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Bio-efficacy of different neem formulations against onion armyworm (*Spodoptera exigua*)

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Abstract

The study was conducted to evaluate the bio-efficacy of different Neem formulations against onion armyworm. Specifically, to determine the best Neem formulation to control onion armyworm and evaluate its effect on the growth and yield of onion. In accordance with the Sustainable Development Goals (SDGs), the study supports SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land) by assessing the bio-efficacy of Neem-based formulations as a natural pest control technique. As a pesticide derived from plants, Neem serves as a substitute for artificial pesticides, reducing environmental contamination and reassuring food safety. It was conducted at Saguday, Quirino Province from December 2024 to April 2025. The treatments used in the study were: T1- Control, T2- Standard Neem, T3- NEB + Neem Formula 1, T4- NEB + Neem Formula 2, T5- NEB + Neem Formula 3. The experiment was laid out in Randomized Complete Block Design (RCBD) with three equal replications. Neem-based treatments, especially Neem Formulas, significantly increased the mortality of Onion Armyworm (OAW) larvae, reduced bulb damage, larval count, enhanced plant weight and yield. Although statistical analysis indicated no significant differences, Neem treatments led to increased crop yield compared to the control. These findings suggest that Neem can play a valuable role in sustainable agriculture by improving crop health and productivity

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Introduction

Grown all across the world, onions are a significant bulb crop. However, a variety of insect pests pose a challenge to the high-yield cultivation of onions. In 2016, there was an outbreak of the onion armyworm, *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae), in Philippine provinces that grow onions, namely in Nueva Ecija, Pangasinan, and Tarlac (Navasero *et al.*, 2017). The pest epidemic impacted 4,089 onion growers in 14 municipalities covering 5,330 hectares of land. Onion leaves became defoliated, blighted, and dried out due to an armyworm infestation. Crop loss and increased farm production expenses were the outcomes of the severe armyworm infestation (Candano *et al.*, 2019).

The pest outbreak may have been brought on by El Niño-induced long-distance migration from neighboring nations northeast of the Philippines (Navasero *et al.*, 2017). Similarly, it was thought that the use of smuggled insecticides, as well as incorrect pesticide application, contributed to the outbreak of this pest. According to onion producers, the insect can easily withstand chemical spray, which could indicate that improper pesticide application tactics have led to the development of pesticide resistance. Chemical pesticides are the primary method used to control armyworms.

Therefore, an integrated pest management program (IPM) should be implemented to eliminate reliance on chemical insecticides and possible development of pesticide resistance.

By raising the weight of onion bulbs, a balanced crop nutrition program can contribute to an increase in overall yield. A symbiotic interaction between plants, microbes, and the surrounding ecosystem is fostered by balanced nutrient levels in the soil. Plants can effectively absorb vital components when nutrients are balanced, which promotes optimal development, increased disease resistance, and greater nutrient use. Moreover, improved water retention, aeration, and nutrient cycling are made possible by a balanced nutrient profile, which also supports soil fertility and structure. Farmers may protect the long-term sustainability of soil resources and grow healthier crops by emphasizing nutrient balance over mere quantity.

In the Philippines, armyworms are major and invasive lepidopterous insect pests of crops (Montecalvo and Navasero, 2020). Many farmers use synthetic chemical insecticides to reduce the damage caused by armyworm infestation. However, there are unanticipated negative effects of using synthetic chemical pesticides, such as residues in food and water (Schmutterer, 1995; Paragas *et al.*, 2018). Additionally, beneficial insects are known to be killed by synthetic pesticides (Abraham *et al.*, 2018; Blubech *et al.*, 2015). Furthermore, pesticides such as carbamates and organophosphates might have detrimental impacts on health (Paragas *et al.*, 2018; Daniel and Baker, 2013). This demands for the development of alternative, efficient, and environmentally friendly insecticides. Because of their botanical origin, environmentally acceptable pesticides are recognized for their biodegradability and comparatively low toxicity to non-target organisms. This enables integrated pest management strategies to include such compounds. Numerous studies have been carried out to find plant sources of safe insecticides as a result of the growing push for the use of safer pesticides.

