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Importance of bio-pesticides formulations in managing insect pests of sesame in Africa

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Abstract

Sesame is an important oil seed crop worldwide. However, its production faces a number of challenges such as infestation by insect pests and diseases, use of unimproved seeds by farmers and drought. Among all, insect pest is considered the most serious challenge affecting sesame production particularly in the Africa region. The common insect pests affecting sesame production in African smallholder farmers are *Myzus persicae, Aphis gossypii*, *Bemisia tabaci*, *Antigastra catalaunalis*, *Orosius albicinctus*, *Tetranychus urticae*, *Spodoptera frugiperda* and *Alocypha bimaculata*. These insect pests infest sesame at different stages of growth posing immense damage resulting into huge loss of yields. To control these insect pests most African smallholder farmers, use synthetic pesticides. However, most of those synthetic pesticides used cause environmental pollution and detriment effects to pollinators and natural enemies. Therefore, this paper reviews sesame insect pests and how they can be managed using bio-pesticides in African..

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Introduction

Sesame (*Sesamum indicum L.*) is an oil seed crop that belongs to the Family Pedaliacea (Khatoon *et al.*, 2019). Due to its importance as oil seed crop, sesame is cultivated in tropical and sub-tropical regions globally (Purru *et al.*, 2018). The largest producers of sesame in the world are India and China followed by Myanmar, Sudan, Nigeria, Ethiopia, Paraguay, Pakistan, Uganda and Tanzania (Boutros-Ghali, 2010; Gebregergis *et al.*, 2018).

In Africa like in other locations globally, sesame production face a number of challenges including infestation by insect pests (Eli-chukwu, 2019). The major damaging insect pests of sesame include *Bemisia tabaci*, *Aphis gossypii, Myzus persicae*, *Antigastra catalaunalis*, *Orosius albicinctus*, *Alocypha bimaculata*, *Tetranychus urticae* and *Spodoptera frugiperda* (Carlsson *et al.*, 2008). These insects, together with other factors such as use of unimproved seed and drought have been cited to be responsible for reduced yield (Dossa *et al.*, 2017; Hanna, 2017; Waddington *et al.*, 2010).

Managing insect pests has mainly been by the use of synthetic chemicals (Chandler, 2008; Hakeem *et al.*, 2016). Synthetic pesticide have been reported to be effective, reliable against a wide range of insect pests, quick responding and easily to be tested for new insect pests (Sadeghi *et al.*, 2009), however, most synthetic pesticides are broad spectrum including organophosphates (profenofos), organochlorines (dichlorodiphenyltrichloroethane), pyrethroids (cypermethrin and deltamethrin) avermectin (abamectin) and carbamates,(Özkara *et al.*, 2016) which have hazardous effects to the environment and non-target organisms . For instance, Profenofos, DDT, cypermethrin and deltamethrin have been categorized as WHO Class II (moderately hazardous) and abamectin has categorized as WHO Class I (highly hazardous) (Kapeleka *et al.*, 2019). These chemicals are currently not encouraged to be used globally due to as previously stated, their detrimental effects to environments and non-target organisms (Fiorenzano *et al.*, 2017). There exist a number of other insect pest management practices which can be used for managing insect pests including use of resistant cultivars, good cultural practices and biological control. In this review, the importance of biopesticides for replacements of synthetic pesticides has been discussed (Glare *et al.*, 2012). This is due to the fact that they have been reported to be effective in controlling insect pest without causing serious damage to ecological chain or exacerbate environmental pollution (Leng *et al.*, 2011).

The common insect pests affecting sesame in Africa

Many insect pests (Table 1) such as aphids, white flies, sesame webworms, jassids sesame flea beetles, spider mites and army worms impede the production of sesame crop in Africa (Carlsson *et al.*, 2008). Those insect pests infest sesame crop at different stages of sesame growth, trigger significant damage to the crop resulting into huge losses in sesame production (Thangjam & Vastrad, 2018). The report shows that insect pests reduce about 25% of potential yield of sesame where the damage ranges from 5% to 50% of the total production (Berhe *et al.*, 2011). *A. catalaunalis* is a major pest which cause huge losses in heavy infestation and sesame small holder farmers have been using synthetic pesticide to combat the pest (Gebregergis *et al.*, 2018). Synthetic pesticides pose environmental adulteration, decimation of non-targeted organisms and jeopardize human being health (Arora *et al.*, 2016; Fiorenzano *et al.*, 2017). This section reviews the major insect pests infesting sesame crop at different stages of growth in African countries.

Aphids

Aphids are tiny insects with their bodies color varies from black, green, brown, yellow and purple (Liu & Sparks, 2001). They are very delicate insects with fragile bodies, adults have the length range from 1.5 to 2.5 mm long depending on the species (Liu & Sparks, 2001). Adult aphids can be alated or apterous, nymph resemble adult but they are small and apterous even though the nymph generation is alated aphids (Liu & Sparks, 2001). Aphids are significant agricultural pests attacking sesame leaves and stems, causing leaf curling by sucking the cell sap and causing plants to wither and die (Iram *et al.*, 2014). Both nymph and adult aphids pierce the plant tissues and feed on plant cell sap (Bissdorf & Weber, 2007). Aphids produce a sugary substance called honey dew which instigates the growth of fungus called sooty mold which grow on the honey dew deposited on the branches and leaves turning them black (Bissdorf & Weber, 2007). However, aphids are responsible for tranmission of viruses which cause disease to crops (Stavrinides *et al*., 2009). Both alated and apterous aphids have cornicles that produce pheromone and sticky droplets chemical that binds the predators and parasitoids insects'mouth parts and appendages (Alfaress *et al*., 2018). Two species of aphids known as the *Aphis gossypii* and *Myzus persicae* are reported to attack sesame.

Table 1. Common pests of sesame.

Common name	Scientific name	Stage of pest	Growth stages sesames damaged	Reference
Aphids	*A. gossypii. M. persicae*	Nymph and Adult	Seedling (leaves), vegetative (foliage), reproductive (flowers and foliage) and maturation stage (fruit capsules)	(Dilipsundar *et al*., 2019; Hegde *et al*., 2011; Langham *et al*., 2008)
Whiteflies	*B. tabaci*	Nymph and Adult	Seedling (leaves), vegetative (foliage) and reproductive (flowers and foliage)	(Dilipsundar *et al.,* 2019; Roda *et al*., 2020)
Leaf roller caterpillar	*A. catalaunalis*	Larva	Seedling, vegetative growth flowering and capsule development stage.	(Gebregergis *et al*., 2016a)
Jassids	*O. albicinctus*	Nymph and Adult	Vegetative (foliage) to capsule stage. They affect leaves, flowers and fruits	(Sathe, 2014)
Sesame flea beetle	*A. bimaculata*	Larva and Adult	Seedling stage to vegetative (foliage)	(Mayoori & Mikunthan, 2009)
Spider mites	*T. urticae*	Adult	Vegetative (foliage) to capsule stage. They affect leaves, flowers and fruits	(Crop *et al*., 2011)
Army worms	*S. frugiperda*	Larva	Vegetative to capsule development stage	(Capinera, 2009)

Cotton aphid (A. gossypii)

The cotton aphid *A. gossypii* is known to infest cotton but it extend its infestation and increase the number of host which it attacks including sesame (Ebert & Cartwright, 1997). Both nymph and adult damage the crop by direct sucking the cell saps of the tender leaves tissues, indirect by excreting honey dew that favor the growth of fungi *capinodium spp* and by tranmission of virus (Fernandes *et al*., 2018) such as cucumber mosaic virus, poty virus and citrus tristeza (Vegette *et al*., 2008). *A. gossypii* is a very destructive pest infesting broad range of host plants world wide (Hegde *et al*., 2011). In heavy infestation of *A. gossypii* lead to the mitigation of quality of the crops and seeds which results into yield losses up to 50% yield loss (Fernandes *et al*., 2018).

