestation assessment of a maize plant.

| Score | Damage symptoms/description |
|---|---|
| 1 | Few pinholes on 1 - 2 older leaves |
| 2 | Small circular lesions and pinholes present on whorl leaves |
| 3 | Several shot-hole injuries on a few leaves (<5 leaves) and small circular hole damage to leaves |
| 4 | Several shot-hole injuries on several leaves (6 - 8 leaves) or small lesions/pinholes, small circular lesions, and a few small elongated (rectangular-shaped) lesions of up to 1.3 cm in length present on whorl and furl leaves |
| 5 | Elongated lesions (>2.5 cm long) on 8 - 10 leaves, plus a few small- to mid-sized uniform to irregular-shaped holes (basement membrane consumed) eaten from the whorl and/or furl leaves |
| 6 | Several large elongated lesions are present on several whorl and furl leaves and/or several large uniform to irregular-shaped holes eaten from furl and whorl leaves |
| 7 | Many elongated lesions of all sizes are present on several whorl and furl leaves plus several large uniform to irregular-shaped holes eaten from the whorl and furl leaves |
| 8 | Many elongated lesions of all sizes are present on most whorl and furl leaves plus many mid to large-sized uniform to irregular-shaped holes eaten from the whorl and furl leaves |
| 9 | Whorl and furl leaves were almost destroyed and plants died as a result of extensive foliar damage |

Source: Modified from [21] and [22].

each parameter (plant height, number of FAW larvae, FAW attack intensity, percentage of ear damage, number of harvested ears, and fresh ear weight) according to each treatment per block using LibreOffice® (version 7.2.0). The percentage of ear damage and number of FAW larvae at 63 DAS were not normally distributed. The former was square root-transformed (%_Ear_Damage + 0.5) and the latter was log10 transformed (#_FAW_larvae + 1) before the summary data was subjected to one-way analysis of variance (ANOVA). When there were significant differences among treatments, the means were separated using Fisher's protected least significant difference test at a 5% level. All these were done using Genstat® (version 20.1) [23].

# 3. Results

## 3.1. Effects of Plant-Derived Pesticides on FAW Infestation and Their Interactive Effects on Maize at Its Vegetative Stages

The application of treatments at 15 and 22 DAS had no significant effects ($p > 0.05$) on plant height, number of FAW larvae, and FAW attack intensity as observed on 19 and 26 DAS respectively. The application of PDPs on 29 DAS had significant effects on the number of FAW larvae and FAW attack intensity as observed at 33 DAS (Table 2). The NBE significantly had the lowest number of FAW larvae (0.6) [$F$ (4, 15) = 5.11, $p$ = 0.02] and FAW attack intensity (29.8%) [$F$ (4, 15) = 8.69, $p$ < 0.001] relative to the control. The NLAS had the lowest plant height as observed from 26 to 40 DAS compared to the control, however, their effects were similar ($p$ > 0.05). The observation made at 40 DAS showed that NBE significantly had the lowest FAW attack intensity (0 %) [$F$ (4, 15) = 3.58, $p$ = 0.04] compared to TRE. Furthermore, TRE had the highest number of FAW larvae (1.7) and attack intensity (46%) compared to the control, however, their effects were similar ($p$ > 0.05).

### 3.2. Effects of Plant-Derived Pesticides on FAW Infestation and Their Interactive Effects on Maize at Its Ripening Stage

The application of treatments had no significant effects ($p$ > 0.05) on FAW infestation and the maize's yield compared to the control (Table 3). However, NBE significantly had the highest number of harvested ears (5.0) [$F$ (4, 15) = 3.72, $p$ = 0.04] and fresh ear weights (447 g) [$F$ (4, 15) = 4.65, $p$ = 0.02] compared to NLAS. The NLAS had the lowest number of harvested ears (3.2) and ear fresh weights (242 g) compared to TRE and the control, however, their effects were similar ($p$ > 0.05).