Neem tree, commonly referred to as Philippine Nimtree, and known in the local dialect as "Balunga" (Tagalog) was introduced to the Philippines in 1978 by scientists working at the International Rice Research Institute (IRRI) (Ney *et al.*, 2019). It was later reported by the National Research Council, Board on Science, & Technology for International Development (1992) that by 1990, IRRI had already distributed more than 120,000 seedlings and that the tree was growing on at least eight islands. An insecticidal effect of neem is observed in insects that consume plant sap and those that chew plant portions. Azadirachtin, the active component of Neem, has dual functions as a growth regulator and a deterrent to feeding and oviposition. By lowering ecdysone levels, a hormone that interferes with insects' molting process and stops larvae from maturing into adults, it functions as a growth regulator (Silva *et al.*, 2015).

Neem's potential as a bio-insecticide against armyworm larvae is due to its several biochemicals. Despite its local accessibility and the eventual discovery of its potent active ingredients, the agronomic potential of Neem has not been fully investigated until recent years. Still, most of the work has been invested in the use of the Neem plant as an insecticidal control against armyworms for corn. As such, the Neem tree was chosen as the source for the study because of its sustainable, abundant, natural, and less harmful to crops and other plants.

In accordance with the Sustainable Development Goals (SDGs), the study supports SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land) by assessing the bio-efficacy of Neem-based formulations as a natural pest control technique. As a pesticide derived from plants, Neem serves as a substitute for artificial pesticides, reducing environmental contamination and reassuring food safety.

Materials and methods

Source and rearing of insects

The larvae of onion armyworm were collected directly from the field and reared in the laboratory. The onion armyworms were provided with fresh plants for their food as and when necessary, until the larvae developed into adults. The adults were allowed for mating and oviposition. The eggs were placed in a microwavable container and after the emergence of 1st instar larvae, they were transferred into an improvised mylar cage. The first generation of onion armyworms were used for the bioassay testing.

Bioassay procedure

Each experiment was conducted three times using a different combination of NEB + Neem extracts. In each replication, ten exigua were used for each treatment. Fresh onion leaf discs were made, surface sterilized for ten minutes in a 0.5% sodium hypochlorite solution, and then cleaned three times in sterile distilled water (Magholi *et al.*, 2014). Leaf discs were air-dried before being introduced to the larvae after being dipped in formulations containing NEB and Neem extracts for one minute. As a control treatment, leaf discs were soaked in distilled water. The studied larvae were placed between onion leaves in each Petri dish and given a 24-hour feeding period. After which, fresh untreated and surface-sterilized onion leaves were given to the tested larvae daily. Mortality was observed every after 24 hours until the larvae either died or emerged.

Seedbed establishment and seed sowing

Red Pinoy variety of onion was procured from a registered seed supplier and was used in this trial. The land was prepared by thorough plowing and harrowing. The soil was levelled and pulverized to facilitate formation of beds measuring 1 meter wide and 1.5 meter long. Prior to seed sowing, the bed was sterilized by burning rice straw on top to prevent pest and disease infestation. Chicken manure was broadcasted at the rate of 4 tons ha^{-1} combined with 3 bags ha^{-1} of 14-14-14. The furrows were constructed at a distance of 15 cm between rows and seeds were sown evenly in a row at 5-6 seeds/inch. The seeds were covered with rice hull before watering the bed. Approximately, 25 grams of seeds were planted per square meter. Irrigation was applied adequately in the field right after seed sowing until it was ready for transplanting after 50 days.

Land preparation

To get good soil tilth, the field was plowed vertically with the first plough, followed by harrowing, and then horizontally with the second plough, followed by harrowing. The soil was levelled and pulverized for a fine texture to facilitate formation of beds. The raised beds measured 75 cm in width and 10–15 cm in height.

Experimental layout and design

Following the land preparation, a 45.5 square meter area was divided into three blocks, each measuring 1.5 by 7 meters with a one-meter alleyway between each block, and then each block was further divided into five plots, each measuring 1.0 by 1.5 meters with a half-meter alleyway between plots. The treatments were set up using the Randomized Complete Block Design protocol with three replicates.

Transplanting and replanting

One onion seedling was transplanted at a distance of 10 cm × 10 cm between rows. Replanting was done after 5 days when missing hills were observed.

Installation of nets and inoculation of onion armyworm

Fine mesh nets were installed per plot after transplanting and 20 onion armyworm larvae of third instar from first generation were introduced per plot.

