## DECLARATION

I, Upendo Lekamoi, do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my original work and has never been submitted for a degree at any other university.

Upendo Lekamoi

3rd August 2022

| Name of the candidate | Signature | Date |
|---|---|---|

This Dissertation has been submitted for examination with our approval as University supervisors:

Dr. Ernest R. Mbega

2/8/2022

| Supervisor 1 | Signature | Date |
|---|---|---|

Prof. Paul Kusolwa

6/9/2022

| Supervisor 2 | Signature | Date |
|---|---|---|

**ABSTRACT**

This study assessed the effects of *Tephrosia vogelii* (*T. vogelii*) formulation with rabbit urine on insect pests and pollinators of sesame in a field experiment in Singida, Tanzania from February 2021 to July 2021. The field experiment consisted of five treatments arranged in a Randomized Complete Block Design (RCBD). The field experiment treatments included (application rates are w/v for *T. vogelii*; v/v for rabbit urine; 2 mils/l for synthetic pesticide) 10 % *T. vogelii*, 50 % rabbit urine, 10% *T. vogelii* + 50 % rabbit urine, water (control) and synthetic pesticide [Duduba 450 EC (Cypermethrin 100g/l. + chlorpyrifos 350g/l)], which was used as a check. The results show that sesame plants sprayed with biopesticide formulations significantly ($p \leq 0.001$) possessed a smaller number of insect pests (*Antigastra catalaunalis* and *Alocypha bimaculata*) same as synthetic pesticide. The larger numbers of pollinators (*Apis mellifera*, *Ornidia obesa* and *Diadegma semiclausum*) and natural enemies (*Tapinoma sessile* and *Coccinella undecimpunctata*) was recorded in sesame plants sprayed with biopesticide formulations than those sprayed with synthetic pesticide. Conversely, the findings of this study revealed that plots treated with 10% *T. vogelii* + 50% rabbit urine produced the highest (740.59 kg/ha) sesame yield, while those in the control gave the lowest yield (672.78 kg/ha). Therefore, this study suggests that *T. vogelii* formulation with rabbit urine can be used by the resource poorly-endowed smallholder farmers as an alternative strategy to control sesame insect pests, while maintaining high yield and beneficial insects like pollinators.

## CERTIFICATION

This is to certify that the accompanying dissertation titled "Effect of *Tephrosia vogelii* formulation with rabbit urine on insect pests and flower visitors of sesame in Singida, Tanzania" was written by Upendo Lekamoi under the supervision of Dr. Ernest R. Mbega and Prof. Paul Kusolwa. The undersigned certify that they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology.

| Dr. Ernest R. Mbega | | 3/8/2022 |
|---|---|---|
| Supervisor 1 | Signature | Date |

| Prof. Paul Kusolwa | | 6/09/2022 |
|---|---|---|
| Supervisor 2 | Signature | Date |

## COPYRIGHT

## CERTIFICATION

This is to certify that the accompanying dissertation titled "Effect of *Tephrosia vogelii* formulation with rabbit urine on insect pests and flower visitors of sesame in Singida, Tanzania" was written by Upendo Lekamoi under the supervision of Dr. Ernest R. Mbega and Prof. Paul Kusolwa. The undersigned certify that they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology.

Dr. Ernest R. Mbega

______________________________________________________________

Supervisor 1 Signature Date

Prof. Paul Kusolwa

______________________________________________________________

Supervisor 2 Signature Date

## ACKNOWLEDGEMENT

I praise and thank my heavenly father for his guidance and protection throughout my studies. For without his hand, I would have met obstacles which might have deterred the successful accomplishment of this work.

I wish to convey my sincere thanks to the Government of Tanzania, District Executive Director (DED) Arusha City, my employer, for permitting me to pursue my studies. I extend my sincere gratitude to the Nelson Mandela Institution of Science and Technology (NM-AIST) for granting me admission to the Master's degree program. Gratefully, I appreciate the Agro Ecology Hub Tanzania (AEHT) and the Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability (CREATES) for funding my research. I wish to convey sincere thanks to my research supervisors, Prof. Paul Kusolwa and Dr. Ernest R. Mbega, for their support, patience, motivation, incessant, and constructive guidance towards the successful consummation of this work. Their profound knowledge and support were prominent in the successful execution of this research.

My sincere gratitude goes to all my lecturers who have taught and taken care of me during my studies at NM-AIST. I profoundly appreciate the contributions of Mr. Nelson Mpumi, Dr. Akida Meya, Ms. Glory Rustis, and Dr. Elmugheira Mohammed in their availability for guidance and encouragement during technical barriers that led to the successful accomplishment of this work. I extend my gratitude to Ms. Florence Rashid Ntua, the Principle Agricultural Field Officer (PAFO 1), Singida region, for providing permission to conduct the study. I appreciate laborers Samweli Mwaluko Mumbeya and Rabeca Rajabu Msindawa for their assistance in the preparation of the study plots, weeding, and spraying of the treatments.

I sincerely thank my husband, Emanuel O. Saitoti, our lovely children, Ebenezer, Emburis, and Edupaesha, my mother Ruth, my brother Heri, my mother in-law Janeth, my sister in-law Zawadi Olodi, and the servants of God (Pastor Kissiba, Ndwati, and Mwakajinga) for their support, prayers, and encouragement in copious aspects to ensure that my studies are accomplished.

# DEDICATION

I dedicate my dissertation to my lovely husband, Emanuel Saitoti, as well as our lovely kids, Ebenezer, Emburis and Edupaesha, together with my mother, Ruth.

## TABLE OF CONTENT

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF PLATES

## LIST OF APPENDICES

## LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| AEHT | Agro Ecology Hub Tanzania |
| ANOVA | Analysis of Variance |
| CREATES | Centre for Research, Agricultural advancement, Teaching Excellence and Sustainability |
| DDT | Dichlorodiphenyltrichloroethane |
| GMO | Genetic Modified Organisms |
| HCH | Hexachlorocyclohexane |
| IPM | Integrated Pest Management |
| LA | Leaf area |
| LSD | Fisher’s least significant difference |
| MCE | Mondul Coffee Estate |
| NB | Number of branches |
| NL | Number of leaves |
| NM-AIST | Nelson Mandela African Institution of Science and Technology |
| NPP | Number of pods per plant |
| PD | Percentage of damage |
| RCBD | Randomized Complete Block Design |
| RH | Relative humidity |
| Ru | Rabbit urine |
| SEM | Standard Error of the mean |
| SY | Seed yield |
| TARI | Tanzania Agriculture Research Institute |
| TPHPA | Tanzania Plant Health and Pesticide Authority |
| Tv | *Tephrosia vogelii* |
| UV | Ultraviolet radiations |
| WHO | World Health Organization |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background of the Problem

Sesame (*Sesamum indicum L.*) is a dicotyledonous oil seed crop which belongs to the family *Pedaliaceae* (Carlsson *et al.,* 2008; Purru *et al.,* 2018). In Africa, sesame is used not only for family consumption as a source of oil but also for local and export markets as a source of income (Gebregergis *et al.,* 2018). In Tanzania, sesame is one of the crops cultivated that mainly contributes to household income (Mkamilo, 2004). Sesame seeds contain 50–60% oil and 19–25% protein, as well as antioxidants (sesamin and sesamolin), which have a cholesterol-lowering effect in humans and thus help to prevent high blood pressure (Anilakumar *et al.,* 2010; Shivhare & Satsangee, 2012). Moreover, sesame oil contains a huge amount of linoleate in triglyceride, which impedes malignant melanoma growth and thus can be used as pharmaceutical, medical, and cosmetics being used as demulcent, laxative, and emollient (Anilakumar *et al.,* 2010; Prasad *et al.,* 2012; Shivhare & Satsangee, 2012). Despite its significance, weeds, diseases, and insect pests are the major production constraints causing significant yield losses in sesame (Bukun, 2011). Among them, insect pests have been identified as a major restricting factor that affects sesame production (Gebregergis *et al.,* 2018; Zenawi & Gebremichael, 2017).

The major devastating insect pests of sesame are white flies *(Bemisia tabaci)*, aphids (*Aphis gossypii* and *Myzus persicae)*, sesame webworm (*Antigastra catalaunalis*), jassids *(Orosius albicinctus*), sesame flea beetle *(Alocypha bimaculata*), spider mites (*Tetranychus urticae*) and fall armyworms ( *Spodoptera frugiperda)* (Carlsson *et al.,* 2008). At various stages of crop development, from seedling to capsule formation, these insect pests cause significant damage to sesame leaves, flower buds, and pods (Barbedo, 2014; Murugesan & Venkatesan, 2016; Škaloudová *et al.,* 2006).

Literature shows that management of insect pests has been mainly by the use of synthetic pesticides (Chandler, 2008; Hakeem *et al.,* 2016). Synthetic pesticides are effective in controlling sesame insect pests by working quickly and significantly reducing crop losses and improving yields (Patra *et al.,* 2016). However, synthetic pesticides have significant negative effects on public health and the environment at large where they lead to soil and water adulteration (Kapeleka *et al.,* 2019; Syafrudin *et al.,* 2021). Synthetic pesticides, including dichlorodiphenyltrichloroethane (DDT) induce insect pest resistance and jeopardize human health (Özkara *et al.,* 2016). Moreover, the use of synthetic pesticides is currently not encouraged globally due to their deleterious effects on the environment and non-target organisms (Fiorenzano *et al.,* 2017). In this light, biopesticides are now being used globally as replacements for synthetic pesticides (Glare *et al.,* 2012). This is because of the fact that biopesticides are effective at eliminating insect pests without posing serious damage to the ecological chain or aggravating environmental adulteration (Leng *et al.,* 2011).

Biopesticides are compounds that are naturally obtained from microbes, plants, and animals (Kumar *et al.,* 2021). Microbes such as fungi, bacteria, viruses, and nematodes have been reported to be effective in managing a wide ambit of insect pests, weeds, and fungi (Thangavel & Sridevi, 2015). Microbial pesticides control insect pests through their specific toxic metabolites that pose disease to them (Hernández-Rosas *et al.,* 2020). For instance, *Bacillus thuringiensis* is usually used to manage insect pests on potatoes, cabbage, and many other crops (Samada & Tambunan, 2020). Bacterium *B. thuringiensis* acts as a pathogen to ruinous lepidopteran larvae pests by producing and releasing a toxin that ruins the mid gut of the insect pests' larvae once they devour the bacteria (Heckel, 2020; Samada & Tambunan, 2020).

Botanical pesticides, extracts from plants like *Eucalyptus camaldulemsis* and *Nicotiana tabacum*, have been used in managing and mitigating the infestations of aphids on common beans (Mpumi *et al.,* 2020). Similarly, extracts from *Annona squamosa*, *Azadirachta indica*, and *Datura stramonium* have managed to control *Bemisia tabaci*, *Antigastra catalaunalis*, and *Alocypha bimaculata* respectively in different crops, including sesame in the fields (Perring *et al.,* 2018; Saritha, 2020; Simoglou *et al.,* 2017; Sultana & Khan, 2019). Furthermore, *Azadirachta indica* extracts from the leaves and seeds have effectively managed to control *Spodoptera frugiperda* in cereal crops (Assefa *et al.,* 2019).

Most biopesticides are important components of insect pest management programs because they are affordable with regard to costs, available in the ambient environment, and feasible in terms of preparations and applications (Amoabeng *et al.,* 2014; de Cássia Seffrin *et al.,* 2010). Moreover, many biopesticides are not detrimental to human beings as well as non-target organisms, including natural enemies and pollinators (Samada & Tambunan, 2020). Research indicates that most biopesticides take a long time to release their effects in controlling insect pests, as such, alternative ways of improving their efficiency are needed (Kumar *et al.,* 2021). Mixing biopesticides can be a good way of increasing their efficiency in controlling insect pests without affecting beneficial incorporating natural enemies and pollinators, as has been reported by Mpumi *et al*. (2021).

Pollinators are very crucial agents for fruiting and food production in flowering plants (Chen & Zuo, 2018). Pollination is very effective in self-pollinated plants when compared to cross-pollinated plants, where opportunity is expected to be limited (Aizen *et al.,* 2017; Rodger *et al.,* 2013; Sukumaran *et al.,* 2020). Sesame is a self-pollinated plant, but cross-pollination by insect pollinators is normal (Feyera Takela Degafa, 2021), thus exploiting both self-pollination and cross-pollination (Andrade *et al.,* 2014). The floral structure of sesame facilitates cross-pollination, although the plant is normally deemed self-pollinating (Kamel *et al.,* 2013) and the rate of cross-pollination normally lies between 0.5% and 65% depending on environmental conditions, insect activity, and the availability of other vegetation (Mahmoud, 2012a). Sesame flowers unfurl early in the morning and drop in the evening. Shortly after the flower unfurls, anthers open and release pollen grains, which are viable for only 24 hours (Andrade *et al.,* 2014). Different species of insect pollinators have been reported visiting sesame flowers. The main pollinators are honey bees, flies, butterflies, and wasps (Shakeel & Inayatullah, 2014). Therefore, this study was conducted to assess the effects of *T. vogelii* formulation with rabbit urine on insect pests, pollinator abundance, and yield of sesame.

Extract from *T. vogelii* leaves is currently known to be effective in managing insect pests on various crops, including sesame. *T. vogelii* is among the ichthyotoxic plants normally grown in tropical countries and employed by artisanal fishermen to stun and kill fish (Ekanem *et al.,* 2004; Said *et al.,* 2020). Apart from being immensely toxic to fish, it has been employed as an insecticide, anthelminthic, and rodenticide (Dzenda *et al.,* 2008). The presence of rotenone, phenol, alkaloids, steroids, tannin, saponin, and volatile oil is revealed by phytochemical analysis of leaf extracts (Ene *et al.,* 2010). The active component rotenone has been revealed to have insecticidal traits (Said *et al.,* 2020). Rotenone exerts its toxic action by impeding the electron transport chain in cellular respiration through inhibition of the enzyme NADH ubiquinone reductase in a wide ambit of insect pests (Golden, 2011). The higher toxicity of rotenone to insects and fish is due to the fact that the lipophilic rotenone is easily conveyed through trachea and gills (Ene *et al.,* 2010). Although *T. vogelii* has been determined to be effective in managing insect pests, it takes a long time to act (Belmain *et al.,* 2012). Therefore, there was a need to test whether or not mixing it with another biopesticide like rabbit urine can improve its efficiency in management of insect pests of sesame and in preserving beneficial insects.

Rabbit urine has been used as a biofertilizer and proved to improve production by boosting plant growth and crop yield (Rahayu *et al.*, 2021). It has primarily been used as a biofertilizer alternative to chemical fertilizer in tomato production and has been shown to improve growth and crop yield due to higher levels of essential nutrients such as nitrogen, phosphates, and potassium (Indabo, 2020). Today, rabbit urine is being used as a biopesticide by smallholder farmers in many African societies, including Tanzania, to control insect pests on various crops, as well as sesame (Rwiza, 2017). Rabbit urine contains a high amount of ammonia (Wandita *et al.,* 2016). Research findings have shown that derivatives of ammonia like ammonium salts such as ammonium chloride ($NH_4Cl$) can be used as a pesticide (Mardones *et al.,* 2019). Also, ammonium bicarbonate has been used to control insect pests like olive flies (*Bactocera oleae)* in olive orchards by extirpating their respiratory systems to death (Epa & Programs, 2004). In this study, and taking into consideration the beneficial effects of *T. vogelii* and that of rabbit urine and their mode of acting as previously described, there is an urgent need to test their combined effect on management of insect pests, beneficial insects, particularly pollinators, and yield performance of sesame in Singida, Tanzania, where sesame is one of the most prominent oil crops.

## 1.2 Statement of the Problem

Insect pests are the major hindrances that reduce between 65 and 80% of sesame yield in most African countries, including Tanzania (Chandler, 2008; Kinati, 2017; Oerke, 2006). To manage insect pests of the crop, farmers have been using synthetic pesticides which, though fast acting, are very expensive in such a way that the majority of smallholder farmers cannot afford to buy them (Arora *et al.,* 2016a; Mansour *et al.,* 2018). In addition, synthetic pesticides affect beneficial insects, including pollinators on plants and the environment at large, whereby they have been cited to be deleterious to humans (Mansour *et al.,* 2018; Nicholls & Altieri, 2013). This has instigated a search for bio-based materials that are environmentally benign for pest control. However, most biopesticides take a long time to reach their maximum efficiency. Thus, there is a need to test whether mixing two or more biopesticides can improve their efficacy. Therefore, this study evaluated the effect of the mixture of the *T. vogelii* formulation with rabbit urine on the insect pests and pollinators of sesame in the Singida region, Tanzania.

### 1.3 Rationale of the Study

This study was organized in order to search for alternative insect pest management options due to the increased negative effects of synthetic insecticides on the environment, humans, and costs of utilization. Thus, the work was proposed to study the effects of *T. vogelii* formulation in combination with rabbit urine on insect pests and pollinators of sesame in the Singida region, Tanzania. The leaf extract from *T. vogelii* alone, rabbit urine alone, and the mixture of *T. vogelii* and rabbit urine were tested for their efficacy against sesame insect pests. Also, the effect of biopesticide formulations on pollinators was tested. In addition, yield was measured to test the effectiveness of biopesticide formulations in sesame production. All biopesticide formulations effectively control and manage sesame insect pests, retaining pollinators for pollination and improving yield. Therefore, the application of these biopesticide formulations for controlling sesame insect pests without affecting pollinators and yield improvement can be used by sesame smallholder farmers in Tanzania.

### 1.4 Objectives

#### 1.4.1 General Objective

To a develop *T. vogelii* formulation using rabbit urine for managing insect pests of sesame without affecting pollination services for improved crop yield.

#### 1.4.2 Specific Objectives

i. To assess the effect of *T. vogelii* formulation with rabbit urine on insect pests of sesame.
ii. To evaluate the effect of *T. vogelii* formulation with rabbit urine on the abundance of pollinators of sesame.
iii. To determine effect of *T. vogelii* formulation in combination with rabbit urine on yield of sesame.

### 1.5 Research Questions

i. To what extent are the sesame insect pests affected by the *T. vogelii* formulation with rabbit urine?
ii. What is the effect *T. vogelii* formulation with rabbit urine on population abundance of pollinators of sesame?

iii. How does the mixture of *T. vogelii* formulation with rabbit urine affect the yield of sesame crop?

## 1.6 Significance of the Study

The outcomes of this study will offer knowledge and skills to sesame smallholder farmers and society at large on the affordable, efficacious, and environmentally benign technological strategy of controlling insect pests affecting the growth and yield of sesame. These study results will also provide awareness, knowledge, and positive attitudes to the policy makers and authorities at large about the potential of biopesticides in protecting the environment from being polluted as well as enhancing yield and increasing income.

## 1.7 Delineation of the Study

This research is concerned with assessing the effects of *T. vogelii* formulation with rabbit urine on insect pets and pollinators of sesame in Singida, Tanzania.  The effects of 10% *T. vogelii*, 50% rabbit urine, and the mixture of 10% *T. vogelii* + 50% rabbit urine were assessed against sesame insect pests and on the population abundance of pollinators after application in the field. The yield of sesame was measured to assess the performance of the biopesticide formulations under smallholder field settings. The efficacy of these biopesticide formulations was assessed on insect pests and pollinators of sesame only. However, they can be assessed on other insect pests and pollinators of other crops.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Common Insect Pests of Sesame in Africa

Most insect pests (Table 1), such as aphids, sesame webworms, white flies, jassids, spider mites, sesame flea beetles, and fall armyworms, deter the production of sesame crops in Africa (Carlsson *et al.*, 2008). These insect pests affect the sesame crop at the different stages of plant growth, pose significant damage to the crop resulting in immense losses in sesame yield (Thangjam & Vastrad, 2018). Previous studies, e.g., Berhe *et al*. (2011) and Oerke (2006), show that insect pests can reduce up to 80% of the yield of sesame with *A. catalaunalis* being a major insect pest. For many years, sesame smallholder growers have been using synthetic pesticide to control insect pests including *A. catalaunalis* (Gebregergis *et al.*, 2018). Synthetic pesticides trigger environmental adulteration, decimation of non-targeted organisms, and jeopardize human health (Arora *et al.*, 2016; Fiorenzano *et al.*, 2017). This section reviews major insect pests commonly infesting sesame crops at the different stages of growth development in African countries.

**Table 1: Common insect pests of sesame in Africa**

| Common name | Scientific name | Stage of pest | Growth stages sesames damaged | Reference |
|---|---|---|---|---|
| Aphids | *M. persicae* and *A. gossypii* | Nymph and Adult | Seedling, leaves, vegetative, reproductive (flowers), and maturation stage (capsules) | Bissdorf and Weber (2007); Dilipsundar *et al.* (2019); Hegde *et al.* (2011); and Sesaco (2008) |
| Whiteflies | *B. tabaci* | Nymph and Adult | Seedling, leaves, vegetative (foliage), and reproductive (flowers) | Bissdorf and Weber (2007); Dilipsundar *et al.* (2019); and Roda *et al.* (2020). |
| Sesame webworm | *A. catalaunalis* | Larva | Seedling, vegetative growth, flowering, and capsule development stage. | Bissdorf and Weber (2007); Gebregergis *et al.* (2016a). |
| Jassids | *O. albicinctus* | Nymph and Adult | Vegetative (foliage) to capsule stage. | Sathe (2014). |
| Sesame flea beetle | *A. bimaculata* | Larva and Adult | Seedling stage to vegetative (foliage) | Mayoori and Mikun than (2009). |
| Spider mites | *T. urticae* | Adult | Vegetative (foliage) to capsule stage. | (Muzemu *et al.* (2011). |
| Fall army worms | *S. frugiperda* | Larva | Vegetative to capsule development stage | Watson (2011). |

### 2.1.1 Aphids

Aphids are the tiny insect pests whose body colors vary from black, green, yellow, brown, and purple (Liu & Sparks, 2001). These insect pests are very delicate, possessing fragile bodies, with a length ambit of 1.5 to 2.5 mm for adults depending on the species (Liu & Sparks, 2001). Adult aphids can either be alated or apterous (Shang *et al.,* 2016). Nymphs resemble adults but they are small and apterous even though the nymph generations are alated aphids (Liu & Sparks, 2001). Aphids are the most common agricultural insect pests that attack sesame leaves and stems, causing the leaves to curl and the plants to wilt and die (Iram *et al.,* 2014). Both nymphs and adult aphids pierce plant tissues and feed on the plant cell sap (Bissdorf & Weber, 2007). Aphids produce honey dew (a sugary substance), which instigates the growth of sooty mold fungus, which grows on the deposited honey dew on leaves and branches (Bissdorf & Weber, 2007). Moreover, aphids are responsible for the transmission of the viruses that pose disease to crops, including sesame (Stavrinides *et al.,* 2009). Both alated and apterous aphids have cornicles that produce pheromone and sticky droplets of chemicals that bind the mouth parts and appendages of the predators and parasitoids (Alfaress *et al.,* 2018). Two species of aphid known as the *Aphis gossypii* and *Myzus persicae* have been reported to attack sesame.

#### (i) Cotton Aphid

The cotton aphid (*A. gossypii*) is an insect pest known to infest cotton crops, but it has extended its infestation by attacking various hosts, including sesame (Ebert & Cartwright, 1997). Both nymphs and adults cause crop damage by sucking cell saps from tender leaf tissues (Table 2), indirectly by excreting honey dew that promotes the growth of fungi (*Capinodium spp*.), and directly by virus transmission (Fernandes *et al.,* 2018) such as cucumber mosaic virus, poty virus, and citrus tristeza (Vegette *et al.,* 2008). The pest *A. gossypii* is a very ruinous insect pest, infesting a broad ambit of host plants world-wide (Hegde *et al.,* 2011). Heavy infestation of *A. gossypii* results in the mitigation of the quality of crops and seeds and leads to yield losses of up to 50% (Fernandes *et al.,* 2018).

To overcome the problem, sesame smallholder farmers in Africa have been using synthetic pesticides such as sulfoximine, carbosulfan, neonicotinoid, omethoate, methomyl, and pyrethroid for the management of *A. gossypii* (Chen *et al.,* 2020). Nevertheless, *A. gossypii* insect pest has developed resistance to the synthetic pesticides like neonicotinoid, methomyl, carbosulfan, omethoate and pyrethroid (Wang *et al.,* 2007). This instigates sesame smallholder farmers to combine two or more synthetic insecticides to control *A. gossypii* (Shahid *et al.,* 2019). Mixing of the synthetic pesticides leads into environmental adulteration and killing of the useful insects like the pollinators and natural enemies (Tosi & Nieh, 2019) and imperiling the human heath (Hopper & McSherry, 2001; Kapeleka *et al.,* 2019).

**Table 2: Signs/Symptoms and effects caused by insect pests damage on sesame**

| Insect pest | Parts of sesame damaged | Signs of the damaged crop | Effects | Reference |
|---|---|---|---|---|
| *A. gossypii* | Leaves, tips, and flowers. | Curling of the leaves, yellowing of the leaves, and stunted growth. | Withering, stunted growth, and finally death of the crops. | Fernandes *et al.* (2018). |
| *A. catalaunalis* | Tender leaves, flower buds, and pods. | Web on tender leaves, which results into holes on the flower buds and pods | Stop the terminal growth leading to low yields | Murugesan and Venkatesan (2016). |
| *M. persicae* | Leaves, tips, and flowers. | Curling of the leaves, yellowing of the leaves, and stunted growth | Withering, stunted growth, and finally death of the crops | Mpumi *et al.* (2020). |
| *B. tabaci* | Leaves, flowers, and pods | Yellowing of the leaves and stunted growth | Withering, stunted growth, and finally death of the crops | Iram *et al.* (2014). |
| *A. bimaculata* | Seedlings' roots and the leaves | Shallow pits and small rounded irregular holes in the leaves. | Loss of the crops at the early stages and the low production | Mayoori and Mikun than (2009). |
| *T. urticae* | Leaves | Tiny stipples or flecks on the top of leaves | Premature drop of infested leaves and finally low yields productions | Škaloudová *et al.* (2006) |
| *S. frugiperda* | Leaves, flower buds and pods | Holes on leaves, flower buds, and pods | Yield loss | Montezano *et al.* (2018). |
| *O. albicinctus* | Leaves | Yellowish and curling of the leaves | Dropping down the flowers and the pods of sesame | Joarder *et al.* (2021. |

To evade effects brought by the utilization of synthetic pesticides, biological agents, which are known to be environmentally benign, have been used in controlling a broad range of insect pests, including the *A. gossypii* pest, and have proved to be efficacious (Isman, 2006). For instance, predatory pests such as lady beetles (*Coccinella septempunctata* and *Propylaea japonica*), lacewings (*Chrysopa phyllochroma,* and *Chrysopa sinica*) and spiders (*Erigonidium graminicola* and *Misumjenops tricuspidatus*) attack and feed on *A. gossypii* while the parasitoid *Aphidius gifuensis* parasitizes and decimates the cotton aphids (Ma *et al.,* 2006). Moreover, predators like *Harmonia axyridis* and *Phytoseiulus persimilis* and the parasitoid *Aphenius asychis,* have been used in controlling potato aphids in the green house. Snyder *et al.* (2004) divulged that the Asian lady beetle (*H. axyridis*) controls pea aphids (*Acyrthosiphon pisum*), English grain aphid (*Sitobion avenae*) and Russian wheat aphid (*Diuraphis noxia*). However, application of the natural enemies in controlling insect pests is expensive, whereby it instigates searching for the alternative biopesticide methods which are available to control *A. gossypii*.

Entomopathogenic bacteria *B. thuringiensis* are effective in controlling *A. gossypii* on cotton by releasing toxins that ruin the gut of *A. gossypii* (Ma *et al.,* 2006). Furthermore, gram-positive bacteria (*Leuconoctoc pseudomesenteriodes*) have been reported to be effective in controlling aphids. In addition, entomopathogenic *Beauveria bassiana*, *Saccharopolyspora spinosa,* and *Burkholderia spp.* have been used and proved to be efficacious in managing a wide ambit of insect pests, including the *A. gossypii* pests (Hiebert *et al.,* 2020). Despite the effectiveness of microbial biopesticides in the management of the *A. gossypii* pest, its adoption by smallholder farmers in Africa is impeded by the high cost of utilization. Sesame smallholder farmers have chosen cultural practices such as intercropping and crop rotations to elude the cost of controlling *A. gossypii* pests (Snyder *et al.,* 2004). However, these cultural practices are rarely effective in managing insect pests, including *A. gossypii* pests (Mpumi *et al.,* 2020).

An alternative way to overcome this problem is by using botanical pesticides (Isman, 2006). Botanical pesticides such as *Annona squamosa* leaves, *Ricinus communis* seed oil, *Polygonum orientale* leaves, *S. indicum* seed oil, and *Azadirachta indica* seed oil are currently used to control insect pests, particularly *A. gossypii* on various crops, including sesame (Ahmed *et al.,* 2014). Moreover, *T. vogelii*, *Syzigium aromaticum*, and *Croton dichogamus* have effectively mitigated aphid infestation on cabbage (*Brassica oleracea*) (Mpumi *et al.,* 2020). Furthermore, botanical pesticides like *Tithonia diversifolia* and *Lantana camara* have been utilized in controlling aphids on common beans (*Phaseolus vulgaris*) (Mkindi *et al.,* 2020). The findings by Mpumi *et al*. (2020) revealed a non significant difference between synthetic pesticide chlorpyrifos and *T. vogelii* in controlling insect pests of cabbage. Therefore, botanical pesticides, including *T. vogelii,* can be used as an alternative to synthetic pesticides, in controlling insect pests on various crops incorporating sesame in African countries.

**(ii) Green Peach Aphid**

The green peach aphid (*M. persicae*) is a deleterious pest found all over the world infesting a wide range of crops (Sun *et al.,* 2018; Umina *et al.,* 2014), possibly available all year round at any time (Gu *et al.,* 2007). *M. persicae* aphids are green in color (Appendix 1), being classified into alated and apterous green peach aphids (Alyokhin & Sewell, 2003). Alated green peach aphids have a dark patch nigh the end of their abdomen, while apterous green peach aphids dearth the dark patch (Umina *et al.,* 2014). They proliferate in the environment with high temperatures (Gu *et al.,* 2007). Moreover, both alated and apterous green peach aphids are harmful to plants.

