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Review Paper

Biological invasion of Tomato leaf miner *Tuta absoluta* (Meyrick) in Nigeria: problems, and control Measures]

ABSTRACT

Background: Tomato (*Lycopersicon esculentum* Mill.) is widely cultivated and consumed as the most important vegetable in every Nigerian pot. It is a good source of vitamins, minerals, essential amino acids, sugar and dietary fibers. It's an excellent source of nutrients, and well-being of the populace.
Aims: The aims are to report the outbreak of Tomato leaf miner (*Tuta absoluta*) on tomato growing regions of Nigeria in 2015 and 2017 and possible control measures.
Place of Study: The study was conducted in Nigeria, in the major tomato-producing areas which lies between latitudes 7.5^{o} 11´ and 13.0^{o} N; with a temperature range of 22-30°C.
Nature of Damage: However, this valuable vegetable recently suffered a devastating attack from invasive insect pest *T. absoluta*, commonly known as Tomato leaf miner. The outbreak caused critical reduction in fruit yield which resulted in high cost of tomato. The damage is done by the pest larvae which tunnel into the stems, apical buds as well as the green and ripe fruits, reducing their yields by 80-100%. *T. absoluta* was reported to have developed resistance to a number of pesticides used in the country. Insufficient research funding also adds up to the existing challenges in controlling the pests. **Methodology and Conclusion:** In this review, we highlighted some important approaches which seem promising in controlling this menace especially when applied in an integrated manner.

Keywords: Tomato; Tomato leaf miner; Tray Trap Technique; NIHORT-Lyptol; NIHORT-Raktin; Nigeria.

1. INTRODUCTION

Tomato has been in cultivation in Nigeria for long time. It is an important component of daily diet, consumed fresh and in paste form. In Nigeria, tomatoes grow well in northern states of the country including Kano, Katsina, Jigawa, Zamfara, Bauchi, Sokoto and Taraba states. However, Kano state has the most suitable comparative advantages for tomato production in commercial scale. The production is beset with many problems, such as diseases, nematode and insect pests, high flower drop, thus resulting in low yield and poor fruit quality. Smallholder farmers cultivating 0.5 to 4 hectares of land account for about 90% of tomato production in the country, with the remaining 10% being supplied by large-scale producers (1). Nigeria has the largest area of land harvested for fresh tomato in Africa with 541,800Ha followed by Egypt with 214,016Ha (2), and the country remains the largest producer of tomato in Africa (3).Unfortunately, huge amount of the crop is lost annually due to post-harvest damages, poor handling and lack of modern storage and processing facilities (4). In 2014, for instance, Nigerian farmers averagely generated the significantly lowest yield of 4.0MT/Ha of tomato as compared to the quantity produced by Egypt (38.7MT/Ha) and South Africa (78.7MT/Ha) (2).

Invasive/introduced species; are non-native species that significantly modify or disrupt the ecosystems they colonize. Such species may arrive in new areas through natural migration, but they are often introduced by the activities of human and other species. In 2016, a sporadic attack by an invasive tomato leaf miner, *T. absoluta* was reported to cause more than 80% yield loss in Nigeria. This caused the price of tomato hiked by 400% within three months, as *T. absoluta* destroyed the annual harvest, affecting tomato farms across Kaduna, Kano, Katsina, Jigawa and Plateau states (**Fig. 1**). The incident resulted in the shortage of supply of tomato to the then newly commissioned Africa largest tomato processing company, the Dangote Farms Tomato Processing Factory, in Kano, Nigeria. *T. absoluta* was spotted again in 2017, this time destroying tomato harvests in Gombe and other states (6). Most of the tomato farms in Kano, Jigawa, Plateau, Katsina and Kaduna states were also affected by the pest, which resulted in yield losses of all the tomato grown in the areas. Currently, Nigeria produces 1.8 million tons annually; according to the Federal Ministry of Agriculture and Rural Development (FMARD) signifying that the output lost from the pest invasion is equivalent to 720,000 metric tons (MT).