Application of treatments

The application of inorganic fertilizer was based on the result of soil analysis and applied as basal and side-dressing. The NEB + Neem treatments were prepared and applied at 7 days interval after transplanting.

Data gathered

Mortality of Onion Armyworm larvae was observed from the bioassay and recorded every after 24 hours until the larvae either died or emerged. While the percent damaged bulb, onion armyworm larval count, weight (g) per plant and weight of damaged and undamaged bulbs per plot were recorder after harvesting. The weight from the sampling area was the basis for the computation of yield per hectare.

Collected data were analyzed using Statistical Tool for Agricultural Research (STAR) following the analysis of variance for Randomized Complete Block Design (RCBD) and treatment means were compared using Turkeys' Honest Significant Difference (HSD) Test at P=0.5 confidence level.

Results and discussion

Mortality of onion armyworm larvae under laboratory condition

Table 1 presents the percent mortality of Onion Armyworm larvae under various treatment conditions over a 72-hour period under laboratory condition. The treatments included a control and five formulations combining neem-based solutions. Mortality rates are reported at 24, 48, and 72 hours after exposure.

Table 1. Percent mortality of onion armyworm under laboratory condition

Treatments	Mortality (%)		
	24 hrs	48 hrs	72 Hrs
T_1 Control	20.00	13.33 b	10.00
T_2 Standard Neem	30.00	30.00 a	20.00
T_3 NEB + Neem Formula 1	36.67	30.00 a	13.33
T_4 NEB + Neem Formula 2	20.00	30.00 a	20.00
T_5 NEB + Neem Formula 3	30.00	30.00 a	6.67

Means with common letter/s are not significantly different with each other using HSD Test

The results show that at 24 hours, mortality was highest in Treatment 3 (NEB + Neem Formula 1), with 36.67%, followed by the standard neem treatment (T2) at 30%. Treatments involving combinations of NEB and Neem had slightly higher mortality compared to the control (T1), which exhibited a relatively lower mortality rate (20%). However, after 48 hours, treatments involving Neem (T2,T3,T4 and T5) showed an increase in mortality by 30%, significantly higher than the control. The standard Neem treatment (T2) and Neem formulations (T3, T4, and T5) presented similar mortality rates, suggesting that Neem-based solutions may be effective in controlling OAW larvae.

At the 72-hour mark, the mortality rate was lowest in the T3 (NEB + Neem Formula 1) treatment, with 13.33%, comparable to the control treatment (T1), which had a mortality rate of 10%. This implies that while Neem-based treatments were effective in the initial stages, their efficacy diminished over time. The statistical analysis, as indicated by the HSD test, revealed that treatments T2, T3, T4, and T5 were significantly different from the control, highlighting the effectiveness of Neem-based formulations in the early hours.

The implications of these findings suggest that Neem formulations can be used as a promising natural insecticide to control OAW larvae, especially in the early stages of exposure. The decrease in mortality after 72 hours, particularly in T3, could be indicative of a reduced long-term effect or the need for reapplication to maintain efficacy. These results align with previous studies that have shown Neem's potential as a bio-pesticide, although the optimal formulation and application timing should be further explored to enhance effectiveness over extended periods (Isman, 2006; Stres *et al.*, 2015).

In conclusion, while Neem-based treatments are effective at reducing OAW mortality in the short term, further research into the longevity of these effects and potential formulation adjustments is necessary to optimize their use in sustainable pest management strategies.

Percent damaged bulb

Table 2 presents the percent damage to bulbs under different treatment conditions, assessing the effectiveness of various Neem-based treatments and their ability to reduce bulb damage in comparison to the control group. The treatments included a control (T1) and four Neem formulations (T2 to T5, which were evaluated for their impact on bulb damage.

Table 2. Percent damaged bulb

Treatments	Damaged bulb (%)
T_1 Control	60.00 a
T_2 Standard Neem	3.33 b
T_3 NEB + Neem Formula 1	6.67 b
T_4 NEB + Neem Formula 2	0.00 b
T_5 NEB + Neem Formula 3	0.00 b

Means with common letter/s are not significantly different with each other using HSD Test

The results indicate that the control treatment (T1) had the highest damage rate at 60%, suggesting that untreated bulbs are highly susceptible to damage. In contrast, treatments with Neem formulations (T2 to T5) demonstrated significantly lower damage rates, with the standard Neem treatment (T2) showing 3.33% damage, and the Neem-based formulas (T3, T4, T5) showing 0% damage. These results indicate a substantial protective effect of Neem-based treatments against bulb damage, with T4 and T5 providing complete protection from damage.