## 4. Discussion

### 4.1. Effects of Plant-Derived Pesticides on FAW Infestation and Their Interactive Effects on Maize at Its Vegetative Stages

The application of treatments under field conditions had no significant effects on maize growth and FAW infestation relative to the control except for the application at 29 DAS. This could be due to maize's ability to compensate for foliar

Table 2. Effectiveness of treatments against FAW infestation and their interactive effects on maize growth performance.

| Treatment | Plant height (cm) DAS | | | | Number of FAW larva DAS | | | | FAW attack intensity (%) DAS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **19** | **26** | **33** | **40** | **19** | **26** | **33** | **40** | **19** | **26** | **33** | **40** |
| Control | 22.9 | 36.3 | 61.1 | 108.3 | 3.2 | 6.8 | 4.0$^{a}$ | 1.2 | 62.2 | 61.5 | 64.9$^{a}$ | 31.1$^{ab}$ |
| TRE | 26.1 | 37.9 | 61.8 | 107.6 | 4.6 | 6.0 | 2.8$^{ab}$ | 1.7 | 54.5 | 73.0 | 76.0$^{a}$ | 46.0$^{a}$ |
| NLAS | 24.7 | 36.0 | 48.0 | 90.6 | 3.4 | 6.2 | 1.8$^{ab}$ | 1.2 | 57.1 | 68.2 | 77.8$^{a}$ | 33.4$^{ab}$ |
| NBE | 26.8 | 41.1 | 75.5 | 125.5 | 2.6 | 2.8 | 0.6$^{b}$ | 0.4 | 53.3 | 51.9 | 28.9$^{b}$ | 0.0$^{b}$ |
| SED | 3.8 | 5.8 | 10.1 | 13.8 | 2.4 | 1.6 | 0.9 | 0.6 | 6.6 | 10.2 | 10.9 | 14.6 |
| $LSD_{0.05}$ | NS | NS | NS | NS | NS | NS | 2.0 | NS | NS | NS | 23.8 | 31.8 |
| CV (%) | 23.7 | 24.2 | 25.9 | 20.2 | 110.0 | 47.1 | 62.3 | 85.1 | 18.4 | 25.2 | 27.9 | 83.6 |
| $p$-value | 0.75 | 0.81 | 0.11 | 0.15 | 0.86 | 0.11 | 0.02 | 0.26 | 0.56 | 0.24 | <0.001 | 0.04 |

Data are means of five replicates. Means with similar superscripts in the same column are not significantly different by Fisher's test. DAS = days after sowing.

**Table 3.** Effectiveness of treatments on FAW infestation and maize's yield performance.

| Treatment | Number of FAW larvae[2] | % of ear damage[1] | Number of harvested ear | Fresh ear weight (g) |
|---|---|---|---|---|
| Control | 0.2 | 5.0 | 4.2[ab] | 349[ab] |
| TRE | 0.2 | 0.0 | 3.8[ab] | 296[ab] |
| NLAS | 0.0 | 0.0 | 3.2[b] | 242[b] |
| NBE | 0.0 | 0.0 | 5.0[a] | 447[a] |
| SED | 0.2 | 3.5 | 0.6 | 57.3 |
| $LSD_{0.05}$ | NS | NS | 1.2 | 124.8 |
| CV (%) | 258.2 | 447.2 | 21.6 | 27.2 |
| *p*-value | 0.43 | 0.43 | 0.04 | 0.02 |

Data are means of five replicates. Means with similar superscripts in the same column are not significantly different by Fisher's test. [1,2]Analysis of variance was done on square root and log10 transformed data respectively.

damage as it is quite capable, under good moisture and nutrition conditions, to compensate for a level of foliar damage [6]. Our field experiment was set up on the land that had been cultivated with *M. pruriens* as a fallow strategy for a year prior field experiment, and an adequate amount of precipitation (>200 mm) was received monthly during the study period which provided suitable growing conditions for maize plants. The observation made on 33 DAS showed NBE to significantly reduce FAW infestation compared to the control as it was the period of peak infestation [22] and plants could not tolerate high attack intensity. Neem-based formulations were found to alter insect behavior, repel them, inhibit feeding, and disrupt their growth and reproduction [24], and this could be the reason for the improvement seen with NBE at 33 DAS. The TRE and NLAS contradicted the effect of NBE. The TRE had the highest number of FAW larvae and attack intensity at 40 DAS. This could be due to the short duration of pesticidal efficacy and its chemical properties favoring FAW feeding after pesticidal efficacy breakdown. There were some limitations to applying *Curcuma*-based botanicals directly in the field for pest and pathogen control because of their short shelf life, volatility of the substance, and its authoritarian effects [25]. The NLAS had the lowest plant height and the highest FAW attack intensity at 33 DAS, and the lowest plant height at 40 DAS. This could be due to the short duration of pesticidal efficacy and its potassium content affecting plant height. [26] reported that wood ash applied at 3-day intervals significantly reduced pest infestation and its protectant effect was due to the presence of potash which contains potassium. Ash concentration above 70% was found to have a deleterious effect on tomato growth [27]. Neem was found to have systemic action on pests, and its efficacy lasted for 10 weeks in protecting food crops [28] and this could be the reason why NBE had more promising effects than TRE and NLAS.