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It is still unknown how *T. absoluta* was introduced into Nigeria. From its initial detection to date, tomato leaf miner has become the most serious pest causing severe agricultural damages at tomato-producing areas of the country (7). Conspicuous economic losses and rapid spread of the devastating pest have been recorded in recent years. Complete eradication may not be impossible but the pest may be controlled by various measures, some of which involve cultural practices (such as Integrated Pest Management, IPM),the use of chemicals and other synthetic products (such as pheromones), Tray Trap Technology (TTT) and biological control agents like the use of predators. Recently, National Horticultural Research Institute, Nigeria (NIHORT) developed and tested the efficacy of three bio-pesticides: NIHORT-Raktin, NIHORT-Lyptol, and O-Ruptur. The use of gene silencing using RNA interference (RNAi) technology has also demonstrated its potential in controlling the insect pests (8). This review combines information on the invasion by *T. absoluta*, its ecology, and potential management strategies, including data that may help the implementation of efficient biological control programs. These programs, together with other management tactics, may allow efficient integrated pest management of *T. absoluta* in Nigeria.

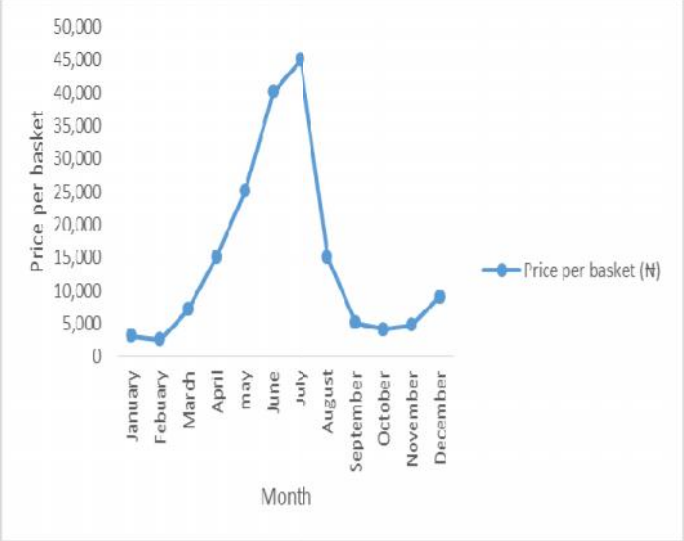

Fig. 1: Tomato Prices during 2015 Outbreak (Naira per Basket).

2. GEOGRAPHICAL DISTRIBUTIONS

The Tomato leaf miner *T. absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is native to South America (Peru) and since 1964 it was declared as major pest in Argentina (9-10). It was first noticed in Spain in 2006; since then, *T. absoluta* spread across Europe, Middle East and Africa. *T. absoluta* was first reported in Algeria and Morocco in 2008 and 2009, respectively (11-12). The pest continues to spread rapidly across African countries. It invaded Egypt in 2010 (13); Sudan and South Sudan in 2011(14- 15), Ethiopia in 2012 (16), Kenya in 2013 *(17),* Tanzania in 2014 (18), Senegal in 2014 (19) and entered Nigeria in 2015 (20). In 2016 it spread to the neighboring Niger Republic (21).

In Nigeria, the major tomato-producing areas lie between latitudes 7.5° 11´ and 13.0 ° N, within a temperature range of 22-30°C (**Fig. 2**). Tomato leaf miner has become widespread and an important pest throughout these regions in both open field and greenhouse tomato production (22).In an interview with Channels TV news station on 24 May 2016, the Minister of Agriculture and Rural Development, Mr. Audu Ogbeh, disclosed that "six tomato producing states, including Plateau, Jigawa, Kano, Abuja and Katsina have been affected" (7).

3. BIOLOGY AND LIFE CYCLE

Tomato leaf miner *T. absoluta* (Meyrick) (Lepidoptera, Gelechiidae) is an important invasive pest of tomato and a noctuid moth that is almost always active at night. In Nigeria, it is commonly called "tomato Ebola or

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Sharon". It mates and lays eggs during the night period. Adults are spackle brown or silver-colored with black spotted wings. The adults are often 5-7 mm long, with wing length of 8-10 mm. *T. absoluta* is a holometabolous insect with high reproduction rate. Females can lay up to 260-300 eggs leading to 12 generations per year depending on environmental conditions (11, 4).