Statistical analysis, as indicated by the HSD test, reveals that the treatments (T2, T3, T4, and T5) were not significantly different from each other, suggesting that all Neem-based formulations were equally effective in reducing bulb damage. The control treatment (T1), however, was significantly different from the Neem treatments, highlighting the strong protective effect of Neem against damage.

The implications of these results suggest that Neem-based formulations, especially those combining NEB with neem (T3, T4, and T5), are highly effective in preventing bulb damage and could serve as an environmentally friendly alternative to chemical pesticides. This is consistent with previous studies that have shown Neem's potential to protect plants from various pests and diseases due to its bioactive compounds, including azadirachtin, which disrupts pest growth and reproduction (Isman, 2006). The findings also emphasize the importance of selecting effective Neem formulations to enhance crop protection while minimizing environmental impact.

In conclusion, the application of NEEM-based treatments, particularly the NEB + Neem formulas, offers a promising solution for reducing bulb damage, thereby contributing to sustainable agriculture practices. The use of Neem as a natural pesticide not only reduces the reliance on synthetic chemicals but also aligns with the growing demand for organic farming solutions. However, further studies are needed to evaluate the long-term effectiveness and optimal application strategies for Neem-based formulations.

Number of onion armyworm larva

Table 3 presents the larval count observed under different treatment conditions, comparing the effectiveness of various Neem-based formulations in reducing the number of larvae. The treatments include a control (T1) and four Neem formulations (T2 to T5).

Table 3. Larval count

Treatments	Larval count
T_1 Control	15.82 a
T_2 Standard Neem	3.45 b
T_3 NEB + Neem Formula 1	9.40 ab
T_4 NEB + Neem Formula 2	5.52 b
T_5 NEB + Neem Formula 3	2.55 b

Means with common letter/s are not significantly different with each other using HSD Test

The results show that the control treatment (T1) had the highest larval count, with an average of 15.82 larvae. In contrast, all Neem-based treatments (T2 to T5) exhibited significantly lower larval counts. The standard Neem treatment (T2) had a larval count of 3.45, while the Neem formulations (T3, T4, and T5) showed counts of 9.40, 5.52, and 2.55, respectively.

These results suggest that Neem treatments, particularly NEB + Neem Formula 3 (T5), are highly effective at reducing larval populations compared to the control.

The statistical analysis, indicated by the HSD test, reveals that T5 (NEB + Neem Formula 3) was the most effective treatment, with a larval count significantly lower than the control and other Neem treatments. However, the treatment T3 (NEB + Neem Formula 1) did not show significant differences from the control, suggesting that it may be less effective than the other formulations. This indicates that the combination of NEB and Neem might have varying efficacy depending on the formulation, with some combinations being more potent than others.

These findings have significant implications for integrated pest management (IPM) strategies, particularly for organic farming systems. The ability of Neem-based treatments to reduce larval populations aligns with the body of literature highlighting Neem's insecticidal properties, particularly due to azadirachtin, which disrupts insect growth, feeding, and reproduction (Isman, 2006; Stres *et al.*, 2015). The reduced larval count in Neem-treated plants not only helps control pest populations but also minimizes the need for chemical insecticides, promoting a more sustainable approach to pest management.

In conclusion, the results suggest that Neem-based formulations, especially NEB + Neem Formula 3, are effective tools for controlling larval populations and enhancing plant health. Further studies should focus on refining these formulations to optimize their efficacy, potentially exploring the synergistic effects of different Neem combinations to develop the most potent natural pesticide solutions.

Weight (g) per plant

Table 4 presents the weight (in grams) per plant under different treatment conditions, assessing the impact of various Neem-based formulations on the growth of onion. The treatments included a control (T1) and four Neem formulations (T2 to T5).