### 4.2. Effects of Plant-Derived Pesticides on FAW Infestation and Their Interactive Effects on Maize at Its Ripening Stage

The application of PDPs under field conditions had no significant effects on FAW infestation and maize yield relative to the control. However, the NBE had significantly increased the number of harvested ears and ear fresh weights compared to NLAS. The high concentration of ash had been found to reduce yield in *Solanum nigrum* as it inhibited the normal transpiration and photosynthesis [29] processes and this could be the reason why NLAS had the lowest yield. However, NBE was not significantly different from TRE and the control and could be due to the genotype's ability to compensate FAW damages under good husbandry and management practices. The application of fertilizer has been shown to improve the yield of defoliated maize plants regardless of the defoliation timing [30]. Furthermore, different genotypes had been found to respond differently to FAW infestation as indicated by the leaf damage rating under screen house conditions [31]. The decline in the number of FAW larvae at the ripening stage could be due to extrinsic and intrinsic obstacles affecting the larvae [22]. Neem had been found to cause histo-physiological alterations such as degeneration of the epithelial lining of the midgut and in the peritrophic matrix of FAW larvae [32], and had shown to decrease the offspring and longevity of this species [33]. The other reason could be the larvae entering the pupae or adult stage.

## 5. Conclusion

The NBE had shown promising results from the vegetative to the ripening stage of maize plants compared to TRE and NLAS. It also reduced FAW infestation at a period of high attack intensity (33 DAS) compared to the control. Hence, NBE can be used to control FAW infestation at a period of high attack intensity. Moreover, this study will provide basic information for future studies on biopesticidal plant extracts as a control of FAW infestation under field conditions in PNG. Thus, future studies should assess the following; 1) the effect of NBE on susceptible maize genotypes; 2) the effects of other parts of *A. indica*; 3) the effects of other biopesticidal plant extracts and synthetic pesticides (positive controls), and the cost involved; and 4) maize genotypes for FAW resistance, using ratio scale for assessing infestation.

## Acknowledgments

The support provided by the Islands Regional Centre of the National Agricultural Research Institute (NARI) in Keravat, East New Britain Province is greatly acknowledged. The authors are also grateful to Dr. Roger Day, Dr. Birte Komolong, and the anonymous reviewers for their comments.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

[1] FAO (2022) Agricultural Production Statistics. 2000-2020. FAOSTAT Analytical Brief Series 41. FAO, Rome.

[2] Huma, B., Hussain, M., Ning, C. and Yuesuo, Y. (2019) Human Benefits from Maize. *Scholar Journal of Applied Sciences and Research*, **2**, 4-7.

[3] Kazerooni, E.G., Atia Sharif, H.N., Rehman, R. and Nisar, S. (2019) Maize (Corn)—A Useful Source of Human Nutrition and Health: A Critical. *International Journal of Chemical and Biochemical Sciences*, **15**, 35-41.

[4] Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y., Corniani, N., Early, R. and Godwin, J. (2017) Fall Armyworm: Impacts and Implications for Africa. *Outlooks on Pest Management*, **28**, 196-201. https://doi.org/10.1564/v28_oct_02

[5] Tambo, J.A., Kansiime, M.K., Rwomushana, I., Mugambi, I., Nunda, W., Mloza Banda, C., Nyamutukwa, S., Makale, F. and Day, R. (2021) Impact of Fall Armyworm Invasion on Household Income and Food Security in Zimbabwe. *Food and Energy Security*, **10**, 299-312. https://doi.org/10.1002/fes3.281

[6] Hruska, A.J. (2019) Fall Armyworm (*Spodoptera frugiperda*) Management by Smallholders. *CABI Reviews*, **14**, 1-11. https://doi.org/10.1079/PAVSNNR201914043

[7] Kalqutny, S.H., Nonci, N. and Muis, A. (2021) The Incidence of Fall Armyworm *Spodoptera frugiperda* J.E. Smith (FAW) (Lepidoptera: Pyralidae), a Newly Invasive Corn Pest in Indonesia. *IOP Conference Series*: *Earth and Environmental Science*, **911**, Article ID: 012056. https://doi.org/10.1088/1755-1315/911/1/012056