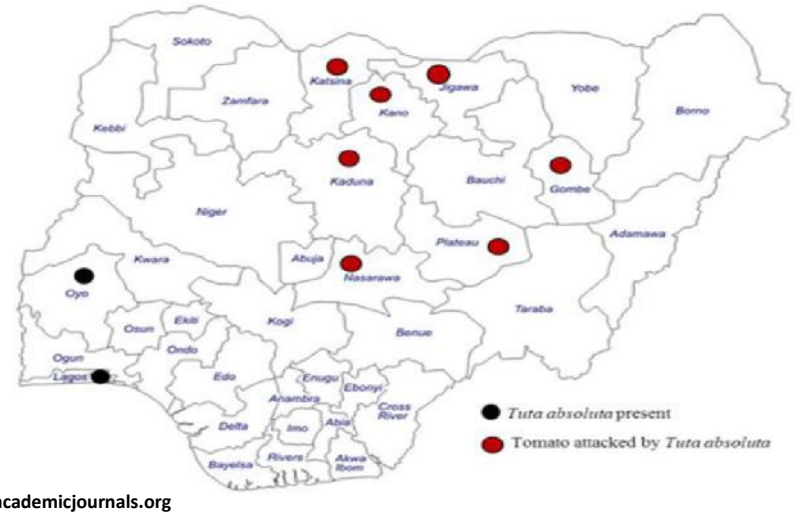

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Fig. 2: Distributions of *Tuta absoluta* in Tomato Growing Areas in Nigeria.

They undergo complete metamorphosis involving four developmental stages which include egg, larva, pupa and adult stages that are completed within 24-30 days at favorable environmental conditions (22, 23). Newly emerged female adults release sex pheromone that attracts the male counterparts towards them for mating (24-25). Females usually deposit their eggs (which are elliptical in shape, measuring up to about 1mm) on tomato leaves within 7 days of mating. The egg color varies from creamy white to bright yellow. The emerging larvae burrow into the leaves where they feed on the mesophyll tissues and develop within 7-11 days (26). The larvae (caterpillars) appear creamy in the first stage before turning greenish and pinkish in the final stage. They measure from 0.6mm to 0.8mm in length in their first larval stage and 7.3mm to 8mm in the fourth stage (24). The caterpillars possess two narrow black bands on the head, one lateral and the other ventral. Pupa (Chrysalis) measures 4mm to 5mm in size and it is initially green in color before turning brown. Pupation lasts for 10-11 days in soil, where chemicals and strong heat cannot herm it. However, *T. absoluta* was reported to exhibit different pupation behaviors depending on the environment, and it can survive the winter as egg, larva or adult depending on the environmental conditions (24).

4. DAMAGE TO TOMATO PRODUCTION IN NIGERIA

The incidence of *T. absoluta* in Nigeria was first reported in 2015 in which the insect pest was found in the Arumeru district and later discovered in the Kadawa Irrigation valley, which is the major tomato-producing area where the famous Dangote's Dansa Tomato Company is sited in Kano State. Damages due to *T. absoluta* invasion are usually caused by the larval instars which attack all parts of the crop (27) (**fig. 3**). Larvae penetrate apical buds, flowers, fruits, leaves and/or stems immediately after hatching. Leaf damages are often due to feeding on the mesophyll tissue, which forms irregular mines on the leaf surface and later become necrotic. In some situations, the larvae form large galleries on the stems and fruits which alter the general development of the plant and develop open wounds that serve as sites for easy invasion by secondary pathogens, leading to fruit rot (28).*T. absoluta* feeds on both green and mature tomato fruits and it can destroy the entire tomato vegetation within two days (**Fig. 2**).The damage caused by this pest is always severe, especially in young plants. The primary host of *T. absoluta* is tomato; however, it also attacks eggplants, peppers, potatoes, beans and tobacco, hence the pest remains persistent in both cultivated and uncultivated areas for long time.

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Fig. 3: Symptoms of *Tuta absoluta* Damages on Leaf, Fruit and Stem.