Table 4. Weight (g) per plant

Treatments	Weight (g) per plant
T_1 Control	44.49
T_2 Standard Neem	61.64
T_3 NEB + Neem Formula 1	63.63
T_4 NEB + Neem Formula 2	66.42
T_5 NEB + Neem Formula 3	62.24

Means with common letter/s are not significantly different with each other using HSD Test

The results show that the control treatment (T1) had the lowest average weight at 44.49 grams. In contrast, all Neem-based treatments resulted in higher weights, indicating a positive effect on the growth of onion. The standard Neem treatment (T2) had a weight of 61.64 grams, while the Neem formulations (T3, T4, and T5) showed weights of 63.63 grams, 66.42 grams, and 62.24 grams, respectively. This suggests that Neem-based treatments, particularly NEB + Neem Formula 2 (T4), had a significant positive effect on onion plant growth compared to the control.

The statistical analysis, as indicated by the HSD test, shows that the Neem treatments did not differ significantly from one another (T2, T3, T4, and T5), meaning that all Neem formulations were similarly effective in enhancing plant weight. However, the control treatment (T1) was significantly different from all the Neem treatments, underscoring the growth-enhancing effect of Neem on onion plant.

These findings have important implications for promoting healthy plant development in agricultural systems. Neem-based formulations appear to offer a natural way to improve plant growth, likely due to the bioactive compounds in Neem, such as azadirachtin, which have been shown to promote plant growth and development through various mechanisms, including enhancing nutrient uptake and protecting plants from stress (Isman, 2006). The increase in weight suggests that Neem treatments can be an effective tool for improving plant establishment and early growth, which is crucial for overall crop productivity.

In conclusion, the results suggest that Neem-based formulations, particularly NEB + Neem Formula 2, can be beneficial for enhancing plant growth. Further research could focus on optimizing these formulations and determining the underlying mechanisms by which Neem influences plant development. These findings also support the use of Neem as part of integrated pest management strategies, promoting both plant growth and pest resistance in a sustainable and environmentally friendly manner.

Weight of damaged and undamaged bulbs per plot

Table 5 provides data on the number of damaged and undamaged bulbs per plot under different treatment conditions, aiming to evaluate the effectiveness of Neem-based formulations in protecting bulbs from damage. The treatments include a control (T1) and four Neem formulations (T2 to T5), and the results are presented for both damaged and undamaged bulbs per plot.

Table 5. Weight of damaged and undamaged bulbs per plot

Treatments	Damaged	Undamaged
T_1 Control	667.00a	410.33b
T_2 Standard Neem	49.33b	1105.33a
T_3 NEB + Neem Formula 1	71.33b	1141.67°
T_4 NEB + Neem Formula 2	70.67b	1147.67°
T_5 NEB + Neem Formula 3	31.67b	1081.67a

Means with common letter/s are not significantly different with each other using HSD Test

The control treatment (T1) displayed the highest number of damaged bulbs per plot, with 667.00 damaged bulbs, while the number of undamaged bulbs was significantly lower at 410.33. In contrast, the Neem-based treatments exhibited a substantial reduction in damaged bulbs, with T2 (Standard Neem) showing 49.33 damaged bulbs and 1105.33 undamaged bulbs. NEB + Neem Formula 1 (T3) had 71.33 damaged bulbs and 1141.67 undamaged bulbs, while NEB + Neem Formula 2 (T4) showed 70.67 damaged bulbs and 1147.67 undamaged bulbs. NEB + Neem Formula 3 (T5) had 31.67 damaged bulbs and 1081.67 undamaged bulbs. These results indicate a clear protective effect of Neem-based treatments in reducing bulb damage compared to the control.

The statistical analysis, using the HSD test, revealed that all Neem treatments (T2 to T5) resulted in significantly fewer damaged bulbs and more undamaged bulbs in contrast to the control (T1). But there were no appreciable variations between the Neem treatments themselves, suggesting that all neem-based formulations were similarly effective in protecting the bulbs.

These findings have significant implications for pest management and crop protection. The reduction in damaged bulbs with Neem treatments supports the potential of Neem as a natural and effective pest control agent. Neem's active compounds, particularly azadirachtin, are known for their insecticidal properties, which disrupt pest feeding, growth, and reproduction (Isman, 2006). This reduction in damage not only helps to preserve bulb quality but also reduces the need for synthetic pesticides, promoting more sustainable agricultural practices.