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

To evade the effects brought by the utilization of synthetic pesticides, bio pesticides known to be environmental friendly, are currently used and they have been performing well in controlling a wide range of pests including *A. gossypii* (Isman, 2006). Predatory pests such as Lady beetles *Coccinella septempunctata*, *Propylaea japonica, Lacewings Chrysopa phyllochroma,* and *Chrysopa sinica* and spiders *Erigonidium graminicola*, *Misumjenops tricuspidatus* attack Cotton aphids *A. gossypii* and parasitoid *Aphidius gifuensis* parasitize and kills the cotton aphids (Ma *et al*., 2006). Moreover, Predator *Harmonia axyridis* and *Phytoseiulus persimilis* and parasitoid *Aphenius asychis,* have been used to control potato aphid in the green house. Snyder *et al*., (2004) divulged that Asian lady beetle *H. axyridis* control pea aphids *Acyrthosiphon pisum*, English grain aphid *Sitobion avenae* and Russian wheat aphid *Diuraphis noxia*.

All those natural enemies help to control the incidence of *A. gossypii* and spread of viruses transmitted by the cotton aphids.

However, entomopathogenic bacteria *B. thuringiensis* control *A. gossypii* in cotton by releasing toxins which breaks the gut of *A. gossypii* and die of the infection and starvation (Ma *et al*., 2006). Furthermore, a gram positive bacteria *Leuconoctoc pseudomesenteriodes* has showed effectiveness in controlling aphids but entomopathogenic *Beauveria bassiana*, *Burkholderia spp* and *Saccharopolyspora spinosa* control a wide range of insect pests including *A. gossypii* pests (Hiebert *et al*., 2020). Biological control method is effective in the management of *A. gossypii* pest impediment is financial power of most of smallholder farmers in Africa. To elude costs, cultural practices such as intercropping and crop rotations have been utilized to control *A. gossypii* pests (Snyder *et al*., 2004). However, cultural practices are rarely efficacy to protect sesame crops from insect pests including *A. gossypii* pests although they are affordable and environmentally friendly (Mpumi *et al*., 2020).

Alternative way to subdue this is by using botanical pesticides (Isman, 2006). Botanical pesticides like *Annona squamosa* leaves, *Polygonum orientale* leaves, *Ricinus communis* seed oil, *Azadirachta indica* seed oil, and *S. indicum* seed oil are successfully suppress sesame insect pests including *A. gossypii* (K. Ahmed *et al*., 2014). However, Botanical pesticides *Tithonia diversifolia* and *Lantana camara* have been used to control aphids in beans *Phaseolus vulgaris* (Mkindi *et al*., 2020). Moreover, *Nicotiana tabacum, Eucalyptus camaldulemsis, Croton dichogamus* and *Syzigium aromaticum* are effectively reduce the infestation of aphids on beans and cabbage *Brassica oleracea* (Mpumi *et al*., 2020). Bio pesticide *T. vogelii* with rabbit urine can be used by the smallholder farmers in Africa to control *A. gossypii* on sesame fields.

Green peach aphid (M. persicae)

The green peach aphid *M. persicae* is a deleterious pest all over the world infesting broad range of crops (Umina *et al*., 2014) possibly available at any time all round the year (Gu *et al*., 2007). These aphids are green in color (Fig. 1) being categorized into two forms; alated and apterous green peach aphids (Alyokhin & Sewell, 2003). Alated green peach aphids own dark patch nigh the end of the abdomen while apterous green peach aphids dearth dark patch (Umina *et al*., 2014). They prefer and proliferate in the environment with high temperatures (Gu *et al*., 2007).

Fig. 1. Nymphs and adults of Green peach aphids, *M. persicae* infestation on sesame plant leaves. Photograph by Upendo Lekamoi, Nm-Aist-Arusha, Tanzania.

There are over 50 plant families that host green peach aphids (Umar & Piero, 2016). Those plants incorporate woody and herbaceous plants including vegetables in the family solanaceae, cucurbitaceae, brassicaceea, compositaceae and chenopodiaceae (Cao *et al*., 2016; Umar & Piero, 2016). Some of the host plants that facilitate growth and development of green peach aphids include tomatoes, cabbages, spinarch, beans, peas, watermelons, lettuces, corns carrots and cucumber (Gu *et al*., 2007). All those crop plants differ in their vulnerability to green peach aphids, but the actively growing plants and youngest plant tissues are highy affected by huge population of green peach aphids (Umina *et al*., 2014).

Both nymph and adult of *M. persicae* damage the crops by direct feeding on young tender plant tissues and pose withering, by producing honey dew which falls onto foliage and blackened by sooty mould fungi and lastly by disseminating over 100 plant viruses (Umina *et al*., 2014). The damaged plant viruses transmitted by *Myzus persicae* include cucumber mosaic virus, potato leaf roll virus,poty viruses in pepper, beet yellow, cucumber mosaic, lettuce mosaic,cauliflower, papaya ringspot, turnip mosaic,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 the crops hence mitigate yielding (Spence *et al.*, 2007). The damaging level of *M persicae* are characterized by their large numbers on the undersides the leaves and extensive feeding of these aphids enforces plants to turn yellow and the leaves to curl downwardly and inwardly from the edges resulting into withering, stunted growth and finally death of the crop plant (Mpumi *et al.*, 2020). Therefore prolonged green peach aphids infestation of the crops can reduce yield of the crop products.

Table 2. The parts of sesame damaged by insect pests, signs and effects.

Insect pest	Parts of sesame damaged	Signs of the damaged crop	Effects	Reference
A. catalaunalis	Leaves, flower buds and pods	Web on smaller leaves, which results into holes, holes on the flower buds and pods	Stop terminal growth leading to low yields	(Murugesan & Venkatesan, 2016)
A. gossypii	Tips, flowers and leaves	Curling of leaves, yellowing of the leaves and stunted growth	Wilting, stunted growth and finally death of the crops	(Fernandes *et al.*, 2018).
M. persicae	Tips, flowers, pods and leaves	Curling of leaves, yellowing of the leaves and stunted growth	Wilting, 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	Wilting, stunted growth and finally death of the plants	(Iram *et al.*, 2014)
A. bimaculata	Seedlings' roots and leaves	shallow pits and small rounded irregular holes in the leaves.	Loss of crops ata earl stages and low production	Mayoori & Mikunthan, 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 leaves	dropping down flowers and fruits/ pods of sesamum	Joarder *et al.*, 2021

Table 3. Life cycle of common insect pests of sesame depicting number of generations per year and number of egg produced in their life time.

Sesame insect pest	Number of eggs	Number of generations	Length of Biological cycle	Reference
A. catalaunalis	Female lay the average of 60 eggs in their life time	They complete 14 generations in a year	The total life cycle of *A. catalaunalis* ranges from 21 to 39 days with an average of 28.1 days, incubation period takes about 47 to 73 hours with an average of 60.6 hours. Larval period takes about 8.21 to 12.16 days with an average of. Pupa stage last from 3.10 to 12.0 days with an average of 7.18 days	(Choudhary *et al.*, 2017)(Simoglou *et al.*, 2017)
M. persicae	Oviporous female deposits 4 to 13 eggs	They complete over 20 generations within a year	*Myzus persicae* takes about 10 to 12 days to complete on generation	(Capinera, 2006)
T. urticae	100 eggs	Many overlapping generations	The life cycle of spider mites from eggs to two nymphal stages to adult ranges from 5 to 20 days	(Fasulo & Denmark, 2012)
B. tabaci	300 eggs in her life time	11 to 15 generations can occur within a year	The life cycle of *Bemisia tabaci* vary with host. For example, in soya bean is 21.2 days, collard is 19.2 days while in tomato is 22 days. The life span of female extends to 60 days, while males' range between 9 to 17 days	(Gangwar & Gangwar, 2018; Perring *et al.*, 2018; Takahashi *et al.*, 2008)
S. frugiperda	The total number eggs are 1500 to over 2000 per female	The number of generations varies and it has been reported to be 1-2, 3 and 4 within a year	The life of *Spodoptera frugiperda* is completed within 30 days, but 60 days in spring and 80 to 90 days in winter	(Capinera, 2009)

Green peach aphids are attacked by the predators predator *H. axyridis, P. persimilis,* and parasitoid *A. asychis,* have been used to control potato and pea aphid in the green house (Snyder *et al.*, 2004). Also predator *Coccinella undecimpunctata* feed on *M. persicae* in fields of sesame crops (Mahmoud, 2012).