There are over 50 plant families that host the green peach aphids (Umar & Piero, 2016). Those plants include woody and herbaceous plants incorporating vegetables in the family solanaceae, brassicaceae, cucurbitaceae, compositaceae, and chenopodiaceae (Cao *et al.,* 2016; Umar & Piero, 2016). Some of the host plants that facilitate the growth and development of the green peach aphids include tomatoes, spinach, cabbages, beans, peas, lettuce, watermelons, corn, carrots, and cucumbers (Gu *et al.,* 2007). All these plant crops differ in their vulnerability to the green peach aphids, but actively growing plants and the youngest plant tissues are highly affected by the huge population of green peach aphids (Umina *et al.,* 2014).

*M. persicae* (Appendix 1) nymphs and adults both cause crop damage by feeding on young, tender plant tissues and causing wilting (Table 2), releasing honey dew that falls onto the and is blackened by the sooty mould fungi, and finally, spreading over 100 plant viruses (Umina *et al.,* 2014). The destructive plant viruses transmitted by *M. persicae* include cucumber mosaic virus, potato leaf roll virus, turnip mosaic, poty viruses in pepper, beet yellow, lettuce mosaic, cauliflower, papaya ringspot, watermelon mosaic, and beet western yellow virus (Mpumi *et al.,* 2020). These viruses, which are transmitted by *M. persicae,* affect the growth and development of crops, thereby mitigating yield (Spence *et al.,* 2007). The damaging level of *M. persicae* is characterized by their large numbers on the undersides of the leaves and the extensive feeding of these aphids triggers plants to turn yellow and the leaves to curl downwardly and inwardly from the edges, leading to withering, stunted growth, and finally death of the plant crop (Mpumi *et al.,* 2020) (Table 2). Therefore, prolonged green peach aphid infestation on the plants can mitigate the yield of the crop products.

Green peach aphids have been controlled by being attacked by predators like *P. persimilis, H. axyridis,* and parasitoid *A. asychis,* on pea and potato aphids in the green house (Snyder *et al.,* 2004). Also, predators like *Coccinella undecimpunctata* feed on *M. persicae* on sesame (Mahmoud, 2012). *Aphidius colemani, Aphidius ervi, Lysiphlebri testaceipes, Aphidius transcaspius, Ephedous persicae, Praon volucre, Praon objectrun, Ephedous plagiator, Lysiphlebri testaceipes, Aphidius matricariae,* and *Diaeretielle* rapae decimate the green peach aphids on peach orchards (Aparicio *et al.,* 2019). All these natural enemies, together with the cultural methods such as crop rotation, intercropping, and destruction of the infected crops avail to impede the incidence and spread of the viruses transmitted by the green peach aphids (Capinera, 2006). However, some cultural practices are less effective in controlling insect pests, including *M. persicae* (Ndakidemi *et al.,* 2021). To surmount that problem, sesame smallholder farmers have been using chemical insecticides such as organochlorines (DDT), organophosphates (profenofos), pyrethroids (permethrin and deltamethrin), avermectin-based formulations (abamectin) and carbamates to control insect pests including green peach aphids (Saritha, 2020; Snyder *et al.,* 2004). However, heavy reliance on using these synthetic pesticides in controlling the green peach aphid population resulted in the strong insect pests' resistance to synthetic pesticides like carbamates (pirimicarb) and pyrethroids (cypermethrin) (Umina *et al.,* 2014). Therefore, broad spectrum insect pest management strategies are needed to ensure that these aphids are completely managed.

Entomopathogenic microbes like *B. bassiana, C. fumosorosea,* and *A. dipterigenus* have shown effectiveness in managing *M. persicae* on potatoes, cabbage, and lettuce in the greenhouse (Prince & Chandler, 2020). However, most microbial pesticides are expensive, so small-scale farmers cannot afford to buy them. To evade the cost of buying microbial pesticides, affordable and feasible botanical extracts that are available in the ambient environment can be utilized in controlling insect pests on copious crops, including sesame (Hikal *et al.,* 2017). Botanical pesticides like *A. squamosa* leaves, *P. orientale* leaves, *A. indica* leaves and seed oil, *R. communis* seed oil, *Ocimum gratissimum*, *Capsicum frutescens* and *S. indicum* seed oil have successfully suppressed *M. persicae* on sesame and cabbage in the field (Ahmed *et al.,* 2014; Mondédji *et al.,* 2021). A study conducted by Mpumi *et al.* (2021), showed that *T. vogelii, Croton dichogamus,* and *Syzygium aromaticum* have managed to mitigate the population of *M. persicae* on cabbage. Therefore, botanical pesticides like *T. vogelii* can be used to control the sesame insect pests on various crops, including sesame in Africa.

### 2.1.2 Whiteflies

Whiteflies *B. tabaci* are polyphagous insect pests reported to infest over 600 plant host species worldwide (Brezeanu *et al.,* 2014; Iram *et al.,* 2014). Both nymphs and adults prick the leaves and suck the cell sap of the leaves, which leads to the withering of the infested plants (Barbedo, 2014). They normally feed on top of the leaves (Table 2), thus mitigating the rate of transpiration and photosynthesis as well as the chlorophyll content (Inbar & Gerling, 2008). Like aphids, whiteflies produce honeydew on the leaves and pods that act as food for the sooty mold fungi (Brezeanu *et al.*, 2014; Gangwar & Gangwar, 2018). Furthermore, the *B. tabaci* pest has been linked to the spread of harmful diseases such as fungal infections (Gangwar & Gangwar, 2018; Roda *et al.*, 2020), as well as the transmission of plant viral diseases (Inbar & Gerling, 2008). Fungi and viruses change the attractiveness and appearance of plants (Roda *et al.,* 2020). According to Roda *et al.* (2020), plant viruses transmitted by the whiteflies act as pathogens to the insects that parasitize both the insect pests and beneficial insects, including pollinators. This insect pest has caused severe damage to different crops, including sweat potatoes, worldwide (Crossley & Snyder, 2020).

To surmount the effect of *B. tabaci* on sesame, sesame smallholder farmers have been using synthetic pesticides to control it (Inbar & Gerling, 2008; Roda *et al.*, 2020). Synthetic pesticides like thiacloprid, monocrotophos, fipronil, cyatraniliprole, oberon, imidacloprid, and diafenthiuron contain hazardous chemicals (Saritha, 2020). Moreover, synthetic pesticides like methamodophos, acephate, bifenthrin, aldicarb, fenprothrin, methomyl, thiamethoxam, dinotefuron, acetamiprid, buprotezin, and pyriproxyfen have been reported to be effective in controlling *B. tabaci* in different ways (Perring *et al.*, 2018). However, heavy applications of synthetic pesticides result in environmental adulteration in the land, water, and air, as well as decimating non-target organisms such as pollinators and natural enemies (Fiorenzano *et al.*, 2017; Özkara *et al.*, 2016). Moreover, *B. tabaci* pests have developed resistance to various groups of synthetic insecticides, including pyriproxyfens and neonicotinoids (Horowitz *et al.*, 2020).

To elude the effects of synthetic pesticides, cultural methods have been used by smallholder farmers to protect the sesame crops from being infested by *B. tabaci* in the fields (Tavares *et al.,* 2021). Cultural methods which have been used by the sesame smallholder farmers to control *B. tabaci* in the fields are intercropping, planting dates, trap crops, host free periods, crop rotations, and living mulches (Perring *et al.*, 2018). However, once these cultural practices are used individually, they are less effective in controlling the sesame insect pests, including the *B. tabaci* pest, in the fields (Mpumi *et al.*, 2020).

Predators that attack and decimate the *B. tabaci* are the *Delphastus catalinae, Nerphaspis oculatus, Serangium parcesetosum, Macrolophus praeclarus, Nesidiocoris tenuis, Chrysoperla rufilabris, Chrysoperla carnea, Tupiocoris cucurbitaceus, Euseius scutalis, Amblyseius swirskii, Macrophagus pigmaeus* and *Dicyphus hesperus* (Perring *et al.*, 2018). Likewise, parasitoids like *Eretmocerus mundus, Encarsia formosa, and Eretmocerus eremicus* can be used to control *B. tabaci* (Qiu *et al.,* 2004; Urbaneja *et al.,* 2007). Moreover, entomopathogenic *B. bassiana, Aschersonia aleyrodis, Lecanicillium lecanii,* and *Isaria fumosorosea* have been used to control *B. tabaci* on various crops (Perring *et al.,* 2018). However, despite the strategies' effectiveness in controlling the *B. tabaci* pest, the impediment is the financial power of most sesame smallholder farmers in Africa.

To surmount the financial constraints of purchasing the microbial pesticides, smallholder farmers in Africa have been adopted to use the botanical pesticide to control *B. tabaci* in the field as they are affordable, feasible and available in the natural environments of the farmers (Amoabeng *et al.*, 2014; de Cássia Seffrin *et al.*, 2010). Plant extracts from *Solanum hirsutum, S. galapagense, S. persicum, S. habrochaites,* and *S. penellii* have managed to control *B. tabaci* by using the bioactive compound 2-tridecanone, which triggers about 72% whitefly mortality (Perring *et al.*, 2018). Moreover, extracts from *A. squamosa, Nicotiana tabacum,* and *A. indica* have been used in the field (Sultana & Khan, 2019). Likewise, methyl ketones from *S. glabratum* are toxic to *B. tabaci* pest in a certain concentration, resulting in significant mortality (Perring *et al.,* 2018). Since botanical pesticides have been effective in controlling *B. tabaci,* even to a higher percent, as has been reported by Perring *et al*. (2018), there is a need to search for the most powerful botanical pesticides for insect pest management on sesame. Therefore, botanical pesticides, including *T. vogelii,* are the best to be used by sesame smallholder farmers to control *B. tabaci* on sesame fields in Africa.

### 2.1.3 Sesame Webworms

Sesame webworm (*A. catalaunalis*) larva is a most serious and devastating insect pest that affects the yield of sesame by posing an immense loss of sesame production (Gebregergis *et al.,* 2018; Rakesh, 2012). The larvae of *A. catalaunalis* attack the *S. indicum* crop at all stages of its growth (Appendix 2; Table 2), normally within two to three weeks after emanating on the ground up to the capsule stage (Gebregergis *et al.,* 2016; Suliman *et al.,* 2013). The *A. catalaunalis* pest feeds greedily on the tender leaves at the early stages of the crops by webbing the tender leaves and boring into the flower buds and pods (Appendix 2) of sesame (Murugesan & Venkatesan, 2016; Simoglou *et al.,* 2017; Suliman *et al.*, 2013). During flowering periods, *A. catalaunalis* moth insects lay eggs within the ovaries of sesame and then hatch into larvae where they feed on seeds in the ovary, which leads to production of the barren galls instead of pods (Bissdorf & Weber, 2007). The *A. catalaunalis* pest attacks seed pods, threatening yield losses of up to 100% in heavy infestations, as seen in Northern Ethiopia (Geremedhin &

Azerefegne, 2020). Furthermore, Egonyu *et al.* (2005) reported that the insect pest *A. catalaunalis* reduced sesame yields in Uganda from 2250 kg/ha to 430 kg/ha.

To subdue the loss brought by the *A. catalaunalis* pest, smallholder farmers in Africa intensively rely on synthetic pesticides to control the *A. catalaunalis* on sesame in the fields (Singh & Burbade, 2021). The synthetic pesticides known to be effective and used world wide to control *A. catalaunalis* infestations on sesame are endosulfan, diazinone, carbaryl, accephate, cypercal, Lambda cyhalothrin, vertimec, indoxacarb, dimethoate (Choudhary *et al.*, 2017; Geremedhin & Azerefegne, 2020). However, some of these synthetic pesticides have been reported to be hazardous and therefore unwise for their utilization, and once overused, they pose severe environmental adulteration, particularly in the soil and water. Hence, they result in health problems for human beings (Özkara *et al.,* 2016). Therefore, there is a need for searching and utilizing biopesticides that are environmentally benign, such as the sesame insect pest control strategy. However, cultural methods like early planting on the onset of rainfall avails to minimize the infestation of *A. catalaunalis* on sesame (Gebregergis *et al.*, 2018).

Currently, biopesticides like entomopathogenic bacteria, fungi, nematodes, viruses, and protozoa have been used to control a wide range of insect pests (Kumar *et al.,* 2021; Thangavel & Sridevi, 2015). Microbial pesticides such as *B. thuringiensis* and baculoviruses effectively control the *A. catalaunalis* pest (Kumar *et al.*, 2021). Microbe *B. thuringiensis* act as pathogen to the most ruinous lepidopterans pests including *A. catalaunalis* by releasing poison that destroy the midgut once they ingest it (Samada & Tambunan, 2020). In addition, the predatory insects such as *Phoneutria fera, C. undecimpunctata, Calidomantis savignyi* (Appendix 4) and *C. septempuctata* feed on the *A. catalaunalis* pest and the parasitoides *Braconidae spp.* and *Ichneumonidae spp.* parasitize and decimate the *A. catalaunalis* pest (Simoglou *et al.,* 2017).

Likewise, botanical biopesticides such as *A. indica*, *T. vogelii*, *Toona ciliata*, *Euphorbia tirucalli*, and *Cymbopogon schoeroanthus* have been used to control insect pests like aphids, webworms, and spider mites on vegetable crops (Tavares *et al.*, 2021). Extracts from *Capsicum annuum, Annona muricata, C. dichogamus, T. diversifolia, S. aromaticum, N. tabacum,* and *Allium satavum* have been used to control the lepidopteran carterpillars on *Phaseolus vulgaris* and *Brassica oleracea* (Mkindi *et al.*, 2020; Mpumi *et al.*, 2020). Several research findings have been reported on the effectiveness of various botanical pesticides in controlling the insect pests incorporating *A. catalaunalis* on copious crops (Ahmed *et al.,* 2010; Souto *et al.*, 2021; Ugwu, 2020). Likewise, mixing of botanicals such as neem oil and sesame oil has been reported to perform well in controlling sesame' insect pests, including *A. catalaunalis* (Ahmed *et al.*, 2014). Therefore, botanical pesticides like *T. vogelii* can also be mixed with rabbit urine to be used in controlling the sesame' insect pests in African countries, including Tanzania.

### 2.1.4 Jassids

Jassid (*O. albicinctus*) (Appendix 3) is a small insect pest with a wedge and elongated shape of about 3 to 5mm long, ambiting from brown, green, and yellow green with black spots on both sides of the head and on the apical area of each forewing (Watson, 2011). Jassids are cell sap sucking insect pests that inject toxins into the host plants' bodies while sucking and posing yellowish curls of leaves, dropping down flowers and fruits or pods of sesame (Joarder *et al.*, 2021; Sathe, 2014) (Table 2). Both nymphs and adults wither plants by sucking the cell sap from the underside of the leaves and the leaf buds (Chakraborty *et al.*, 2015; Joarder *et al.*, 2021). Nymphs resemble adults but they are smaller than adults, wingless, paler and slower in movement (Watson, 2011). Adults jump quickly and fly away once slightly disturbed (Sultana & Khan, 2019; Watson, 2011). Both nymphs and adults transmit viruses to healthy plants and pose phyllody, a very serious disease accompanied by the floral virescence, cracking of pods and seeds germinating inside the pods, floral proliferation (Plate 1), and the formation of dark mucilage on the foliage (Akhtar *et al.*, 2009). In severe infestations, jassids cause yield losses of up to 24.45 % (Hakim *et al.*, 2018).


**Plate 1: A: Floral virescence, B: phyllody symptom, C: cracking of the seed capsules and seeds germination inside the capsules and D: Foral proliferation (Akhtar *et al.*, 2009)**

Sesame smallholder farmers in Africa have been controlling the jassid infestation through the application of synthetic insecticides (Bonmatin *et al.,* 2021). Synthetic insecticides like imidacloprid, oberon, cyatraniliprole, thiacloprid, thiamethoxam, monocrotophos, fipronil, flonicamid, fenazaquin, ethion, acetamiprid, spiromesifen, endosulfan, and diafenthiuron contain hazardous chemicals (Ram *et al.,* 2020; Saritha, 2020; Sultana & Khan, 2015, 2019). As these synthetic pesticides contain hazardous chemicals, they lead to environmental pollution, particularly in the soil and water, as well as decimation of beneficial insects such as natural enemies and pollinators (Tosi & Nieh, 2019). Problems emanating from utilizing synthetic pesticides instigate exploration of biopesticides as an alternative strategy to synthetic pesticides. Microbial biopesticide derived from the entomopathogenic bacterium *B. thuringiensis* has been used and proved to be effective in controlling *O. albicinctus* (Kumar *et al.,* 2021; Soomro *et al.,* 2020). Also, entomopathogenic fungi such as *Metarhizium spp., B. bassiana, L. lecanii*, and *Trichoderma spp.* have been reported to be effective in controlling *O. albicinctus* significantly (Dahal *et al.,* 2020; Halder *et al.,* 2021).

Likewise, the predator *C. carnea* has caused significant mortality in jassids on cotton in the field (Soomro *et al.,* 2020). Also, predators such as *Cheilomenes sexmaculata, Micraspis discolor, Menichilus sexmaculatus, Marpissa spp.,* and *Oxyopes lineatipes* have been used to control sucking pests, including jassids on okra (Halder *et al.*, 2021). Moreover, parasitoids like *Arescon enocki* and *Anagrus spp.* have been mitigating the population of jassids by feeding on their eggs on okra and cotton crops (Hakim *et al.*, 2018).

Various research findings have indicated the efficacy of botanical pesticides in controlling insect pests on copious crops (Lengai *et al.*, 2020). Furthermore, botanical pesticides such as *A. sativum, A. squamosa, A. indica* leaves and oil, *N. tabacum, R. communis,* and *Polygonum hydropiper* have been used to control the sucking insect pests like jassids on various crops, including sesame in the fields (Ahmed *et al.,* 2014; Sultana & Khan, 2015, 2019).

### 2.1.5 Sesame Flea Beetles

The sesame flea beetle (*A. bimaculata*) is a major noxious insect pest that reduces sesame yield in southern Tanzania (Lekamoi *et al*., 2022). Both larvae and adults are pests to their host plants (Patole, 2017). Within 21 days of germination, sesame seedlings are the most vulnerable to sesame flea beetle attack (Zeit, 2021). Flea beetle larvae of *A. bimaculata* feed on the roots of newly planted seedlings aged 21 days after germination (Lekamoi *et al*., 2022). Adult flea beetles of the *A. bimaculata* cause damage by feeding on the leaves and stems (Table 2), whereby they form shallow and small rounded irregular holes in the leaves (Baker & Webber, 2008).

To surmount the effects brought by *A. bimaculata*, smallholder farmers use hazardous synthetic pesticides like carbaryl, emmemectin benzoate, lambda-cyhalothrin, cyfluthrin, permetrin, binenthrin, acetamiprid, imidacloprid, pyrethrin, malathion, estenvalerate, bifenthrin, and dinotefuran to control *A. bimaculata* in the field (Ali *et al.,* 2017; Bunn *et al.,* 2015). Synthetic pesticides beside posing threat to human health and the non target organisms, they result into insect pests resistance (Kapeleka *et al.*, 2019; Özkara *et al.,* 2016). To overcome the problem of insect pest resistance, sesame smallholder farmers combine two or more synthetic pesticides in combating a very ruinous insect pest, *A. bimaculata* (Shahid *et al.,* 2019; Xu *et al.,* 2009). Mixing of the synthetic pesticides results in water and soil pollution, hence affecting the aquatic organisms, microorganisms in the soil as well as the macro organisms (Syafrudin *et al.*, 2021).

To evade the effects of heavy utilization of synthetic pesticides, sesame smallholder farmers in Africa have been practicing cultural methods like trap cropping to control sesame flea beetles (*A. bimaculata*) in the fields (Kuepper, 2015). However, the cultural practices used are not solely enough to control the insect pests of sesame (Ndakidemi *et al.,* 2021). To solve the problem, biopesticides such as entomopathogenic nematodes are efficacious agents for controlling sesame flea beetles by attacking the larvae to reduce root feeding, which avail to deter the next adult generation from emanating (Kuepper, 2015). Nematodes such as *Steinernema spp* and *Heterorhabditis spp* are the most common biopesticides used to control various species of flea beetles, including sesame flea beetles, by attacking their larvae and mitigating the perpetuation of successive generations (Bunn *et al.,* 2015). In addition, the microbial pesticide *B. thuringiensis* has been reported to be effective in controlling flea beetles by releasing a toxin that binds to the receptors of the insect's midgut, causing it to stop feeding and finally die within a few days once it ingests it (Adsule *et al.*, 2009; Borden *et al.,* 2018). Moreover, entomopathogenic *Saccharopolyspora spinosa* controls a wide ambit of insect pests including flea beetles caterpillars and the spider mites by producing insecticidal toxin which attack the insect nervous system, making it to stop feeding and ultimately die within two days later (Borden *et al.,* 2018). In addition, the entomopathogenic fungus *B. basssiana* has been used to control flea beetles, including sesame beetles, by releasing toxins into the insect pest's body and melting the internal contents, generating a source of food for the fungus and causing the decimation of the insect pest (Bunn *et al.*, 2015).

Furthermore, biological control methods, which are also known as natural enemies such as predators, parasites, and pathogens, are currently used to control insect pests in fields (Mpumi *et al.*, 2020). A parasitoid braconid wasp (*Microcotonus vittage*) decimates adult flea beetles (Kuepper, 2015). Also, predators such as *Nabis spp.*, *Chrysopa spp.,* and *Geocoris spp.* feed on the adult flea beetles (Bunn *et al.*, 2015). However, the method is too expensive and smallholder farmers cannot afford it.

To surmount the problem, botanical pesticides like *T. vogelii, A. sativum,* and *A. indica* are currently recommended for managing the flea beetles in fields (Kuepper, 2015). According to Bunn *et al.* (2015), botanical extracts from *Euphorbia helioscopid*, *Chenopodium spp, Datura stramonium, Calotropis procera,* and *A. indica* have been significantly mitigating the number of flea beetles in the *Zea mays* field. In addition, botanical pesticides like *A. squamosa, A. indica* leaves and oil, *N. tabacum*, *A. sativum*, *R. communis,* and *Polygonum hydropiper* are currently used to control coleopteran beetles, including sesame beetles on various crops in fields (Ahmed *et al.,* 2014; Sultana & Khan, 2015, 2019). According to Manonmani *et al.* (2018) extracts of *Cymbopogon citratus* have the highest percentage mortality of *Trogoderma granium* and *Tribolium castaneum* beetle species, up to 100%. However, there is little information about the botanical pesticides to control sesame flea beetles on sesame in the fields. Therefore, the sesame flea beetle on sesame can be controlled by botanical pesticides like *T. vogelii* in Africa.

### 2.1.6 Spider Mites

Spider mites **(***T. urticae*) are polyphagous serious insect pests of copious crops (Škaloudová *et al.,* 2006), with over 200 host plants infested (Capinera, 2006). Spider mites are tiny and very difficult to see with the naked eye; hence, a magnifying glass is needed to see them clearly, for they look like tiny dots and their presence is recognized easily by the webs that spider mites spin (Watson, 2011). Spider mites have an oval-shaped body without wings and antennae (Zinov'ev & Sole, 2004). They damage plants by sucking the cell saps, which normally feed on the underside of the leaves, posing tiny stipples on top of the leaves (Škaloudová *et al.,* 2006) (Table 2) and are reported to devastate over 18 to 22 cells in a minute (Capinera, 2006). The damage caused by spider mites is often associated with the premature drop of infested leaves (Zinov'ev & Sole, 2004), chlorophyll depletion, and ultimately low yields (Watson, 2011).

To control the infestation of crops by this insect pest, sesame smallholder farmers in Africa have been relying on the use of synthetic pesticides (Bonmatin *et al.,* 2021). Synthetic pesticides like cyatraniliprole, imidacloprid, monocrotophos, thiacloprid, and diafenthiuron are broad spectrum pesticides containing hazardous chemicals that decimate non-target organisms and pose environmental adulteration, jeopardizing human health and the ecosystem at large (Fiorenzano *et al.,* 2017; Özkara *et al.,* 2016; Saritha, 2020; Sultana & Khan, 2015, 2019).

To elude risks caused by the utilization of synthetic pesticides, biological control or natural enemies can be employed to control spider mites in the field. Natural enemies such as predatory insects, parasitoid insects, and pathogens are effective in controlling spider mites in various crops (Samada & Tambunan, 2020). For example, predatory insects such as A*mblyseius californicus, Deraeocoris punctullatus, Stethorus punctillum, P. persimilis, Scolothrips longicornis, Amblyseius fallacis, Conwentzia psociformis,* and *Panonychus ulmi* have been used worldwide to control *T. urticae* on strawberry plants in Spain (García-Marí & González-Zamora, 1999). Another predatory insect like *Typhlodromus occidentalis* has been reported to be effective in controlling spider mites on various crops, including sesame (Waked *et al.,* 2016). Additionally, entomopathogenic pesticide *Pseudomonas fluorescens* has been used in Africa to control spider mites by using the enzyme chitinase through the hydrolysis of the insect pest's exoskeleton (Waked *et al.,* 2016). Both biological control and microbial pesticides are effective in controlling insect pests, including *T. urticae*. However, feasibility and affordability can be an impediment to most sesame smallholder farmers.

To surmount the problem, botanical pesticides are currently utilized by smallholder farmers as one of the biopesticides to control insect pests, including *T. urticae* on various crops (Kumar *et al.,* 2021). Extracts from *Citrullus colocynthis, E. tirucalli, T. vogelii, Bobgunnia madagascariensis, and A. indica* have been reported to be effective in controlling *T. urticae* pests on various crops, including sesame (Mwaura *et al.,* 2012). Several findings have been reported on various botanical pesticides as effective in controlling the insect pests on copious crops (Saleem *et al.,* 2019). Because many botanical pesticides have been shown to be effective in controlling a wide range of insect pests on various crops, pesticidal plants like *T. vogelii* are best used by smallholder farmers in Africa to control the *T. urticae* pest on sesame.

#### 2.1.7 Fall Armyworms

Fall armyworm (*S. frugiperda*) larvae are the polypagous insect pest that is invasive in Africa but native in America (Assefa *et al.,* 2019), devastating various crops and reported to infest over 80 host crops and pose huge economic yield losses (Babendreier *et al.,* 2020). The *S. frugiperda* larvae attack a wide ambit of cultivated crops, including sesame (Montezano *et al.,* 2018). In early 2016, the fall armyworm pest was reported to invade West African countries (Babendreier *et al.,* 2020), spreading to the entirety of Sub-Saharan Africa along with South and Southeast Asia in 2018 and 2019, causing severe devastation and significant yield losses (Du Plessis *et al.,* 2020). *S. frugiperda* affects crops at different stages of growth and development, starting from early vegetative to the late maturity stage (Watson, 2011) (Table 2).

Cultural methods such as early planting, crop rotation, intercropping, handpicking, wood ashes and soils have been practised by the sesame smallholder farmers in Africa in controlling Fall armyworm pest for many years (Assefa *et al.,* 2019). However, the cultural practices used are less effective in controlling the insect pests of sesame, especially the fall armyworm pest (Mpumi *et al.,* 2020; Ndakidemi *et al.,* 2021). This compels sesame smallholder farmers to focus on the use of broad spectrum insecticides in combating the fall armyworm pest in their fields.

Hazardous synthetic pesticides like pyrethroids, organophosphates, organochlorines, carbamates, emamectin benzoate and organophosphorus have been used in controlling armyworm pests by sesame smallholder farmers in Africa (Assefa *et al.,* 2019; Babendreier *et al.,* 2020). Examples of the synthetic pesticides used are pyrethrum, thiamethoxicam, thiocarb, trichlorfon, pyrethrins, chloratraniliprole, cyantraniliprole, clothianidin, chlorprifon, and fipronil (Assefa *et al.,* 2019). However, utilization of these synthetic pesticides leads to soil and water adulteration (Özkara *et al.,* 2016; Syafrudin *et al.,* 2021). Soil adulteration has an impact on soil quality as well as important micro- and macro organisms that degrade organic matter in the soil (Mpumi *et al.,* 2020). Furthermore, these synthetic pesticides can affect farmers’ health, particularly during preparation and application of the pesticides (Kapeleka *et al.,* 2019; Özkara *et al.,* 2016). Due to these impedements, there is a need to focus on finding an alternative method to these hazardous synthetic pesticides.

Biopesticides application is an alternative method to synthetic pesticides use (Samada & Tambunan, 2020). Microbial pesticides such as entomopathogenic fungi, baculoviruses, bacteria, nematodes, and protozoa are currently being utilized to control *S. spodoptera* in the fields and have been reported to be efficacious. The most effective microbial pesticides that have been reported to control *S. spodoptera* in the fields are *B. thuringiensis, Metarhizium anisophae,* baculoviruses, and *B. bassiana* (Assefa *et al.*, 2019). Also, species of nematodes such as *Steinernema carpocapsae, S. feltiae S. websteri, S. downesi, S. glaseri, S. longicaudum, S. yirgalemense, S. karii, S. abbasi, S. jeffereyense, S. kraussei, S. affine,* and *S. riobrave* have been used as entomopathogenic parasites in controlling *S. spodoptera* in maize (Winisia, 2020).

In addition, the importation of natural enemies from their native areas to invaded areas for the permanent settlement there may be considered (Babendreier *et al.,* 2020). For example, the parasitoid *Eiphosoma vitticole* has been imported from South Florida to Africa. Moreover, parasitoids *Apantoles marginiventris, Campoletis grioti, Rogus laphygmae, Chelenus insularis, Terrelucha spp, Ophion spp,* and *Meteorus autographae* are native in Africa but, in Kenya and Tanzania, parasitoids *Chorops alter* and *Coccygidium luteum* are available (Assefa *et al.,* 2019). In addition, biological control by using the parasitoid *Telemonus remus* is currently available in Africa. The only remaining part is the proliferation of these parasitoids and their release to be used as a biological control agent (Babendreier *et al.,* 2020). Moreover, predators such as *Doru luteips, D. lineare, Forficula auricularia, Carabidae spp, Pentatomidae spp, Podius maculiventris,* and *Orius insidiosus* feed on larvae and pupae (Assefa *et al.*, 2019).