5. Control Measures of *Tuta absoluta*

There is no single control method that is 100% effective for the control of this invasive pest. Given its vicious nature and crop destruction potential in the invaded regions, however, various control strategies can be used to manage *T. absoluta* (6). According to the National Horticultural Research Institute, Nigeria (NIHORT), the integrated pest management of *T. absoluta* must focused on realizing the following national goals: 1) to contain the economic damage of leaf miner, 2) to prevent the development of resistant strains of *T. absoluta* and 3) to prevent the accumulation of insecticide residues in the food chain. The management strategies can be categorized as follows;

a. Chemical control.

b. The use of pheromone traps and mass trapping (Tuta trap tray).

c. Cultural control.

d. Biological control.

e. Resistant varieties.

f. Bio-pesticides.

5.1 CHEMICAL CONTROL

Chemical control of *T. absoluta* often fails not only due to the resistance of the pest against many pesticides, but also because a big part of its development takes place inside the plant or the soil; out of reach of pesticides. A resistance management strategy for *T. absoluta* is critical in the search for a sustainable solution to chemical control of *T. absoluta* in the medium. The new active ingredient which is likely to be the mainstay of the IPM programme is Chlorantraniliprole (Trade name: Rynaxypyr®) from Dupont. At present, there are no records of resistance of *T. absoluta* to this active ingredient and it is also known to be compatible with other natural enemies. Although a number of pesticides have been registered for the management of the pest, they are of low to moderate effectiveness due to the cryptic nature of the larvae and the high biotic potential of the insect. In addition, several cases of insecticide resistance have been reported, including resistance to organophosphates, Ampligo, Pyrethroids, Abamectin, Chlorantraniliprole, Flubendiamide, Permethrin and Spinosad (29-31).

5.2 PHEROMONE

Sex pheromones are powerful chemicals secreted by female insects to attract the male counterparts for mating. They can either be natural or synthetic. These chemicals are detected by the males, assisting them in locating the females for mating. Many pheromones from different species have been identified and are synthetically produced for use in insect pest management. The majority of female sex pheromones identified in Lepidoptera consist of a mixture of two or more compounds, which not only evoke long-range male attraction

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but also elicit courtship behavior (31). As an example, the female sex pheromone of *T. absoluta* consists of two components. The major component, which represents about 90% of the volatile material found in the sex gland of calling females, was (3*E*, 8*Z*, 11Z)-3,8,11-tetradecatrien-l-yl acetate or TDTA. Sex pheromones have been widely used to monitor, forecast or control populations of moth pests (33). The most widespread and successful applications of sex pheromones concern their use in detection and population monitoring (34). They are also used to control insect populations, which is achieved by two main techniques; mass annihilation and mating disruption (34). Sex pheromone management strategies are based on the sexual reproduction of the targeted pest. However, a study by Caparros, Megido *et al.* (35) recently confirmed that *T. absoluta* females were also able to reproduce without mating (i.e. parthenogenically). Asexual reproduction as well as the polygenic nature of *T. absoluta* males could have strong implications on the efficiency of sex pheromone management strategies and must be considered for further studies on these control measures (36-37). Although the female sex pheromone of *T. absoluta* was identified in 1995, virgin females were already used to capture more than 100 males per trap per day (38). Uchôa-Fernandes *et al.,* (39) also used virgin females to compare different trap designs, heights, and displacement in tomato fields for capturing *T. absoluta* males. A high specificity and sensitivity of traps baited with virgin females was recorded and they seemed to be more economical and convenient than light traps. Moreover, wind tunnel experiments under laboratory conditions indicated that the mixture of the two pheromone components was more effective in evoking long-range female location and short-range courtship behavior in males than TDTA alone (36). However, it has been observed in laboratory experiments that *T. absoluta* males were far less sensitive to the absence of the minor component than most other lepidopteran (39).To monitor *T. absoluta*, pheromone lures are principally coupled with Delta traps (40-41). Various companies such as ISCA Technologies (United States), Russell IPM Ltd. (United Kingdom), Koppert Biological Systems (The Netherlands), and PRI Pherobank (The Netherlands) manufacture these traps (28).