Parasitoid wasps *Aphidius colemani, Lysiphlebri testaceipes, Aphidius transcaspius, Aphidius ervi, Ephedous persicae, Praon volucre, Ephedous plagiator Praon objectrun, Lysiphlebri testaceipes, Aphidius matricariae,* and *Diaeretielle rapae* kill the green peach aphids in peach orchards (Aparicio *et al.*, 2019). Entomopathogenic microbes such as *B. bassiana, A. dipterigenus* and *C. fumosorosea* have showned effectivess controlling M. persicae on potato, letuce and cabbage in the greenhouse (Prince & Chandler, 2020).

All those natural enemies together with cultural control such as crop rotation and destruction of the infected crops deter the incidence and spread of viruses transmitted by the green peach aphids (Capinera, 2006). Chemical insecticides such as organophosphates (profenofos), organochlorines (DDT), pyrethroids (cypermethrin and deltamethrin) and avermectin based formulations (abamectin), carbamates have been used by the smallholder farmers in the management of green peach aphids in the field (Mpumi *et al.*, 2020). However, heavy reliance on synthetic pesticides to control aphids population results into strong insect pests resisitance to synthetic pesticides like carbamates and pyrethroids (Umina *et al.*, 2014). Therefore broad spectrum insect pests management strategies are needed to ensure that these aphids are managed. Botanical pesticides such as *A. squamosa* leaves, *P. orientale* leaves, *R. communis* seed oil, *A. indica* seed oil, and *S. indicum* seed oil are successfully suppress sesame insect pests including *M. persicae* in the field (Ahmed *et al.*, 2014). *T. vogelii* formulation with rabbit urine and sunflower oil can be used by the smallholder farmers to control *M. persicae* in sesame fields in Africa.

Whiteflies (B. tabaci)

Whiteflies *B. tabaci* (Gennadius) are small insects about 1.5 mm long, having two pairs of wings white and light yellow bodies covered with waxy powdery materials (Brezeanu *et al.*, 2014). *B. tabaci* (Genn) is a polyphagous pest reported to infest on more than 600 host plant species worldwide (Iram *et al.*, 2014). Both nymph and adults pierce the plant tissues and suck the sap of the leaves results into wilting and finally death of the plants (Barbedo, 2014). They feed on top of plants hence reduce transpiration and the rate of photosynthesis as well as chlorophyll content (Inbar & Gerling, 2008). As aphids, whiteflies produce honeydew that acts as a substrate to sooty mold fungi on leaves and pods (Brezeanu *et al.*, 2014; Gangwar & Gangwar, 2018). However, *B. tabaci* has been reported carrying devastating diseases like fungal infection (Gangwar & Gangwar, 2018; Roda *et al.*, 2020), as well as transmitting plant damaging viral diseases (Inbar & Gerling, 2008). Fungi and viruses may alter the attractiveness and vulgarity of the plants (Roda *et al.*, 2020). According to Roda *et al* (2020), plant viruses transmitted by whiteflies can act as pathogens to insects of which they can parasitize both pests and the beneficial insects.

To surmount the effect of *B. tabaci* in sesame fields, sesame smallholder farmers have been using synthetic pesticides (Inbar & Gerling, 2008; Roda *et al.*, 2020). Synthetic pesticides thiacloprid, monocrotophos, fipronil, cyatraniliprole, spinosad, oberon, imidacloprid and diafenthiuron contain hazardous chemicals (Saritha, 2020). Moreover, methamodophos, acephate, bifenthrin, fenprothrin, aldicarb, methomyl, thiamethoxam, acetamiprid, dinotefuron, buprotezin and pyriproxyfen have showed effectiveness in controlling *B. tabaci* in diffrent ways (Perring *et al.*, 2018). Heavy applications of synthetic pesticides result into environmental pollution in the land, water and in the air, and also devastate non-target organisms (Fiorenzano *et al.*, 2017). Moreover, *B. tabaci* pests have developed resistance to various groups of insecticides including neonicotinoids and pyriproxyfens (Horowitz *et al.*, 2020). To elude the effects and costs of using synthetic pesticide cultural methods have been used by smallholder farmers to control in sesame fields (Tavares *et al.*, 2021). Cultural methods which are used by the smallholder farmers to control *B. tabaci* in fields are planting dates, host free periods, intercropping, trap crops, crop management and living mulches (Perring *et al.*, 2018). However, these cultural practices are less effective managing insect pests of sesame (Mpumi *et al.*, 2020).

Predators which attack and kill *B. tabaci* are, *Delphastus catalinae, Serangium parcesetosum, Macrolophus praeclarus, Nerphaspis oculatus, Nesidiocoris tenuis, Chrysoperla carnea, Chrysoperla rufilabris, Tupiocoris cucurbitaceus, Amblyseius swirskii, Euseius scutalis, Macrophagus pigmaeus* and *Dicyphus hesperus* (Perring *et al.*, 2018) while the parasitoids used to control *B. tabaci* are *Eretmocerus mundus, Encarsia formosa and Eretmocerus eremicus* (Qiu *et al.*, 2004; Urbaneja *et al.*, 2007). Moreover, entomopathogenic *B. bassiana, Lecanicillium lecanii, Aschersonia aleyrodis,* and *Isaria fumosorosea* are used to control *B. tabaci* (Perring *et al.*, 2018). This method is effective in the management of *B. tabaci* pest constraint is financial power of most of smallholder farmers in Africa

To surmount the problem, smallholder farmers have been using botanical pesticide to control *B. tabaci* in the field as they are affordable available to farmers' environment and easy to prepare and to use Amoabeng *et al.*, 2014; de Cássia Seffrin *et al.*, 2010). Plant extracts from *Solanum hirsutum, Solanum habrochaites, Solanum galapagense, Solanum persicum* and *Solanum penellii* manage *B. tabaci* by using bioactive compound 2-tridecanone which pose about 72% whiteflies mortality (Perring *et al.*, 2018). Moreover, Extracts from *A. squamosa, A. indica* and *Nicotiana tabacum* have been used to control *B. tabaci* in the field (Sultana & Khan, 2019). In addition, methyl ketones from *Solanum glabratum* are toxic to *B. tabaci* depicting significant mortality in a certain concentration (Perring *et al.*, 2018). Biopesticides have been effective in management of *B. tabaci* in different crops but there is little information on bio pesticides to control *B. tabaci* in sesame. Therefore, biopesticide *T. vogelii* formulation with rabbit urine can be used by the sesame smallhoder farmers in Africa to combat *B. tabaci* in sesame fields.