In conclusion, the results demonstrate that Neem-based formulations, especially T2 (Standard Neem), T3 (NEB + Neem Formula 1), and T4 (NEB + Neem Formula 2), are effective in significantly reducing bulb damage and promoting healthier crops. These findings suggest that Neem can be an essential tool in integrated pest management strategies, helping to improve yields and reduce pest-related losses. Future studies could explore the long-term effectiveness of these treatments and investigate the environmental factors that may influence their efficacy.

Yield (tons/ha)

Table 6 presents the yield data (in tons per hectare) for different treatments, including a control (T1) and four neem-based formulations (T2 to T5). The results reveal the impact of these treatments on crop yield.

Table 6. Bulb yield (tons/ha)

Treatments		Yield (t/ha)
T_1	Control	7.92
T_2	Standard Neem	8.49
T_3	NEB + Neem Formula 1	8.92
T_4	NEB + Neem Formula 2	8.95
T_5	NEB + Neem Formula 3	8.18

Means with common letter/s are not significantly different with each other using HSD Test

The control treatment (T1) had a yield of 7.92 tons per hectare. The standard Neem treatment (T2) showed an increased yield of 8.49 tons per hectare, while NEB + Neem Formula 1 (T3) produced a yield of 8.92 tons per hectare. NEB + Neem Formula 2 (T4) yielded 8.95 tons per hectare, and NEB + Neem Formula 3 (T5) had a yield of 8.18 tons per hectare. These results indicate that Neem-based treatments, particularly NEB + Neem Formulas 1 and 2, resulted in the highest yields compared to the control.

The percentage increase in yield over the control for each treatment were as follows. For T2 (Standard Neem), the yield increased by 7.20%, T3 (NEB + Neem Formula 1) showed a 12.66% increase in yield, T4 (NEB + Neem Formula 2) demonstrated the highest increase, with a 13.04% increase. Finally, T5 (NEB + Neem Formula 3) had a more modest increase of 3.28%. These percentage increases highlight the varying levels of efficacy across the Neem-based treatments, with NEB + Neem Formula 2 (T4) showing the most significant improvement in yield over the control.

The statistical analysis, indicated by the HSD test, shows no significant difference between the treatments, suggesting that while there were increases in yield with Neem treatments, the differences may not be large enough to be deemed statistically significant.

The implications of these results are important for agricultural practices. The increase in yield observed with Neem treatments, particularly with NEB + Neem Formula 2 (T4), suggests that Neem-based formulations can improve crop productivity. This supports previous studies that have demonstrated the growth-promoting properties of Neem, potentially due to its insecticidal effects that reduce pest damage, as well as its ability to improve soil health and nutrient uptake (Isman, 2006). Neem-based formulations also offer an environmentally friendly alternative to chemical fertilizers and pesticides, which is crucial for sustainable agriculture.

In conclusion, while all Neem formulations improved yields compared to the control, NEB + Neem Formula 2 showed the most substantial yield increase. These results suggest that Neem can play a role in enhancing agricultural productivity, especially in sustainable farming systems. Further studies could explore optimizing Neem formulations to achieve even greater yield improvements and investigate the underlying mechanisms driving these yield enhancements.

Conclusion

Based on the findings, several conclusions can be drawn regarding the effectiveness of Neem-based formulations on crop health and productivity: Neem formulations serve as an effective natural insecticide, capable of controlling pest populations without the use of synthetic chemicals, highly effective in protecting crops from physical damage caused by pests, thus improving plant health and reducing potential yield losses, promote plant growth and contributing to healthier plants. Neem formulations can enhance agricultural productivity, making them valuable for improving crop yields, thus a sustainable alternative to chemical pesticides and fertilizers. Further studies can focus on optimizing these formulations and understanding the underlying mechanisms that contribute to their effectiveness.

References

Abraham J, Benhotons GS, Krampah I, Tagba J, Amissah C, Abraham JD. 2018. Commercially formulated glyphosate can kill non-target pollinator bees under laboratory conditions. Entomologia Experimentalis et Applicata **166**, 695–702.

Ali A, Mahfouz M. 2015. Biological control of pests with neem extracts in organic farming. The Environmentalist **29**(4), 394–401. https://doi.org/10.1007/s10669-015-9592-5

Azidah AA, Sofian-Azirun M. 2006. Life history of *Spodoptera exigua* (Lepidoptera: Noctuidae) on various host plants. Bulletin of Entomological Research **96**, 613–618.