5.3 TUTA TRAP TRAY AND TRAY TRAP TECHNOLOGY (TTT)

Syngenta Bioline conducted trials in 2013 to test Black Sticky Traps as a new tool for capturing *T. absoluta* in tomato crops. High capture rates were achieved. Correct placement of the traps is critical for successful captivity. Traps placed at 15-20cm above the ground captured 5 times as many adult pests as traps placed at 1m above the ground. Interestingly, the traps do not attract predators of the *T. absoluta* such as Nesidiocoris. Similarly, the National Horticultural Research Institute, Nigeria (NIHORT) developed simple technology known as Tray Trap Technology (TTT) that can attract, trap and kill more than five thousand adults per tray. It was the only control measure employed and recorded massive successes in curtailing the menace of this pest in Nigeria. It was sold to the farmers at an affordable price within the outbreak areas. The technology was easy to handle. It involves a tray filled with water containing small amount of detergent (without foam). A lamp is placed on a solid support at the center but not completely dipped into the water (**Fig. 4**).The whole system is placed in the farm, away from canopies. The lamp is put on at night to attract the adult *T. absoluta* pests. The adults flap around the light and suddenly fall into the solution and remain captive**.**

Fig. 4: Tray Trap Technique (TTT) in Nigeria.

5.4 BIOLOGICAL CONTROL MEASURES

Predators of *T. absoluta* are present in Africa but may not be found in the field in sufficient number at the time when the adult Tuta moths move into the crop and begin laying eggs. For example, predatory mites, bugs as well as parasitic wasps usually migrate into the crop in high number only when there is a lot of the specific prey present. This may be too late to prevent damage from occurring. To tackle this problem, the predators

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could be reared in mass and released into the farm prior to domination by the pests. Several scientific reports established the importance of these control agents in reducing the risks of the epidemics to a significantly low level for a considerable period of time (42-44). However, the control agents here may also be severely affected when this approach is integrated with the chemical control method. Pyrethroids (e.g. Alphacypermethrin, deltamethrin, cypermethrin etc.) can kill up to 75% of many natural enemies and the harmful effect could last for up to 12 weeks after a single spray. Massive production of the bio-agents could be expensive; therefore the grower must be aware of the importance of using compatible pesticides that do not kill the introduced natural enemies or those which may try to migrate into the crop field from the local environment. The following bio-agents could be used to control:

a. *Trichogramma pretiosum*
b. *Trichogramma achaeae*
c. *Macrolophus pygmaeus*
d. *Nesidiocoris tenuis*
e. *Nabis pseudoferus*
f. *Amblyseius* spp

5.4.1*Trichogramma achaeae*

The egg parasitoid *Trichogramma achaeae* has been identified as a candidate for biological control of the South American Tomato Pinworm, *T. absoluta*. On greenhouse conditions a high efficacy of 91.74 % damage reduction was obtained when 30 adults were released per plant (equivalent to 75 adults/ m^2) in every 3-4 days in south-eastern Spain (44).Biological control of *T. absoluta* using the damsel bug, *Nabis pseudoferus*, has also been conducted in Spanish greenhouses(44). Two semi field bioassays on tomato plants, under controlled conditions, have shown significant reduction in the number of eggs of *T. absoluta*, between 92 and 96 %, when 8-12 first stage nymphs of *N. pseudoferus* were released per plant (44).Trichogramma is normally introduced onto crops as an irradiated *Ephestia kuehniella* caterpillar egg parasitized by the Trichogramma wasp. These wasps are extremely sensitive to broad-spectrum chemicals and can only be used in a spray programme that has been carefully designed to conserve Trichogramma parasitoids. Moreover, Trichogramma parasitoids can be used in combination with *M. pygmaeus* to enhance biological control of *T. absoluta* in tomato crops.