Leaf roller Carterpillars (A. catalaunalis)

A catalaunalis larva is a most serous damaging insect pests that affect the production of sesame by causing huge loss of sesame production (Gebregergis *et al.*, 2018) (Rakesh, 2012). *S. indicum* crop is attacked by the larvae of *A. catalaunalis* within all stages of growth (Fig. 2) normally within two weeks after emerging up to the stage of harvesting (Gebregergis *et al.*, 2016; Suliman *et al.*, 2013). Carterpillar *A. catalaunalis* feeds voraciouly on tender foliage at early stages of the crops by webbing the top leaves and bores into flower buds and pods of the sesame crops (Murugesan & Venkatesan, 2016; Simoglou *et al.*, 2017; Suliman *et al.*, 2013). The larvae of *A. catalaunalis* attack seed capsules and cause yield loss up to 100% in heavy infestation (Geremedhin & Azerefegne, 2020). According to Egonyu *et al.*, (2005) *A. catalaunalis* insect pests reduced sesame yields from 2250kg/ha to 430kg/ha in Uganda. During flowering periods insects lay eggs in the ovaries of sesame, and hatch larva where they devour the inside of the ovary and produce barren galls instead of pods (Bissdorf & Weber, 2007).

Fig. 2. A: Larvae of *A. catalaunalis* forage in the sesame tender leaves B: Damage of *A. catalaunalis* on sesame tender leaves and C: Damage of *A. catalaunalis* on sesame pods. Photograph by Upendo Lekamoi, Nm-Aist-Arusha, Tanzania.

Smallholder farmers in Africa intensively rely on the application of chemical pesticides in controlling *A. catalaunalis* in sesame in the fields (Singh & Burbade, 2021). The effective synthetic pesticides which are used world wide and in Africa particularly to combat against *A. catalaunalis* infestations in sesame are carbaryl, accephate, diazinone, endosulfan, cypercal, Lambda cyhalothrin, vertimec, indoxacarb, dimethoate (Choudhary *et al.*, 2017; Geremedhin & Azerefegne, 2020). However some of those synthetic pesticides are reported harzadous and therefore unwise to use and once overused they can result into severe environmental pollution especially soil and water, development of insect resisitance to some insecticides (Shahid *et al.*, 2019) and health problem to human being (Özkara *et al.*, 2016).

Therefore there is a need of searching and utilizing benign and environmental friendly biopesticides as sesame insect pests control strategy. Cultural method such as planting sesame early on the onset of rainfall avails to minimize the infestation of *A. catalaunalis* (Gebregergis *et al.*, 2018).

However, biopesticides such as entomopathogenic bacteria, viruses, fungi, nematodes and protozoa are currently used to control a wide range og insect pests (Kumar *et al.*, 2021; Thangavel & Sridevi, 2015). Microbial pesticide like *B. thuringiensis* and baculoviruses are effectively control *A. catalaunalis* larvae (Kumar *et al.*, 2021). *B. thuringiensis* act as pathogen to most destructive lepidopterans larvae pests including *A. catalaunalis* larvae by releasing toxin which destroy the mid gut once they feed on it (Samada & Tambunan, 2020). Also predatory insects like *Coccinella. undecimpunctata, C. septempuctata, Phoneutria fera* and *Praying mantis* feed on *A. catalaunalis* larvae and the parasitoides *Ichneumonidae spp* and *Braconidae spp* parasitize and kill the larvae of *A. catalaunalis* (Simoglou *et al.*, 2017).

In addition, biopesticides such as botanical extracts like A. indica, *Euphorbia tirucalli, Toona. ciliata, T. vogelii* and *Cymbopogon schoeroanthus* have been used to control insect pests like webworm carterpillars, spider mites and aphids on vegetable crops (Tavares *et al.*, 2021). Morover, extracts from *Annona muricata, Capsicum annuum, T. diversifolia, C. dichogamus, S. aromaticum, N. tabacum* and *Allium satavum* have been used to control the carterpillars in *Phaseolus vulgaris* and *Brassica oleracea* (Mkindi *et al.*, 2020; Mpumi *et al.*, 2020). Nevertheless, hitherto the information on biopesticides which control sesame pests is lacking. Therefore there is a need to focus on biopesticide *T. vogelii* formulation with rabbit urine to be used to control insect pests of sesame in sesame fileds in Africa.

Jassid (O. albicinctus)

Jassids *O. albicinctus* is a small, elongated and wedge shaped insects of about 3 to 5mm long ranging from green, yellow green and brown with black spots on both sides of the head (Fig. 3) another on the apical area of each forewing (Watson, 2011). They are the cell sap sucking insects injecting toxins into the body while sucking inducing yellowish and curling of leaves, dropping down flowers and fruits/ pods of sesamum (Joarder *et al.*, 2021; Sathe, 2014). Both nymph and adults desiccate plants by sucking cell sap from the leaves whereby they sucks sap from the underside of leaves and leaf buds (Chakraborty *et al.*, 2015; Joarder *et al.*, 2021). Nymph resemble adults but they more smaller than adults, paler, wingless and slower in moving (Watson, 2011). Adults jump and fly away at the slightest disturbance (Sultana & Khan, 2019; Watson, 2011). Both nymph and adult transmit viruses to healthy plants and cause phyllody a very serious disease go along with floral virescence, formation of dark mucilage on the foliage, proliferation, cracking of seed capsules and seeds germinating inside the capsules (Akhtar *et al.*, 2009). In severe infestation jassids cause yield reduction up to 24.45 % (Hakim Ali Sahito *et al.*, 2018).

Fig. 3. Jassid *O. albicinctus* forages on sesame plant leaves. Photograph by Upendo Lekamoi, Nm-Aist-Arusha, Tanzania.

African smallholders sesame farmers have been controlling jassids by the application of chemical insecticides (Bonmatin *et al.*, 2021). Synthetic pesticides oberon, imidacloprid, cyatraniliprole, thiacloprid, monocrotophos, thiamethoxam, flonicamid, fipronil, fenazaquin, spiromesifen, ethion, acetamiprid, spinosad, endosulfan and diafenthiuron contain hazardous chemicals (Ram *et al.*, 2020; Saritha, 2020; Sultana & Khan, 2015, 2019). These synthetic pesticides are not environmental friendly and may cause pollution to the environment especially in the water and soil and sometimes decimating the useful insects like natural enemies and pollinators (Tosi & Nieh, 2019). Effects emanating from using synthetic pesticides instigate searching for biopesticides alternative to synthetic pesticides.

Biopesticides are categorizes into microbial biopesticides, botanical biopesticides (biochemical pesticides) and genetic modified organisms (GMO) based biopesticides (Kumar *et al.*, 2021). Microbial biopesticides such as entomopathogenic bacteria *B. thuringiensis,* has been effectively used to control *O. albicinctus* (Soomro *et al.*, 2020). Also entomopathogenic fungi *B. bassiana, Metarhizium spp L. lecanii*, and *Trichoderma spp* are significantly control *O. albicinctus* (Dahal *et al.*, 2020; Halder *et al.*, 2021). Predator *C. carnea* has significantly cause mortality to jassids on Bt cotton and the insect is distributed in Kenya, Tanzania, Egypt and Nigeria in Africa (Soomro *et al.*, 2020). Also predators *Micraspis discolor, Cheilomenes sexmaculata, Menichilus sexmaculatus, Marpissa spp* and *Oxyopes lineatipes* have been effective in controlling sucking pests including jassids in okra (Halder *et al.*, 2021). Parasitoids *Arescon enocki* and *Anagrus spp* have been reducing the population of *O. albicintus* by feeding on jassids eggs in cotton and okra crops (Hakim Ali Sahito *et al.*, 2018).

Furthermore, botanical pesticides such as *A. indica* leaves and oil, *A. sativum*, *N. tabacum*, *A. squamosa, R. communis* and *Polygonum hydropiper* are used to control leaf sucking including jassids in crop fields (Ahmed *et al.*, 2014; Sultana & Khan, 2015, 2019). Biopesticides synergistic of *T. vogelii,* rabbit urine all together can be effectively used in controlling jassids in sesame fields in Africa.

Sesame flea beetle (A. bimaculata)

Sesame flea beetle *A. bimaculata*, is the most prominent insect pest constraint to sesame production in southern Tanzania (Mponda & Morse, 1997). Both larvae and adults are the pests (Patole, 2017). Sesame seedlings are known to be particularly vulnerable to flea beetle attack up to 21 days after germination (Zeit, 2021). Larvae of sesame flea beetle *A. bimaculata* feed on roots of newly planted seedlings aged 21 days after germination (Mponda & Morse, 1997).