[8] Qi, G., Ma, J., Wan, J., Ren, Y., McKirdy, S., Hu, G. and Zhang, Z. (2021) Source Regions of the First Immigration of Fall Armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) Invading Australia. *Insects*, **12**, Article No. 1104. https://doi.org/10.3390/insects12121104

[9] Bourke, M. and Sar, S. (2020) Fall Armyworm in Papua New Guinea: How Big Is the Risk? Devpolicy Blog, 26th May. https://reliefweb.int/report/papua-new-guinea/fall-armyworm-papua-new-guinea-how-big-risk#:~:text=Conclusions-,Fall%20armyworm%20has%20the%20potential%20to%20cause%20significant%20damage%20to,rice%20and%20other%20food%20crops

[10] Bourke, R.M. and Harwood, T. (2009) Food and Agriculture in Papua New Guinea. ANU E Press, Canberra. https://doi.org/10.22459/FAPNG.08.2009

[11] Seta-Waken, P., Malie, R., Utama, P. and Palaniappan, G. (2016) Introduction to Basic Crop Production, Post-Harvest and Financial Management Practices: A Training Manual for Smallholder Vegetable Farmers in Western Pacific Island Nations. Australian Centre for International Agricultural Research, Canberra.

[12] Kona, N.E.M., Taha, A.K., Adam, A.H.M. and Mahmoud, M.E.E. (2021) The Efficacy of Some Plants Extracts on Fallarmyworm (*Spodoptera frugiperda*, J.E. Smizh) in Sudan. *Journal of Agronomy Research*, **3**, 31-37. https://doi.org/10.14302/issn.2639-3166.jar-21-3857

[13] Sakadzo, N., Makaza, K. and Chikata, L. (2020) Biopesticidal Properties of Aqueous Crude Extracts of Tobacco (*Nicotiana tabacum* L.) against Fall Armyworm (*Spodoptera frugiperda* J.E Smith) on Maize Foliage (*Zea mays* L.) Diets. *Agricultural Science*, **2**, 47-55. https://doi.org/10.30560/as.v2n1p47

[14] Jiménez-Durán, A., Barrera-Cortés, J., Lina-García, L.P., Santillan, R., Soto-Hernández, R.M., Ramos-Valdivia, A.C., Ponce-Noyola, T. and Ríos-Leal, E. (2021)

Biological Activity of Phytochemicals from Agricultural Wastes and Weeds on *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). *Sustainability*, **13**, Article No. 13896. https://doi.org/10.3390/su132413896

[15] Barbosa, M.S., Dias, B.B., Guerra, M.S. and da Costa Vieira, G.H. (2018) Applying Plant Oils to Control Fall Armyworm (*Spodoptera frugiperda*) in Corn. *Australian Journal of Crop Science*, **12**, 557-562. https://doi.org/10.21475/ajcs.18.12.04.pne822

[16] Tulashie, S.K., Adjei, F., Abraham, J. and Addo, E. (2021) Potential of Neem Extracts as Natural Insecticide against Fall Armyworm (*Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae). *Case Studies in Chemical and Environmental Engineering*, **4**, Article ID: 100130. https://doi.org/10.1016/j.cscee.2021.100130

[17] McAlpine, J.R., Keig, G. and Falls, R. (1989) Climate of Papua New Guinea. Common Wealth Scientific and Industrial Research Organization. Australian National University Press, Canberra.

[18] Bleeker, P. (1983) Soils of Papua New Guinea. The Commonwealth Scientific and Industrial Research Organization. Australian National University Press, Canberra.

[19] Nzanza, B. and Mashela, P.W. (2012) Control of Whiteflies and Aphids in Tomato (*Solanum lycopersicum* L.) by Fermented Plant Extracts of Neem Leaf and Wild Garlic. *African Journal of Biotechnology*, **11**, 16077-16082. https://doi.org/10.5897/AJB12.775

[20] Department of Primary Industries and Regional Development (2018) Identification of Fall Armyworm. DPIRD Press, South Perth. https://www.agric.wa.gov.au/sites/gateway/files/DPIRD%20FAW%20Identification_0.pdf

[21] Prasanna, B.M., Huesing, J.E., Eddy, R. and Peschke, V.M. (2018) Fall Armyworm in Africa: A Guide for Integrated Pest Management. CIMMYT, Mexico.