5.4.2 *Amblyseius* spp

Amblyseius swirskii is a beneficial predatory mite endemic to the Eastern Mediterranean region. This species is considered a generalized predator, and readily consumes small soft-bodied arthropod pest species as well as pollen or plant exudates. *A. swirskii* has attracted substantial interest as a biological control agent of mites, thrips and whiteflies in greenhouse and nursery crops and is currently reared and sold commercially in Europe and North America for this purpose (45). Both *Amblyseius swirskii* and *A. cucumeris* have been observed feeding on very young *T. absoluta* caterpillars. In laboratory studies, these and other predator mites have been observed feeding on the eggs of *T. absoluta*, though they could not complete their life cycle on Tuta eggs alone (46-47)

5.4.3 *Nesidiocoris spp*

Nesidiocoris tenuis (Reuter) (Hemiptera: Miridae) is an effective predator of pests of tomato crops and a promising biocontrol agent of *T. absoluta* in the Mediterranean area. *N. tenuis* has catholic habits, feeding on almost every small arthropod dwelling on tomato plants (48).This bug is indigenous to Kenya and is also commercially reared and has been widely used in Spain against *T. absoluta* in tomato farms (49). It has also been tested for this purpose in Southeastern Algeria. However, one should be cautious when using them as biocontrol agents; because they are capable of causing serious economic damage to tomato plants if they remain in large number after a successful targeted control. Natural migration of *N. tenuis* to tomato vegetation is unlikely to be of any risk to the crops due to a much lower population of the bugs as compared to their artificially large inundatory release.

5.4.4 *Macrolophus spp*

Both *Macrolophus pygmaeus* and *M. caliginosus* have been observed feeding on young Tuta caterpillars. *Macrolophus* can be a common insect in natural vegetation and has been recorded as becoming established inside tomato greenhouses in Northern Europe (50). Both *Nesidiocoris* and *Macrolophus* have been observed to be preying on *T. absoluta*, immediately after its detection in the Spanish Mediterranean coastal region (51-52). *M. pygmaeus* And *N. tenuis* have already been tested under laboratory conditions to assess their suitability as *T.*

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absoluta predators (51). Adults of both predator species were able to prey on more than 100 eggs per individual per day with no significant differences between them. In contrast, nymphs of *M. pygmaeus* consumed significantly fewer eggs than nymphs of *N. tenuis* (51). Furthermore, both species preyed on larvae at all larval stages, with greater preference for first- instar larvae (43, 52), although the number of larvae preyed upon was significantly lower that of eggs preyed upon. Molla *et al*. (43) showed that when *M. pygmaeus* and *N. tenuis* were established in the crop, they were able to reduce up to 75% and 97% of leaflet infestations or 56% and 100% of fruit infestations, respectively.

5.4.5 *Bacillus thuringiensis*

Bacillus thuringiensis var. kurstaki has exhibited satisfactory efficacy against *T. absoluta* larval infestations in Spanish outbreaks. Tuta caterpillars get infected by *B. thuringiensis* through contact and ingestion of a lethal dose of the pathogen. Delayed application of *B. thuringiensis* may cause higher insect mortality if the insects become more susceptible to the pathogen after a longer period of feeding on the resistant crop (53). Joel and Rosa (54) reported that in a combined application of mass release of *T. pretiosum* Riley and *B. thuringiensis* resulted in fruit damage only by 2 % in South America. Therefore the only life stage that is likely to be affected by *B. thuringiensis* is the first instar, free -living stage. Due to many over-lapping generations of *T. absoluta*, this will require a very intensive spray programme to provide sufficient coverage of the vulnerable life stage. This raises questions of resistance management and cost-effectiveness of the programme (54). *B. thuringiensis* is proved to be highly efficient in reducing the damage produced by first, second, and third *T. absoluta* larval instars, with statistically significant differences between controls and treated plants in all cases.