Adult flea beetles *A. bimaculata* cause the most damage by feeding on the leaves and stems (Fig. 4) whereby they create shallow pits and small rounded irregular holes in the leaves (Baker & Webber, 2008).

Fig. 4. Sesame flea beetle, *A. bimaculata* foraging feeding on sesame leaves and stems in the field. Photograph by Upendo Lekamoi, Nm-Aist-Arusha, Tanzania.

Fig. 5. atural enemies of insect pests of sesame A: *Coccinella undecimpunctata* B: *Pentatomidae spp* C: *Phoneutria fera*.

Smallholder farmer use hazardous synthetic pesticides such as emmemectin benzoate, carbaryl, cyfluthrin, lambda-cyhalothrin, permetrin, binenthrin, estenvalerate, pyretrin, imidacloprid, acetamiprid, malathion, bifenthrin and dinotefuran in controlling *A bimaculata* in the field (Ali *et al.*, 2017; Bunn *et al.*, 2015). Synthetic pesticides apart from posing threat to human health and decimating non target organisms, synthetic pesticides cause insect pests resistance (Kapeleka *et al.*, 2019; Özkara *et al.*, 2016). To overcome the problem, sesame smallholder farmers mix two to more chemical pesticides in the action of controlling a very dangerous pest sesame flea beetle *(Xu et al.*, 2009). Mixing of synthetic pesticides results to water and soil pollution hence affecting aquatic organisms, macro and microorganisms (Syafrudin *et al.*, 2021).

To elude the effects of synthetic pesticides, sesame smallholder farmers in Africa have been employed cultural method such as trap cropping in controlling sesame flea beetls *A. bimaculata* in fields (Kuepper, 2015). However, the cultural practice is not enough to manage insect pests of sesame, hence there is a need of looking for other mehods like biological control. Biological control or natural enemies such as predators, parasites and pathogens is currently utilized to control insect pests in fields (Mpumi *et al.*, 2020). Parasitoid braconid wasp *Microctonus vittage* kill adult flea beetle (Kuepper, 2015). Also *Chrysopa spp*, *Nabis spp* and *Geocoris spp* eat adult flea beetles (Bunn *et al.*, 2015).

Moreover, entomopathogenic nematodes efficacious agents for managing flea beetles, by attacking the larvae reducing root feeding and help to prevent the next adult cycle from emerging (Kuepper, 2015). Nematodes *Steinernema spp* and *Heterorhabditis spp* are common biopesticides controlling flea beetles by attacking the flea beetles larvae, mitigating the perpetuation of flea beetle generation (Bunn *et al.*, 2015). In addition, microbial pesticides *B. thuringiensis* has been efficacy in controlling flea beetles by producing toxins which bind to the receptors of the insect gut causing it to stop feeding and ultimately die within few days once the insect ingests it (Adsule *et al.*, 2009; Borden *et al.*, 2018). However, entomopathogenic *Saccharopolyspora spinosa* controls a broad range of insect pests including, flea beetles carterpillars and spider mites by producing insecticidal toxin which attack the insect nervous system, making insect to stop feeding and finally die within two days later (Borden *et al.*, 2018). Moreover, entomopathogenic fungi *B. basssiana* have been used to control flea beetles by releasing toxins into the insect's body and melt the internal contents soon after entering the insect's body generating source of food to fungus and next decimation of the pest (Bunn *et al.*, 2015).

Moreover, botanical pesticides such as *A. indica, A, sativum* and *T. vogelii* are currently recommended for managing flea beetles in fields (Kuepper, 2015). According to Bunn *et al.*,(2015), botanical extracts from *Datura stramonium, Chenopodium spp, Calotropis procera, Euphorbia helioscopid* and *A. indica* have been significantly subside the number of flea beetles in the *Zea mays* field (Bunn *et al.*, 2015). Furthermore, botanical pesticides such as *A. indica* leaves and oil, *A. sativum*, *N. tabacum*, *A. squamosa, R. communis* and *Polygonum hydropiper* are used to control coleopteran beetles including sesame beetles in crop fields (K. Ahmed *et al.*, 2014; Sultana & Khan, 2015, 2019). However, report revealed that methanolic extract of *Cymbopogon citratus* have highest percentage mortality of *Trogoderma granium* and *Tribolium castaneum* up to 100% (Manonmani *et al.,* 2018). But there is little information on botanical pesticides to control sesame flea beetles in sesame fields. Therefore bio pesticide, *T. vogelii* formulation with rabbit urine can be used by the sesame smallholder farmers as a biopesticide to control sesame flea beetle on sesame in Arica fields.

Spider mites (T. urticae)

Spider mite, *T. urticae* is a polyphagous serious pest to various crops (Škaloudová *et al.*, 2006), reported to infest over 200 species of plants (Capinera, 2006). It is very tiny insects of about 0.5mm long of which they are very difficult to be seen by our naked eyes that a magnifying glass is needed to see them clearly, they look like tiny moving dots, but the webs that spider mites spin are much easier to see (Watson, 2011). It has oval shaped body without wings and antennae (Zinov'ev & Sole, 2004). It damages plants by sucking cell saps, usually feed on the underside of the leaves causing tiny stipples or flecks on the top of leaves (Škaloudová *et al.*, 2006), reported to devastate 18 to 22 cells in a minute (Capinera, 2006). The damage caused by spider mites is often associated with premature drop of infested leaves (Zinov'ev & Sole, 2004), which lead to chlorophyll depletion and finally low yields productions (Watson, 2011).

To control the infestation of this pest, African sesame smallholder farmers have been relying on the use of chemical pesticides to control spider mites (Bonmatin *et al.*, 2021). Synthetic pesticides imidacloprid, cyatraniliprole, thiacloprid, monocrotophos, spinoad and diafenthiuron contain hazardous chemicals

(Saritha, 2020) which are broad spectrum pesticides affecting the non-target organisms and causing environmental pollution, jeopardizing human health and ecosystem at large (Fiorenzano *et al*., 2017; Özkara *et al*., 2016).

Spider mites are also controlled by predatory insects, Parasitoid insects and pathogens in various crops (Samada & Tambunan, 2020). Entomopathogenic pesticides *Pseudomonas fluorescens* has been using to control spider mites in Africa by hydrolyzing the exoskeleton of the pest by using the enzyme chitinase (Waked *et al*., 2016). Predatory insects A*mblyseius californicus, Stethorus punctillum, P. persimilis, Deraeocoris punctullatus, Scolothrips longicornis, Conwentzia psociformis, Amblyseius fallacis* and *Panonychus ulmi* have been used worldwide to control *T. urticae* in strawberry plantings in Spain (García-Marí & González-Zamora, 1999). Another predatory insect *Typhlodromus occidentalis* has reported to effectively controlling spider mites (Waked *et al*., 2016).

Furthermore, biopesticides such as botanical biopesticides have been utilized as pests control by smallholder farmers (Kumar *et al*., 2021). Extracts from *A. indica, T. vogelii, E. tirucalli, Bobgunnia madagascariensis and Citrullus colocynthis* have been effectively controlling *T. urticae* pests in various crops (Mwaura, P.C. Stevenson, D.A. Ofori, P. Anjarwalla, 2012; Tavares *et al*., 2021). Hitherto there is little information on bio pesticides which control sesame pests, hence bio pesticide *T. vogelii* formulation with rabbit urine can be a promising biopesticide to control *T. urticae* pest in sesame fields in Africa.