Moreover, botanical pesticides like the leaves and seeds of neem plant (*A indica*) is readly available accross the African countries (Babendreier *et al.,* 2020). According to Assefa *et al.* (2019), the high mortality of fall armyworm larvae in maize fields in Ethiopia was caused by *A. indica,* followed by the other botanical pesticides such as *Phytolacea docendra, N. tabacum, Milletia ferruginea, Jatropha curcas, Croton macrostachyus,* and *Chrysanthemum cinerasiifollium*. Another biopesticide known as maltodextrin organic pesticide, prepared by mixing starch, vegetable oils and water, is currently used to control *S. spodoptera* in the fields and it has been reported to be fast acting on insect pests, posing death by suffocating them through blocking the spiracles (Babendreier *et al.,* 2020). Findings by Kardina and Maris (2021) divulged that *N. tabacum and Derris elliptica,* once applied, directly cause mortality to *S. frugiperda* of about 50% and 56.7 %, respectively. Another study by Mora and Blanco (2018) revealed that mixing of two or more botanical pesticides improved efficiency in controlling pests than when the botanical pesticides were used individually. Therefore, *T. vogelii* can be mixed with rabbit urine to be used as a biopesticide in controlling sesame insect pests in African countries.

### 2.2 Biological Life Cycle of Sesame Insect Pests' Species

For the perfect management of the insect pests of sesame, understanding their biological life cycles is of paramount. This involves the number of generations of the insect pest within a year, the number of eggs the insect pest produces within a generation or the entirety of its life time, and the length of the insect pest's biological cycle (Table 3).

**Table 3: Number of eggs, number of generations and length of biological cycle**

| Sesame insect pest | Number of generations | Number of eggs | Length of Biological cycle | Reference |
|---|---|---|---|---|
| *A. catalaunalis* | They complete 14 generations in a year | Female deposits the average of 60 eggs in their life time | The total life cycle of *A. catalaunalis* ranges from 21 to 39 days, average being 27 days. Incubation period ranges from 47 to 73 hours with an average of 60.6 hours. Larval period ranges from 8.21 to 12.16 days with an average of 9 days. Pupa stage last between 3.10 to 12.0 days with an average of 7.18 days | Choudhary *et al.* (2017) and Simoglou *et al.* (2017) |
| *M. persicae* | They complete over 20 generations within a year | Oviparous female lays 4 to 13 eggs | The life cycle of *M. persicae* to complete one generation takes about 10 to 12 days | Capinera (2006) |
| *B. tabaci* | They complete about 11 to 15 generations in a year | Oviparous female lays 300 eggs in her life time | The life cycle of *B. tabaci* varies with host. For example, in collard is 19.2 days, in soya bean is 21.2 days. The life span of female can extends to 60 days, while that of males range between 9 to 17 days | Gangwar and Gangwar (2018) and Takahashi *et al.* (2008) |
| *T. urticae* | Many overlapping generations | Female lay the average of 100 eggs | The life cycle of spider mites ranges from 5 to 20 days | Fasulo and Denmark (2012) |
| *S. frugiperda* | The number of generations varies and it has been reported to be 1 up to 4 generations in a year | Female lays a total 1500 to 2000 eggs and over in her life time | The life of *S. frugiperda* varies with seasons, in spring the half-life is 30 days, in spring is 60 days while in winter and autumn is 80 and 90 days, respectively | Capinera (2009) |

## 2.3 Common Practices Used to Control the Insect Pests of Sesame

### 2.3.1 Cultural Practices

Several cultural practices have been used by sesame smallholder farmers in African countries to alleviate the insect pests' infestations (Tengö & Belfrage, 2004). Cultural practices such as site selection, intercropping, seed selection, planting date, and crop rotation have been mitigating the insect pests' infestation to a certain degree (Egonyu *et al.,* 2005). The planting date is important to be observed for it effectively mitigates the insect pests' infestation. For example, the infestation of the sesame webworm on sesame can be mitigated by planting sesame early at the beginning of rainfall (Gebregergis *et al.,* 2018). Moreover, cultural practices like crop free periods, crop rotation, and crop residue disposal have been used to reduce infestation of *B. tabaci* on various crops (Hilje *et al.,* 2001). Intercropping, the common cultural method, has been commonly used by sesame growers in Africa to curtail the infestation of the insect pest. For example, in Nigeria, sesame smallholder farmers have been practicing row intercropping in sesame fields by mixing it with other crops to lessen the infestation of insect pests in the field (Uddin & Osagie, 2017) (Table 4). Also, in Uganda, *A. catalaunalis,* a very ruinous pest, and other sesame insect pests have been managed by intercropping sesame with other crops like finger millet, maize, and sorghum (Egonyu *et al.,* 2005). Despite cultural practices being less expensive, environmentally benign, and not deleterious to human health as well as the natural enemies and the pollinating insects, most of these cultural practices are not adequate to control sesame insect pests in the field (Mpumi *et al.,* 2020). To overcome the less effective cultural practices, sesame smallholder farmers in African countries have opted to utilize synthetic pesticides.

**Table 4: Sesame pest management options**

| Pest | Synthetic pesticide | Microbial based | Plant based | Natural enemies | Cultural method | Reference |
|---|---|---|---|---|---|---|
| *A. gosspii* | Fipronil | *B. bassiana* | *P. orientale* | *P. japonica* | Intercropping | Ma *et al.* (2006), |
| | Diafenthiuron | *L. pseudomesenteriodes* | *T. diversifolia, L. camara* | *C. septempuctata* | Crop rotation | Hiebert *et al.* (2020), |
| | Thiacloprid | *B. thirungiensis* | *N. tabacum* | *C. phyllochroma* | Trap crops | Mkindi *et al.* (2020), |
| | imidacloprid | *Burkholderia spp* | *E. camaldulemsis* | *Chrysopa sinica* | | Ahmed *et al.* (2014), Hiebert *et al.* (2020), |
| | Cyatraniliprole | *spinosa* | *A. indica, S. indicum* | *M. tricuspidatus* | | Saritha (2020) and |
| | Monocrotophos | | *Annona squamosa* | *Aphidius gifuensis* | | Snyder *et al.* (2004). |
| *M. pericae* | Carbamates | *L. pseudomesenteriodes* | *P. orientale, L. camara* | *P. persimilis,,* | Crop rotation | Snyder *et al.* (2004), |
| | Pyrethroids | *B. thirungiensis* | *T. diversifolia* | *H. axyridis, A. asychis* | Intercropping | Ahmed *et al.* (2014), |
| | Imidacloprid | *B. bassiana* | *N. tabacum, A. squamosa* | *E. persicae, E .plagiator, A. colemani, L.* | Trap crops | Mkindi *et al.* (2020), |
| | Diafenthiuron | *Burkholderia spp* | *E. camaldulemsis* | *testaceipes,* | | Mpumi *et al.* (2020), |
| | Thiacloprid, Monocrotophos, | *S. spinosa* | *R. communis* | *A. matricariae* | | Hiebert *et al.* (2020), |
| | Fipronil, Cyatraniliprole, | | *A. indica* seed oil | *D. rapae* | | Capinera (2006) and |
| | | | *S. indicum, C. annuum C. undecimpunctata* | *P. volucre, A. ervi,* | | Saritha (2020). |
| *B. tabaci* | Imidacloprid, Buprotezin, | *A. aleyrodis* | *S. hirsutum,* | *D. catalinae, M. pigmaeus,* | Host free periods | Sultana and Khan, (2019), |
| | Diafenthiuron, Acephate, | L. lecanii | *S. glabratum* | *N. tenuis, C. rufilabris, S. parcesetosum, E.* | Planting dates | Saritha (2020) and |
| | Thiacloprid, Fipronil, | *B. bassiana* | *S. habrochaites* | *mundus, N. oculatus,* | Intercropping | Perring *et al.* (2018). |
| | Aldicarb, Methomyl, | *I. fumosorosea* | *S. persicum* | *M. praeclarus,* | Living mulches | |
| | Bifenthrin, Pyriproxyfen, | | *S. penellii, A. indica* | *T. cucurbitaceus,* | | |
| | Cyatraniliprole, Acetamiprid, | | *A. squamosa,* | *D. hesperus, A. swirskii,* | Trap crops | |
| | Monocrotophos, Fenprothrin | | *N. tabacum* | *E. scutalis, C. carnea,* | Crop management | |
| | Methamodophos, | | | | | |
| | Thiamethoxam, Dinotefuron. | | | | | |
| *T. urticae* | Imidacloprid | *P. fluorescens* | *E. tirucalli* | *P. persimilis* | Crop rotation | Tavares *et al.* (2021), |
| | Diafenthiuron, | | *T. vogelii, T. ciliata* | *S. punctillum* | Intercropping | Mwaura *et al.* (2012), |
| | Thiacloprid | | *B. madagascariensis* | *A. californicus* | Trap crops | Saritha (2020) and |
| | Fipronil, | | *A. indica* | *T. occidentalis* | Early sowing | Waked *et al.* (2016). |
| | Cyatraniliprole | | *C. colocynthis* | | | |
| | Monocrotophos | | *N. tabacum* | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| *A. catalaunalis* | carbaryl | *B. thirungiensis* | *A. indica, T. vogelii,* | *Ichneumonidae spp* | Early sowing | Choudhary *et al.* (2017), |
| | acephate | Baculoviruses | *E. tirucalli, T .ciliata* | *Braconidae spp* | Intercropping | Kumar *et al.* (2021), |
| | indoxacarb | | *C. schoerianthus* | *P. fera, P. mantis* | Crop rotation | Simoglou *et al.* (2017) |
| | vertimec | | *C. annuum, A. sativum* | *Pentatomidae spp* | | Tavares *et al.* (2021) |
| | Lambda cyhalothrin | | *A. muricata, N. tabacum* | *C. undecimpunctata* | | Mkindi *et al.* (2020) |
| | Dimethoate | | *T. diversifolia* | *C. septempuctata* | | Mpumi *et al.* (2020) and |
| | | | | | | Gebregergis *et al.* |
| | Cypercal, Endosulfan | | *Croton dichogamus* | *T. flavo-orbitalis* | | (2018). |
| | Diazinone | | *S. aromaticum* | | | |
| | Emmemectin benzoate, | | | | | |
| *A. bimaculata* | malathion | *B. thuringiensis* | *D. stramonium* | *M. vittage* | Trap cropping | Ali *et al.* (2017), |
| | carbaryl, cyfluthrin, permethrin | *Steinernema spp* | *Chenopodium spp* | *Chrysopa spp* | Intercropping | Borden *et al.* (2018), |
| | lambda-cyhalothrin, | | | | | Kuepper (2015), |
| | acetamiprid | *Heterorhabditis spp* | *C. procera, C. citratus* | *Nabis spp* | rotating crops | |
| | | | | | | Manonmani *et al.* |
| | pyrethrin, bifenthrin, binenthrin | *S. spinosa* | *E. helioscopid, A. sativum* | *Geocoris spp* | Handpicking | (2018) and |
| | imidacloprid, dinotefuron | *Beauveria basssiana* | *A. indica, T. vogelii* | | Wood ashes | Bunn *et al.* (2015). |
| *S. frugiperda* | Emmemectin benzoate | *T. thuringiensis, S. karii,* | *C. macrostachyus* | *T. remus* | | |
| | | | | | Intercropping | Babendreier *et al.* |
| | pyrethrin, pyrethrum | Baculoviruses, S. affine, | *M. ferruginea* | *E. vitticole* | Early planting | (2020), |
| | thiamethoxam | *M. anisophae* | *A. indica* | *A. marginiventris* | Crop rotation | Assefa *et al.* (2019) and |
| | thiocarb, trichlorfon | *S. carpocapsae,* | *P. docendra* | *C. insularis* | Handpicking | Winisia (2020). |
| | chloratraniliprole, | *S. riobrave, B. bassiana.* | *C. cinerasiifollium* | *C. grioti* | Soils | |
| | chlorpyrifos, clothianidin, | *S. downesi, S. kraussei,* | *Phytolacea docendra* | *R. laphygmae* | Wood ashes | |
| | cyantraniliprole, | *S. longicaudu, S. abbasi,* | *N. tabacum, J. curcas* | *Ophion spp,* | | |
| | | *S. feltiae, S.* | | | | |
| | fipronil | *yirgalemense,* | Maltodextrin | *Terrelucha spp,* | | |
| | | *S. websteri, S. glaseri,* | | *M. Autographae,* | | |
| *O. albicinctus* | Imidacloprid, flonicamid,, | *B. thuringiensis* | *A. sativum* | *C. carnea, A. enocki* | Mulches | Saritha (2020), |
| | | | | | | Sultana and Khan, |
| | Diafenthiuron, oberon, Ethion, | *B. bassiana* | *P. hydropiper* | *M. discolor, Anagrus spp* | Intercropping | (2019), |
| | cyatraniliprole, acetamiprid, | *Metarhizium spp* | *A. indica* | *C. sexmaculata* | rotating crops | Halder *et al.* (2021), |
| | thiacloprid, monocrotophos, | *L. lecanii* | *A. squamosa* | *M. sexmaculatus* | Handpicking | Dahal *et al.* (2020), |
| | spiromesifen, thiamethoxam, | *Metarhizium spp* | *R. communis* | *Marpissa spp,* | Wood ashes | Hakim *et al.* (2018) and |
| | endosulfan, fenazaquin, | | | *O. lineatipes,* | | Ahmed *et al.* (2014). |

### 2.3.2 Synthetic Pesticides

Smallholder farmers in African countries have been controlling the insect pests of sesame by intensively using synthetic insecticides (Karuppaiah, 2014). Most of these synthetic insecticides are pyrethroids, carbamates, organochlorines, and organophosphates (Dawkar *et al.,* 2013). Pyrethroid insecticides like cypermethrin, entofentrox, and deltamethrin are commonly used to control the insect pests of sesame (Egonyu *et al.,* 2005). According to WHO, cypermethrin and deltamethrin have been classified into Class II, which is considered moderately hazardous (Kapeleka *et al.,* 2019). Despite its toxic effect and long lasting nature in the environment, hazardous organochlorine pesticides like DDT have been used by sesame growers in Africa to control insect pests (Jayaraj *et al.,* 2016).

In addition, many synthetic pesticides like hexachlorocyclohexane (HCH), lindane, and DDT have developed environmental adulteration and the effects on public health (Carvalho, 2006). Innumerable synthetic pesticides exist in the ambient environment, decimating beneficial insects like pollinators and natural enemies as well as jeopardizing human health (Smith & Perfetti, 2020). DDT, for example, inhibits the acetylcholinesterase enzyme, which is important for nerve function in insects, animals, and humans (Jayaraj *et al.,* 2016). The high persistence rates of synthetic pesticides in the environment have resulted in bioaccumulation and biomagnification in the organisms' bodies in the ambient environment (Pérez-Lucas *et al.,* 2019). Biomagnification is the  increment of pollutants like toxic from the chemical pesticides into the bodies of the organisms and passed on from the one trophic level to another (Ali *et al.,* 2019). Furthermore, synthetic pesticides normally affect farmers' health, particularly during application. Therefore, biopesticides, which are environmentally benign, not inimical to the health of the applicators, and sometimes easily accessible, can be used in controlling sesame insect pests (Muhammad & Kashere, 2020).

### 2.3.3 Biopesticides

Biopesticides are naturally occurring compounds that are obtained from plants, animals, and microorganisms (Kumar *et al.,* 2021). For example, entomopathogenic viruses, bacteria, fungi, algae, and nematodes derived from these microorganisms have been used to control a wide ambit of insect pests, weeds, and fungi  (Thangavel & Sridevi, 2015). Biopesticides have been classified into microbial pesticides, botanical pesticides, and genetically modified organism (GMO) based pesticides (Kumar *et al.,* 2021).

### (i) Microbial Pesticides

Microbial pesticides are the products from microorganisms normally used to control the insect pests by using the specific toxic metabolites which trigger disease to the insect pests; For example, *B. thuringiensis* is the common microbial pesticide commonly used to control insect pests on many crops including potato and cabbage (Samada & Tambunan, 2020). The microbe *B. thuringiensis* works as a pathogen to the most pernicious lepidopteran larvae pests by producing and releasing a toxin, that ruins the larvae pests' midgut once they ingest it (Kumar *et al.,* 2021).

### (ii) Botanical Pesticides

Botanical pesticides are naturally occurring compounds obtained from medicinal plants that contain groups of bioactive compounds of diverse chemical nature and normally have an average half-life of 2 to 5 days (Mudzingwa *et al.*, 2013). Botanical pesticides such as *Lantana camara, Monodora myristica,* and *Euphorbia lateriflora* have been reported to be effective in managing *Callosobruchus maculatus* and *Sitophilus zeamais* (Kareru *et al.,* 2013). In addition, botanical pesticides such as *A sativum, Aristolochia ringens, Ficus exasperate,* and *Garcinia kola* have been found to be effective against the maize weevil, *Sitophilus zeamais* (Arannilewa *et al.,* 2006). Also, extracts from *N. tabacum* and *Eucalyptus camaldulemsis* are currently used in the management of the cabbage aphid pest (Mpumi *et al.*, 2020). Furthermore, botanical pesticides such as *T. vogelii, Chromolaena odorata, R. communis, Synedrella nodiflora, A. indica, A. squamosa, C. frutescens,* and *Argeratum conyzoides* are used as an alternative strategy to synthetic pesticides in controlling insects on cereal crops (Amoabeng *et al.,* 2014; Koona & Dorn, 2005). Table 5 depicts some of the botanical pesticides that can be used to control sesame insect pests in smallholder farmers' fields.

Most botanical pesticides are less expensive, more widely available, less toxic to mammals, including humans, decompose faster in sunlight, moisture, and air, and have a faster kill rate against insect pests (Amoabeng *et al.,* 2014). Moreover, most botanical pesticides have fewer effects on non-target organisms such as pollinators and the natural enemies of the insect pests than synthetic pesticides on the growth of the sprayed plants (Arannilewa *et al.,* 2006). Therefore, botanical pesticides can be utilized in managing sesame pests as well. However, mixing of the bioactive compounds of different plants has the potential to be important in terms of efficacy and is not convenient for the insect pests to develop resistance (Kareru *et al.,* 2013).

**Table 5: Examples of the botanical pesticides used to control the sesame insect pests**

| Botanical pesticides | Insect pests controlled | Reference |
|---|---|---|
| Neem powder and oil from *A. indica, N. tabacum, Tagetes erecta, Cynodon dactylon,* (tobacco)*, Allium cepa,* and *Carica papaya,* | Spider mites, caterpillars, and sesame flea beetles. | Mondal and Chakraborty (2016), Ojo *et al.*, 2014, Simoglou *et al.* (2017) and Sultana and Khan, (2015) |
| *A. sativum* (garlic), *A. muricata* (Soursop), *P. hydropiper* (water pepper) | Jassids, caterpillars, and thrips. | Ahmed *et al.* (2014), Bissdorf and Weber (2007), Saritha (2020) and Ugwu (2020) |
| Custard apple (*A. squamosa*) | Whiteflies, sesame flea beetle, aphids, and spider mites. | Lin *et al.* (2009) |
| Sesame (*S. indicum*) seed oil and neem (*A. indicum*) seed oil | Flea beetles and caterpillars. | Ahmed *et al.* (2010) |
| *Ginger* (*rhizome*), wild chili pepper (*Capsicum frutescens*) and *C. schoerianthus* | Aphids | Tavares *et al.* (2021) |
| *T. vogelii* (fish-poison bean) *T. ciliate, E. tirucalli,* and *B. madagascariensis* | Diamondback moth, webworms aphids, and red spider mites. | Mwaura *et al.* 2012 and Tavares *et al.* (2021) |
| *E. camaldulemsis* (river red gum), *C. dichogamus* and *S. aromaticum* (Clove) and *N. tabacum* (tobacco). | Aphids such as *M. persicae* and *A. gossypii*, Diamondback moth (*Plutella xylostella*), and cabbage head caterpillar (*Crocidolomia binotalis*) | (Mpumi *et al.* 2020) |
| *L. camara and T. diversifolia* | Flower and foliage beetles, aphids, and pod suckers. | (Mkindi *et al.* 2020) |
| *Dolichos kilimandscharicus* | Fall armyworms *S. frugiperda* | Winisia (2020) and |
| *C. citratus* (Lemongrass) | Sesame flea beetles | Manonmani *et al.* (2018) |
| *Tagetes minuta, C. annuum* | Aphids | Koleva Gudeva *et al.* (2013) and Phoofolo (2013) |
| *Parthenium argentatum* | Fall armyworms (*S. frugiperda*) | Céspedes *et al.* (2001) |

### (iii) Genetic Modified Organisms (GMO) Based Biopesticides

Genetic modified organism (GMO) based biopesticides are produced by transferring naturally occurring toxic-coding genes from microbes into plant crops where they induce the production of toxins that can be used to decimate insect pests (Abbas, 2018). These biopesticides are pathogens to pests of interest and they are grouped into three categories, which are: bioherbicides such as Phytophthora, biofungicides like Trichoderma, and biopesticides such as *B. thuringiensis* (Kareru *et al.*, 2013). Bacteria like *B. thuringiensis* produce protein crystals called delta endotoxins that are eaten by the insect pests and broken down by the action of proteases into smaller toxins that then bind to the insect pests' midgut receptors, which results in disintegration of the cells, paralysis of the insect pests' midgut and ultimately cell death

(Kumar *et al.,* 2021). Crops like potatoes, tobaco, corn, and cotton have been approved by the Environmental Protection Agency (EPA) USA in 1995 to be produced commercially and distributed as *B. thuringiensis* crops (Abbas, 2018). Bacteria like *B. thuringiensis* have been used and proved to be effective in controlling lepidopterans, dipterans, and coleopteran insect pests (Federici, 2013).

### 2.4 Biological Control

Biological control is the prominent method of controlling insect pests that involves the use of the natural enemies of the insect pests, such as pathogens, parasitoids, and predators (Dwyer *et al.,* 2004). Predators of the sesame insect pests are spiders *Phoneutria fera*, ladybird beetles *C. undecimpunctata*, praying mantis *Calidomantis savignyi* (Appendix 4), *assassin* bugs, *Reduviid bugs,* and lacewing *C. carnea* (Jonsson *et al.,* 2014; Korlapati *et al.,* 2014; Mahmoud, 2012b). Mantids, ladybird beetles, and spiders feed on the sesame web worm (*A. catalaunalis*) (Simoglou *et al.,* 2017). Both adults and larvae of ladybird beetles feed on aphids and mitigate their population in the field (Snyder *et al.,* 2004). For example, *A. gossypii* aphids are attacked by the ladybird beetle, *C. septempunctata* (Ma *et al.,* 2006). While *M. persicae* aphids are eaten by *Coccinella undecimpunctata* in the sesame fields (Mahmoud, 2012). Other predators which attack aphids, especially *A. gossypii,* are lacewings, *C. sinica* and *C. phyllochroma,* as well as spiders, *E. graminicola* (Ma *et al.,* 2006). Also, the larvae of hoverflies, silverflies, and lacewings are the aphid predators, while parasitoid wasps such as *Aphidius colemani* can parasitize and kill aphids (Watson, 2011).

Likewise, *C. sexmaculatus* and *C. carnea* feed on nymph and adult jassids (Sahito, 2016). Also, predatory bugs and spiders such as *P. fera* and *E. graminicola* attack and decimate jassids (Watson, 2011). Moreover, *P. persimilis* is a predator of spider mites, feeding on all stages of growth and development of the spider mite pest (Capinera, 2006). Also, a small species of black ladybird beetle feeds on spider mites (Cranshaw, 2014). Additionally, predators such as *S. parcesetosum, C. carnea, D. catalinae, M. praeclarus, I. fumosorosea, N. oculatus, N. tenuis, C. rufilabris, E. scutalis, T. cucurbitaceus, A. swirskii, M. pigmaeus* and *D. Hesperus* control whiteflies in fields (Perring *et al.,* 2018; Roda *et al.,* 2020). Also, predators like the larvae of lacewing *Chrysopa spp.,* adult big-eyed bugs *Geocoris spp.,* and damsel bugs *Nabis spp.* feed on adult flea beetles (Bunn *et al.,* 2015).

Moreover, parasitoid wasps like *Lysiphlebus testaceipes* have been controlling aphid pests effectively by the parasitism method (Ma *et al.,* 2006; Snyder *et al.,* 2004; Watson, 2011). Also, parasitoids such as *Encarsia sophia*, *E. eremicus, E. Formosa, and E. mundus* have been controlling whiteflies in fields (Perring *et al.,* 2018). Furthermore, parasitoides like *Ichneumonidae spp.* and *Braconidae spp.* parasitize and decimate the *A. catalaunalis* larvae pest (Simoglou *et al.,* 2017). Likewise, adult flea beetles are killed by the parasitoid wasp *M. vittage* (Bunn *et al.,* 2015; Kuepper, 2015).

In addition, entomopathogenic bacteria such as *B. thuringiensis* and *L. pseudomesenteriodes* are used to control aphids by releasing poison that ruins the insect pests' midgut once they ingest the microbes (Moustafa-Farag *et al.,* 2020). Moreover, microbes such as baculoviruses and *B. thuringiensis* have been reported to be effective in controlling the larvae of *A. catalaunalis* pests (Kumar *et al.,* 2021). Similarly, entomopathogenic bacteria like *B. thuringiensis, Pseudomonas spp., Chomobacterium spp.,* and *Yersinia spp.* have shown effectiveness in controlling jassids (*O. albicinctus*) (Kumar *et al.,* 2021).

Likewise, entomopathogenic fungi such as *B. bassiana, L. lecanii, I. fumosorosea,* and *A. aleyrodis* have been currently used to control *B. tabaci* on copious crops (Perring *et al.,* 2018). Also, microbial fungi like *Metarhizium spp., B. bassiana, L. lecanii, Hirsutella spp., Paecilomyces spp.,* and *Verticillium spp.* have been reported to control the *O. albicinctus* pest very effectively (Kumar *et al.,* 2021). Furthermore, microbial nematodes such as *Heterorhabditis spp.* and *Steinernema spp.* are commonly used as biopesticides in the control of flea beetles through attacking the larvae and mitigating the perpetuation of the flea beetle generations (Bunn *et al.,* 2015). Similarly, *Heterorhabdus spp.* and *Steinernema spp.* "nematodes" are commonly efficacious in controlling jassids (*O. albicinctus*) by introducing bacteria *Xenorhabdus spp.* and *Photorhabdus spp.* into the host's blood after entering into hosts and finally posing death (Kumar *et al.,* 2021).

### 2.5 Common Pollinators of Sesame in Africa

The common pollinators of sesame in Africa (Plate 2; Table 6) are the hymenopterans, dipterans, lepidopterans, and coleopterans (Kamel *et al.*, 2013; Mahmoud, 2012b). The leading group by possessing a higher percentage is the hymenopterans, followed by dipterans, lepidopterans, and coleopterans (Kamel *et al.*, 2013). Honey bees from the family Apidae and wasps from Ichneumonidae are the most common hymenopterans known to be found on sesame flowers in large numbers compared with other hymenopterans (Sann *et al.,* 2018). Pollinators have been commonly observed as the key agents in most flowering plants for ensuring fruit and seed production (Chen & Zuo, 2018). About 90% of flowering plant species depend on insects for pollination, reproduction, and preserving genetic variability (Menz *et al.,* 2011). For instance, pollination by honey bees has been increasing yield in sesame by an average of 62 percent, while a reduction in the number of honey bees in sesame fields causes a yield loss of about 59 percent (Stein *et al.,* 2017). Honey bee pollination impacts on pods and seed yields of sesame by increasing the number of seeds per pod (Fohouo, 2018).

Dipterans which are involved in pollination in sesame are from the families Muscidae, Syrphidae, Calliphoridae, and Sarcophagidae, while lepidopterans belonging to the families Nymphalidae, Lycanidae, and Peridae, as well as coleopterans, are from the Coccinellidae (Kamel *et al.,* 2013). Inadequate number of pollinators result into reduction of fruits and seeds production (Chen & Zuo, 2018). Maintaining a thriving population of pollinators is crucial for the agricultural market and for ensuring the diversity of food supply (Sawe *et al.,* 2020).