5.4.6 ENTOMOPATHOGENIC NEMATODES (EPN) AND FUNGI

Insect killing nematodes are massively produced commercially, and have been used in high value protected crops against a range of pests. Entomopathogenic nematodes have been tested for the management of *T. absoluta*. Both Laboratory and field trials revealed high larval mortality (78.6-100%) but low pupal mortality (10%) when *Steinernema feltiae* was evaluated against the pest (55). However, the efficiency of Entomopathogenic fungi on *T. absoluta* has not been widely investigated. Several fungal species, including *Metarhizium anisopliae* and *Beauveria bassiana are* reported to attack the eggs, larvae and adults of the pest. Studies revealed up to 54% mortality of *T. absoluta* adults by *M. anisopliae* (56). The Entomopathogenic fungus *Metarhizium anisopliae* could result in female mortality of up to 37.14%. Laboratory studies indicated *Beauveria bassiana* caused 68% larval mortality (57-58). Scientists have recorded complete control of *T. absoluta* pupae in laboratory bioassays with another commercial Metarhizium (57). Scientists in Algeria have reported similar results with Metarhizium (58). The eggs and early instars of *T. absoluta* were also readily infected and destroyed by *M. anisopliae*. Some investigations carried out in Turkey compared the efficacy of *B. bassiana* and *M. anisopliae* on Tuta eggs and first instar larvae; these entomo-pathogens were 42 –67% and 92 to 100% efficient in controlling tuta larvae, respectively. However, only *Metarhizium* seemed to be effective against the tuta egg stage, providing 92% effective control, whilst *Beauveria* provided only 12.5% control of tuta eggs. These results show the potential of *M. anisopliae* to control pupae of the tomato leaf miner in integrated pest management programs.

5.4.7 BIO-PESTICIDES

Azadirachtin is a complex of tetranortri-terpenoidlimonoid from neem seeds and it is the major active component responsible for both anti-feeding and toxic effects in insects. Other limonoid and sulphur-containing compounds with repellent, antiseptic, contraceptive, antipyretic and anti-parasitic properties are also found in other parts of the tree such as the leaves, flowers, bark, roots (59). The neem seed extract, Azadirachtin, acts as a contact and systemic insecticide against *T. absoluta*. A soil application of Azadirachtin caused 48.9-100 % larval mortality (60). Application of Neem oil on the adaxial surface of the foliage causes 57-100% larval mortality. However, it was reported that direct application on larvae caused 52.4-95 % mortality (61). Azadirachtin has a knockdown power towards larvae of *T. absoluta* as in a laboratory test, aqueous neem seed extract induced high larval mortality by both systemic and trans laminar actions (61). Azadirachtin prevents oviposition by inhibiting oogenesis and synthesis of ovarian ecdysteroid. In males, Azadirachtin acts by interrupting the meiotic process responsible for sperm production (62). Previous studies showed that, in laboratory tests, isolates of *B. bassiana* induce high mortality to tomato leaf miner eggs and larvae (57-58) where the eggs appear more susceptible than the first instars larvae (56). Thus, the use of Azadirachtin significantly reduces *T. absoluta* population on tomato plants in the field. Azadirachtin is much more effective in controlling larvae at first and second instar. Azadirachtin treatment against the third and fourth instars is less

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effective. Generally, the efficacy of azadirachtin treatment is low during the first few days of application; it suddenly increases until the 14th day, during which it exerts its maximum efficacy (63).Recently, the National Horticultural Research Institute, Nigeria (NIHORT) developed three new bio-pesticides for the control of *T. absoluta* at different stages (**Fig. 5**). The bio-pesticides were NIHORT-Raktin, NIHORT-Lyptol and O-Ruptur. NIHORT-Raktin is an emulsifiable suspension from neem tree that contains azadirachtin as the primary active ingredient. NIHORT-Raktin is a natural extract that controls *T. absoluta,* army worm, aphids, biting and sucking insects. It is capable of poisoning *T. absoluta* larvae by mere contact. NIHORT-Raktin is sprayed on tomato leaves after a dilution of 1 litre NIHORT-Raktin in 15 liters of water. NIHORT-Lyptol is another emulsifiable suspension from Eucalyptus tree, with Cineole as the major active ingredient. It has powerful poisoning effect against *T. absoluta* larvae after direct contact. It is also sprayed on tomato leaves after a dilution similar to NIHORT-Raktin. O-Ruptur is a wettable concentrate containing the active ingredient Tropine. It has contact poison against tomato leaf miner pupae. O-Ruptur can be applied at the rate of 250 g in 7 liters of water to an area of 4 m^2.