Armyworm (S. frugiperda)

Armyworm *S. frugiperda* larvae is a polypagous insect pest that is invasive in Africa but native in America (Assefa *et al*., 2019), devastating crop pest infesting over 80 different crops and cause economic yield losses (Babendreier *et al*., 2020). *S.frugiperda* larvae attack a wide range of cultivated crops including sesame (Montezano *et al*., 2018). Fall armyworms was reported to invade West Africa countries in early 2016 *(Babendreier et al*., 2020), disseminating to entirety Sub saharan African along with South and Southeast asia in 2019 posing severe damage and significant yield losses (Du Plessis *et al*., 2020). Armyworm affects crops from different stages of growth ranges from early vegetative to harvesting stage (Watson, 2011).

Smallholder farmers in Africa control armyworm pests by using hazardous synthetic pesticides such as emamectin benzoate, pyrethroids, carbamates, organochlorines, organophosphates and organophophosphorus (Assefa *et al*., 2019; Babendreier *et al*., 2020). Examples of synthetic pesticides used are pyrethrins, pyrethrum, thiamethoxicam, thiocarb, chloratraniliprole, trichlorfon, chlorprifon, cyantraniliprole, clothianidin and fipronil (Assefa *et al*., 2019). Nevertheless, the use of synthetic pesticides results into soil and water contamination *(Özkara et al., 2016; Syafrudin et al*., 2021). Soil contamination affects the quality of soil and the signifant macro and microorganisms that decompose the organic matters found in the soil (Mpumi *et al*., 2020). Synthetic pesticides affect the health of the farmers during preperation and application of the insecticides (Kapeleka *et al*., 2019; Özkara *et al*., 2016). Due to these impedements there is a need to focus for alternative to synthetic pesticides.

Aiming to solve these problems more sustainably, the importation of natural enemies from their native areas for pemanent establishment in invaded areas can be considered (Babendreier *et al*., 2020). Parasitoid *Eiphosoma vitticole* has imported from South Florida, while *Apantoles marginiventris, Chelenus insularis, Campoletis grioti, Rogus laphygmae, Ophion spp, Terrelucha spp spp* and *Meteorus autographae* are native in Africa and parasitoids *Chorops alter* and *Coccygidium luteum* are found in Kenya and Tanzania (Assefa *et al*., 2019). Biological control by parasitoide *Telemonus remus* is currently avaibale in Africa, the only remaining part is proliferation of these parasitoides and released as biological control agent (Babendreier *et al*., 2020). Predators such as *Carabidae spp, Doru luteips, Forficulidae, D. lineare, Podius maculiventris, Pentatomidae* spp and *Orius insidiosus* feeds on larva and pupae (Assefa *et al*., 2019). In addition, Microbial pesticides including entomopathogenic, bacteria, fungi, baculoviruses, protozoa and nematodes are currently used to control FAW in fields and reported to be effective. The most effictive microbial pesticides reported to control FAW in fields are *B. thuringiensis, B. bassiana, Metarhizium anisophae* and baculoviruses (Assefa *et al*., 2019). Also species of nematodes such as *Steinernema carpocapsae, S. websteri, S. glaseri, S. downesi, S. longicaudum, S. kraussei, S. feltiae, S. yirgalemense, S. abbasi, S. karii, S. riobrave, S. affine* and *S. jeffereyense* have been used as entomopathogenic parasites controlling *S. spodoptera* in maize (Winisia, 2020).

Smallholder farmers in Africa have been managing Fall armyworm pest successfully for many years by practising cultural methods such as early planting, rotating, intercropping, handpicking, wood ashes and soils (Assefa *et al*., 2019). However, these cultural practices are less effective managing insect pests of sesame including armyworms (Mpumi *et al.,* 2020).

Botanical pesticidal like seeds and leaves of neem plant *A indica* which is readly available acoss the Africa countries (Babendreier *et al*., 2020). According to Assefa *et al*., (2019) the high mortality of armyworm larvae in maize fields in Ethiopia was caused by *A indica* subsequent by other botanical pesticides such as *Croton macrostachyus, Milletia ferruginea, Phytolacea docendra, N. tabacum, Jatropha curcas,* and *Chrysanthemum cinerasiifollium*. Another biopesticides used to control FAW in fields is maltodextrin organic pesticide made from mixing starch, vegetable oils and water which is relatively fast acting on pests and causes death by suffocation through blocking the spiracles (Babendreier *et al*., 2020). Inspite of the effectiveness of the biopesticides in controlling insect pests to different crops, but there is little information on bioepesticides which control *S. frugiperda* in sesame crops. Therefore Biopesticide *T. vogelii* formulation with rabbit urine is a promising biopesticide efficaceous to control *S. frugiperda* in sesame smallholder farmers fields in Africa.

Biological life cycle of sesame insect pests' species

For the proper management of insect pests of sesame there is a need for at least understanding their biological life cycles. This involves the length of the insect pest biological cycle, number of generations of the insect pest within a year and the number of eggs insect pest produces in a generation.

Common practices used to control sesame insect pests

The common practices such as application of synthetic pesticides, cultural practices, biopesticides and biological control (Table 4) have been used by the smallholder farmers in Africa to control insect pests in crops.

Cultural practices on sesame insect pests

Sesame smallholders' farmers in Africa have been using several traditional or cultural practices to mitigate insect pests' infestations (Tengö & Belfrage, 2004). Traditional practices like seed selection, site selection, crop rotation, intercropping and planting date have been minimizing insect pests' infestation to a certain degree (Egonyu *et al*., 2005). Planting date is significant to be observed as it effectively avails to minimize the infestation of insect pests,

For example, the infestation of sesame webworm in sesame can be minimized by planting sesame early on the beginning of rainfall (Gebregergis *et al*., 2018). Also cultural practices like crop rotation, crop free periods and crop residue disposal have been used to mitigate infestation of *B. tabaci* (Hilje *et al*., 2001).

Intercropping is a common cultural method which has been commonly used by the sesame grower in Africa to minimize the infestation of insect pests, for example, smallholders farmers in Nigeria have been practiced row intercropping in sesame fields to mitigate the infestation of insect pests in the field (Uddin & Osagie, 2017).

Also in Uganda *A. catalaunalis* and other sesame insect pests have been managed by intercropping sesame with other crops like sorghum, maize and finger millet (Egonyu *et al*., 2005). Apart from that, cultural practices being less costly, environmentally friendly, not posing problems to human beings health as well as to pollinators and natural enemies insects, but, most of these cultural practices alone are not enough to control insect pests of sesame in the field though they are affordable and environmentally friendly (Mpumi *et al.*, 2020). To surmount this, sesame smallholder farmers in Africa have been utilizing synthetic pesticides.

Table 4. Sesame pest management options.