**Plate 2: Common pollinators of sesame in Africa, A: *Apis mellifera*, B: *Xylocopa pubescens*, C: *Eumenes maxillosus*, D: *Musca domestica,* E: *Danaus Chrysippus*, and F: *C. undecimpunctata* (Mahmoud, 2012a)**

## Table 6: Common pollinators of sesame in Africa

| Order name | Family name | Common name | Scientific name | Role | Reference |
|---|---|---|---|---|---|
| Hymenoptera | Apidae | Honey bee. | *Apis mellifera* | Pollinator, visitor | Kamel *et al.* (2013) and Mahmoud (2012) |
| | | Small carpenter bee | *Ceratina tarsata* | Pollinator, visitor | Mahmoud (2012) |
| | | Large carpenter bee | *Xylocopa pubescens* | Pollinator, visitor | Kamel *et al.* (2013) and Mahmoud (2012) |
| | | Cuckoo bee | *Thyreus hyalinatus* | Cleptoparasite, Pollinator, visitors | Kamel *et al.* (2013) |
| | | Blue-banded bee | *Amegilla spp.* | Pollinator, visitor | Kamel *et al.* (2013) |
| | Ichneumonidae | Scorpion wasp | *Diadegma spp.* | Parasitoid, pollinator, visitors | Kamel *et al.* (2013) |
| | Formicidae | Wood ant | *Formica spp.* | Pollinator, visitor | Kamel *et al.* (2013) |
| | | Desert dwelling ant | *Cataglyphis bicolor* | Pollinator, visitor | Kamel *et al.* (2013) |
| | Vespidae | Yellow wasp | *Polistes gallicus* | Pollinator, visitor | Kamel *et al.* (2013) and Mahmoud (2012) |
| | Scoliidae | Digger wasp | *Dielis collaris* | Pollinator, visitor | Kamel *et al.* (2013) and Mahmoud (2012) |
| | Eumenidae | Potter wasp | *Eumenes maxillosus* | Pollinator, visitor | Kamel *et al.* (2013) and Mahmoud (2012) |
| | Crabronidae | Beewolf wasp | *Philanthus Triangulum* | Pollinator, visitor | Kamel *et al.* (2013) |
| | Sphecidae | Sand wasp | *Bembix priesneri* | Pollinator, visitor | Kamel *et al.* (2013) and Mahmoud (2012) |
| | Halictidae | Nomia bee | *Nomia spp.* | Pollinator, visitor | Kamel *et al.* (2013) |
| | Anthophoridae | Mining bee | *Anthophora albigena* | Pollinator, visitor | Kamel *et al.* (2013) and Mahmoud (2012) |
| | Megachilidae | Wool-Carder bee | *Anthidium spp.* | Pollinator, visitor | Kamel *et al.* (2013) and Mahmoud (2012) |
| | | Leafcutter bee | *Megachile spp.* | Pollinator, visitor | Kamel *et al.* (2013) and Mahmoud (2012) |
| | | Mason bee | *Osmia spp.* | Pollinator, visitor | Kamel *et al.* (2013) and Mahmoud (2012) |
| Diptera | Muscidae | House fly | *Musca domestica* | Medical, pollinators | Kamel *et al.* (2013) and Mahmoud (2012) |
| | Muscidae | Little-House fly | *Fannia canicularis* | Medical, pollinators | Kamel *et al.* (2013) |
| | Syrphidae | Drone fly | *Eristalis spp.* | Pollinator, visitor | Kamel *et al.* (2013) and Mahmoud (2012)) |
| | Syrphidae | Hover fly | *Syrphus spp.* | Predator, pollinator | Kamel *et al.* (2013) and Mahmoud (2012) |
| | Calliphoridae | Blow fly | *Lucilia sericata* | Medical, pollinators | Kamel *et al.* (2013) |
| | Sarcophagidae | Flesh fly | *Sarcophaga spp.* | Medical, pollinators | Kamel *et al.* (2013) and Mahmoud (2012) |
| | Sarcophagidae | Flesh fly | *Wohlfahrtia spp.* | Medical, pollinators | Kamel *et al.* (2013) |
| Lepidoptera | Nymphalidae | Monarch butterfly | *Danaus Chrysippus* | Destructive, pollinator | Kamel *et al.* (2013) and Mahmoud (2012) |
| | Lycaenidae | Bean butterfly | *Cosmolyce baeticus* | Destructive, pollinator | Kamel *et al.* (2013) |
| | Peridae | Cabbage butterfly | *Pieris rapae* | Destructive, pollinator | Kamel *et al.* (2013) and Mahmoud (2012) |
| Coleoptera | Coccinellidae | Lady beetle | *C. undecimpunctata* | Pollinator, predator | Kamel *et al.* (2013) and Mahmoud (2012) |

### 2.6 Effects of Synthetic Pesticides on Pollinators of Sesame

Recent studies have revealed the effects of neonicotinoids like imidacloprid, thiamethoxam, and clothianidin on honey bees, both larvae and adult bees (Lundin *et al.,* 2015; Sponsler *et al.,* 2019). Several research findings have been reported about the higher toxicity level of imidacloprid to honey bees (Challa *et al.,* 2019). The study conducted in the United States of America (USA) by Saleem et al. (2020) reported that imidacloprid and thiamethoxam in concentrations of 0.25 ppm and 0.125 ppm (parts per million) respectively are inimical to *A. mellifera*. Furthermore, Domingues *et al.* (2017) discovered that neonicotinoids thiamethoxam and picoxystrobin, at very low concentrations of 0.001 ng/mL and 0.018 ng/mL, respectively, caused significant loss in honey bees. Moreover, the synthetic pesticide pyriproxyfen has high toxicity to bees by interfering with larva development and altering the development of larvae into adults (Devillers & Devillers, 2020). Another study conducted to assess the lethal and sub-lethal effects of the neonicotinoid insecticide thiacloprid on the larval development of mason bees (*Osmia spp.*) proved thiacloprid to be associated with increased sustainable mortality and larval development time and decreased cocoon weight (Claus *et al.,* 2021).

Likewise, studies conducted to survey the presence of pesticide residues in top soils to a depth of less than 25 cm in arable fields in the Czech Republic and Central Europe, revealed that over 30 insecticides of pyrethroids and neonicotinoids were detected accumulated in the soil, whereby tebuconazole was 28 ppt (parts per trillion), azoxystrobin 23 ppt, and boscalid 29 ppt (Hvězdová *et al.,* 2018; Vašíčková *et al.,* 2019). This is attributed to the fact that most synthetic pesticides persist longer in the environment, whereby they affect pollinators through toxification of nectar ( Bonmatin *et al.,* 2015). Synthetic pesticide thiacloprid has a half-life of 74 days, acetamiprid of 450 days, while prometon and paraquat have the half-lives of 500 and 1000 days respectively (Aktar *et al.,* 2009; Bonmatin *et al.,* 2015; Deer, 2004). Conversely, the half-lives of most of the biopesticides can hardly reach one week (Kang *et al.,* 2016) thus, possess little effect to the environment and beneficial insects, including pollinators.

### 2.7 Effects of Biopesticides on Pollinators of Sesame

Most biopesticides have been reported to have fewer effects on pollinators (Hubbard *et al.,* 2014). For example, a biopesticide obtained by mixing two toxins the protein from the snowdrop plant *Galanthus nivalis* was mixed with venom from the Australian spider *Hadronyche versuta* had less effect on honeybees even at higher doses (Nakasu & Edwards, 2014). However, some biopesticides such as azadiractin and spinosad derived from the soil bacterium actinomycete *Saccharopolyspora spinosa* are highly toxic to bees (Barbosa *et al.,* 2015; Challa *et al.,* 2019; Sann *et al.,* 2018). As it has been reported by Seide *et al*. (2018), neem-based insecticides have been shown to derange the neuroendocrine and reproductive systems of pollinator bees. Nevertheless, there is no documented report on the botanical biopesticide *T. vogelii* having an effect on beneficial insects, including pollinators. Therefore, the *T. vogelii* formulation with rabbit urine can be used as the best biopesticide in controlling insect pests of sesame without affecting pollination activities.

## 2.8 Effectiveness of Biopesticides in Controlling Insect Pests

### 2.8.1 *Tephrosia vogelii*

*Tephrosia vogelii* normally contains the bioactive phytochemical rotenone, which has a robust insecticidal effect against a vast ambit of pests, posing it to be used as a natural insecticide (Zhang *et al.*, 2020). Rotenone is naturally found in the leaves, stems, seeds, and in the roots of *T. vogelii* plants (Mpumi *et al.,* 2016). Although rotenone is distributed in various parts of the *T. vogelii* plant, the higher amount is concentrated in the leaves than in other parts of the plant (Aritho *et al.*, 2017). Many studies on *T. vogelii* leaves extract as a botanical pesticide have been conducted and proved it to be efficacious in controlling insect pests in many crops, as well as a growth booster and improving production (Mamuye *et al.*, 2020). For example, fall armyworm, *S. frugiperda*, a very noxious insect pest, has been controlled by *T. vogelii* extract from the leaves on cereal crops (Phambala *et al.*, 2020). Many studies have reported that *T. vogelii* leaf extract in a concentration of 10% has been effective in controlling insect pests on various crops in the field (Mwaura *et al.,* 2012). Bioactive compound rotenone is immensely toxic to fish thus, it is usually used to terminate the undesired fish from the water bodies including lakes (Radad *et al.,* 2019; Smith-vaniz, 2008). Phytochemical rotenone is easily transported through gills and trachea into the bloodstream of the fish and the insects respectively, for their respiratory systems are direct connected to environments; for example, gills are direct connected to water also, trachea are not covered they are just open and contact with the environment easily (Mpumi *et al.,* 2016).

However, rotenone is less toxic to warm-blooded animals, including birds and mammals, because the path of ingestion is via the digestive system, whereby the compound is easily dilapidated to non-toxic compounds before entering the bloodstream (Boboescu, 2020;

Juliansyah Noor, 2019; Kang *et al.,* 2016). Since rotenone has a short half-life, which ranges between a few hours and a week, it does not assemble in the ambient environment (Kang *et al.,* 2016). This way, *T. vogelii* has fewer detrimental effects on non-target organisms, including pollinators and natural enemies (Mpumi *et al.,* 2016). As such, *T. vogelii* is supposed to be used at short intervals and is normally applied in the evening to elude degradation by sunlight (Juliansyah Noor, 2019).

### 2.8.2 Rabbit Urine

Rabbit urine contains a high amount of nitrogen since they barely drink water (Durán-Lara *et al.,* 2020). One rabbit can produce 25 to 100ml of urine depending on species of the rabbit (Wandita *et al.,* 2016). Several studies on rabbit urine as a biofertilizer have been conducted and proved to be efficacious in improving growth and yield in different crops (Rahayu *et al.,* 2021). Rabbit urine has been reported to be effective in improving yield in crops and soil fertility since it contains essential nutrient composition than the commercial foliar feed fertilizer (Mutai, 2020). The essential nutrients found in rabbit urine are nitrogen, phosphates, and potassium, which are crucial for plant growth (Indabo, 2020). At a concentration of 300 ml/L, rabbit urine has improved the growth and yield of melon plants (Sunadra *et al.,* 2019). A study on rabbit urine revealed that in a concentration of 80 ml/L, it increased soya bean plant height by 3.3 cm, higher than plants grown under the control treatment plots (Rahayu *et al.,* 2021).

Despite the fact that rabbit urine is used by smallholder farmers as a biofertilizer, the urine has been reported to be efficacy in managing insect pests as well (Rwiza, 2017). Rabbit urine contains higher amounts of ammonia than in other mammalian animals' urine (Durán-Lara *et al.,* 2020). Ammonia in rabbit urine is highly volatile and it is easily dissolves in water to produce toxic ammonium ion (Leoni *et al.,* 2018). According to Epa and Programs (2004) ammonium ion such as ammonium bicarbonate has been used to control insect pests on orchard crops. For instance, farmers in Uganda have been using rabbit urine to control pests in a ratio 1:1 (rabbit urine: water) in various crops like sorghum, finger millet, cassava, coffee, banana, sunflower, beans, maize and a wide range of vegetables like cabbage, watermelon, tomatoes and onions (FAO, 2012). However, there is limited reports on rabbit urine being used as biopesticide to control insect pests of sesame within the field. Research about the relevant amount of rabbit urine to be used as a biopesticide is highly needed.

CHAPTER THREE

MATERIALS AND METHODS

## 3.1 The Study Location

The field study was conducted in the Singida region, Tanzania (Fig. 1). The experiment was established at Mwamisye street, located at latitude 4° 47′ 35.3′′ S, longitude 34° 42′ 53.5′′ E, at an elevation of 1513 m above sea level. The experiment was conducted between late January and early June of the year 2021. The mean annual rainfall during the experiment period was between 500 and 800 mm. Likewise, the mean minimum and maximum ambient temperatures ranged between 15 and 30°C and the relative humidity was 58% during the wet season months (Province *et al.*, 2007).

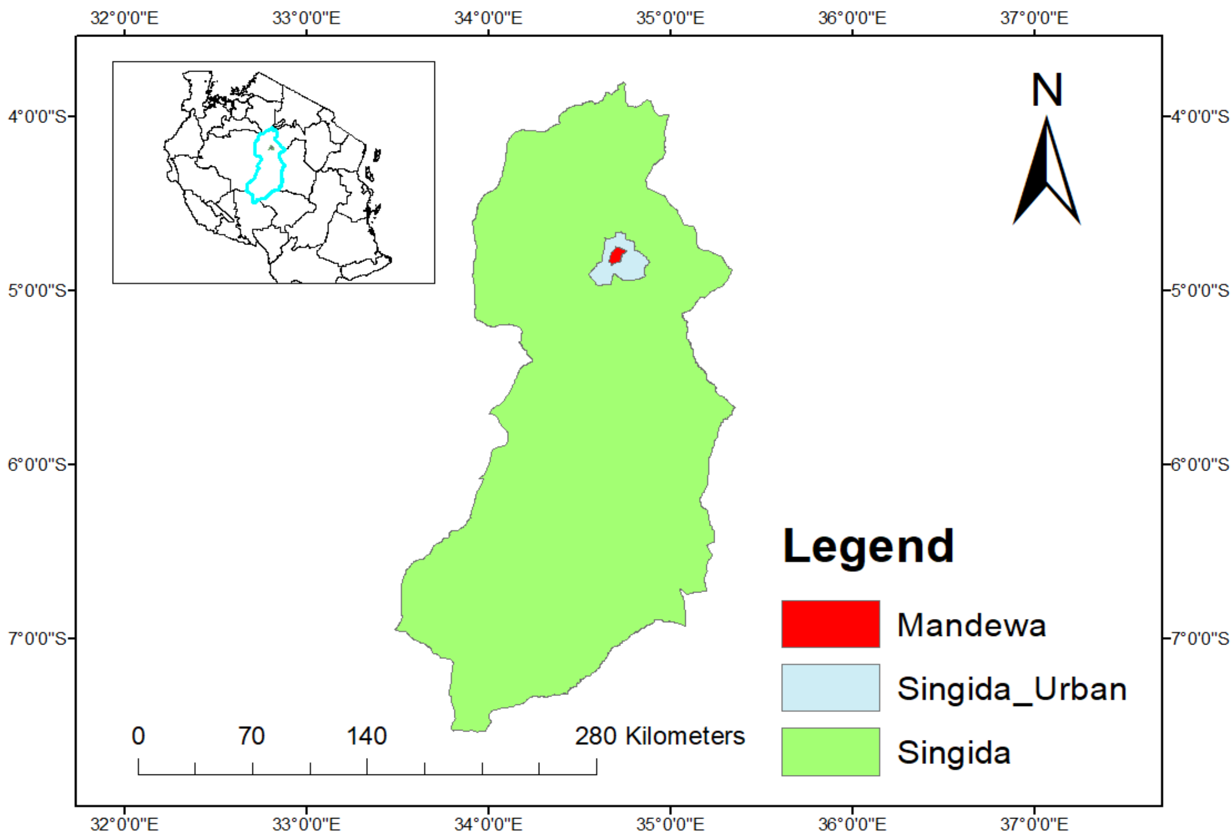



**Figure 1: The map depicting the study area where experimental field was established**

## 3.2 Source of Materials and Land Preparation

### 3.2.1 Source of Planting Materials and Biopesticides

Sesame seeds were purchased from the authorized shop at Tanzania Agriculture Research Institute (TARI) Ilonga in the Morogoro region. On the other hand, *T. vogelii* leaves were obtained from Mondul coffee estate (MCE) located in Kisongo, Arusha, Tanzania and confirmed by the botanist at the Tanzania Plant Health and Pesticide Authority (TPHPA). Rabbit urine was collected from smallholder rabbit-keeping farmers in Sekei street in the Arusha region, Tanzania (Plate 3).


**Plate 3: Components of research treatments, A: Sesame seeds, B: *T. vogelii* plant and C: Rabbit urine collection. Photograph by Upendo Lekamoi, 21/1/2021**

### 3.2.2 Land Preparation

Land was ploughed and harrowed by using a disc plough and harrow two weeks before sesame seed planting to allow sufficient time for weeds to die (Bubbolini *et al.*, 2016). Sesame was planted in January and harvested in June 2021. Sesame plant spacing was 60 cm x 30 cm (Yousif *et al.*, 2020). Each treatment plot had five plant rows, and each row contained ten plants, making a total population of 50 plants. Each treatment plot measured 9 $m^2$. Two to four seeds were sown per hole. Thinning was done two weeks after germination to maintain one vigorous seedling per hole (Abdalla *et al.,* 2015). Weeding was done manually using a hand hoe when needed.

## 3.3 Experimental Design and Treatments Applications

### 3.3.1 Experimental Design

The experimental field research was done in a Randomized Complete Block Design (RCBD) with five treatments, namely 10% *T. vogelii* (w/v)**,** 50% rabbit urine (v/v), 10% *T. vogelii* + 50% rabbit urine, water, and synthetic pesticide (Duduba 450 EC) v/v. Each treatment had three replicates, making a total of 15 treatment plots. Water was applied as a control, whilst synthetic pesticide was used as a check.

### 3.3.2 Treatments Applications

Treatment applications were started in the fifth week after planting sesame. The tested pesticides were applied to sesame plants at an interval of 7 days throughout the crop's growing period. A synthetic pesticide was applied according to manufacturer recommendations. The formulations were sprayed on top and under the leaves of sesame plants by wielding a 2 L hand sprayer pump. The spraying was carried out during the evening hours to elude direct sunlight, which may cause decomposition of bioactive compounds found in *T. vogelii* and rabbit urine. Each treatment plot received between 250 ml and 500 ml per spray depending on the crop growth stage, tantamount to 278 L/ha and 556 L/ha, respectively. The sprayer pump was thoroughly washed with water and soap prior to re-filling it again with another formulation.

## 3.4 Extraction and Preparation of Treatments

### 3.4.1 *Tephrosia vogelii*

The leaves of *T. vogelii* were washed thoroughly to remove dust and dried until constant weight under shade to avoid degradation of bioactive compounds (Kang *et al.*, 2016). Then the dried leaves of *T. vogelii* were pulverized into powder by using an electric blender. The 100g of pulverized dry leaves of *T. vogelii* were dissolved in one liter of water, containing 1% equivalent to 10 mL of liquid soap, for 24 hours to attain a 10% concentration (Mwaura *et al.,* 2012). The mixture was filtered by using muslin cloth to obtain the filtrate.

### 3.4.2 Rabbit Urine

Rabbit urine was collected from the rabbit keeping farmer at Sekei in the Arusha region, Tanzania to get at least 30 L. Rabbit urine was diluted in a ratio of 1:2 (urine: water) to get a 50% solution for treatment application. The collected rabbit urine was stored in a closed container for three weeks to mitigate the risk of disseminating diseases which might emanate as a result of the microbes that may be present in the urine (FAO, 2012). The rabbit urine solution was stored under shade to evade degradation of the bioactive compounds contained within the urine by the sunlight rays (Abdallah *et al.*, 2019; Gong *et al.*, 2015).

### 3.4.3 *Tephrosia vogelii* with Rabbit Urine Formulation and Synthetic Pesticide (Duduba)

A formulation of *T. vogelii* with rabbit urine was prepared by mixing 10% *T. vogelii* with 50% rabbit urine. The synthetic pesticide (Duduba) was obtained from the retailer shops (businesses that sell pesticides to the public) and it was diluted as per the manufacturer's recommendation, whereby 2 millilitres of the synthetic pesticide was mixed with one litre of water (1L).

## 3.5 Data Collection

### 3.5.1 Identification and Scoring of the Field Sesame' Insect Pests

Identification of the field sesame insect pests was done weekly. Insect pests were scored one day before spraying the pesticide treatments on the five randomly selected sesame plants in the central row of each treatment plot. The collected insect pests were identified to species level by the entomologist at TPHPA.

### 3.5.2 Assessment of Plants Damage Caused by Insect Pests of Sesame

The damage severity of sesame plants caused by insect pests was assessed by counting the number of damaged leaves and pods per plant. Damage severity was scored using the scale of 0%, 25%, 50%, 75%, and 100% damage depending on the number of leaves and pods damaged (Mkenda *et al.*, 2015). 0% indicated that there was no damage, while 100% showed that the damage was severe.

### 3.5.3 Collection and Identification of Pollinators

During the flowering period, sesame plants were examined for the presence of pollinators weekly, thrice a day: early in the morning, afternoon, and before evening (Kamel *et al.*, 2013).

The pollinators were collected and identified to species level by the entomologist at TPHPA. The methods utilized to collect pollinators from the sesame plants were the sweep net, pitfall, and observation methods. A sweep net was used in the collection of the flying insect pollinators while a pitfall was used to collect walking insect pollinators (Mahmoud, 2012b).

### 3.5.4 Growth Parameters Collection

Sesame's growth parameters were assessed before the flowering period. The growth parameters measured included plant height, leaf area, number of branches and leaves. Leaf area was obtained by direct measurements of the length, which is the distance between the base and the apex of the leaflet, as well as the width of the leaflet, as described in Tanko and Oluwaseun (2020). Leaf area was then calculated using equation 1.

$$\mathrm{LA} = \mathrm{L} \times \mathrm{W} \qquad \textit{Equation } 1$$

with *LA:* leaf area, *L:* leaf length and *W:* leaf width

### 3.5.5 Yield Parameters Collection

The yield parameters were assessed during the maturity of the sesame while the seed yield was assessed after harvesting the crop. Yield parameters included the number of seeds per pod, number of pods per plant, weight of seeds per plot, and 1000 seed weight per plot. The number of seeds per pod and the number of pods per plant were counted, while the weight of seeds per plot and the weight of 1000 seeds in each treatment plot were measured by using an electronic balance. Yield/ha was calculated by using equation 2.

$$\text{Seed yield (kg/ha)} = \frac{\text{Yield (kg per plot)}}{\text{Plot size (m}^2\text{)}} \times 10{,}000 \qquad \textit{Equation } 2$$

### 3.6 Data Analysis

Data on insect pests, pollinators of sesame, damage severity, growth parameters, and yield parameters were analyzed using the STATISTICA software program version 8, while the graphs were drawn using the excel software program. The Fisher's Least Significant Difference (LSD) was used to compare treatment means at a $p = 0.05$ level of significance.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Results

### 4.1.1 Effects of *T. vogelii* Formulation with Rabbit Urine on the Identified Insect Pests of Sesame

The results showed that the insect pests identified include sesame webworm (*A. catalaunalis*), sesame flea beetles (*A. bimaculata*), green peach aphids (*M. persicae*) and jassids (*O. albicinctus*) (Table 7). However, the effects of the treatments were assessed only for the sesame webworm and sesame flea beetles due to their high levels of infestations.

**Table 7: Insect pest identified on sesame plants during this study**

| General name | Common name[a] | Scientific name | Number per plot |
|---|---|---|---|
| Leaf roller caterpillar | Sesame webworm | *Antigastra catalaunalis* | 10 |
| Beetle | Sesame flea beetle | *Alocypha bimaculata* | 8 |
| Aphid | Green peach aphid | *Myzus persicae* | 2 |
| Leaf hopper | Jassid | *Orosius albicinctus* | 1 |

**a: Identification was conducted at Tanzania Plant Health and Pesticide Authority TPHPA**

#### (i) Effects of *T. vogelii* Formulation with Rabbit Urine on *Antigastra catalaunalis* Pest

The results of this study show that before application of the treatments, there was no significant difference ($p > 0.05$) among tested treatments in the number of *A. catalaunalis* (Table 8). Population abundance of *A. catalaunalis* (Plate 4) appeared to differ significantly ($p \leq 0.001$) among treatments used in this study (Table 8). Sesame plants sprayed with the biopesticide formulations and a synthetic pesticide possessed a significantly ($p \leq 0.001$) lower number of *A. catalaunalis* in weeks 1, 2, 3, 4 and 5, respectively, which decreased from week 1 up to week 5 (Table 8). However, sesame plants in the control treatment possessed a significantly ($p \leq 0.001$) larger number of *A. catalaunalis* pests that persisted from week one before and after application of the treatment from week 1 up to the 5$^{th}$ week (Table 8).

**Table 8: Effects of pesticides treatments on the population of *A. catalaunalis***

| Treatments | Population of *A. catalaunalis* per week | | | | | |
|---|---|---|---|---|---|---|
| | **0** | **1** | **2** | **3** | **4** | **5** |
| *T. vogelii* 10% | 1.74 ± 0.14a | 1.74 ± 0.14bc | 1.20 ± 0.00bc | 1.06 ± 0.14bc | 0.66 ± 0.14bc | 0.40 ± 0.00b |
| Rabbit urine 50% | 1.60 ± 0.00ba | 1.86 ± 0.14b | 1.46 ± 0.14b | 1.20 ± 0.00b | 0.80 ± 0.00b | 0.54 ± 0.14b |
| Tv+Ru | 1.60 ± 0.00a | 1.34 ± 0.14c | 1.06 ± 0.14c | 0.80 ± 0.00c | 0.40 ± 0.00c | 0.26 ± 0.14b |
| Sp 2% | 1.60 ± 0.00a | 1.74 ± 0.14bc | 1.20 ± 0.00bc | 1.06 ± 0.14bc | 0.66 ± 0.14bc | 0.54 ± 0.14b |
| Water | 1.86 ± 0.26a | 2.94 ± 0.14a | 3.46 ± 0.14a | 3.74 ± 0.14a | 4.26 ± 0.14a | 4.56 ± 0.14a |
| **1 - way ANOVA (F- Statistics)** | 0.80ns | 20.30*** | 95.5*** | 138.67*** | 319.25*** | 207.5*** |

Each value represents mean ± standard error of five treatments and three replicates, *, **, and *** is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$ respectively while ns means not significant. Means within the same column possessing same letter (s) are not significantly different at $p = 0.05$ from each other accredited by Fishers Least Significant Difference (LSD) test; Tv means *T vogelii* 10%, Ru means rabbit urine 50% and Sp 2% means synthetic pesticide (Duduba 450EC), week 0 means one week before treatments application.

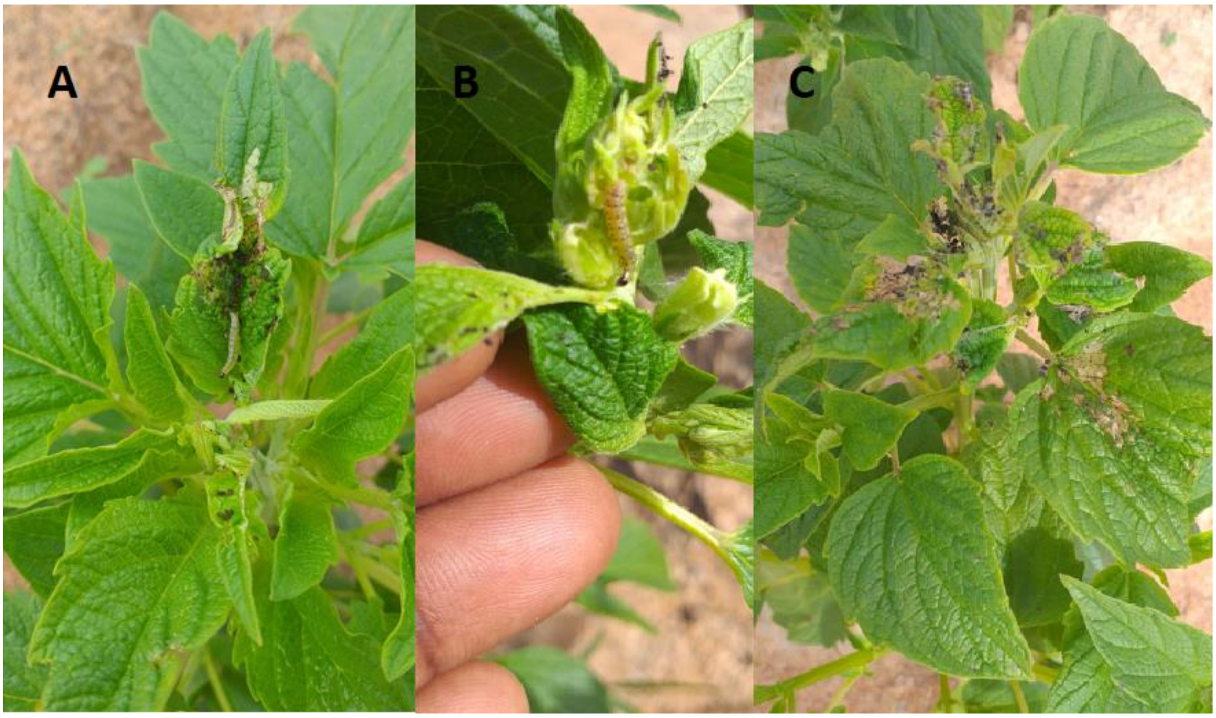



**Plate 4: A: Sesame webworm *A. catalaunalis* on sesame plant before flowering period, B: Sesame webworm *A. catalaunalis* on sesame plant during flowering period and C: Sesame plant damage caused by the *A. catalaunalis*. Photograph by Upendo Lekamoi, Singida, Tanzania taken from March to May 2021**

### (ii) Effects of *T. vogelii* Formulation with Rabbit Urine on *Alocypha bimaculata* Pest

The result of this study indicated that before application of the treatments, there was no significant difference ($p > 0.05$) in the number of *A. bimaculata* among the tested treatments (Table 9). After application of treatments, there was a significant difference among the treatments used from week 1 up to 5 (Table 9). However, there was no significant difference between the biopesticide formulations and synthetic pesticide treatments from week 1 up to week 5 of treatment applications (Table 9). Generally, the results of this study showed that sesame plants sprayed with biopesticide formulations and synthetic pesticide treatments had a significantly ($p \leq 0.001$) lower number of *A bimaculata* (Plate 5) than those in control treatment, which was decreasing from week 1 up to 5 (Table 9). Conversely, the highest number of *A. bimaculata* was recorded in sesame plants in control treatment, which was increasing from week 1 up to 5 of treatments application (Table 9).

**Table 9: Effect of pesticides treatments on the population of *A. bimaculata***

| **Treatments** | **Population of *A. bimaculata* per week** | | | | | |
|---|---|---|---|---|---|---|
| | **0** | **1** | **2** | **3** | **4** | **5** |
| *T. vogelii* 10% | 1.46 ± 0.26a | 1.20 ± 0.00b | 1.06 ± 0.14b | 0.94 ± 0.14bc | 0.80 ± 0.00bc | 0.66 ± 0.14b |
| Rabbit urine 50% | 1.46 ± 0.26ba | 1.34 ± 0.14b | 1.20 ± 0.14b | 1.06 ± 0.14b | 0.94 ± 0.14b | 0.80 ± 0.00b |
| Tv+Ru | 1.60 ± 0.24a | 1.06 ± 0.14b | 0.94 ± 0.00b | 0.80 ± 0.00c | 0.66 ± 0.14c | 0.54 ± 0.14b |
| Sp 2% | 1.48 ± 0.26a | 1.34 ± 0.14b | 1.06 ± 0.00b | 0.80 ± 0.00c | 0.80 ± 0.00bc | 0.66 ± 0.14b |
| Water | 1.46 ± 0.26a | 2.40 ± 0.00a | 2.94 ± 0.00a | 3.20 ± 0.00a | 3.20 ± 0.00a | 3.46 ± 0.14a |
| **1 - way ANOVA (F- Statistics)** | 0.21ns | 26.67*** | 49.63*** | 150.5*** | 163.25*** | 110.88*** |

Each value represents mean ± standard error of five treatments and three replicates, *, **, and *** is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$ respectively while ns means not significant. Means within the same column possessing same letter (s) are not significantly different at $p = 0.05$ from each other accredited by Fishers Least Significant Difference (LSD) test; Tv means *T vogelii* 10%, Ru means rabbit urine 50% and Sp 2% means synthetic pesticide (Duduba 450EC), week 0 means one week before treatments application.