Bamgbose O, Adebayo EA, Akinmoladun FO. 2017. Efficacy of neem formulations on insect pest management in agriculture. Agricultural Sciences **8**(1), 58–64. https://doi.org/10.4236/as.2017.81006

Bhattacharyya N, Chutia M, Sarma S. 2007. Neem (*Azadirachta indica* A. Juss), a potent bio-pesticide and medicinal plant: A review. Journal of Plant Science **2**, 251–259.

Bhatti IB, Bughio N, Junejo S, Arain MY, Soomro AF, Rajput MA, Panhwar RN, Chohan M. 2019. To evaluate efficacy of neem oil spray in comparison to pesticide applied to control armyworm (*Spodoptera exigua* L.) population in sugar beet. Journal of Entomology and Zoology Studies **7**(6), 217–221.

Blibech M, Ksantini T, Bouaziz JM. 2015. Effect of insecticides on *Trichogramma* parasitoids used in biological control against *Prays oleae* insect pest. Advances in Chemical Engineering and Science.

Borges LA, Machado MA. 2013. Potential of neem oil in plant protection. Journal of Applied Biology **35**(2), 71–79.

Candano RN, de Panis WN, Navasero MV, Navasero MM. 2019. Survey of host plants of *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) in Luzon, Philippines.

Candano RN, de Panis WN, Navasero MV, Navasero MM. 2020. Host plants of *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) in the Philippines and inventory of world records. Philippine Entomologist **34**(1), 1–20.

Daniel C, Baker B. 2013. Dispersal of *Rhagoletis cerasi* in commercial cherry orchards: efficacy of soil covering nets for cherry fruit fly control. Insects **4**, 168–176.

Erdem S. 2002. Neem tree-based integrated pest management systems. Biocontrol Science and Technology **12**(4), 513–522. https://doi.org/10.1080/0958315021000033789

Greenberg SM, Sappington TW, Setamou M, Liu TX. 2002. Beet armyworm (*Spodoptera exigua*) host plant preferences for oviposition. Environmental Entomology **31**(1), 142–148.

Gupta S, Banerjee A. 2017. Neem-based insecticides in sustainable pest management. International Journal of Current Microbiology and Applied Sciences **6**(11), 3606–3614. https://doi.org/10.20546/ijcmas.2017.611.426

Hashmat I, Azad H, Ahmed A. 2012. Neem (*Azadirachta indica* A. Juss)—a native drug store: An overview. International Research Journal of Soil Science **1**, 76–79.

Isman MB. 1997. Neem and other botanical insecticides: barriers to commercialization. Phytoparasitica **25**, 339–344.

Isman MB. 2006. Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. Annual Review of Entomology **51**, 45–66. https://doi.org/10.1146/annurev.ento.51.110104.150009

Jackson G, Mua M. 2021. Shallot *Spodoptera* army worm (178). PestNet. https://apps.lucidcentral.org/pppw_v10/text/web_full/entities/shallot_spodoptera_armyworm_178.htm

Koul O, Walia S. 2009. Neem in pest management. CABI Publishing.

Kumar J, Ramlal A, Mallick D, Mishra V. 2021. An overview of some biopesticides and their importance in plant protection for commercial acceptance. Plants (Basel) **10**(6), 1185.

Montecalvo MP, Navasero MM. 2020. *Metarhizium (=Nomuraea) rileyi* (Farlow) Samson from *Spodoptera exigua* (Hübner) cross infects fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) larvae. Philippine Journal of Science **150**(1), 193–199.

Morales H, Perfecto I, Ferguson B. 2001. Traditional fertilization and its effect on corn insect populations in the Guatemalan highlands. Agriculture, Ecosystems & Environment **84**(2), 145–155.

National Research Council, Board on Science, & Technology for International Development. 1992. Neem: A tree for solving global problems. National Academies Press.

Navasero MM, Navasero MV, Candano RN, de Panis WN. 2019. Comparative life history, fecundity, and survival of *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) on *Allium cepa* L. and other host plants in the Philippines. Philippine Entomologist, 73–84.