Pest	Synthetic pesticide	Microbial based	Plant based	Natural enemies	Cultural method	Reference
A. gosspii	Imidacloprid	*B. thirungiensis*	*P. orientale*	*P. japonica*	Intercropping	(Ma *et al.*, 2006),
	Diafenthiuron	*L. pseudomesenteriodes*	*T. diversifolia, L. camara*	*C. septempuctata*	Crop rotation	Saritha, 2020),
	Thiacloprid	*B. bassiana*	*N. tabacum*	*C. phyllochroma*	Trap crops	(Mkindi *et al.*, 2020),
	Fopronil	*Burkholderia spp*	*E. camaldulemsis*	*Chrysopa sinica*		(Ahmed *et al.*, 2014),
	Spinosad	*S.spinosa*	*R. communis*	*E. graminicola*		(Mpumi *et al.*, 2020),
	Cyatraniliprole	*spinosa*	*A. indica, S. indicum*	*M. tricuspidatus*		(Hiebert *et al.*, 2020),
	Monocrotophos		*Annona squamosa*	*Aphidius gifuensis*		(Snyder *et al.*, 2004)
M. pericae	Carbamates	*L. pseudomesenteriodes*	*P. orientale, L. camara*	*P. persimilis, P. objectrun,*	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,*	Trap crops	(Mkindi *et al.*, 2020),
	Diafenthiuron	*Burkholderia spp*	*E. camaldulemsis*	*A. colemani, L. testaceipes,*		(Mpumi *et al.*, 2020).
	Thiacloprid, Monocrotophos,	*S.spinosa*	*R. communis*	*A. matricariae*		(Capinera, 2006
	Fopronil, Cyatraniliprole,		*A. indica* seed oil	*D. rapae*		(Hiebert *et al.*, 2020),
	Spinosad.		*S. indicum, C. annuum*	*P. volucre, A. ervi,*		(Saritha, 2020),
			C. undecimpunctata			
B. tabaci	Imidacloprid, Buprotezin,	*A. aleyrodis*	*S. hirsutum,*	*D. catalinae, M. pigmaeus,*	Planting dates	(Saritha, 2020),
	Diafenthiuron, Acephate,	L. lecanii	*S. glabratum*	*N. tenuis, C. rufilabris,*	Host free periods	(Sultana & Khan, 2019)
	Thiacloprid, Fopronil,	*B. bassiana*	*S. habrochaites*	*S.parcesetosum, E. mundus,*	Intercropping	(Perring *et al.*, 2018).
	Spinosad, Aldicarb, Methomyl,	*I. fumosorosea*	*S. persicum*	*M. praeclarus, N. oculatus,*	Trap crops	
	Bifenthrin, Pyriproxyfen,		*S.penellii, A. indica*	*T.cucurbitaceus,*	Crop management	
	Cyatraniliprole, Acetamiprid,		*A. squamosa,*	*D. hesperus, A. swirskii,*	Living mulches	
	Monocrotophos, Fenprothrin		*N. tabacum*	*E. scutalis, C. carnea,*		
	Methamodophos,					
	Thiamethoxam, Dinotefuron.					
T. urticae	Imidacloprid	*P. fluorescens*	*T. vogelii,T. ciliata*	*A. californicus*	Intercropping	(Saritha, 2020),
	Diafenthiuron,		*E. tirucalli*	*S. puntillum*	Crop rotation	(Tavares *et al.*, 2021)
	Thiacloprid		*B. madagascariensis*	*P. persimilis*	Trap crops	(Mwaura *et al.*,2012;
	Fopronil, Spinosad		*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),
	accephate	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		*A. muricata, N. tabacum,*	*Pentatomidae spp*		(Tavares *et al.*, 2021)
	Lambda cyhalothrin		*C. annuum, A. sativum*	*C. undecimpunctata*		(Mkindi *et al.*, 2020)
	Dimethoate		*T. diversifolia*	*C. septempuctata*		(Mpumi *et al.*, 2020)
	Cypercal, Endosulfan		*Croton dichogamus*	*T. flavo-orbitalis*		(Gebregergis *et al.*, 2018)
	Diazinone		*S. aromaticum*			
A. alocypha	Emmemectin benzoate, malathion	*B. thuringiensis*	*D. stramonium*	*M. vittage*	Trap cropping	(Ali *et al.*, 2017),

Pest	Synthetic pesticide	Microbial based	Plant based	Natural enemies	Cultural method	Reference
	carbaryl, cyfluthrin, permetrin	*Steinernema spp*	*Chenopodium spp*	*Chrysopa spp*	Intercropping	(Borden *et al.*, 2018).
	lambda-cyhalothrin, acetamiprid	*Heterorhabditis spp*	*C. procera, C. citratus*	*Nabis spp*	rotating crops	(Kuepper, 2015).
	pyrethrin, bifenthrin, binenthrin	*S. spinosa*	*E. helioscopid, A. sativum*	*Geocoris spp*	Handpicking	(Manonmani *et al.*, 2018)
	imidacloprid, dinotefuran	*Beauveria basssiana*	*A. indica, T. vogelii*		Wood ashes	(Bunn *et al.*, 2015).
S. frugiperda	Emamectin benzoate	*T. thuringiensis, S. karii,*	*C. macrostachyus*	*T. remus*	Early planting	(Babendreier *et al.*, 2020)
	pyrethrins, pyrethrum	Baculoviruses, S. affine,	*M. ferruginea*	*E. vitticole*	Intercropping	(Assefa *et al.*, 2019)
	thiamethoxicam	*M. anisophae*	*A. indica*	*A. marginiventris*	rotating crops	(Winisia, 2020)
	thiocarb, trichlorfon	*S. carpocapsae,*	*P. docendra*	*C. insularis*	Handpicking	
	chloratraniliprole,	*S. websteri, S. glaseri,*	*C. cinerasiifollium*	*C. grioti*	Wood ashes	
	chlorprifon, clothianidin,	*S. downesi, S. kraussei,*	*Phytolacea docendra*	*R. laphygmae*	Soils	
	cyantraniliprole,	*S. longicaudu, S. abbasi,*	*N. tabacum, J. curcas*	*Ophion spp,*		
	fipronil	*S. feltiae, S. yirgalemense,*	Maltodextrin	*Terrelucha spp spp,*		
		S. riobrave, B. bassiana.		*M. Autographae,*		
O. albicinctus	Imidacloprid, flonicamid,,	*B. thuringiensis*	*A. sativum*	*C. carnea, A. enocki*	Mulches	(Saritha, 2020)
	Diafenthiuron, oberon, Ethion,	*B. bassiana*	*P. hydropiper*	*M. discolor, Anagrus spp*	Intercropping	Sultana & Khan, 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).
	endosulfan, fenazaquin,			*O. lineatipes,*		Ahmed *et al.*, 2014;

Synthetic pesticides on pest management

Sesame growers in Africa have been intensively control the sesame insect pests by utilizing synthetic insecticides (Karuppaiah, 2014). Most of these synthetic pesticides are organochlorine, organophosphates, carbamates and pyrethroids (Dawkar *et al.*, 2013). Pyrethroids like deltamethrin, entofentrox and cypermethrin have been used to control insect pests of sesame (Egonyu *et al.*, 2005).

According to WHO, cypermethrin and deltamethrin, are grouped into Class II which is considered as moderately hazardous (Kapeleka *et al.*, 2019). Despite its toxic effect and long lasting nature in the environment, organochlorines like DDT has been used by the sesame growers in Africa to control insect pests (Jayaraj *et al.*, 2016).

Nevertheless, most of chemical pesticides such as lindane, hexachlorocyclohexane and DDT have potential environment pollution and the effects to public health (Carvalho, 2006). Many chemical pesticides persist in the environment, killing the useful insects like pollinators and natural enemies as well as threatening the human health for example DDT interfere with acetylcholinesterase enzyme essential for nerve function in insects, human and many animals (Jayaraj *et al.*, 2016). Chemical pesticides have high persistence in the environment which result into bioaccumulation and biomagnification to the bodies of organisms in the environment (Pérez-Lucas *et al.*, 2019). Biomagnification refers to increase of pollutants such as chemical pesticides into the bodies of organisms and these toxic get transferred from one trophic level to another (Ali *et al.*, 2019). Apart from that, synthetic pesticides affects the health of farmers during application, therefore biopesticides which are inexpensive and have health benefits to the applicators and to the environment should be used to control insect pests of the crops (Muhammad & Kashere, 2020).

Biopesticides in insect pest management

Bio-pesticides are naturally occurring compounds which are obtained from plants, animals and microorganisms such as entomopathogenic bacteria, viruses, fungi, algae and nematodes have been efficacy in controlling a wide range of insect pests, fungi and weeds (Thangavel & Sridevi, 2015). Biopesticides have been grouped into microbial biopesticides, biochemical pesticides or botanical biopesticides and genetic modified organisms (GMO) based biopesticides (Kumar *et al.*, 2021).