**Plate 5: Sesame flea beetle (*A. bimaculata*) foraging feeding on sesame leaves and stems in the field. Photograph by Upendo Lekamoi, Singida, Tanzania on 20th March 2021**

**(iii) The percentage damage of sesame crop caused by insect pests' infestations**

The percentage damage of the sesame caused by insect pests' infestations was not significantly ($p > 0.05$) among the treatments used before the application of treatments (Table 10). After the application of treatments, percentage damage was significantly ($p \leq 0.001$) lower in the biopesticide formulations and synthetic pesticide treatments than in the control. Sesame plants sprayed with biopesticide formulations and synthetic pesticide treatments had significantly ($p \leq 0.001$) low percentage damage when compared with those control treatments from week 1 up to week 5 (Table 10). However, sesame plants in the control treatment had the highest percentage of damage and appeared to increase from week 1 to week 5 (Table 10).

**Table 10: Percentage leaf damage levels in sesame plants sprayed with different treatments**

| Treatments | % Leaf damage by insect pests per week | | | | | |
|---|---|---|---|---|---|---|
| | **0** | **1** | **2** | **3** | **4** | **5** |
| *T. vogelii* 10% | 35.00 ± 0.00a | 33.33 ± 1.67b | 26.67 ± 1.67b | 25.00 ± 2.89bc | 20.00 ± 0.00b | 16.67 ± 1.67bc |
| Rabbit urine 50% | 35.00 ± 0.00a | 33.33 ± 1.67b | 28.33 ± 1.67b | 26.67 ± 1.67b | 20.00 ± 0.00b | 16.67 ± 1.67bc |
| Tv+Ru | 35.00 ± 0.00a | 25.00 ± 0.00c | 23.33 ± 1.67b | 20.00 ± 0.00c | 16.67 ± 1.67b | 15.00 ± 2.89b |
| Sp 2% | 36.67 ± 1.67a | 33.33 ± 1.67b | 26.67 ± 1.67b | 23.33 ± 1.67bc | 18.33 ± 1.67b | 16.67 ± 1.67bc |
| Water | 35.00 ± 0.00a | 40.00 ± 0.00a | 50.00 ± 2.89a | 60.00 ± 0.00a | 68.33 ± 1.67a | 75.00 ± 2.89a |
| **1 - way ANOVA (F- Statistics)** | 1.00ns | 17.00*** | 29.86*** | 96.80*** | 296.17*** | 138.17*** |

Each value represents mean ± standard error of five treatments and three replicates, *, **, and *** is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$ respectively while ns means not significant. Means within the same column possessing same letter (s) are not significantly different at $p = 0.05$ from each other accredited by Fishers Least Significant Difference (LSD) test; Tv means *T vogelii* 10%, Ru means rabbit urine 50% and Sp 2% means synthetic pesticide (Duduba 450EC), week 0 means one week before treatments application.

### (iv) Effects of *T. vogelii* Formulation with Rabbit Urine on Identified Natural Enemies of Sesame' Insect Pests

The identified natural enemies in the experimental field were odorous ants (*Tapinoma sessile*), ladybird beetles (*C. undecimpunctata*), spiders (*P. fera*), praying mantis (*C. savignyi*), and true bugs (*Pentatomidae spp.*) (Table 11). Of these, *C. undecimpunctata* and *T. sessile* (Plate 6) were found abundantly during the study period, and they were controlling *A. catalaunalis* insect pests. Figure 2 describes the effect of the treatments on the population of the natural enemies *T. sessile* and *C. undecimpunctata*. Generally, the mean number of natural enemies was higher in the sesame plants sprayed with biopesticide formulation treatments than in those sprayed with the synthetic pesticide (Fig. 2). It was observed that sesame plants sprayed with the biopesticide formulations possessed a higher population of the natural enemies *C. undecimpunctata* and *T. sessile* compared with those sprayed with a synthetic pesticide in the field. Figure 2 shows that the formulations prepared have less effect on the natural enemies. The sesame plants sprayed with the check (synthetic pesticide) treatment possessed the least population of natural enemies, while those sprayed with the control treatment possessed as high a number of natural enemies as in biopesticide formulations. It was also noted that the population of *C. undecimpunctata* was lower in number compared with *T. sessile* throughout the growing season of sesame (Fig. 2). These natural enemies, combined with biopesticide formulations, were used to reduce the population of *A. catalaunalis* and, ultimately, mitigate damage caused by this insect pest in the sesame field.

**Table 11: Natural enemies of sesame insect pests identified in the experimental field**

| General name | Common name[a] | Scientific name | Number per plot |
|---|---|---|---|
| Ants | Odorous ant | *Tapinoma sessile* | 10 |
| beetles | Ladybird beetle | *Coccinella undecimpunctata* | 7 |
| Spiders | Spider | *Phoneutria fera* | 1 |
| Mantids | Praying mantis | *Calidomantis savignyi* | 2 |
| True bug | True bug | *Dolycoris baccarum* | 1 |

**a: Identification was conducted at Tanzania Plant Health and Pesticide Authority TPHPA**

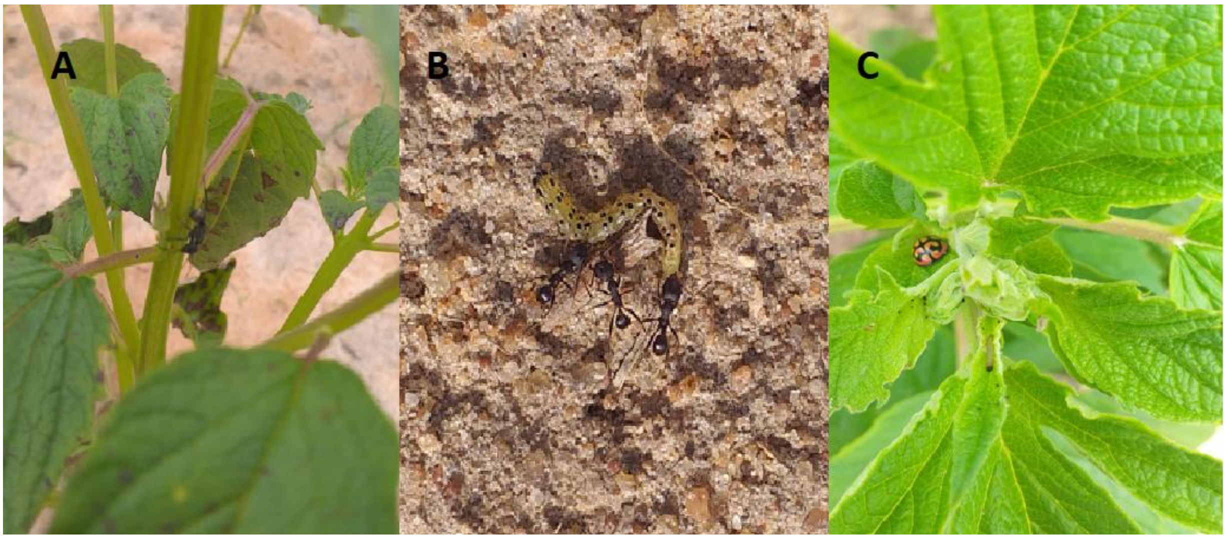



**Plate 6: A: This is *T. sessile* foraging for *A. catalaunalis* larva on sesame plant B: *T. sessile* feed on a fallen down *A. catalaunalis* larva. C: This is *C. undecimpunctata* foraging for *A. catalaunalis* larva on sesame plant. Photograph by Upendo Lekamoi, Singida, Tanzania from March to May 2021**

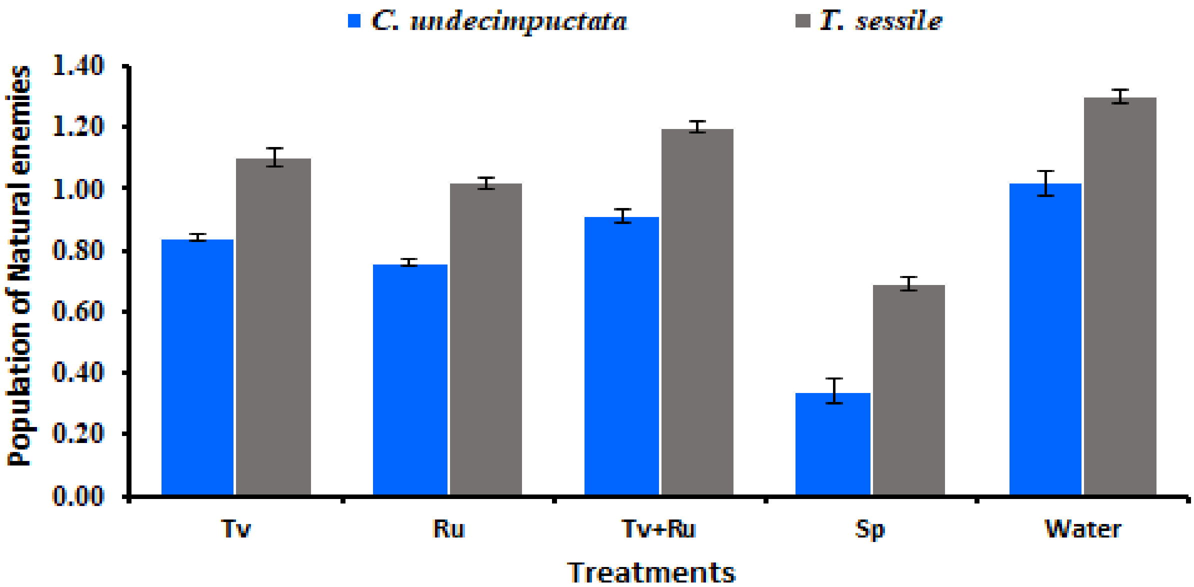



**Figure 2: Effects of *T. vogelii* formulations with rabbit urine on population of *C. undecimpunctata* and *T. sessile* in sesame experimental field. Tv means *T. vogelii* 10%, Ru means rabbit urine 50% and Sp means synthetic pesticide 2%**

### 4.1.2 Effect of *T. vogelii* Formulation with Rabbit Urine on Identified Pollinators of Sesame

The study identified four pollinators, which were honey bees (*A. melifera*), green jewel flies (*O. obesa*), scorpion wasps (*D. semiclausum*) and monarch butterflies (*D. chrysippus*) (Table 12). However, *D. chrysippus* was rare and limited in number, which made its assessment insignificant. Identification of the identified insect pollinators of sesame was conducted at the Tanzania Plant Health and Pesticide Authority (TPHPA).

**Table 12: Pollinators identified on sesame plants during this study**

| General name | Common name[a] | Scientific name | Number per plot |
|---|---|---|---|
| Bee | Honey bee | *Apis mellifera* | 8 |
| Fly | green jewel fly | *Ornidia obesa* | 6 |
| Wasp | Wasp | *Diadegma semiclausum* | 3 |
| Butterfly | Monarch butterfly | *Danaus Chrysippus* | 1 |

**a: Identification was conducted at Tanzania Plant Health and Pesticide Authority TPHPA**

### (i) Effect of *T. vogelii* Formulation with Rabbit Urine on *Apis mellifera* Population

*Apis mellifera* was found in the field's plots of sesame in the first week of the flowering period during treatment application, and the mean population increased week after week (Table 13). The results revealed the presence of significant differences ($p \leq 0.001$) among treatments used, which were the biopesticide formulations (10% *T. vogelii*, 50% rabbit urine, and the mixture of 10% *T. vogelii* + 50% rabbit urine), synthetic pesticide, and control in the population abundance of *A. mellifera* (Table 13). Table 13 showed that sesame plants sprayed with biopesticide formulations possessed a significantly higher population of *A. mellifera* in weeks 1 to 5 of the flowering period compared with those sprayed with synthetic pesticide. Likewise, sesame plants sprayed with control treatment (water) had a large number of *A. mellifera*, the same as those sprayed with biopesticide formulations (Table 13). On the contrary, synthetic pesticide treatment had the least number of *A. mellifera* (Table 13). Therefore, the biopesticide formulations used in this study maintained a significantly large number of *A. mellifera* compared with the synthetic pesticide, which had a very low number of *A. mellifera* (Table 13).

**Table 13: Effects of *T. vogelii* formulations with rabbit urine on the population of *A. mellifera***

| Treatments | Week | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| *T. vogelii* 10% | 4.00 ± 0.00bc | 6.00 ± 0.00bc | 8.00 ± 0.00bc | 9.30 ± 0.70b | 11.30 ± 0.70b |
| Rabbit urine 50% | 3.30 ± 0.70cd | 4.70 ± 0.70c | 6.70 ± 0.70c | 8.00 ± 0.00b | 10.00 ± 0.00b |
| *T. vogelii* + rabbit urine | 5.30 ± 0.70ab | 7.30 ± 0.70ab | 9.30 ± 0.70ab | 11.30 ± 0.70a | 13.30 ± 0.70ab |
| Duduba 450 EC 2% | 2.00 ± 0.00d | 1.30 ± 0.70d | 0.70 ± 0.70d | 0.00 ± 0.00c | 0.00 ± 0.00c |
| Water | 6.70 ± 0.70a | 8.70 ± 0.70a | 10.00 ± 0.00a | 12.70 ± 0.70a | 14.70 ± 0.70a |
| **1 - way ANOVA (F- Statistics)** | 12.17*** | 22.25*** | 52.17*** | 92.17*** | 126.17*** |

Each value represents mean ± standard error of five treatments and three replicates, *, **, and *** is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively. Means within the same column possessing same letter (s) are not significantly different at $p = 0.05$ from each other accredited by Fishers Least Significant Difference (LSD) test. Duduba 450 EC is the synthetic pesticide

### (ii) Effect of *T. vogelii* Formulation with Rabbit Urine on *Ornidia obesa* Population

This pollinator was identified on sesame plants in the first week of the sesame flowering period in the experimental field during treatment application whereby the mean population was increasing as the crop stayed longer in the field (Table 14). The results further indicated significant differences ($p \leq 0.001$) among treatments used, which were the biopesticide formulations (10% *T. vogelii*, 50% rabbit urine and the mixture of 10% *T. vogelii* + 50% rabbit urine), synthetic pesticide and control (Table 14). Sesame plants sprayed with biopesticide formulations possessed significantly large number of *O. obesa* in week 1 to 5 of the flowering period compared with those sprayed with a synthetic pesticide (Table 14). Similarly, sesame plants sprayed with control (water), had large number of *O. obesa* same as biopesticide formulation treatments (Table 14). However, sesame plants sprayed with a synthetic pesticide had least number of *O. obesa* relative to other treatments which was decreasing from week 1 up to 5 of the flowering period (Table 14).

**Table 14: Effect of *T. vogelii* formulations with rabbit urine on the population of *O. obesa***

| Treatments | Week | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| *T. vogelii* 10% | 4.20 ± 0.00bc | 4.70 ± 0.70b | 6.00 ± 0.00bc | 7.30 ± 0.70b | 8.00 ± 0.00bc |
| Rabbit urine 50% | 3.10 ± 0.70c | 4.00 ± 0.00b | 5.30 ± 0.70c | 6.70 ± 0.70b | 7.30 ± 0.70c |
| *T. vogelii* + rabbit urine | 5.40 ± 0.70ab | 6.00 ± 0.00a | 7.30 ± 0.70ab | 8.70 ± 0.70a | 9.30 ± 0.70ab |
| Duduba 450 EC 2% | 1.30 ± 0.70d | 1.30 ± 0.70c | 0.70 ± 0.70d | 0.70 ± 0.70c | 0.00 ± 0.00d |
| Water | 6.00 ± 0.00a | 6.00 ± 0.00a | 8.70 ± 0.70a | 9.30 ± 0.70a | 10.70 ± 0.70a |
| **1 - way ANOVA (F- Statistics)** | 12.50*** | 20.75*** | 26.00*** | 26.70*** | 64.67*** |

Each value represents mean ± standard error of five treatments and three replicates, *, **, and *** is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively. Means within the same column possessing same letter (s) are not significantly different at $p = 0.05$ from each other accredited by Fishers Least Significant Difference (LSD) test. Duduba 450 EC is the synthetic pesticide

### (iii) Effect of *T. vogelii* Formulation with Rabbit Urine on *Diadegma semiclausum* Population

*Diadegma semiclausum* was observed in the third week of the sesame flowering period during the application of treatments. The study results divulged the presence of significant difference ($p \leq 0.05$) among treatments used which were the biopesticides formulations (10% *T. vogelii*, 50% rabbit urine and the mixture of 10% *T. vogelii* + 50% rabbit urine), synthetic pesticide and control (Table 15). Treatment plots sprayed with biopesticides formulations had higher population of *D. semiclausum* in week 3 to 5 of the flowering period compared those sprayed with synthetic pesticide (Table 15). Likewise, sesame plants in control treatment had higher population of *D. semiclausum* same as biopesticides formulations (Table 15). Conversely, sesame plants sprayed with synthetic pesticide treatment had the least number of *D. semiclausum* compared with other treatments throughout the flowering period (Table 15). In general, the number of *D. semiclausum* appeared to decrease significantly in week 6 and 7 (Table 15). This can be attributed to the fact that week 6 and 7 was late flowering period of the sesame where the flowers started to disappear. Still, the biopesticides formulations maintained higher population of *D. semiclausum* (Table 15).

**Table 15: Effect of *T. vogelii* formulations with rabbit urine on the population of *D. semiclausum***

| Treatments | Week | | | | |
|---|---|---|---|---|---|
| | 3 | 4 | 5 | 6 | 7 |
| *T. vogelii* 10% | 2.70 ± 0.70abc | 3.30 ± 0.70ab | 3.30 ± 0.70b | 2.70 ± 0.70b | 1.30 ± 0.70b |
| Rabbit urine 50% | 2.00 ± 0.00bc | 2.70 ± 0.70b | 2.70 ± 0.70b | 2.00 ± 0.00bc | 1.70 ± 0.70b |
| *T. vogelii* + rabbit urine | 3.30 ± 0.70ab | 4.00 ± 0.00ab | 4.00 ± 0.00b | 3.30 ± 0.70ab | 1.30 ± 0.70b |
| Duduba 450 EC 2% | 1.30 ± 0.70c | 0.70 ± 0.70c | 0.70 ± 0.70c | 0.70 ± 0.70c | 0.00 ± 0.00c |
| Water | 4.00 ± 0.00a | 4.70 ± 0.70a | 5.30 ± 0.70a | 4.70 ± 0.70a | 3.30 ± 0.70a |
| **1 - way ANOVA (F- Statistics)** | 4.17* | 6.63** | 8.38** | 6.25** | 4.38* |

Each value represents mean ± standard error of five treatments and three replicates, *, **, and *** is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively. Means within the same column possessing same letter (s) are not significantly different at $p = 0.05$ from each other accredited by Fishers Least Significant Difference (LSD) test. Duduba 450 EC is the synthetic pesticide

### (iv) Effect of *T. vogelii* Formulation with Rabbit Urine on the Abundance of sesame pollinators

Figure 3 elucidates the effect of treatments upon the number of pollinators of sesame. Population of *A mellifera, O. obesa* and *D. semiclausum* were higher in *T. vogelii* formulation compared with synthetic pesticide (Fig. 3). The plots sprayed with water had a large number of pollinators, the same as those in biopesticide formulations (Fig. 3). Conversely, sesame plants sprayed with a synthetic pesticide possessed the least number of pollinators (Fig. 3).

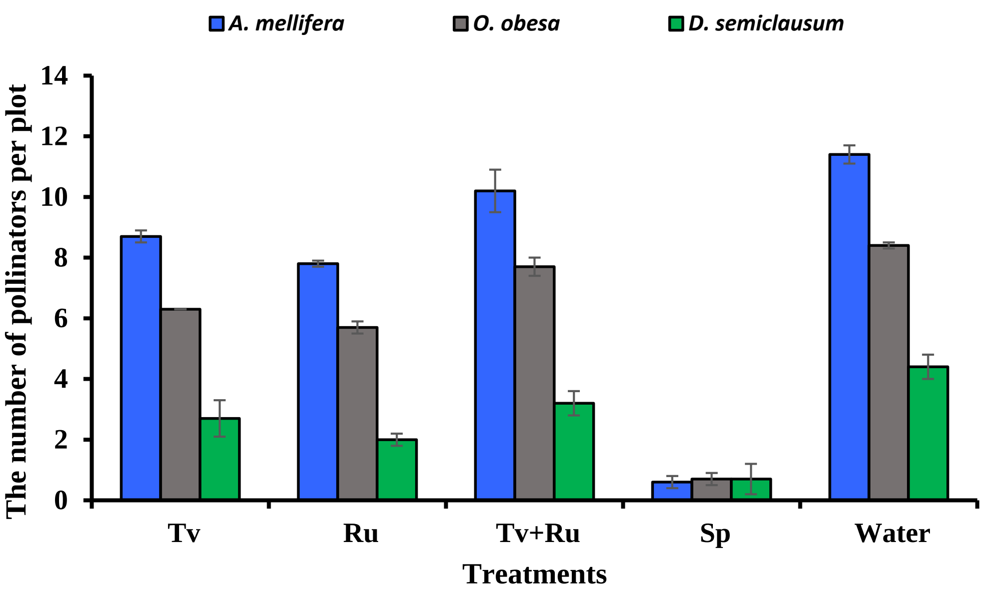



**Figure 3: The number of pollinators of sesame in response to treatments. Tv means *T. vogelii* 10%, Ru means rabbit urine 50% and Sp means synthetic pesticide 2%**

### 4.1.3 Effect of *T. vogelii* Formulation with Rabbit Urine on Yield of Sesame

**(i) Effect of Treatments on Sesame Growth**

Treatments were sprayed on plants to compare their effects on the growth of sesame plants. The results showed that the biopesticide formulation of 10% *T. vogelii* + 50% rabbit urine had the largest leaf area, followed by synthetic pesticide and 10% *T. vogelii*, while the control treatment had the least leaf area (Fig. 4). Moreover, the results showed that the biopesticide formulations and a synthetic pesticide resulted in significantly higher plant height, number of branches, and leaves (Table 16-18), respectively, than the control treatment. The control treatment, on the other hand, had significantly lower plant height, number of branches, and number of leaves (Table 16-18).

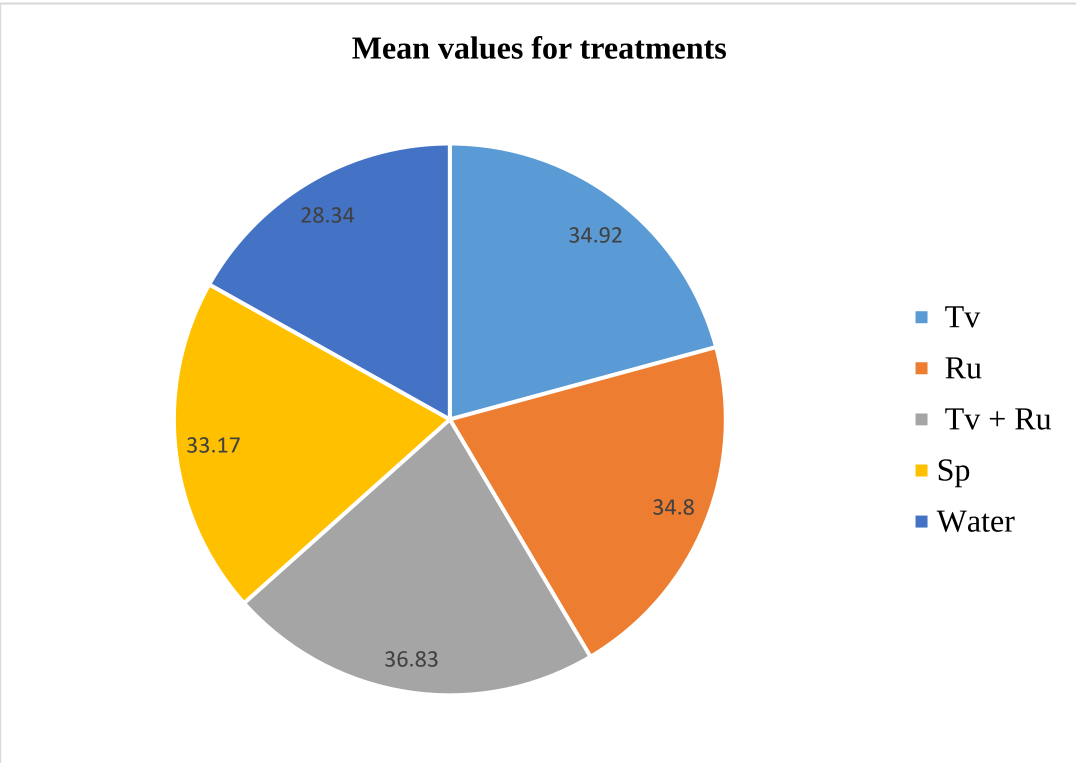



**Figure 4: Effect of *T. vogelii* formulations with rabbit urine on the leaf area of sesame. Tv means *T. vogelii* 10%, Ru means rabbit urine 50% and Sp means synthetic pesticide 2%**

**Table 16: Effects of *T. vogelii* formulations with rabbit urine on sesame plant height**

| Treatments (cm) | Week | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| *T. vogelii* 10% | 17.67 ± 0.18ab | 30.60 ± 0.35ab | 51.00 ± 0.12ab | 71.20 ± 0.31a | 96.33 ± 0.18b |
| Rabbit urine 50% | 17.33 ± 0.24bc | 30.20 ± 0.12b | 50.67 ± 0.18b | 71.93 ± 0.35a | 96.47 ± 0.33b |
| *T. vogelii* + rabbit urine | 18.33 ± 0.18a | 30.93 ± 0.07a | 51.60 ± 0.20a | 71.73 ± 0.13a | 97.67 ± 0.07a |
| Duduba 450 EC 2% | 17.67 ± 0.24ab | 30.47 ± 0.24ab | 51.13 ± 0.24ab | 71.13 ± 0.35a | 96.60 ± 0.00b |
| Water | 16.73 ± 0.29c | 29.27 ± 0.13c | 47.47 ± 0.35c | 68.27 ± 0.41b | 91.13 ± 0.24c |
| **1 - way ANOVA (F- Statistics)** | 6.46** | 9.4** | 51.6*** | 17.8*** | 162*** |

Each value represents mean ± standard error of five treatments and three replicates, *, **, and *** is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively. Means within the same column possessing same letter (s) are not significantly different at $p = 0.05$ from each other accredited by Fishers Least Significant Difference (LSD) test. Duduba 450 EC is the synthetic pesticide

**Table 17: Effects of *T. vogelii* formulations with rabbit urine on branches number of sesame**

| Treatments | Week | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| *T. vogelii* 10% | 5.60 ± 0.00ab | 7.60 ± 0.00ab | 9.60 ± 0.00ab | 11.60 ± 0.00a | 12.00 ± 0.00b |
| Rabbit urine 50% | 5.47 ± 0.13b | 7.47 ± 0.13b | 9.47 ± 0.13b | 11.47 ± 0.13a | 11.87 ± 0.13b |
| *T. vogelii* + rabbit urine | 5.87 ± 0.13a | 7.87 ± 0.13a | 9.87 ± 0.13a | 11.87 ± 0.13a | 12.67 ± 0.13a |
| Duduba 450 EC 2% | 5.60 ± 0.00ab | 7.60 ± 0.00ab | 9.60 ± 0.00ab | 11.60 ± 0.00a | 12.00 ± 0.00b |
| Water | 4.93 ± 0.13c | 6.93 ± 0.13c | 8.93 ± 0.13c | 10.93 ± 0.13b | 11.07 ± 0.13c |
| **1 - way ANOVA (F- Statistics)** | 11.17*** | 11.17*** | 11.17*** | 11.17*** | 30.5*** |

Each value represents mean ± standard error of five treatments and three replicates, *, **, and *** is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively. Means within the same column possessing same letter (s) are not significantly different at $p = 0.05$ from each other accredited by Fishers Least Significant Difference (LSD) test. Duduba 450 EC is the synthetic pesticide

**Table 18: Effects *T. vogelii* formulations with rabbit urine on sesame' number of leaves**

| Treatments | Week | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| *T. vogelii* 10% | 9.47 ± 0.13a | 17.93 ± 0.18ab | 20.93 ± 0.27ab |
| Rabbit urine 50% | 9.33 ± 0.13a | 17.60 ± 0.23b | 20.60 ± 0.31b |
| *T. vogelii* + rabbit urine | 9.73 ± 0.13a | 18.60 ± 0.20a | 21.47 ± 0.29a |
| Duduba 450 EC 2% | 9.33 ± 0.13a | 17.87 ± 0.24ab | 20.87 ± 0.24ab |
| Water | 8.53 ± 0.35b | 16.87 ± 0.24c | 19.53 ± 0.07c |
| **1 - way ANOVA (F- Statistics)** | 5.14* | 8.18** | 8.19*** |

Each value represents mean ± standard error of five treatments and three replicates, *, **, and *** is significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively. Means within the same column possessing same letter (s) are not significantly different at $p = 0.05$ from each other accredited by Fishers Least Significant Difference (LSD) test. Duduba 450 EC is the synthetic pesticide

### (ii) Effects of *T. vogelii* formulation with rabbit urine on the Yield of Sesame

The yield of sesame was assessed by observing the number of pods per plant and the seed yield per plot (Fig. 5). The highest number of pods per plant and the highest seed yield per plot were significantly obtained in the biopesticide formulation of 10% *T. vogelii* + 50% rabbit urine, followed by synthetic pesticide. The control had the lowest number of pods per plant and the seed yield per plot compared to all pesticide treatments (Fig. 5). The highest total yield was obtained in plots treated with the biopesticide formulation 10% *T. vogelii* + 50% rabbit urine (740.59 kg/ha), followed by synthetic pesticide (721.78 kg/ha), while the lowest yield was obtained in the control (672.78 kg/ha) (Fig. 5).