5.5 PHYTOSANITARY MEASURES

Prevention is the best way to counter the Tuta epidemic because it is almost impossible to get rid of the pest and save the harvest at the same time without significant damage. Clearing all the crop residues reduces the pest survival rate. These include crop rotation, covering plants or sealing greenhouses with insect proof netting to exclude the pest. The selective removal and destruction of infested plant parts and the total destruction of plants after harvest (64) and the management of alternate wild hosts on the other hand. Establishment and maintenance of habitats within and surrounding open-field grown tomato crops that supply food and provide shelter for oviposition and overwintering encourage natural antagonists of *T. absoluta* (52).

Fig. 5: NIHORT-Raktin, NIHORT-Lyptol and O-Ruptur (National Horticultural Research Institute, Ibadan, Nigeria).

5.6 RESISTANT VARIETIES

Breeding tomatoes for *T. absoluta* resistance has so far been unsuccessful and so there are no commercial tomato hybrids available that have an acceptable degree of resistance to *T. absoluta* (65). This is thought to be due mainly to a lack of genetic variability for this trait within the gene pool used for domestic tomato production, resulting from long periods of breeding/selection for other traits. However, to-date, there seems limited or no clear information as whether there are successful tomato varieties which are resistant to *T. absoluta*. Efforts to develop resistant varieties are going on in different parts of the world, and this may need more research efforts to identify the adaptation mechanisms and areas of weakness for effective control (19).

5.7 GENETIC CONTROL USING RNA INTERFERENCE (RNAi)

RNA interference (RNAi) technology has demonstrated an effective potential to control insect pests. However, the efficiency of RNAi can vary greatly between the different insect orders. It is a new and promising technique because interfering with important insect RNA transcripts using RNAi may lead to the death of the pests (67).Camargo *et al.* (8) show-cased the possibility of using RNAi as an alternative method for controlling the

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tomato leafminer- *T. absoluta*. They selected two target genes (coding for Vacuolar ATPase-A and Arginine kinase) based on the RNAi response reported for these genes in other pest species. The first was based on the uptake of dsRNA by leaflets and the second was based on ''in planta-induced transient gene silencing'' (PITGS), method. It has been demonstrated that the *T. absoluta* larvae that fed on the leaves containing *dsRNA* of the target genes had about 60% reduction in the accumulation of the target gene transcript and an increased larval mortality resulting in less leaf damage. Furthermore, they generated transgenic 'Micro-Tom' tomato plants that expressed hairpin sequences for both transcripts and observed a reduction in foliar damage by *T. absoluta* in those plants (8).

6.0 CONCLUSIONS

T. absoluta is an impending threat to tomato production in Nigeria. The ongoing spread of *T. absoluta* throughout Africa and its status as a severe pest for tomato is followed by the lack of fully satisfactory effective management options. Appearance of *T. absoluta* has spurred extensive insecticide use by local tomato growers; potentially causing a multitude of undesired side effects. Currently, no single control option has proven to be effective against *T. absoluta*. Use of host resistant varieties and or integrated pest management (IPM) strategies is slightly or not in use, thus making the pest reign in the majority of African countries. Multilateral measures are proposed in controlling the tomato leaf miner which consider combination of biological control methods, massive trapping and chemical or microbiological treatments with authorized products on crops. Others include agricultural extensions to communicate practical agricultural solutions to farmers; policy makers to establish appropriate control policies; and farmers to apply developed/recommended solutions for sustainable tomato production in Africa. In the longer term, use of resistant tomato varieties could be the most sustainable option. Effective accomplishment of these preventive/control measures requires coordinated efforts of the European and African research scientists, management specialists and growers.

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FIGURE CAPTIONS

1. Distributions of *T. absoluta* in Tomato Growing Areas in Nigeria
2. Symptoms of *T. absoluta* Damages on Leaf, Fruit and Stem
3. Tomato Prices during 2015 *T. absoluta* Outbreak (Naira per Basket)
4. Tray Trap Technique (TTT) in Nigeria
5. NIHORT-Raktin, NIHORT-Lyptol and O-Ruptur (National Horticultural Research Institute, Ibadan, Nigeria).