Microbial biopesticides

Microbial pesticides include products from microorganisms control insect pests with their specific toxic metabolites which cause disease to insect pests; For example *B. thuringiensis* is often used to control insect pests on cabbage, potato and other many crops (Samada & Tambunan, 2020). *B. thuringiensis* act as pathogen to most destructive lepidopterans larvae pests by releasing toxin which destroy the mid gut of the larvae pest once they ingest it (Kumar *et al.*, 2021).

Botanical biopesticides

Botanical pesticides are naturally occurring compounds derived from medicinal plants and they contain groups of active compounds of diverse chemical nature, having an average residual life of 2 to 5 days (Mudzingwa *et al.*, 2013). Botanical pesticides like *A. satavum* have been effective in managing *Sitophilus maize* (Arannilewa *et al.*, 2006). Also plants such as *Eucalyptus camaldulemsis*, and *N. tabacum*, have been used in controlling aphids attacking bean plants (Mpumi *et al.*, 2020). Generally, botanical pesticides like *T. vogelii, R. communis, A. indica, Synedrella nodiflora, Argeratum conyzoides, Chromolaena odorata, Capsicum frutensces* and *A. squamosa* could be used as alternative to synthetic pesticide in controlling insects in cereal crops (Amoabeng *et al.*, 2014; Koona & Dorn, 2005). Nevertheless, there is little information on the application of botanical pesticides for the management of sesame insect pests in the field. Table 1 shows some of the botanical pesticides which can be used to control sesame pests in the fields.

Therefore those significant botanical pesticides as mentioned above can be utilized in managing sesame pests in the field, but mixing the bioactive compounds of plants have potential advantage in terms of efficacy and short time of developing resistance (Kareru *et al.*, 2013). Those bioactive compounds have little toxicity to mammalians, deteriorate rapidly in air, sunlight and moisture and less persistence in the environment and are swift action to the insect pests (Amoabeng *et al.*, 2014). Moreover, botanical pesticides have little effects to non-target organisms and to natural enemies of the insect pests, have no or little toxic effect on the growth of the plants, are affordable and easily available in the environment. Hitherto there is little information on the biopesticides which can control the sesame insect pests; Hence, a concoction of *T. vogelii* with rabbit urine can be used to control the insect pests of sesame.

Genetic modified organisms (GMO) based biopesticides

GMO based biopesticide which is produced by transferring gene into plants induces the production of toxins that can be used to resist pests (Abbas, 2018). For example, bacteria *B. thuringiensis* produce delta endotoxins which are broken down into smaller toxins by the action of proteases in the gut of the insect pests, which then bind to the mid gut receptors posing cell expansion, rupture and ions leakage to ultimately cell death (Kumar *et al.*, 2021). Currently, corn, potato, tobacco and cotton are commercially produced and distributed *B. thuringiensis* crops and have been efficaceous in controlling lepidopterans, hymenopterans, dipterans and coleopterans insect pests (Abbas, 2018).

Importance of Biopestcides

Biopesticides are important components of pest management programs for they are affordable in terms of costs and easy to be prepared and use (Amoabeng *et al.*, 2014; de Cássia Seffrin *et al.*, 2010) and also they are environmentally friendly do not harm human beings as well as non-target organisms (Samada & Tambunan, 2020). Hitherto there is little information on the biopesticides which can control the sesame insect pests; Hence, a concoction of *Tephrosia vogelii* with rabbit urine can be used to control the insect pests of sesame.

Biological control

Biological control such as natural enemies of insect pests include parasitoids, predators and pathogens (Dwyer *et al.*, 2004). Predators species of sesame insect pests are lady beetles *C. undecimpunctata*, spiders, Green Lacewing *C. carnea,* assassin bugs *Reduviid bugs,* and Small praying mantis *Calidomantis savignyi* sp (Jonsson *et al.*, 2014;

Korlapati *et al.*, 2014; Mahmoud, 2012). Lady beetles, spiders and mantis feed on sesame web worm *A. catalaunalis* (Simoglou *et al.*, 2017). Ladybird beetles, both adults and larvae feed on aphids and minimize the population of aphids in the field (Snyder *et al.*, 2004). *Aphis gossypii* are attacked by the predators such as Lady bird beetles *C. septempunctata*, Lacewings *C. phyllochroma* and *C. sinica* and spiders *E. graminicola* (Ma *et al.*, 2006). Predatory bugs and spiders attack and kill jassids and the larva of lacewings, hoverflies and silverflies are the aphids predators (Watson, 2011). *C. sexmaculatus* (Fabricius) and *C. carnea* (Stephens) feed on nymph and adult jassids (Sahito, 2016). *P. persimilis* is a most common predator of spider mites feed on all stages of spider mites (Capinera, 2006).

A small species of black lady beetles feed on spider mites (Cranshaw, 2014). Predators *C. carnea, D. catalinae, S. parcesetosum, I. fumosorosea M. praeclarus, N. oculatus, N. tenuis, C. rufilabris, A. swirskii, E. scutalis, T. cucurbitaceus, M. pigmaeus* and *D. Hesperus* control whiteflies in fields (Perring *et al.*, 2018; Roda *et al.*, 2020). Also *Chrysopa spp* and *Geocoris spp Nabis* spp feed on adult flea beetles (Bunn *et al.*, 2015).

Table 5. Some of the botanical biopesticides used to control sesame insect pests.

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

Parasitoid *L. testaceipes* is effective in controlling aphids through parasitism method (Ma *et al.*, 2006; Snyder *et al.*, 2004; Watson, 2011). Parasitoids *E. Formosa, E. mundus and E. eremicus* control whiteflies in fields (Perring *et al.*, 2018). Parasitoides *Braconidae spp* and *Ichneumonidae spp* parasitize and kill the larvae of *A. catalaunalis* (Simoglou *et al.*, 2017). Also parasitoid *M. vittage* kill adult flea beetle (Kuepper, 2015). Entomopathogenic bacteria *L. pseudomesenteriodes* and *B. thuringiensis* control aphids by producing toxin which destruct the mid gut of the insect pests which ingests the microbes (Moustafa-Farag *et al.*, 2020). Moreover, *B. thuringiensis* and baculoviruses are efficacy in controlling *A. catalaunalis* larvae pests (Kumar *et al.*, 2021). Also, entomopathogenic bacteria *Pseudomonas spp, Chomobacterium spp, B. thuringiensis* and *Yersinia spp* have been effectively used to control jassids *O. albicinctus* (Kumar *et al.*, 2021). Moreover, entomopathogenic fungi *L. lecanii, B. bassiana, A. aleyrodis* and *I. fumosorosea* are used to control *B. tabaci* (Perring *et al.*, 2018). Entomopathogenic fungi *B. bassiana, Metarhizium spp, Paecilomyces spp* and *Verticillium spp,* are efficacy in controlling *O. albicinctus* (Kumar *et al.*, 2021). Entomopathogenic nematodes *Steinernema* spp and

Heterorhabditis spp have been common biopesticides controlling flea beetles by attacking larvae, reducing proliferation of flea beetles (Bunn *et al.*, 2015). In addition, entomopathogenic nematodes *Steinernema spp* and *Heterorhabdus spp* are very effective in controlling jassids *O. albicinctus* by entering into hosts and introducing bacteria *Xenorhabdus spp* and *Photorhabdus spp* into the blood of the host and eventually cause death (Kumar *et al.*, 2021).

Conclusion

Biopesticides play a significant role in insect pest management, becoming more widely used because they are ecofriendly, affordable and efficacy in controlling a wide range of insect pests. They are paramount to the extent of alleviating the utilization of synthetic pesticides which are noxious to human health, environment and non-target organisms such as pollinators and natural enemies of the insect pests. The use of biopesticides like botanical pesticides should be highly encouraged and supported to African sesame growers to subside environmental pollution through the use of synthetic pesticides. This review focus on the use of bio pesticides for sesame insect pests' management in the field concurrent with conserving useful insects like pollinator and natural enemies of sesame insect pest in Africa.

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