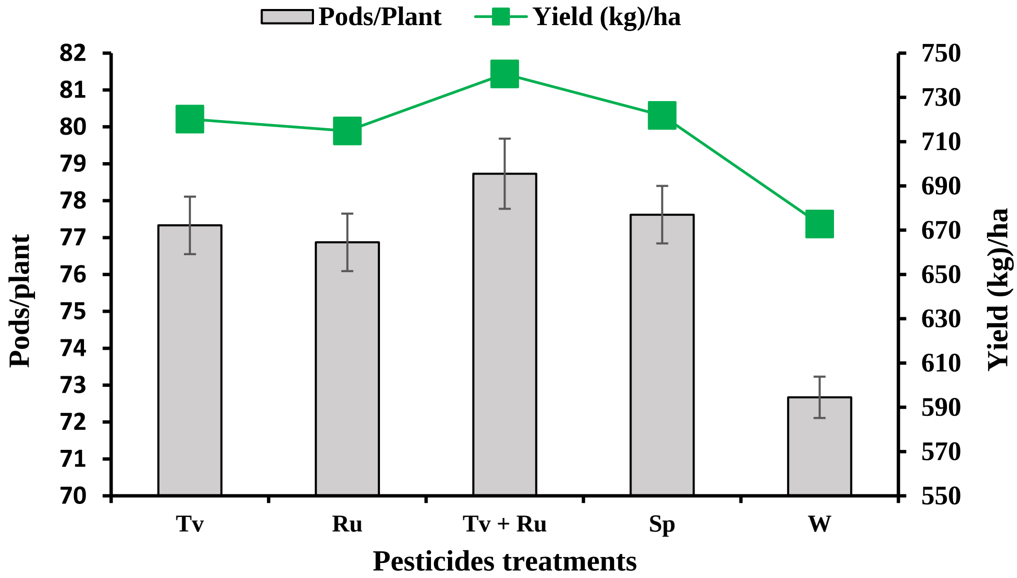



**Figure 5: Effect of different treatments on yield per plot and pods per sesame plant and their mean relationship. Tv means *T. vogelii* 10%, Ru means rabbit urine 50%, W is water and Sp is a synthetic pesticide 2%**

Figure 5 depicts the relationship existing between the number of pods per plant and seed yield per plot. The higher yield per plot was obtained on sesame plots sprayed with the biopesticide formulation 10% *T. vogelii* + 50% rabbit urine, which had a higher pod number per plant (Fig. 5). However, the findings showed sesame plants grown in the control had a low mean seed yield per plot, the same as the low number of pods per plant among all treatments (Fig. 5). These results show the effectiveness of the *T. vogelii* formulation with rabbit urine in controlling yield loss by the insect pests on sesame without devaluing the product.

## 4.2 Discussion

### 4.2.1 Effectiveness *T. vogelii* Formulation with Rabbit Urine in Controlling Insect Pests of Sesame

The findings of this study revealed that the biopesticide formulations used (10% *T. vogelii*, 50% rabbit urine, and the mixture of 10% *T. vogelii* + 50% rabbit urine) were effective in controlling sesame insect pests as well as a synthetic pesticide. It was observed that the lower number of *A. catalaunalis* and *A. bimaculata* pests was significantly recorded in the biopesticide formulations and a synthetic pesticide treatment. The findings further revealed that the numbers of *A. catalaunalis* and *A. bimaculata* appeared to decrease from week 1 to week 5. The superior performance observed in the biopesticide formulations in controlling *A. catalaunalis* and *A. bimaculata*, which seemed to be the major insect pests of sesame in the study area, can be attributed to the bioactive compounds found within these biopesticide formulations.

The effectiveness of the mixture biopesticide formulation 10% *T. vogelii* + 50% rabbit urine can be contributed by the synergistic effect of bioactive compounds found within mixture *T. vogelii* extract and rabbit urine. The results of synergistic effects showed that the complex mixture of bioactive compounds within bio pesticides has a synergistic effect (Sitarek *et al.,* 2020; Tak & Isman, 2017). A synergistic effect occurs when a mixture of two or more chemical compounds interacts and produces combined effects on the biological system that are greater than the effects of those chemical compounds when acting solely (Mpumi *et al.,* 2020).

Likewise, the formulation of 10% *T. vogelii* extract alone was effective in reducing the number of insect pests. Thus, damage of sesame by *A. catalaunalis* and *A. bimaculata* insect pests was the same as with other biopesticide formulations. Several studies have reported on the effectiveness of *T. vogelii* in managing insect pests on various plant crops and have been proved to be effective (Mkindi *et al.,* 2020; Mpumi *et al.,* 2021). The superior performance of the *T. vogelii* formulation in controlling *A. catalaunalis* and *A. bimaculata* insect pests could be contributed by the bioactive compound rotenone, which has been revealed to possess insecticidal traits (Said *et al.,* 2020). Rotenone ($C_{23}H_{22}O_6$) is a selective phytochemical compound, which act as both a contact and stomach toxin to insects that kills pest slowly by stupefying them (Ekanem *et al.,* 2004). Rotenone exerts its toxic action by impeding respiration by limiting electron transport chains through inhibition of the enzyme NADH ubiquinone reductase in a diverse ambit of insect pests, including *A. catalaunalis* and *A. bimaculata* (Golden, 2011). The toxicity of rotenone to insects is due to the fact that it is easily conveyed to insects through trachea (Ene *et al.*, 2010). Rotenone is highly effective against insect pests because most insect pests are slow walking insects, for example, *A. catalaunalis* larvae pest.

The effectiveness of rabbit urine in controlling insect pests of sesame could be attributed to the fact that rabbit urine contains a high amount of ammonia, which is caused by a high level of nitrogen (Wandita *et al.*, 2016). Ammonia is toxic and, at certain concentrations, may harm organisms depending on the species. For example, at a concentration higher than 5 ppm, ammonia affects invertebrates when compared with vertebrates, and even within invertebrates, it may vary from species to species (Dias *et al.*, 2019). Currently, ammonia has been reported to be effective in controlling insect pests (Epa & Programs, 2004). Insect pests are affected by ammonia through direct contact and by breathing in ammonia, which extirpates the respiratory surface of the insect pest to death. Since ammonia is corrosive in nature, once it gets into insect pest bodies directly, it ruins the insect to the point of death. The toxicity of ammonia to insects is higher due to the fact that, in a very low concentration, invertebrates, including insects, get harmed, but that same concentration does not affect vertebrates, including humans. This can be posed by body size (Mathew *et al.*, 2015).

Furthermore, this study also assessed the magnitude of the sesame plant damage posed by the insect pests in the sesame field. The findings showed that sesame plants sprayed with the biopesticide formulations and a synthetic pesticide had significantly ($p \leq 0.001$) lower damage when compared with those sprayed with the control treatment. However, the highest damage was recorded in sesame plants in plots sprayed with the control treatment. The lower sesame damage was attributed to their effectiveness in managing the identified insect pests; hence, they possessed the least number of insect pests compared with those sprayed with control treatment, where the number of insect pests was very high.

Also, the study assessed the population abundance of the natural enemies in the sesame field after the application of experimental treatments. The findings showed that sesame plants sprayed with the biopesticide formulations used to control insect pests had a higher population of natural enemies than those sprayed with synthetic pesticide. The high population of natural enemies in sesame plants grown under the biopesticide formulation treatments can be attributed to the fact that most of the natural enemies found in the experimental field had hard outer coats, which protect them from direct contact with the biopesticide formulations used. Kardinan and

Maris, (2021) reveal that to ensure efficient performance of the botanical pesticides in managing insect pests, direct contact application is of paramount importance. Because most natural enemies' insects have hard covers, it is difficult for them to come into direct contact with biopesticide formulations used to the extent that they are affected. Also, other natural enemies can fly away just like pollinators and come back when the toxicity level of the biopesticide formulations used has been reduced due to the fact that most of the biopesticides persist only for a short time in the ambient environment. Rotenone's half life in *T.vogelii* ambits from a few hours to a week (Kang *et al.,* 2016), whereas ammonia in rabbit urine is only 2 minutes (Diana *et al.,* 2018).

### 4.2.2 Effectiveness of *T. vogelii* Formulation with Rabbit Urine on the Population of Pollinators of Sesame

This study evaluated the effects of using *T. vogelii* formulation with rabbit urine on the population of pollinators after being exposed to it during the application of experimental treatments. The findings of this study revealed that sesame plants sprayed with bio-pesticide formulations possessed a higher population of pollinators relative to those sprayed with a synthetic pesticide throughout the flowering period. The potential of the tested biopesticide formulations to possess a high number of pollinators is attributed to the fact that biopesticides are usually transient in the ambient environment, so their effect on beneficial insects, including pollinators, is least juxtaposed with synthetic pesticides like Duduba 450 EC, which persist longer (Kumar *et al.,* 2021). The phytochemical rotenone in *T. vogelii*, for example, has a half-life that ranges from a few hours to a week (Kang *et al.,* 2016). Also, rotenone in nature is less volatile and can be degraded rapidly in the ambient environment by hydrolysis and photolysis (Turner *et al.,* 2007). Moreover, rotenone is a selective biochemical acting as a contact and stomach toxin for insect pests that decimates insect pests steadily by stunning them to death (Ekanem *et al.,* 2004; Wang *et al.,* 2019). Therefore, as most pollinators are mobile compared with the field insect pests of sesame, they can easily escape the effect of toxic rotenone once applied by flying over, and turning back when the toxic effect of *T. vogelii* has been attenuated.

Likewise, the capacity of the rabbit urine formulation to possess a large number of pollinators can be explained by the availability of large concentrations of ammonia in the rabbit urine (Durán-Lara *et al.,* 2020). Ammonia in rabbit urine is highly volatile and can be degraded by photolysis (Gong *et al.,* 2015; Leoni *et al.,* 2018). Since ammonia is volatile in nature, it does not exist very long in the ambient environment as its half-life is almost 2 minutes (Diana *et al.,* 2018). Consequently, pollinators may escape during treatment application through flying over activities and come back shortly after spraying of the formulation. Moreover, the toxicity level of ammonia differs from one organism to another, even from one species to another (Gerberding, 2004). Ammonia at concentrations greater than 5 ppm affects more invertebrates than vertebrates, and the effect varies between species within invertebrates (Dias *et al.,* 2019). Based on the results, the number of pollinators was significantly higher in plots sprayed with rabbit urine than in those sprayed with synthetic pesticide, as the effect of rabbit urine on pollinators was the least. However, sesame plants grown under synthetic pesticide (Duduba 450 EC) treatment had the least number of pollinators relative to other experimental treatments. Duduba 450 EC contains a combination of two hazardous chemicals, Cypermethrin 100 g/l and Chlorpyrifos 350 g/l, both of which are broad-spectrum insecticides, decimating insects indiscriminately (Sadeghi *et al.,* 2009). Moreover, the majority of the synthetic pesticides incorporating Duduba 450 EC persist longer in the environment, resulting in environmental adulteration, thus affecting beneficial insects, including pollinators (Kalyabina *et al.,* 2021; Sharma *et al.,* 2019; Tudi *et al.*, 2021). Therefore, this revealed evidence that the least number of pollinators was obtained in sesame plots sprayed with synthetic pesticide when compared with those sprayed with the biopesticide formulations.

#### 4.2.3. Effects of *T. vogelii* Formulation with Rabbit Urine on Yield of Sesame

The study reports the effects of *T. vogelii* formulation with rabbit urine on the yield of sesame. The findings revealed that sesame plants sprayed with the biopesticide formulations in an attempt to manage insect pests had a significantly higher number of branches, plant height, and number of leaves similar to those under synthetic pesticide. The biopesticide formulation of 10% *T. vogelii* + 50% rabbit urine possessed a large leaf area compared with other biopesticide formulations and a synthetic pesticide. This can be attributed to the fact that both *T. vogelii* and rabbit urine are growth boosters (Mkindi *et al.,* 2020; Mutai, 2020).

Furthermore, the results of the study revealed that sesame plants treated with the biopesticide formulation of 10% *T. vogelii* + 50% rabbit urine had a significantly higher seed yield than those treated with other biopesticide formulations and a synthetic pesticide. The observed high seed yield in the biopesticide formulation of 10% *T. vogelii* + 50% rabbit urine can be explained by the fact that both *T. vogelii* and rabbit urine contain potential nutrients like nitrogen, phosphates, and potassium essential for plant growth (Indabo, 2020; Sunadra *et al.,* 2019; Kayange *et al.,* 2019; Mkindi *et al.,* 2020) and can increase crop yields by up to 25% (Zhang *et al.,* 2020). Also, the combined effects of the potential elements found in these two growth boosters might have contributed much to this performance (Sitarek *et al.,* 2020). Conversely, the lowest yield was obtained in sesame plots treated with the control treatment. The low yield in the control treatment plots can be attributed to the heavy infestation of insect pests (Dossa *et al.,* 2017).

Therefore, this study suggests that the formulation of 10% *T. vogelii* + 50% rabbit urine can be utilized by smallholder farmers as an alternative strategy to manage sesame insect pests and promote yield in Tanzania. The suggested ingredient amount enough to be used in one hectare is 27.8 kg of *T. vogelii* leaves plus 139 liters of rabbit urine per spray.

.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

Total reliance on the utilization of synthetic pesticides in managing sesame insect pests practiced by the smallholder farmers in the Singida region should be highly mitigated because they are immensely contributing to environmental adulteration and decimation of beneficial insects, including pollinators. This study was to assess the effects of biopesticide formulations on insect pests and pollinators of sesame. The biopesticide formulations tested (10% *T. vogelii*, 50% rabbit urine, and the mixture of 10% *T. vogelii* + 50% rabbit urine) significantly reduced the number of sesame insect pests in the field.

Likewise, the results of the study showed that sesame plants sprayed with biopesticide formulations possessed a higher population of pollinators than those sprayed with a synthetic pesticide. Similarly, plots sprayed with the biopesticide formulation of 10% *T. vogelii* + 50% rabbit urine produced a higher yield than plots sprayed with other biopesticide formulations and a synthetic pesticide. Therefore, this signifies the potential of the formulation of *T. vogelii* with rabbit urine in managing sesame insect pests and promoting growth while preserving beneficial insects, including pollinators, in fields.

## 5.2 Recommendations

The findings of the study emphasize the role of *T. vogelii* formulation with rabbit urine in the management of sesame insect pests, but it is underutilized because of limited information on its efficacy, toxicity, and cost of instruments used for identification of the secondary metabolites for commercialization. Hence, a comprehensive study to explore the toxicity of many biopesticides is needed as soon as possible to ensure the safety of beneficial insects such as natural enemies and pollinators.

Moreover, there should be emphasis on public health law and environmental regulatory agents to encourage the utilization of biopesticides that are environmentally benign, affordable, and safe for ecosystems and human health. In addition, the study recommends more studies on rabbit urine as a biopesticide and the optimum dose for the control of field insect pests. Also, detailed and appropriate studies to investigate the bioactive compounds in the rabbit urine against insect pests are needed.

Lastly, simple, affordable, and feasible tools are needed to investigate bioactive compounds that are found in biopesticides to enhance their efficacy and utilization for protection of crops from insect pest infestations.

## REFERENCES


Abbas, M. S. T. (2018). Genetically engineered (Modified) crops (*Bacillus thuringiensis* crops) and the world controversy on their safety. *Egyptian Journal of Biological Pest Control*, 28(1), 1–12. https://doi.org/10.1186/s41938-018-0051-2

Abdalla, E. A., Osman, A. K., Maki, M. A., Nur, F. M., Ali, S. B., & Aune, J. B. (2015). The response of sorghum, groundnut, sesame, and cowpea to seed priming and fertilizer micro-dosing in South Kordofan State, Sudan. *Agronomy*, 5(4), 476–490. https://doi.org/10. 3390/agronomy5040476

Abdallah, S. A., El-ramady, H. R., & El-sharkawy, M. S. (2019). The Photocatalytic Degradation of Aqueous Ammonia. *IOSR Journal Of Environmental Science, Toxicology And Food Technology*, 13(7 (1)), 27–35. https://doi.org/10.9790/2402-1307012735

Adsule, R. N., Nalawade, R. G., Kanase, R. V, Divergence, G., & Lakra, A. (2009). Influence of Land Configurations and Fertilizer Levels on Production Potential of Maize Hybrids in Vertisols under Rainfed conditions. *Journal of Maharashta Agricultural Universities*, 34(1), 001–003.

Ahmed, K. N., Pramanik, S. H. A., Khatun, M., Nargis, A., & Hasan, M. R. (2010). Efficacy of plant extracts in the suppression of insect pests and their effect on the yield of sunflower crop under different climatic conditions. *The Journal of Plant Protection Sciences*, 2(1), 53–58.

Ahmed, K. N., Pramanik, S. H., Khatun, M., Hasan, M.R., Mohanta, L.C., Hoq, T., & Ghose, S.K. (2014). Suppression of dominant insect pests and yield of sesame with plant materials in different climatic conditions. *Bangladesh Journal of Scientific and Industrial Research*, 49(1), 31–34. https://doi.org/10.3329/bjsir.v49i1.18851

Aizen, M. ., Basu, P., Dicks, L., Fonseca, V. ., Galetto, L., Garibaldi, L., Gemmil-Herren, B., Howlett, B., Johnson, S., Kobayashi, M., Lattorff, M., Lyver, P., Ngo, H., Potts, S., Senapathi, D., Seymour, C., & Vanbergen, A. (2017). Review of Pollination Relevant to the Conservation and Sustainable use of Biodiversity in all Ecosystems, Beyond their Role in Agriculture and Food production. *Conference of the Parties to the Convention on Biological Diversity_COP 14, under Agenda Item 23 Conservation and Sustainable Use of Pollinators*, 2016, 1–72.

Akhtar, K. P., Sarwar, G., Dickinson, M., Ahmad, M., Haq, M. A., Hameed, S., & Iqbal, M. J. (2009). Sesame phyllody disease: Its symptomatology, etiology, and transmission in Pakistan. *Turkish Journal of Agriculture and Forestry*, 33(5), 477–486. https://doi.org/10.3906/tar-0901-23

Aktar, W., Sengupta, D., & Chowdhury, A. (2009). Impact of pesticides use in agriculture: Their benefits and hazards. *Interdisciplinary Toxicology*, 2(1), 1–12. https://doi.org/10.2478/v10102-009-0001-7

Alfaress, S., Brodersen, C. R., Ammar, E. D., Rogers, M. E., & Nabil, K. (2018). Laser surgery reveals the biomechanical and chemical signaling functions of aphid siphunculi (cornicles). *PLoS ONE*, 13(10), 1–16. https://doi.org/10.1371/journal.pone.0204984

Ali, H., Khan, E., & Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry*, 2019(6730305), 1–14. https://doi.org/10.1155/2019/6730305

Ali, K., Shuaib, M., Ilyas, M., Hussain, F., Arif, M., & Ali, S. (2017). Efficacy of Various Botanical and Chemical Insecticides against Flea Beetles on Maize (*Zea maize* L.). *Science and Technology Serving Society PSM*, 2(1), 6–9.

Alyokhin, A., & Sewell, G. (2003). On-Soil Movement and Plant Colonization by Walking Wingless Morphs of Three Aphid Species (Homoptera: Aphididae) in Greenhouse Arenas. *Environmental Entomology*, 32(6), 1393–1398. https://doi.org/10.1603/0046-225X-32.6.1393

Amoabeng, B. W., Gurr, G. M., Gitau, C. W., & Stevenson, P. C. (2014). Cost: Benefit analysis of botanical insecticide use in cabbage: Implications for smallholder farmers in developing countries. *Crop Protection*, 57, 71–76. https://doi.org/10.1016/j.cropro.2013.11.019

Anilakumar, K. R., Pal, A., Khanum, F., & Bawa, A. S. (2010). Nutritional, medicinal and industrial uses of sesame (*Sesamum indicum* L.) seeds - An overview. *Agriculturae Conspectus Scientificus*, 75(4), 159–168.

Aparicio, Y., Gabarra, R., Riudavets, J., Starý, P., Tomanović, Ž., Kocić, K., Villar, J. P., Suay, M. F., Porta, V. C., & Arnó, J. (2019). Hymenoptera complex associated with *Myzus persicae* and *Hyalopterus spp.* in Peach Orchards in Northeastern Spain and Prospects for Biological Control of Aphids. *Insects-MDPI*, 10(4), 1–12. https://doi.org/10.3390/insects 10040109

Arannilewa, S. T., Ekrakene, T., & Akinneye, J. O. (2006). Laboratory evaluation of four medicinal plants as protectants against the maize weevil, *Sitophilus zeamais* (Mots). *African Journal of Biotechnology*, 5(21), 2032–2036.

Aritho, N., Ndungu, P., Inyangala, J., Mwangi, M., & Gicheru, M. (2017). Efficacy of Allopatric *Tephrosia Vogelii* (Fabales: Fabaceae) against Pre-Emerginal Stages of Phlebotomus (Phlebotomus) Duboscqi (Diptera: Psychodidae). *Open Journal of Plant Science*, *2*(1), 007–010. https://doi.org/10.17352/ojps.000006

Arora, N. K., Mehnaz, S., & Balestrini, R. (2016). Use of Indigenous Cyanobacteria for Sustainable Improvement of Biogeochemical and Physical Fertility of Marginal Soils in Semiarid Tropics. In *Bioformulations For Sustainable Agriculture*, 10, 50019. https://doi. org/10.1007/978-81-322-2779-3

Assefa, F., Ayalew, D., & Moral, M. T. (2019). Status and control measures of fall armyworm (*Spodoptera frugiperda*) infestations in maize fields in Ethiopia: A review. *Cogent Food & Agriculture*, 5(1), 1–16. https://doi.org/10.1080/23311932.2019.1641902

Babendreier, D., Agboyi, L. K., Beseh Patrick, Osae, M., Nboyine, J., Ofori, S. E. K., Frimpong, J. O., Clottey, V. A., & Kenis, M. (2020). The Efficacy of Alternative, Environmentally Friendly Plant Protection Measures for Control of Fall Armyworm, *Spodoptera frugiperda*, in maize. *Insects-MDPI*, 11(240), 2–21. https://doi.org/doi:10. 3390/insects11040240

Baker, J. L., & Webber, N. A. P. (2008). Feeding Impacts of a Leafy Spurge (*Euphorbia esula*) Biological Control Agent on a Native Plant, *Euphorbia robusta . Invasive Plant Science and Management*, 1(1), 26–30. https://doi.org/10.1614/ipsm-07-018.1

Barbedo, J. G. A. (2014). Using digital image processing for counting whiteflies on soya bean leaves. *Journal of Asia-Pacific Entomology*, 17(4), 685–694. https://doi.org/10.1016/j. aspen.2014.06.014

Barbosa, W. F., Tomé, H. V. V., Bernardes, R. C., Siqueira, M. A. L., Smagghe, G., & Guedes, R. N. C. (2015). Biopesticide-induced behavioral and morphological alterations in the stingless bee *Melipona quadrifasciata*. *Environmental Toxicology and Chemistry*, 34(9), 2149–2158. https://doi.org/10.1002/etc.3053

Belmain, S. R., Amoah, B. A., Nyirenda, S. P., Kamanula, J. F., & Stevenson, P. C. (2012). Highly Variable Insect Control Efficacy of *Tephrosia vogelii* Chemotypes. *Journal of Agricultural and Food Chemistry*, 60(10055–10063). https://doi.org/dx.doi.org/10.1021/jf3032217

Berhe, M., Abraha, B., Terefe, G., & Walle, M. (2011). Sesame harvest loss caused by sesame seed bug, *Elasmolomus sordidus* F. at Kafta-Humera sesame fields. *Ethiopian Journal of Science*, 31(2), 147–150. https://doi.org/10.4314/sinet.v31i2.66645

Bissdorf, J., & Weber, C. (2007). Field Guide to Non-chemical Pest Management in Sesame Production Pesticide Action Network (PAN) Germany. *Pesticide Action Network*, 1–20.

Boboescu, N. (2020). *Perspectives on the Use of Biopesticides in Pest*. 23(2), 135–146.

Bonmatin, J. M., Giorio, C., Girolami, V., Goulson, D., Kreutzweiser, D. P., Krupke, C., Liess, M., Long, E., Marzaro, M., Mitchell, E. A., Noome, D. A., Simon-Delso, N., & Tapparo, A. (2015). Environmental fate and exposure; neonicotinoids and fipronil. *Environmental Science and Pollution Research*, 22(1), 35–67. https://doi.org/10.1007/s11356-014-3332-7

Bonmatin, M. J., Giorio, C., Sánchez-Bayo, F., & Bijleveld, V.L.M. (2021). An update of the Worldwide Integrated Assessment (WIA) on systemic insecticides. *Environmental Science and Pollution Research*, 28(10), 11709–11715. https://doi.org/10. 1007/s11356-021-12853-6

Borden, M. A., Buss, E. A., Park Brown, S. G., & Dale, A. G. (2018). Natural products for managing landscape and garden pests in Florida. *UF/IFAS Extention University of Florida*, 2018(5), 1–13. https://doi.org/10.32473/edis-in197-2018

Brezeanu, P. M., Brezeanu, C., Ambărus, S., Călin, M., & Cristea, T. O. (2014). A Review of the Most Important Pest Insects and Its Influence on Tomato Culture. *Scientific Studies & Research. Series Biology / Studii Si Cercetari Stiintifice. Seria Biologie*, 23(2), 68–73.

Bubbolini, R., And, D. O., & Atamba, E. (2016). *Sesame Production manual for Small-Scale Farmers in Somalia*.

Bukun, B. (2011). Sesame (*Sesamum indicum* L.) yield loss estimation with common cocklebur (*Xanthium strumarium* L.) interference. *African Journal of Biotechnology*, 10(71), 15953–15958. https://doi.org/10.5897/AJB11.2468

Bunn, B., Alston, D., & Murray, M. (2015). Flea Beetles on Vegetables (Coleoptera: Chrysomelidae). *UTAH Pests Fact Sheet*, 1–7.

Cao, H. H., Liu, H. R., Zhang, Z. F., & Liu, T. X. (2016). The green peach aphid *Myzus persicae* perform better on pre-infested Chinese cabbage *Brassica pekinensis* by enhancing host plant nutritional quality. *Scientific Reports*, 6(21954), 1–12. https://doi.org/10.1038/srep 21954

Capinera. (2009). Fall Armyworm: *Spodoptera frugiperda* (J.E Smith) (Insecta: Lepidoptera: Noctidae). *UF/IFAS Extention University of Florida*, 1–6.

Capinera, J. L. (2006). Green Peach Aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae). *Encyclopedia of Entomology*, 1023–1025. https://doi.org/10.1007/0-306-48380-7_1882

Carlsson, A. S., Chanana, N. P., Gudu, S., & Suh, M. C. (2008). *Sesame* (Chittaranjan Kole and Timothy C. Hall (ed.); 6$^{th}$ ed.). Blackwell Publishing Ltd.

Carvalho, F. P. (2006). Agriculture, pesticides, food security and food safety. *Environmental Science and Policy*, 9(7–8), 685–692. https://doi.org/10.1016/j.envsci.2006.08.002

Céspedes, C. L., Martínez-Vázquez, M., Calderón, J. S., Salazar, J. R., & Aranda, E. (2001). Insect Growth Regulatory Activity of Some Extracts and Compounds from *Parthenium argentatum* on Fall armyworm *Spodoptera frugiperda*. *Verlag Der Zeitschrift Für Naturforschung*, 56(1–2), 95–105. https://doi.org/10.1515/znc-2001-1-216

Chakraborty, K., Bengal, W., & Malda, M. (2015). Integrated Field Management of Jassid (*Amrasca biguttula* Ishida.) Infesting Ladysfinger (*Abelmoschus esculentus* L.) Using Bio-Pesticides. *International Journal of Science Envirinment and Technology*, 4(2), 459–467.

Challa, G. K., Firake, D. M., & Behere, G. T. (2019). Bio-pesticide applications may impair the pollination services and survival of foragers of honey bee, *Apis cerana* Fabricius in oilseed brassica. *Environmental Pollution*, 249, 598–609. https://doi.org/10.1016/j.envpol.2019.03.048

Chandler, D. (2008). Herbivorous insects and mites, plant diseases and weeds are major impediments to the production of food crops. *Trends in Food Science & Technology*, 19, 275–283. https://doi.org/http://dx.doi.org/ 10.1016/j

Chen, X., Tang, C., Ma, K., Xia, J., Song, D., & Gao, X. W. (2020). Overexpression of UDP-glycosyltransferase potentially involved in insecticide resistance in *Aphis gossypii* Glover collected from Bt cotton fields in China. *Pest Management Science*, 76(4), 1371–1377. https://doi.org/10.1002/ps.5648

Chen, M., & Zuo, X., (2018). Pollen limitation and resource limitation affect the reproductive success of *Medicago sativa* L. *BMC Ecology*, 18(1), 1–10. https://doi.org/10.1186/s12898-018-0184-x

Choudhary, M. D., Kumawat, K. C., & Yadav, M. K. (2017). Bionomics of leaf and capsule borer, *Antigastra catalaunalis* (dup.) infesting sesame, *Sesamum indicum* (Linn.). *Journal of Pharmacognosy and Phytochemistry*, 6(4), 736–739.