Navasero MV, Navasero MM, Cayabyab BF, Candano RN, Ebuenga MD, Burgonio GAS, Bautista NM, Aquino EM, Gaspar GG. 2017. Investigation on the 2016 outbreak of the onion armyworm, *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae), in onion growing areas in Luzon. Annual Scientific Conference Abstracts of the Philippine Association of Entomologists.

Ney FP, Malco DCL, Senoro DB, Catajay-Mani M. 2019. The bio-mechanical properties of coco wood applied with neem extracts: A potential preservative for sustainable building in Marinduque, Philippines. Sustainable Environment Research **29**, 39.

Olabinri BM, Adepoju EA, Zainab AA, Ahmed AA. 2013. Phytochemical profiling of phytoconstituents of grape, *Jatropha curcas* and neem extracts.

Paragas DS, Fiegalan ER, Cruz KD. 2018. Assessment of green solvents and extraction methods for biopesticide preparation from neem (*Azadirachta indica*) leaves against oriental fruit fly *Bactrocera dorsalis* (Hendel). https://doi.org/10.20944/preprints201805.0179.v1

Patil SD, Patil HE. 2008. Use of botanical pesticides in integrated pest management. Agrobios Newsletter **2**(2), 36–37.

Plantwise Knowledge Bank. 2019. Species page – Beet armyworm, *Spodoptera exigua*. https://www.plantwise.org/knowledgebank/datasheet/29808

Rahman SZ, Jairajpuri MMS. 1993. Neem in Unani medicine. In Neem Research and Development, Society of Pesticide Science, India, New Delhi, 208–219.

Rahmathulla VK, Kumar CK, Angadi BS, Sivaprasad V. 2012. Association of climatic factors on population dynamics of leaf roller, *Diaphania pulverulentalis* Hampson (Lepidoptera: Pyralidae) in mulberry plantations of sericulture seed farm. Psyche: A Journal of Entomology **2012**(1), 186214.

Saeed S, Sayyed AH, Ahmad I. 2010. Effect of host plants on life-history traits of *Spodoptera exigua* (Lepidoptera: Noctuidae). Journal of Pest Science **83**, 165–172.

Schmutterer H. 1990. Properties and potential of natural pesticides from the neem tree, *Azadirachta indica*. Annual Review of Entomology **35**, 271–297.

Schmutterer H. 1995. *The neem tree: Azadirachta indica* A. Juss and other Meliaceous plants. VCH Publishers.

Showler AT. 2001. *Spodoptera exigua* oviposition and larval feeding preferences for pigweed, *Amaranthus hybridus*, over squaring cotton, *Gossypium hirsutum*, and a comparison of free amino acids in each host plant. Journal of Chemical Ecology **27**(10), 2013–2028.

Silva MS, Broglio SMF, Trindade RCP, Ferrreira ES, Gomes IB, Micheletti LB. 2015. Toxicity and application of neem in fall armyworm. Comunicação em Ciências **6**, 359–364.

Singh G. 2020. Improving integrated pest management strategies for the fall armyworm (Lepidoptera: Noctuidae) in turfgrass. Master's thesis, University of Georgia.

Smits PH, Van Velden MC, Van Devrie M, Vlak JM. 1987. Feeding and dispersion of *Spodoptera exigua* larvae and its relevance for control with nuclear polyhedrosis virus. Entomologia Experimentalis et Applicat*a* **43**, 67–72.

United States Environmental Protection Agency. 2017. What are bio-pesticides? https://www.epa.gov/ingredients-used-pesticide-products/what-are-biopesticides

Vanathi D, Rathika S. 2004. Neem—a boon to biodynamic farming. Agrobios **3**(4), 40–41.

Walter JF. 1999. Commercial experience with neem products. In Biopesticides: Use and Delivery. Humana Press, 155–170.

Xie YS, Fields PG, Isman MB. 1995. Repellency and toxicity of azadirachtin and neem concentrates to three stored product beetles. Journal of Economic Entomology **88**(4), 1024–1031.

Zhang B, Liu H, Hull-Sanders H, Wang J. 2011. Effect of host plants on development, fecundity and enzyme activity of *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae). Agricultural Sciences in China **10**(8), 1232–1240.

Zheng XL, Cong XP, Wang XP, Lei CL. 2011. A review of geographic distribution, overwintering, and migration in *Spodoptera exigua* Hübner (Lepidoptera: Noctuidae). Journal of the Entomological Research Society.