[22] Supartha, I.W., Susila, I.W., Sri Sunari, A.A., Febri Mahaputra, I.G., Wisma Yudha, I.K. and Wiradana, P.A. (2021) Damage Characteristics and Distribution Patterns of Invasive Pest, *Spodoptera frugiperda* (J.E Smith) (Lepidoptera: Noctuidae) on Maize Crop in Bali, Indonesia. *Biodiversita*, **22**, 3378-3389. https://doi.org/10.13057/biodiv/d220645

[23] VSN International (2019) The Guide to the Genstat Command Language (Release 20), Part 2 Statistics. VSN International, Hemel Hempstead.

[24] Adhikari, K., Bhandari, S., Niraula, D. and Shrestha, J. (2020) Use of Neem (*Azadirachta indica* A. Juss) as a Biopesticide in Agriculture: A Review. *Journal of Agriculture and Applied Biology*, **1**, 100-117. https://doi.org/10.11594/jaab.01.02.08

[25] Pandey, A.K., Silva, A.S., Varshney, R., Chávez-González, M.L. and Singh, P. (2021) Curcuma-Based Botanicals as Crop Protectors: From Knowledge to Application in Food Crops. *Current Research in Biotechnology*, **3**, 235-248. https://doi.org/10.1016/j.crbiot.2021.07.004

[26] Wahedi, J.A., Zakariya, R., Elkanah, O.S., Ishuwa, M.N., Vincent, V.M. and Enoch, T.G. (2017) Activities of Neem and Wood Ash as Biopesticides in the Control of Insect Pests on Vegetable Crops in Mubi. *GSC Biological and Pharmaceutical Sciences*, **1**, 6-10. https://doi.org/10.30574/gscbps.2017.1.1.0006

[27] Khan, M.R. and Khan, M.W. (1996) The Effect of Fly Ash on Plant Growth and Yield of Tomato. *Environmental Pollution*, **92**, 105-111. https://doi.org/10.1016/0269-7491(95)00098-4

[28] Salako, E.A., Anjorin, S.T., Garba, C.D. and Omolohunnu, E.B. (2008) A Review of Neem Biopesticide Utilization and Challenges in Central Northern Nigeria. *African*

*Journal of Biotechnology*, **7**, 4758-4764.

[29] Robab, M.I., Azam, H. and Azam, T. (2010) Impact of Fly Ash on Vegetative Growth and Photosynthetic Pigment Concentrations of *Solanum nigrum* L. *Nanobiotechnica Universale*, **1**, 133-138.

[30] Blanco, C.A., Conover, K., Hernandez, G., Valentini, G., Portilla, M., Abel, C.A., Williams, P., Nava-Camberos, U., Hutchison, W.D. and Dively, G.P. (2022) Grain Yield Is Not Impacted by Early Defoliation of Maize: Implications for Fall Armyworm Action Thresholds. *Southwestern Entomologist*, **47**, 335-344. https://doi.org/10.3958/059.047.0209

[31] Soujanya, P.L., Sekhar, J.C., Yathish, K.R., Karjagi, C.G., Rao, K.S., Suby, S.B., Jat, S.L., Kumar, B., Kumar, K., Vadessery, J., Subaharan, K., Patil, J., Kalia, V.K., Dhandapani, A. and Rakshit, S. (2022) Leaf Damage Based Phenotyping Technique and Its Validation Against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith), in Maize. *Frontiers in Plant Science*, **13**, Article ID: 906207. https://doi.org/10.3389/fpls.2022.906207

[32] Roel, A.R., Dourado, D.M., Matias, R., Porto, K.R.A., Bednaski, A.V. and da Costa, R.B. (2010) The Effect of Sub-Lethal Doses of *Azadirachta indica* (Meliaceae) Oil on the Midgut of *Spodoptera frugiperda* (Lepidoptera, Noctuidae). *Revista Brasileira de Entomologia*, **54**, 505-510. https://doi.org/10.1590/S0085-56262010000300024

[33] Duarte, J.P., Redaelli, L.R., Jahnke, S.M. and Trapp, S. (2019) Effect of *Azadirachta indica* (Sapindales: Meliaceae) Oil on *Spodoptera frugiperda* (Lepidoptera: Noctuidae) Larvae and Adults. *Florida Entomologist*, **102**, 408-412. https://doi.org/10.1653/024.102.0218