Claus, G., Pisman, M., Spanoghe, P., Smagghe, G., & Eeraerts, M. (2021). Larval oral exposure to thiacloprid: Dose-response toxicity testing in solitary bees, *Osmia spp.* (Hymenoptera: Megachilidae). *Ecotoxicology and Environmental Safety*, 215, 112143. https://doi.org/10.1016/j.ecoenv.2021.112143

Cranshaw, W. S. (2014). Lady Beetles. *Colorado State University Extension*, 5/01(311), 1. http://www.ext.colostate.edu/pubs/insect/05594.html

Crossley, M. S., & Snyder, W. E. (2020). What Is the Spatial Extent of a *Bemisia tabaci* Population? *Insects-MDPI*, 11(813). https://doi.org/doi:10.3390/insects11110813

Dahal, B. R., Rijal, S., Poudel, N., Gautam, B., & Neupane, R. B. (2020). Influence of different bio-pesticides and mulching in management of Okra Jassids *Amrasca biguttula* (Hemiptera: Cicadellidae) in Chitwan district of Nepal. *Cogent Food and Agriculture*, 6(1). https://doi.org/10.1080/23311932.2020.1829271

Dawkar, V. V., Chikate, Y. R., Lomate, P. R., Dholakia, B. B., Gupta, V. S., & Giri, A. P. (2013). Molecular insights into resistance mechanisms of lepidopteran insect pests against toxicants. *Journal of Proteome Research*, 12(11), 4727–4737. https://doi.org/10.1021/pr400642p

Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y., Corniani, N., Early, R., Godwin, J., Gomez, J., Moreno, P. G., Murphy, S. T., Oppong-Mensah, B., Phiri, N., Pratt, C., Silvestri, S., & Witt, A. (2017). Fall armyworm: Impacts and implications for Africa. *Outlooks on Pest Management*, 28(5), 196–201. https://doi.org/10.1564/v28_oct_02

de Andrade, P. B., Freitas, B. M., de Macêdo Rocha, E. E., de Lima, J. A., & Rufino, L. L. (2014). Floral biology floral and pollination reqirements of sesame (*Sesamum indicum* L.). *Acta Scientiarum - Animal Sciences*, 36(1), 93–99. https://doi.org/10.4025/actascianimsci.v36i1.21838

Deer, H. (2004). Pesticide Adsorption and Half-Life. *Utah State University Extension*, 10(15), 99–100. https://extension.usu.edu/waterquality/files-ou/Agriculture-and-Water-Quality/Pest/FactSheet151.pdf

Devillers, J., & Devillers, H. (2020). Lethal and sublethal effects of pyriproxyfen on apis and non-apis bees. *Toxics*, 8(4), 1–21. https://doi.org/10.3390/toxics8040104

Diana, M. P., Roekmijati, W. S., & Suyud, W. U. (2018). Why it is often underestimated: Historical Study of Ammonia Gas Exposure Impacts towards Human Health. *E3S Web of Conferences*, 73. https://doi.org/10.1051/e3sconf/20187306003

Dias, A. C. A., Rodrigues, M. M. S., & Silva, A. A. (2019). Effect of acute and chronic exposure to ammonia on different larval instars of *Anopheles darlingi* (Diptera: Culicidae). *Journal of Vector Ecology*, 44(1), 112–118. https://doi.org/10.1111/jvec.12335

Dilipsundar, N., Chitra, N., & Gowtham, V. (2019). Checklist of insect pests of sesame. *Indian Journal of Entomology*, 8*1*(4), 928. https://doi.org/10.5958/0974-8172.2019.00141.x

Dossa, K., Konteye, M., Niang, M., Doumbia, Y., & Cissé, N. (2017). Enhancing sesame production in West Africa's Sahel: A comprehensive insight into the cultivation of this untapped crop in Senegal and Mali. *Agriculture and Food Security*, 6(1), 1–15. https://doi.org/10.1186/s40066-017-0143-3

Du Plessis, H., Schlemmer, M. L., & Van den Berg, J. (2020). The effect of temperature on the development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Insects MDPI*, 11(4), 228. https://doi.org/10.3390/insects11040228

Durán-Lara, E. F., Valderrama, A., & Marican, A. (2020). Natural organic compounds for application in organic farming. *Agriculture (Switzerland)*, 10(2), 1–22. https://doi.org/10.3390/agriculture10020041

Dwyer, G., Dushoff, J., & Yee, S. K. (2004). The combined effects of pathogens and predators on insect outbreaks. *Nature*, 430(6997), 341–345. https://doi.org/10.1038/nature02569

Dzenda, T., Ayo, J. O., Adelaiye, A. B., & Adaudi, A. O. (2008). Ethnomedical and veterinary uses of *Tephrosia vogelii* Hook F (Fabaceae): A review. In *Australian Journal of Medical Herbalism* (Vol. 20, Issue 2, pp. 71–80).

Ebert, T. A., & Cartwright, B. (1997). Biology and ecology of *Aphis gossypii* glover (Homoptera: Aphididae). *Southwestern Entomologist*, 22(1), 116.

Egonyu, J. P., Kyamanywa, S., Anyanga, W., & Ssekabembe, C. K. (2005). Review of pests and diseases of sesame in Uganda. *African Crop Science Conference Proceeding*, 7(1023-070X/2005 $ 4.00), 1411–1416.

Ekanem, A. P., Meinelt, T., Kloas, W., & Knopf, K. (2004). Early life stage toxicity of extracts from the African fish poison plants *Tephrosia vogelii* Hook. f. and *Asystasia vogeliana* Benth. on zebrafish embryos. *Journal of Fish Biology*, 65(2), 489–494. https://doi.org/10.1111/j.1095-8649.2004.00464.x

Ene, L., Okechukwu, M. N., Sambo, B., & Mbuya, S. (2010). Effects of fish bean (*Tephrosia vogelii*) leave extract exposed to freshwater Cichlid fish – *Tilapia zilli*. *Animal Research International*, 7(3), 1236–1241.

Epa, U. S., & Programs, P. (2004). *Ammonium Bicarbonate ( 073401 ) Fact sheet*. *073401*, 70051–70096.

FAO. (2012). Using Urine and Ash To Control Crop Pests and Diseases. *Food and Agriculture Organization of United Nations*, 1, 4–8.

Fasulo, T. R., & Denmark, H. A. (2012). Twospotted Spider Mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). *SpringerReference*, 1–5. https://doi.org/10.1007/springer reference_87762

Federici, B. A. (2013). Overview of the Basic Biology of *Bacillus thuringiensis* with Emphasis on Genetic Engineering of Bacterial Larvicides for Mosquito Control. *The Open Toxinology Journal*, 3(1), 83–100. https://doi.org/10.2174/1875414701003010083

Fernandes, F. S., Godoy, W. A. C., Ramalho, F. D. S., Malaquias, J. B., & Santos, B. D. B. (2018). The behavior of *Aphis gossypii* and *Aphis craccivora* (Hemiptera: Aphididae) and of their predator *Cycloneda sanguinea* (coleoptera: Coccinellidae) in cotton-cowpea intercropping systems. *Anais Da Academia Brasileira de Ciencias*, 90(1), 373–383. https://doi.org/10.1590/0001-3765201820160212

Feyera Takela Degafa. (2021). Review on Sesame (*Sesamum indicum* L.) Breeding in Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 9(17), 39–45. https://doi.org/10.7176/ JBAH

Fiorenzano, J. M., Koehler, P. G., & Xue, R. De. (2017). Attractive toxic sugar bait (ATSB) for control of mosquitoes and its impact on non-target organisms: A review. *International Journal of Environmental Research and Public Health*, 14(4). https://doi.org/10.3390/ ijerph14040398

Fohouo, F. T. (2018). Pollination Efficiency of *Apis mellifera* L. (Hymenoptera: Apidae) on Flowers of *Sesamum indicum* L. (Pedaliaceae) at Bilone (Obala, Cameroon). *International Journal of Research Studies in Agricultural Sciences*, 4(3), 12–20. https://doi.org/10. 20431/2454-6224.0403003

Gangwar, R., & Gangwar, C. (2018). Lifecycle, Distribution, Nature of Damage and Economic Importance of Whitefly, *Bemisia tabaci* (Gennadius). *Acta Scientific Agriculture*, 2(4), 36–39.

García-Marí, F., & González-Zamora, J. E. (1999). Biological control of *Tetranychus urticae* (Acari: Tetranychidae) with naturally occurring predators in strawberry plantings in Valencia, Spain. *Experimental and Applied Acarology*, 23(6), 487–495. https://doi.org/10.1023/A:1006191519560

Gebregergis, Z., Assefa, D., & Fitwy, I. (2016a). Assessment of Incidence of Sesame Webworm *Antigastra catalaunalis* (Duponchel) in Western Tigray, North Ethiopia. *Journal of Agriculture and Ecology Research International*, 9(4), 1–9. https://doi.org/10.9734/jaeri/2016/28483

Gebregergis, Z., Assefa, D., & Fitwy, I. (2016b). Insecticide Application Schedule to Control Sesame Webworm *Antigastra catalaunalis* (Duponchel) Humera, North Ethiopia. *Journal of Applied Life Sciences International*, 8(4), 1–8. https://doi.org/10.9734/jalsi/2016/28620

Gebregergis, Z., Assefa, D., & Fitwy, I. (2018). Sesame sowing date and insecticide application frequency to control sesame webworm *Antigastra catalaunalis* (Duponchel) in Humera, Northern Ethiopia. *Agriculture and Food Security*, 7(1), 1–9. https://doi.org/10.1186/s40066-018-0190-4

Gerberding, J. L. (2004). Toxicological Profile for Ammonia. In *Federal Register*, 15–16. http://www.atsdr.cdc.gov/toxprofiles/tp126.pdf

Geremedhin, Z., & Azerefegne, F. (2020). Infestation and Yield Losses Due to Sesame Webworm (*Antigastra catalaunalis*, (Duponchel) on Different Sesame Varieties in Western Tigray, Northern Ethiopia. *Journal of Agriculture and Ecology Research International*, 21(3), 25–33. https://doi.org/10.9734/jaeri/2020/v21i330134

Glare, T., Caradus, J., Gelernter, W., Jackson, T., & Keyhani, N. (2012). Have biopesticides come of age? *Trends in Biotechnology*, 949(0167-7799/$), 1–9. https://doi.org/10.1016/j.tibtech.2012.01.003

Golden, M. (2011). *Chemicals and Application of the Proposed Action Specialist Report East Fork Boulder Creek Native Trout Restoration Project*. 1–62. https://www.fs.usda.gov/Internet/FSE_Documents/stelprdb5325948.pdf

Gong, X., Wang, H., Yang, C., Li, Q., Chen, X., & Hu, J. (2015). Photocatalytic degradation of high ammonia concentration waste water by $TiO_2$. *Future Cities and Environment*, 1(0), 12. https://doi.org/10.1186/s40984-015-0012-9

Gu, H., Fitt, G. P., & Baker, G. H. (2007). Invertebrate pests of canola and their management in Australia: A review. *Australian Journal of Entomology*, 46(3), 231–243. https://doi.org/10.1111/j.1440-6055.2007.00594.x

Hakeem, K. R., Akhtar, M. S., & Abdullah, Siti, N. A. (2016). Plant, soil and microbes: Volume 1: Implications in crop science. *Springer International Publishing Switzerland*, 1–366. https://doi.org/10.1007/978-3-319-27455-3

Hakim, A. S., Soomro, F., Kousar, T., & Shah, Z. H. (2018). Population management of cotton Jassid, *Amrasca biguttula* Ishida through its biological control agent, *Arescon enocki* (Rao and Kaur) under field and laboratory conditions. *International Journal of Biosciences (IJB),* 13(2), 210–216. https://doi.org/10.12692/ijb/13.2.210-216

Halder, J., Divekar, P. A., & Rani, A. T. (2021). Compatibility of entomopathogenic fungi and botanicals against sucking pests of okra: an ecofriendly approach. *Egyptian Journal of Biological Pest Control*, 31(1). https://doi.org/10.1186/s41938-021-00378-6

Heckel, D. G. (2020). How do toxins from *Bacillus thuringiensis* kill insects? An evolutionary perspective. *Archives of Insect Biochemistry and Physiology*, 104(2), 1–12. https://doi.org/10.1002/arch.21673

Hegde, M., Oliveira, J. N., da Costa, J. G., Bleicher, E., Santana, A. E. G., Bruce, T. J. A., Caulfield, J., Dewhirst, S. Y., Woodcock, C. M., Pickett, J. A., & Birkett, M. A. (2011). Identification of Semiochemicals Released by Cotton, *Gossypium hirsutum*, Upon Infestation by the Cotton Aphid, *Aphis gossypii*. *Journal of Chemical Ecology*, 37(7), 741–750. https://doi.org/10.1007/s10886-011-9980-x

Hernández-Rosas, F., Figueroa-Rodríguez, K. A., García-Pacheco, L. A., Velasco-Velasco, J., & Sangerman-Jarquín, D. M. (2020). Microorganisms and biological pest control: An analysis based on a bibliometric review. *Agronomy*, 10(11), 1–14. https://doi.org/10.3390/agronomy10111808

Hiebert, N., Kessel, T., Skaljac, M., Spohn, M., Vilcinskas, A., & Lee, K. Z. (2020). The gram-positive bacterium *Leuconostoc pseudomesenteroides* shows insecticidal activity against drosophilid and aphid pests. *Insects-MDPI*, 11(8), 1–15. https://doi.org/10.3390/insects11080471

Hikal, W. M., Baeshen, R. S., & Ahl, H. A. H. S. (2017). Botanical insecticide as simple extractives for pest control. *Cogent Biology*, 35(1), 1–16. https://doi.org/10.1080/23312025.2017.1404274

Hilje, L., Costa, H. S., & Stansly, P. A. (2001). Cultural practices for managing *Bemisia tabaci* and associated viral diseases. *Crop Protection*, 20(9), 801–812. https://doi.org/10.1016/S0261-2194(01)00112-0

Hopper, S., & McSherry, B. (2001). The insanity defence and international human rights obligations. *Psychiatry, Psychology and Law*, 8(2), 161–173. https://doi.org/10.1080/13218710109525016

Horowitz, A. R., Ghanim, M., Roditakis, E., Nauen, R., & Ishaaya, I. (2020). Insecticide resistance and its management in *Bemisia tabaci* species. *Journal of Pest Science*, 93(3), 893–910. https://doi.org/10.1007/s10340-020-01210-0

Hubbard, M., Hynes, R. K., Erlandson, M., & Bailey, K. L. (2014). The biochemistry behind biopesticide efficacy. *Sustainable Chemical Processes*, 2(1), 1–8. https://doi.org/10.1186/s40508-014-0018-x

Hvězdová, M., Kosubová, P., Košíková, M., Scherr, K. E., Šimek, Z., Brodský, L., Šudoma, M., Škulcová, L., Sáňka, M., Svobodová, M., Krkošková, L., Vašíčková, J., Neuwirthová, N., Bielská, L., & Hofman, J. (2018). Currently and recently used pesticides in Central European arable soils. *Science of the Total Environment*, 613–614, 361–370. https://doi.org/10.1016/j.scitotenv.2017.09.049

Inbar, M., & Gerling, D. (2008). Plant-mediated interactions between whiteflies, herbivores, and natural enemies. *Annual Review of Entomology*, 53, 431–448. https://doi.org/10.1146/annurev.ento.53.032107.122456

Indabo, S. S. (2020). *Effect of Rabbit Urine Application Rate as a Bio- Fertilizer on Agro-Mophorlogical Traits Of UC82B Tomato ( Lycopersicon Esculentum Mill ) Variety in Zaria, Nigeria*. 0–9.

Iram, A., Khan, J., Aslam, N., Ehsan-ul-Haq, Javed, H. I., Irfan, M., Rasool, A., Mastoi, M. I., & Aslam, S. (2014). Efficacy of plant derived oils and extracts against white- fly, *Bemisia tabaci* (Gennadius) on sesame crop. *Pakistan Journal of Agricultural Research*, 27(3), 250–255.

Isman, M. B. (2006). Botanical Insecticides, Deterrents, and Repellents in Modern Agriculture and Increasingly Regulated World. *Annual Review of Entomology*, 45–66. https://doi.org/10.1146/annurev.ento.51.110104.151146

Jayaraj, R., Megha, P., & Sreedev, P. (2016). Organochlorine pesticides , their toxic effects on living organisms and their fate in the environment. *Interdisciplinary Toxicology*, 9(3–4), 90–100. https://doi.org/10.1515/intox-2016-0012

Joarder, J., Abul, M., Khan, M., & Das, G. (2021). Efficacy of chitin synthesis inhibitors in arresting growth and development of okra jassid, *Amrasca biguttula* (Ishida). *Sustainability in Food and Agriculture*, 2(2), 64–68. https://doi.org/10.26480/sfna.02.2021.

Jonsson, M., Bommarco, R., Ekbom, B., Smith, H. G., Bengtsson, J., Caballero-Lopez, B., Winqvist, C., & Olsson, O. (2014). Ecological production functions for biological control services in agricultural landscapes. *Methods in Ecology and Evolution*, 5(3), 243–252. https://doi.org/10.1111/2041-210X.12149

Juliansyah Noor. (2019). Bio Pesticides : An Insecticide from Plant Derivatives. *Journal of Chemical Information and Modeling*, 53(9), 1689–1699.

Kalyabina, V. P., Esimbekova, E. N., Kopylova, K. V., & Kratasyuk, V. A. (2021). Pesticides: formulants, distribution pathways and effects on human health: A review. *Toxicology Reports*, 8, 1179–1192. https://doi.org/10.1016/j.toxrep.2021.06.004

Kamel, S. M., Blal, A. E. H., Mahfouz, H. M., & Said, M. (2013). The most common insect pollinator species on sesame crop (*Sesamum Indicum* L.) in Ismailia Governorate, Egypt. *Cercetari Agronomice in Moldova*, 2(2), 66–74. https://doi.org/10.2478/v10298-012-0083-9

Kang, H. Y., Othman, Z. S., & Zubairi, S. I. (2016). Accumulation of Biopesticide-Based Rotenone from an Optimized [BMIM][OTf] Green Binary Solvent Mixture in Different Parts of Terong Plant (*Solanum melongena*). *Procedia Engineering*, 148, 702–709. https://doi.org/10.1016/j.proeng.2016.06.578

Kapeleka, J. A., Sauli, E., Sadik, O., & Ndakidemi, P. A. (2019). Biomonitoring of Acetylcholinesterase (AChE) Activity among Smallholder Horticultural Farmers Occupationally Exposed to Mixtures of Pesticides in Tanzania. *Journal of Environmental and Public Health*, 2019. https://doi.org/10.1155/2019/3084501

Kareru, P., Kipkorir, Z., & Wamaitha, E. (2013). Use of Botanicals and Safer Insecticides Designed in Controlling Insects: The African Case. In *Insecticides Development of Safer and More Effective Technologies*. https://doi.org/10.5772/53924

Karuppaiah, V. (2014). Eco-friendly Management of Leaf Webber and Capsule Borer (*Antigastra catalaunalis* Duponchel) Menace in Sesame. *Popular Kheti*, 2(2), 162–163.

Kayange, C. D. M., Njera, D., Nyirenda, S. P., & Mwamlima, L. (2019). Effectiveness of *Tephrosia vogelii* and *Tephrosia candida* Extracts against Common Bean Aphid (*Aphis fabae*) in Malawi. *Advances in Agriculture*, 2019. https://doi.org/10.1155/2019/6704834

Koleva, G. L., Mitrev, S., Maksimova, V., & Spasov, D. (2013). Content pf capsaicin extracted from hot pepper (*Capsicum annum* L.) and its use as an ecopesticide. *Hemijska Industrija*, 67(4), 671–675. https://doi.org/10.2298/HEMIND120921110K

Koona, P., & Dorn, S. (2005). Extracts from *Tephrosia vogelii* for the protection of stored legume seeds against damage by three bruchid species. *Annals of Applied Biology*, 147, 43–48. https://doi.org/10.1111/j.1744-7348.2005.00006.x

Korlapati, S., Sushil, S. N., & Jeyakumar, P. (2014). *AESA based IPM package for Sesame*.

Kuepper, B. G. (2015). Flea Beetle : Organic Control Options. *ATTRA Sustainable Agriculture*, 1–4.

Kumar, J., Ramlal, A., Mallick, D., & Mishra, V. (2021). An overview of some biopesticides and their importance in plant protection for commercial acceptance. *Plants*, 10(6), 1–15. https://doi.org/10.3390/plants10061185

Lekamoi, U., Paul, K., & Mbega, E. R. (2022). Importance of bio-pesticides formulations in managing insect pests of sesame in Africa Importance of bio-pesticides formulations in managing insect pests of sesame in Africa. *International Journal of Biosciences*, 20(2220–6655), 342–367. https://doi.org/http://dx.doi.org/10.12692/ijb/20.2.342-367

Leng, P., Zhang, Z., Pan, G., & Zhao, M. (2011). Applications and development trends in biopesticides. *African Journal of Biotechnology*, 10(86), 19864–19873. https://doi.org/10.5897/AJBX11.009

Lengai, G. M. W., 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. https://doi.org/10.1016/j.sciaf.2019.e00239

Leoni, B., Patelli, M., Soler, V., & Nava, V. (2018). Ammonium transformation in 14 lakes along a trophic gradient. *Water- MDPI*, 10(3), 2–13. https://doi.org/10.3390/w10030265

Lin, C.Y., Wu, D.C., Yu, J.Z., Chen, B.H., Wang, C.L., & Ko, W.H. (2009). Control of silverleaf whitefly, cotton aphid and kanzawa spider mite with oil and extracts from seeds of sugar apple. *Neotropical Entomology*, 38(4), 531–536. https://doi.org/10.1590/s1519-566x2009000400016

Liu, T., & Sparks, A. N. (2001). Aphids on Cruciferous Crops: Identification and Management. *AgriLife Extension*, 7(1), 1–12. http://galveston.agrilife.org/files/2012/03/Aphids-on-Cruciferous-Crops-Publ.-B-6109.pdf

Lundin, O., Rundlöf, M., Smith, H. G., Fries, I., & Bommarco, R. (2015). Neonicotinoid insecticides and their impacts on bees: A systematic review of research approaches and identification of knowledge gaps. *PLoS ONE*, 10(8), 1–20. https://doi.org/10.1371/journal.pone.0136928

Ma, M., Liu, X., Zhang, W., Zhao, Z., Cai, N., Ma, A., & Chen, M. (2006). Assessment of cotton aphids, *Aphis gossypii*, and their natural enemies on aphid-resistant and aphid-susceptible wheat varieties in a wheat-cotton relay intercropping system. *Entomologia Experimentalis et Applicata*, 121(3), 235–241. https://doi.org/10.1111/j.1570-8703.2006.00484.x

Mahfouz, H., Said, M., Kamel, S., & Blal, A. (2013). Insect pollinator species of sesame crop (*Sesamum indicum* L.) in Ismailia, Egypt. *Insects MDPI*, 2(2), 66–74.

Mahmoud, F. (2012a). Insects associated with sesame (*Sesamun indicum* L.) and the impact of insect pollinators on crop production. *Journal of Pesticide Phytomedicine*, 27(2), 117–129. https://doi.org/10.2298/pif1202117m

Mahmoud, F. (2012b). Insects associated with sesame (*Sesamun indicum* L.) and the impact of insect pollinators on crop production. *Pesticidi i Fitomedicina*, 27(2), 117–129. https://doi.org/10.2298/pif1202117m

Mamuye, M., Nebiyu, A., Elias, E., & Berecha, G. (2020). Short-term improved fallows of *Tephrosia vogelii* and *Cajanus cajan* enhanced maize productivity and soil chemical properties of a degraded fallow land in Southwestern Ethiopia. *Agroforestry Systems*, 94(5), 1681–1691. https://doi.org/10.1007/s10457-020-00485-7

Manonmani, P., Rathi, G., & Ilango, S. (2018). Toxicity Effect of *Cymbopogon Citratus* (Lemon Grass) Powder and Methanol Extract Against Rust-Red Flour Beetle , T*ribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). *International Journal of Applied and Advanced Scientific Research*, 3(1), 70–77.

Mansour, R., Belzunces, L. P., Suma, P., Zappalà, L., Mazzeo, G., Grissa-Lebdi, K., Russo, A., & Biondi, A. (2018). Vine and citrus mealybug pest control based on synthetic chemicals. A review. *Agronomy for Sustainable Development*, 38(4). https://doi.org/10.1007/s13593-018-0513-7

Mardones, A., Vega, R., Augsburger, A., & Encina, F. (2019). Determination of acute toxicity of ammonium in juvenile Patagonian blenny (*Eleginops maclovinus*). *Brazilian Journal of Biology*, 79(4), 646–650.

Mathew, T., Pownraj, P., Abdulla, S., & Pullithadathil, B. (2015). Technologies for Clinical Diagnosis Using Expired Human Breath Analysis. In *Diagnostics-MDPI* (Vol. 5, Issue 1). https://doi.org/10.3390/diagnostics5010027

Mayoori, K., & Mikunthan, G. (2009). Damage Pattern of Cabbage Flea Beetle, *Phyllotreta cruciferae* (Goeze) (Coleóptera: Chrysomelidae) and its Associated Hosts of Crops and Weeds Promotion of Medicinal plants cultivation View project. *American-Eurasian Journal of Agricultural and Environmental Science*, 6(3), 303–307. https://www.researchgate.net/publication/224861998

Menz, M. H. M., Phillips, R. D., Winfree, R., Kremen, C., Aizen, M. A., Johnson, S. D., & Dixon, K. W. (2011). Reconnecting plants and pollinators: challenges in the restoration of pollination mutualisms. *Trends in Plant Science*, 16(1), 4–12. https://doi.org/10.1016/j.tplants.2010.09.006

Mkamilo, G. S. (2004). *Maize-sesame intercropping in Southeast Tanzania Farmers ' practices and perceptions , and intercrop performance*.

Mkenda, P., Mwanauta, R., Stevenson, P. C., Ndakidemi, P., Mtei, K., & Belmain, S. R. (2015). Extracts from field margin weeds provide economically viable and environmentally benign pest control compared to synthetic pesticides. *PLoS ONE*, 10(11). https://doi.org/10.1371/journal.pone.0143530

Mkindi, A. G., Tembo, Y. L. B., Mbega, E. R., Smith, A. K., Farrell, I. W., Ndakidemi, P. A., Stevenson, P. C., & Belmain, S. R. (2020). Extracts of Common Pesticidal Plants Increase Plant Growth and Yield in Common Bean Plants. *Plants-MDPI*, 1–11.

Mondal, E., & Chakraborty, K. (2016). *Azadirachta indica* - A tree with multifaceted applications: An overview. *Journal of Pharmaceutical Sciences and Research*, 8(5), 299–306.

Mondédji, A. D., Silvie, P., Nyamador, W. S., Martin, P., Agboyi, L. K., Amévoin, K., Ketoh, G. K., & Glitho, I. A. (2021). Cabbage production in West Africa and ipm with a focus on plant-based extracts and a complementary worldwide vision. *Plants-MDPI*, 10(3), 1–36. https://doi.org/10.3390/plants10030529

Montezano, D. G., Specht, A., Sosa-Gómez, D. R., Roque-Specht, V. F., Sousa-Silva, J. C., Paula-Moraes, S. V., Peterson, J. A., & Hunt, T. E. (2018). Host Plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. *African Entomology*, 26(2), 286–300. https://doi.org/10.4001/003.026.0286

Moustafa-Farag, M., Almoneafy, A., Mahmoud, A., Elkelish, A., Arnao, M. B., Li, L., & Ai, S. (2020). Melatonin and its protective role against biotic stress impacts on plants. *Biomolecules*, 10(1), 1–12. https://doi.org/10.3390/biom10010054

Mpumi, N., Machunda, R. S., Mtei, K. M., & Ndakidemi, P. A. (2020). Selected insect pests of economic importance to *Brassica oleracea*, their control strategies and the potential threat to environmental pollution in Africa. *Sustainability (Switzerland)*, 12(9). https://doi.org/10.3390/su12093824

Mpumi, N., Mtei, K. M., MacHunda, R. L., & Ndakidemi, P. A. (2021). Efficacy of Aqueous Extracts from *Syzygium aromaticum*, *Tephrosia vogelii*, and *Croton dichogamus* against *Myzus persicae* on *Brassica oleracea* in Northern Tanzania. *Psyche: Journal of Entomology*, 2021. https://doi.org/10.1155/2021/2525328

Mpumi, N., Mtei, K., Machunda, R., & Ndakidemi, P. A. (2016). The Toxicity, Persistence and Mode of Actions of Selected Botanical Pesticides in Africa against Insect Pests in Common Beans, *P. vulgaris*: A Review. *American Journal of Plant Sciences*, 07(01), 138–151. https://doi.org/10.4236/ajps.2016.71015

Mudzingwa, S., Muzemu, S., & Chitamba, J. (2013). Pesticidal efficacy of crude aqueous extracts of *Tephrosia vogelii* L., *Allium sativum* L. and *Solanum incanum* L. in controlling aphids (*Brevicoryne brassicae* L.) in rape (*Brassica napus* L.). *Journal of Research in Agriculture*, 2(1), 6–10. http://ficuspublishers.com/Documents/AG0002.pdf

Muhammad, A., & Kashere, M. A. (2020). Neem, *Azadirachta indica* L. (A. Juss):An Eco-friendly Botanical Insecticide For Managing Farmers' Insect Pest Problems. *FUDMA Journal of Sciences*, 4(51775071), 484–491. https://doi.org/doi:: https://doi.org/10.33003/fjs-2020-0404-506

Murugesan, S., & Venkatesan, S. (2016). Sesame webworm, *Antigastra catalaunalis* duponchel (Crambidae : Lepidoptera) survives on a new alternate host in Southern India. *International Journal of Entomology Research*, 1(7), 46–48.

Mutai, P. A. (2020). The Potential Use of Rabbit Urine as a Bio-fertilizer Foliar Feed in Crop Production. *Africa Environmental Review Journal*, 4(1), 137-144. http://www.aer-journal.info/index.php/journals/article/view/112

Muzemu, S., Mvumi, B. M., Nyirenda, S. P., Sileshi, G., Sola, P., Kamanula, J., & Belmain, S. R. (2011). Pesticidal effects of indigenous plants extracts against rape aphids and tomato red spider mites. *African Crop Science Conference Proceeding*, 10, 169–171.

Mwaura, S., Ofori, A., & Jamnadas.S. (2012). Pesticidal Plant Leaflet *Tephrosia vogelii* Hook. f. *Plant Leaflets*, 23–24.

Nakasu, E.Y.T., Williamson, S.M., & Edwards, M.G. (2014). Biopesticide based on a spider venom peptide shows no adverse effects on honeybees. *Proceedings of the Royal Society B: Biological Sciences*, 281(201), 40619. https://doi.org/10.1098/rspb.2014.06

Ndakidemi, B. J., Mbega, E. R., Ndakidemi, P. A., Stevenson, P. C., Belmain, S. R., Arnold, S. E. J., & Woolley, V. C. (2021). Natural pest regulation and its compatibility with other crop protection practices in smallholder bean farming systems. *Biology*, 10(8), 1–21. https://doi.org/10.3390/biology10080805

Nicholls, C. I., & Altieri, M. A. (2013). Plant biodiversity enhances bees and other insect pollinators in agroecosystems. A review. *Agronomy for Sustainable Development*, 33(2), 257–274. https://doi.org/10.1007/s13593-012-0092-y

Oerke, E. C. (2006). Crop losses to pests. *Journal of Agricultural Science*, 144(1), 31–43. https://doi.org/10.1017/S0021859605005708

Ojo, J. A., Olunloyo, A. A., & Ibitoye, O. (2014). Evaluation of botanical insecticides against flea beetles *Podagrica sjostedti* and *Podagrica uniforma* of okra. *International Journal of Advanced Research*, 2(4), 236–244. http://www.journalijar.com/uploads/457_IJAR-2447.pdf

Özkara, A., Akyil, D., & Konuk, M. (2016). Pesticides, Environmental Pollution, and Health. In *Environmental Health Risk - Hazardous Factors to Living Species*, 3–28. https://doi.org/10.5772/63094

Patole, D. S. S. (2017). Review on Beetles (Coleopteran): An Agricultural Major Crop Pests of the World. *International Journal of Life-Sciences Scientific Research*, 3(6), 1424–1432. https://doi.org/10.21276/ijlssr.2017.3.6.1

Patra, S., Das, B. C., Sarkar, S., & Samanta, A. (2016). Efficacy of newer insecticides against major lepidopteran pests of *Sesamum indicum*. *Research on Crops*, 17(1), 144–150. https://doi.org/10.5958/2348-7542.2016.00026.7

Pérez-Lucas, G., Vela, N., El Aatik, A., & Navarro, S. (2019). Environmental Risk of Groundwater Pollution by Pesticide Leaching through the Soil Profile (Pesticides - Use and Misuse and Their Impact in the Environment). In *Intechopen*, 1–27. https://doi.org/10.5772/intechopen.82418

Perring, T. M., Stansly, P. A., Liu, T. X., Smith, H. A., & Andreason, S. A. (2018). Whiteflies: Biology, Ecology, and Management. In *Sustainable Management of Arthropod Pests of Tomato*, 73–110. https://doi.org/10.1016/B978-0-12-802441-6.00004-8

Phambala, K., Tembo, Y., Kasambala, T., Kabambe, V. H., Stevenson, P. C., & Belmain, S. R. (2020). Bioactivity of common pesticidal plants on fall Armyworm Larvae (*Spodoptera frugiperda*). *Plants-MDPI*, 9(1), 1–10. https://doi.org/10.3390/plants9010112

Phoofolo, P. (2013). Laboratory assessment of insecticidal properties of *Tagetes minuta* crude extracts against *Brevicoryne brassicae* on cabbage. *Journal of Entomology and Nematology*, 5(6), 70–76. https://doi.org/10.5897/jen2013.0080

Prasad, N. M., Sanjay K.R, Prasad, D. S., Vijay, N., Kothari, R., & S, N. S. (2012). A Review on Nutritional and Nutraceutical Properties of Sesame. *Journal of Nutrition & Food Sciences*, 02(02). https://doi.org/10.4172/2155-9600.1000127

Prince, G., & Chandler, D. (2020). Susceptibity of *Myzus persicae*, *Brevicoryne brassicae* and *Nasonovia ribisnigri* to Fungal Biopesticides in Laboratory and Field Experiments. *Insects-MDPI*, 12–14.

Province, S., Kemtsop, G. A., & Starkey, P. (2007). *A rapid assessment of rural transport services in Singida Region, Tanzania*.

Purru, S., Sahu, S., Rai, S., & Bhat, A. R. R. K. V. (2018). GinMicrosatDb : A genome-wide microsatellite markers database for sesame (*Sesamum indicum* L.). *Physiology and Molecular Biology of Plants*. https://doi.org/10.1007/s12298-018-0558-8

Qiu, Y. T., van Lenteren, J. C., Drost, Y. C., & Posthuma-Doodeman, C. J. A. M. (2004). Life-history parameters of *Encarsia formosa*, *Eretmocerus eremicus,* and *E. mundus*, aphelinid parasitoids of *Bemisia argentifolii* (Hemiptera: Aleyrodidae). *European Journal of Entomology*, 101(1), 83–94. https://doi.org/10.14411/eje.2004.017

Radad, K., Al-Shraim, M., Al-Emam, A., Wang, F., Kranner, B., Rausch, W. D., & Moldzio, R. (2019). Rotenone: From modelling to implication in Parkinson's disease. *Folia Neuropathologica*, 57(4), 317–326. https://doi.org/10.5114/fn.2019.89857

Rahayu, M., Purwanto, E., Setyawati, A., Sakya, A. T., Samanhudi, Yunus, A., Purnomo, D., Handoyo, G. C., Arniputri, R. B., & Na'imah, S. (2021). Growth and yield response of local soya bean in the giving of various organic fertilizer. *IOP Conference Series: Earth and Environmental Science*, 905(1), 012028. https://doi.org/10.1088/1755-1315/905/1/012028

Rakesh, K. (2012). Incidence of *Antigastra catalaunalis*, Dup. in Different Varieties of Sesame. *Molecular Entomology*, 3(1), 15–17. https://doi.org/10.5376/me.2012.03.0003

Ram, A. A., Baraiya, K. P., & Kotak, J. N. (2020). Efficacy of newer insecticides against sucking pest complex in summer sesame. *Journal of Entomology and Zoology Studies*, 8(3), 1599–1604.

Roda, A., Castillo, J., Allen, C., Urbaneja, A., Pérez-Hedo, M., Weihman, S., & Stansly, P. A. (2020). Biological control potential and drawbacks of three zoophytophagous mirid predators against *Bemisia tabaci* in the United States. *Insects-MDPI*, 11(10), 1–17. https://doi.org/10.3390/insects11100670

Rodger, J. G., Van Kleunen, M., & Johnson, S. D. (2013). Pollinators, mates and Allee effects: The importance of self-pollination for fecundity in an invasive lily. *Functional Ecology*, 27(4), 1023–1033. https://doi.org/10.1111/1365-2435.12093

Rwiza, I. (2017). *Tanzania Experience on FAW & IPM-FAW Project implementation (TARI-Ukiriguru-Mwanza, Tanzania)*.

Sadeghi, A., Van Damme, E. J. M., & Smagghe, G. (2009). Evaluation of the susceptibility of the pea aphid, *Acyrthosiphon pisum*, to a selection of novel biorational insecticides using an artificial diet. *Journal of Insect Science*, 9(65), 1–8. https://doi.org/10.1673/031.009.6501

Sahito, H. A. (2016). Preliminary Studies on Egg Parasitoids of Cotton Jassid *Amrasca biguttula* (Ishida) Preliminary Studies on Egg Parasitoids of Cotton Jassid *Amrasca biguttula* (Ishida). *European Academic Research*, 5(9).

Said, A. H., Solhaug, A., Sandvik, M., Msuya, F. E., Kyewalyanga, M. S., Mmochi, A. J., Lyche, J. L., & Hurem, S. (2020). Isolation of the *Tephrosia vogelii* extract and rotenoids and their toxicity in the RTgill-W1 trout cell line and in zebrafish embryos. *Toxicon*, 183(2020), 51–60. https://doi.org/10.1016/j.toxicon.2020.05.013

Saleem, M. S., Batool, T. S., Akbar, M. F., Raza, S., & Shahzad, S. (2019). Efficiency of botanical pesticides against some pests infesting hydroponic cucumber, cultivated under greenhouse conditions. *Egyptian Journal of Biological Pest Control*, 29(1), 1–7. https://doi.org/10.1186/s41938-019-0138-4

Samada, L. H., & Tambunan, U. S. F. (2020). Biopesticides as promising alternatives to chemical pesticides: A review of their current and future status. *OnLine Journal of Biological Sciences*, 20(2), 66–76. https://doi.org/10.3844/ojbsci.2020.66.76

Sann, M., Niehuis, O., Peters, R. S., Mayer, C., Kozlov, A., Podsiadlowski, L., Bank, S., Meusemann, K., Misof, B., Bleidorn, C., & Ohl, M. (2018). Phylogenomic analysis of Apoidea sheds new light on the sister group of bees. *BMC Evolutionary Biology*, 1–15. https://doi.org/https://doi.org/10.1186/s12862-018-1155-8

Saritha, R. (2020). Bio-efficacy of insecticides for management of sucking pests in sesame. *Journal of Entomology and Zoology Studies*, 8(1), 1072–1076.

Sathe, T. V. (2014). Biodiversity of Jassids From Agroecosystems of Kolhapur District, India. *International Journal of Science*, 3(3), 1053–1058. http://ijset.net/drbsar/1/ijset 35.pdf

Sawe, T., Nielsen, A., & Eldegard, K. (2020). Crop pollination in small-scale agriculture in Tanzania: Household dependence, awareness and conservation. *Sustainability (Switzerland)*, 12(6), 1–13. https://doi.org/10.3390/su12062228

Seffrin, C., Shikano, I., Akhtar, Y., & Isman, M. B. (2010). Effects of crude seed extracts of *Annona atemoya* and *Annona squamosa* L. against the cabbage looper, *Trichoplusia ni* in the laboratory and greenhouse. *Crop Protection*, 29(1), 20–24. https://doi.org/10.1016/j.cropro.2009.09.003

Seide, V. E., Bernardes, R. C., Pereira, E. J. G., & Lima, M. A. P. (2018). Glyphosate is lethal and Cry toxins alter the development of the stingless bee *Melipona quadrifasciata*. *Environmental Pollution*, 243, 1854–1860. https://doi.org/10.1016/j.envpol.2018.10.020

Sesaco. (2008). *Sesame grower guide*.

Shahid, N., Liess, M., & Knillmann, S. (2019). Environmental Stress Increases Synergistic Effects of Pesticide Mixtures on *Daphnia magna*. *Environmental Science and Technology*, 53(21), 12586–12593. https://doi.org/10.1021/acs.est.9b04293

Shakeel, M., & Inayatullah, M. (2014). Impact of Insect Pollinators on the Yield of Canola (*Brassica napus*) in Peshawar, Pakistan. *Journal of Agriculture Urban Entomology*, 29(1-5), 434–446.

Shang, F., Ding, B. Y., Xiong, Y., Dou, W., Wei, D., Jiang, H. B., Wei, D. D., & Wang, J. J. (2016). Differential expression of genes in the alate and apterous morphs of the brown citrus aphid, *Toxoptera citricida*. *Scientific Reports*, 6(32099), 1–12. https://doi.org/10. 1038/srep32099

Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G. P. S., Handa, N., Kohli, S. K., Yadav, P., Bali, A. S., Parihar, R. D., Dar, O. I., Singh, K., Jasrotia, S., Bakshi, P., Ramakrishnan, M., Kumar, S., Bhardwaj, R., & Thukral, A. K. (2019). Worldwide pesticide usage and its impacts on ecosystem. *SN Applied Sciences*, 1(11), 1–16. https://doi.org/10.1007/s42452-019-1485-1

Shivhare, N., & Satsangee, N. (2012). Chemistry of Phytopotentials: Health, Energy and Environmental Perspectives. *Chemistry of Phytopotentials: Health, Energy and Environmental Perspectives*, *August*. https://doi.org/10.1007/978-3-642-23394-4

Simoglou, K. B., Anastasiades, A. I., Baixeras, J., & Roditakis, E. (2017). First report of *Antigastra catalaunalis* on sesame in Greece. *Entomologia Hellenica*, 26(1), 6. https://doi. org/10.12681/eh.14824

Singh, S. N., & Burbade, R. G. (2021). *Drying Characteristics and Development of Easy-To-Cook ( ETC ) Fenugreek (Trigonella foenum-graecum) Leaves*.

Sitarek, P., Merecz-Sadowska, A., Kowalczyk, T., Wieczfinska, J., Zajdel, R., & Śliwiński, T. (2020). Potential synergistic action of bioactive compounds from plant extracts against skin infecting microorganisms. *International Journal of Molecular Sciences*, 21(14), 1–25. https://doi.org/10.3390/ijms21145105

Škaloudová, B., Křivan, V., & Zemek, R. (2006). Computer-assisted estimation of leaf damage caused by spider mites. *Computers and Electronics in Agriculture*, 53(2), 81–91. https://doi.org/10.1016/j.compag.2006.04.002

Smith-vaniz, W. F. (2008). *Rotenone : An Essential but Demonized Tool for Assessing Marine Fish Diversity* (Vol. 58, Issue 2).

Smith, C. J., & Perfetti, T. A. (2020). A comparison of the persistence , toxicity , and exposure to high-volume natural plant-derived and synthetic pesticides. *Toxicology Research and Application*. 4, 1–15. https://doi.org/10. 1177/2397847320940561

Snyder, W. E., Ballard, S. N., Yang, S., Clevenger, G. M., Miller, T. D., Ahn, J. J., Hatten, T. D., & Berryman, A. A. (2004). Complementary biocontrol of aphids by the ladybird beetle *Harmonia axyridis* and the parasitoid *Aphelinus asychis* on greenhouse roses. *Biological Control*, 30(2), 229–235. https://doi.org/10.1016/j.biocontrol.2004.01.012

Soomro, A. S., Wagan, T. A., & Hulio, M. H. (2020). Evaluation of *Chrysoperla carnea* for Population Management of Jassid *Amrasca devastans* in B.t. Cotton Crop. *Advances in Life Science and Technology*, 77, 14–19. https://doi.org/10.7176/alst/77-03

Souto, A. L., Sylvestre, M., Tölke, E. D., Tavares, J. F., Barbosa-Filho, J. M., & Cebrián-Torrejón, G. (2021). Plant-derived pesticides as an alternative to pest management and sustainable agricultural production: Prospects, applications and challenges. *Molecules*, 26(16). https://doi.org/10.3390/molecules26164835

Spence, N. J., Phiri, N. A., Hughes, S. L., Mwaniki, A., Simons, S., Oduor, G., Chacha, D., Kuria, A., Ndirangu, S., Kibata, G. N., & Marris, G. C. (2007). Economic impact of Turnip mosaic virus, Cauliflower mosaic virus and Beet mosaic virus in three Kenyan vegetables. *Plant Pathology*, 56(2), 317–323. https://doi.org/10.1111/j.1365-3059.2006.01498.x

Sponsler, D. B., Grozinger, C. M., Hitaj, C., Rundlöf, M., Botías, C., Code, A., Lonsdorf, E. V, Melathopoulos, A. P., Smith, D. J., Suryanarayanan, S., Thogmartin, W. E., Williams, N. M., Zhang, M., & Douglas, M. R. (2019). Science of the Total Environment Pesticides and pollinators : A socioecological synthesis. *Science of the Total Environment*, 662, 1012–1027. https://doi.org/10.1016/j.scitotenv.2019.01.016

Stavrinides, J., McCloskey, J. K., & Ochman, H. (2009). Pea aphid as both host and vector for the phytopathogenic bacterium *Pseudomonas syringae*. *Applied and Environmental Microbiology*, 75(7), 2230–2235. https://doi.org/10.1128/AEM.02860-08

Stein, K., Coulibaly, D., Stenchly, K., Goetze, D., Porembski, S., Lindner, A., Konaté, S., & Linsenmair, E. K. (2017). Bee pollination increases yield quantity and quality of cash crops in Burkina Faso, West Africa. *Scientific Reports*, 1–10. https://doi.org/10.1038/s41598-017-17970-2

Sukumaran, A., Khanduri, V. P., & Sharma, C. M. (2020). Pollinator-mediated self-pollination and reproductive assurance in an isolated tree of *Magnolia grandiflora* L. *Ecological Processes*, 9(1). https://doi.org/10.1186/s13717-020-00254-5

Suliman, E. N. H., Bashir, N. H. H., Ameen, E., El, M. A., & Asad, Y. O. H. (2013). Biology and Webbing behaviour of Sesame webworm, *Antigastra catalaunalis* Duponchle (Lepidoptera : Pyraustidae). *Global Journal of Medicinal Plant Research*, 1(2), 210–213.

Sultana, R., & Khan, B. (2015). Effect of Botanical Pesyicicides Against Red Spider mite *Tetranychus urticae*. *Pakistan Journal of Entomology*, 30(2), 145–153.

Sultana, R., & Khan, B. (2019). Field Evaluation of Bio-Pesticides Against Jassid, *Amrasca biguttula* (Ishida) in Okra Crop. *Sindh University Research Journal (Science Series)*, 45(2), 311–316.

Sun, M., Voorrips, R. E., Steenhuis-broers, G., Westende, W. Van, & Vosman, B. (2018). Reduced phloem uptake of *Myzus persicae* on an aphid resistant pepper accession. *MBC Plant Biology*, 1–14.

Sunadra, I. K., Luh, N., Sulasmini, K., Agung, A., & Mayun, N. (2019). Response to Growth and Yield Melon Plant (*Cucumis melo* L.) in the Giving of Rabbit Urine and KNO 3. *Sustainable Environment Agricultural Science*, 3(2), 106–112. https://doi.org/10.22225/ seas.3.2.1490.107-112

Syafrudin, M., Kristanti, R. A., Yuniarto, A., Hadibarata, T., & Rhee, J. (2021). Pesticides in Drinking Water-A Review. *International Journal of Environmental Research and Public Health-MDPI*, 18(468). https://doi.org/https://doi.org/10.3390 ijerph18020468 Received:

Tak, J. H., & Isman, M. B. (2017). Penetration-enhancement underlies synergy of plant essential oil terpenoids as insecticides in the cabbage looper, *Trichoplusia ni*. *Scientific Reports*, 7(42432), 1–11. https://doi.org/10.1038/srep42432

Takahashi, K. M., Berti Filho, E., & Lourenção, A. L. (2008). Biology of *Bemisia tabaci* (Genn.) B-biotype and parasitism by *Encarsia formosa* (Gahan) on collard, soya bean and tomato plants. *Scientia Agricola*, 65(6), 639–642. https://doi.org/10.1590/S0103-9016 2008000600011

Tanko, U., & Oluwaseun, S. (2020). Leaf Area Determination for Sesame (*Sesamum indicum*), Wheat (*Triticum aestivuma*), Groundnut (*Arechis hypogaea*) and Bambaranut (*Vigna subterrane*) Crops Using Linear Measurements. *Journal of Biology, Agriculture and Healthcare*, 10(12), 20–26. https://doi.org/10.7176/jbah/10-12-04

Tavares, W. R., Barreto, M. D. C., & Seca, A. M. L. (2021). Aqueous and ethanolic plant extracts as bio-insecticides— establishing a bridge between raw scientific data and practical reality. *Plants-MDPI*, 10(5), 12–29. https://doi.org/10.3390/plants10050920

Tengö, M., & Belfrage, K. (2004). Local Management Practices for Dealing with Change and Uncertainty: A Cross-scale Comparison of Cases in Sweden and Tanzania. *Ecology and Society*, 9(3). https://doi.org/10.5751/es-00672-090304

Thangavel, P., & Sridevi, G. (2015). Environmental sustainability: Role of green technologies. *Environmental Sustainability: Role of Green Technologies*, 1–324. https://doi.org/10.1007/978-81-322-2056-5

Thangjam, R., & Vastrad, A. S. (2018). Studies on pest complex of sesame and their natural enemies in North Karnataka, India. *Journal Of Entomology and Zoology Studies*, 6(6), 57–60.

Tosi, S., & Nieh, J. C. (2019). Lethal and sublethal synergistic effects of a new systemic pesticide, flupyradifurone (Sivanto), on honeybees. *Proceedings of the Royal Society Biological Sciences*, 286(1900). https://doi.org/10.1098/rspb.2019.0433

Tudi, M., Ruan, H. D., Wang, L., Lyu, J., Sadler, R., Connell, D., Chu, C., & Phung, D. T. (2021). Agriculture development, pesticide application and its impact on the environment. *International Journal of Environmental Research and Public Health*, 18(3), 1–24. https://doi.org/10.3390/ijerph18031112

Turner, L., Jacobson, S., & Shoemaker, L. (2007). Risk assessment for pesticidal formulations of rotenone. *Compliance Services International, Lakewood,* 1–140.

Uddin, R. O., & Osagie, E. (2017). Evaluation of Row Intercropping on Insect Pests and Yield of *Sesamum Indicum* in Ilorin. *Albanian Journal of Agricultural Sciences*, 16(1), 14–18.

Ugwu, J. A. (2020). Insecticidal activity of some botanical extracts against legume flower thrips and legume pod borer on cowpea *Vigna unguiculata* L. Walp. *The Journal of Basic and Applied Zoology*, 81(1). https://doi.org/10.1186/s41936-020-00153-3

Umar, A., & Piero, N. M. (2016). Bio Efficacy of Aqueous Crude Fruit Sap Extract of *Solanum incanum* against Green Peach Aphids *Myzus persicae* Sulzer (Homoptera: Aphididae). *Entomology, Ornithology & Herpetology: Current Research*, 5(1), 1–5. https://doi.org/10.4172/2161-0983.1000169

Umina, P. A., Edwards, O., Carson, P., Rooyen, A. V., & Anderson, A. (2014). High levels of resistance to carbamate and pyrethroid chemicals widespread in Australian *Myzus persicae* (Hemiptera: Aphididae) populations. *Journal of Economic Entomology*, 107(4), 1626–1638. https://doi.org/10.1603/EC14063

Urbaneja, A., Sánchez, E., & Stansly, P. A. (2007). Life history of *Eretmocerus mundus,* a parasitoid of *Bemisia tabaci*, on tomato and sweet pepper. *BioControl*, 52(1), 25–39. https://doi.org/10.1007/s10526-006-9014-8

Vašíčková, J., Hvězdová, M., Kosubová, P., & Hofman, J. (2019). Ecological risk assessment of pesticide residues in arable soils of the Czech Republic. *Chemosphere*, 216, 479–487. https://doi.org/10.1016/j.chemosphere.2018.10.158

Waked, D.A., Eleawa, D., & Salama, A. (2016). Using *Pseudomonas fluorescens* as Microbial Biocontrol Agent Against the Spider Mite, *Tetranychus cucurbitacearum* (Sayed)(Acari: Tetranychidae). *Egyptian Journal of Agricultural Research*, 94(3), 625–631. https://doi.org/10.21608/ejar.2016.152670

Wandita, T. G., Darmawan, Setyo Rahmat Triatmojo, S., & Fitriyanto, N. A. (2016). Quality of Liquid Organic Fertilizer from Rabbit Urine with the Addition of Nitrifying Bacteria, Urea, and *Leucaena leucocephala*. *The 17$^{th}$ Asian-Australasian Association of Animal Production Societies Animal Science Congress*, 2017, 679–684.

Wang, K. Y., Guo, Q. L., Xia, X. M., Wang, H. Y., & Liu, T. X. (2007). Resistance of *Aphis gossypii* (Homoptera: Aphididae) to selected insecticides on cotton from five cotton production regions in Shandong, China. *Journal of Pesticide Science*, 32(4), 372–378. https://doi.org/10.1584/jpestics.G06-51

Wang, Y.Q., Wang, R.F., Ma, Q.L., Chen, X.T., Li, Y.M., & Zhang, Z.X. (2019). Analysis on safety assessment of *Tephrosia vogelii* Hook. to *Apis cerana*. *Ecotoxicology and Environmental Safety*, 183(2019), 109468. https://doi.org/10.1016/j.ecoenv.2019.109468

Watson, A. (2011). Pests and Beneficials in Australian Cotton Landscapes. In *The Development and Delivery Team (Cotton Catchment Communities CRC)2011. Reprinted by CottonInfo* 2016. https://doi.org/10.1007/0-306-48380-7_450

Winisia, E. (2020). *Development of bio-pesticide for management of spodoptera frugiperda (j. e. smith) and other lepidoptera pests of maize in Tanzania*.

Xu, D., Huang, Z., Cen, Y. J., Chen, Y., Freed, S., & Hu, X. G. (2009). Antifeedant activities of secondary metabolites from *Ajuga nipponensis* against adult of striped flea beetles, *Phyllotreta striolata*. *Journal of Pest Science*, 82(2), 195–202. https://doi.org/10.1007/s10340-008-0239-4

Yousif, A., Ali, A., Guisheng, Z., Hassan, A., Yagoub, S. O., Farah, G. A., Ahamed, N. E., Ibrahim, A. M., Eldeen, M., Ibrahim, H., Suliman, M., Elradi, S. B., Ibrahim, E. G., & Omer, S. M. (2020). Sesame Seed Yield and Growth Traits Response to Different Row Spacing in Semi-Arid Regions. *Universal Journal of Agricultural Research*, 8(4), 88–96. https://doi.org/10.13189/ujar.2020.080402

Zeit, D. (2021). Susceptibility of several cotton varieties to the cotton flea beetle, *Podagrica puncticollis* Weise (Coleoptera: Chrysomelidae), in a hot dry tropical environment of Ethiopia. *Entomologia Hellenica*, 30(1), 1–19. https://doi.org/https://doi.org/10.12681/eh.23270

Zenawi, E., & Gebremichael, G. (2017). Assessment of *Sesamum indicum* grain storage loss due to Indian Meal Moth, *Plodia interpunctella* (Lepidoptera) for Small Scale-Farmers in Western Zone of Tigray, North Ethiopia. *Academic Journal,* 8(2), 11–15. https://doi.org/10.5897/JSPPR2016.0224

Zhang, P., Qin, D., Chen, J., & Zhang, Z. (2020). Plants in the genus Tephrosia: Valuable resources for botanical insecticides. *Insects-MDPI*, 11(10), 1–18. https://doi.org/10.3390/insects11100721

Zinov’ev, D. V., & Sole, P. (2004). Quaternary codes and biphase sequences from Z8-codes. *Problemy Peredachi Informatsii*, 40(2), 50–62. https://doi.org/10.1023/B

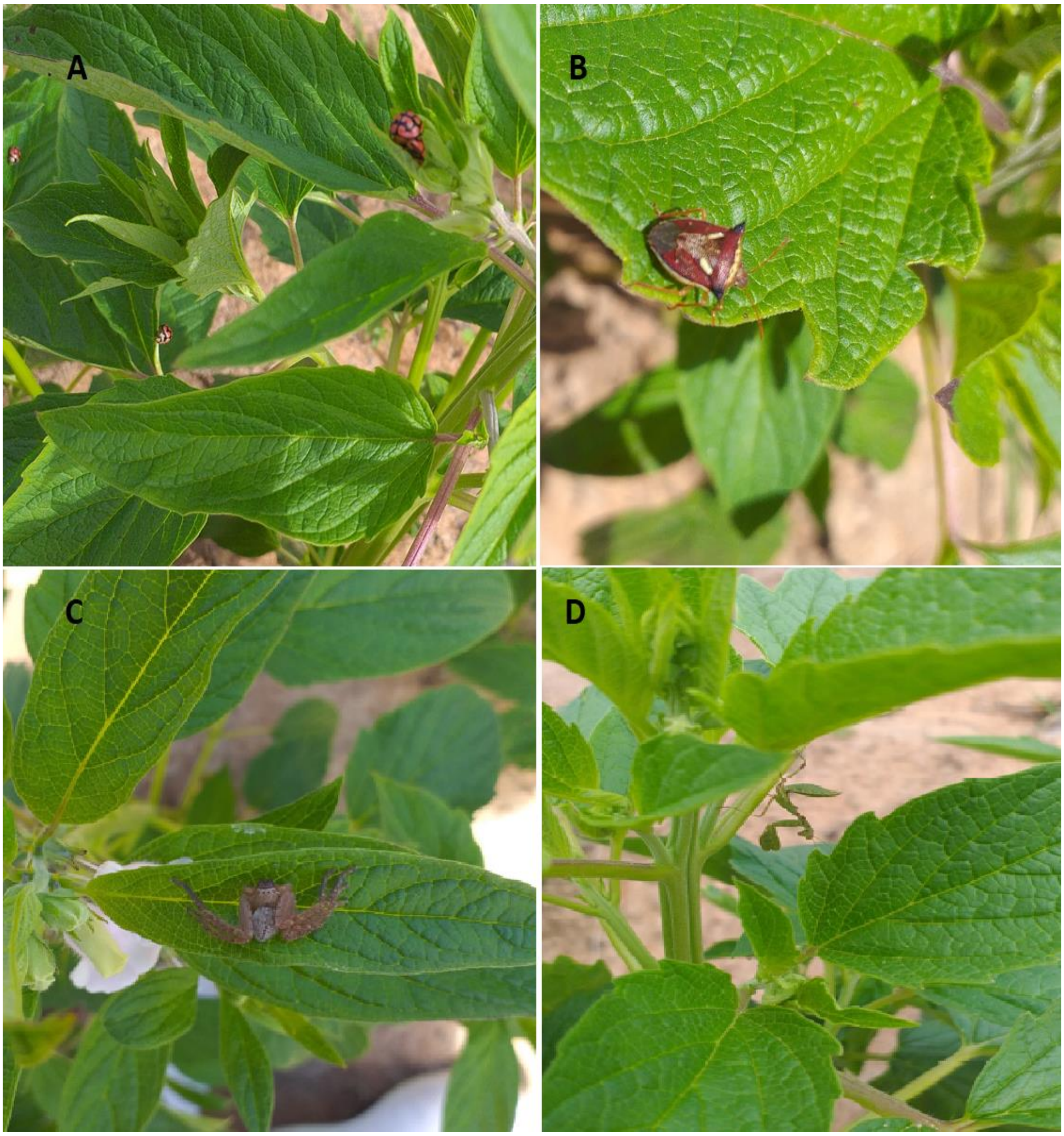
# APPENDICES

**Appendix 1: Nymphs and adults of Green peach aphids, *M. persicae* infestation on sesame plant leaves. Phograph by Upendo Lekamoi, Singida, Tanzania 21st May 2021.**

**Appendix 2: A: Larvae of *A. catalaunalis* forage in the sesame tender leaves B: Damage of *A. catalaunalis* on sesame tender leaves, D: Damage of *A. catalaunalis* on sesame pods. Photograph by Upendo Lekamoi, Singida, Tanzania from March to June 2021 and C: Damage of *A. catalaunalis* on sesame pods. Source: (Gebregergis *et al.*, 2016)**

**Appendix 3: Jassid *O. albicinctus* forages on sesame plant leaves. Photograph by Upendo Lekamoi, Singida, Tanzania 27th March 2021**

**Appendix 4: Natural enemies of insect pests of sesame A: *Coccinella undecimpunctata*, B: *Pentatomidae spp (Dolycoris baccarum)*, C: *Phoneutria fera* and D: *Calidomantis savignyi*. Photograph by UpendoLekamoi, Singida, Tanzania, From March to June 2021**



## RESEARCH OUTPUTS

1. **Lekamoi, U.,** Kusolwa, P., & Mbega, E. R. (2022). Importance of bio-pesticides formulations in managing insect pests of sesame in Africa. *International Journal of Biosciences*, *6655*, 342–367. https://doi.org/http://dx.doi.org/10.12692/ijb/20.2.342-367

**2.** Accepted paper for publication

INNSPUB: Your Submitted Manuscript has been Accepted for Publish

**Dear** lekamoiu@nm-aist.ac.tz,
Congratulations! Based on paper materials and reviewer comments, it decided that your article now eligible for **publish** in International Network for Natural sciences (INNSPUB) network.

So, Editor-in-chief pleased to inform you that your manuscript entitled: **Effect of Tephrosia vogelii formulation with rabbit urine on insect pests and yield of sesame in Singida, Tanzania** has been accepted now for publish in **Journal of Biodiversity and Environmental Sciences**.

**3.** Poster presentation