Asian Journal of Agricultural and Horticultural Research

1(4): 1-14, 2018; Article no.AJAHR.41959
ISSN: 2581-4478

Biological Invasion of Tomato Leaf Miner, *Tuta absoluta* (Meyrick) in Nigeria: Problems and Management Strategies Optimization: A Review

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Authors' contributions

This work was carried out in collaboration between all authors. Author NBS initiated and designed the study, performed the basic review, wrote the protocol and first draft of the manuscript. Authors BSW, AMA and MS critically reviewed the manuscript. Authors HSH and HS managed the literature searches and provided the field information. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJAHR/2018/41959
Editor(s):
(1) Dr. T. Selvamuthukumaran, Assistant Professor, Department of Entomology, Faculty of Agriculture, Annamalai University, Tamil Nadu, India.
Reviewers:
(1) Adriana Neske, National University of Tucumán, Argentina.
(2) Rubens Barros, State University of Alagoas, Brazil.
(3) Vanessa de Andrade Royo, Universidade Estadual de Montes Claros, Brazil.
Complete Peer review History: http://prh.sdiarticle3.com/review-history/25257

Review Article

Received 5th April 2018
Accepted 15th June 2018
Published 25th June 2018

ABSTRACT

Nigeria is the largest producer of tomato in Africa while the Northern regions are the main producers of tomatoes in the country. Tomato (*Lycopersicon esculentum* Mill.) is widely cultivated and consumed in every part of Nigeria. It is an important commercial crop and good source of vitamins, minerals, essential amino acids, sugar and dietary fibers. The study aimed to report the outbreak of Tomato leafminer (*Tuta absoluta*) in tomato growing regions of Nigeria with a view to bring out its management strategies in Nigeria. The study was conducted in the major tomato

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producing regions which lies between latitudes 7.5°11´ and 13.0°N and a temperature range of 22 - 30°C. *Tuta absoluta* has been attributed to causing tomato shortage in Nigeria as a result of its devastating attack. The outbreak caused critical reduction in fruit yield which resulted in high cost of tomato. The damage is done by the larvae which tunnel into the stems, apical buds as well as the green and ripe fruits reducing their quality and subsequently the yields. Nonetheless, about 80 -100% yield loss had been reported. *Tuta absoluta* was reported to have developed resistance to a number of pesticides used in the country. Meanwhile, the Government had either less concern or neglect on the pest invasion or areas of researches especially on invasive species, thus poor funding which overstresses the existing challenges in controlling the pest. This paper intends to review some important highlights of Integrated Pest management (IPM) approaches for effective and efficient management strategies of the pest in Nigeria and beyond.

Keywords: Tomato in Nigeria; Tuta absoluta; tomato leaf miner; tray trap technique; NIHORT-Lyptol and NIHORT-Raktin.

1. INTRODUCTION

Nigeria is the largest producer of tomato in Africa and significantly contributes to the production of other major agricultural commodities [1]. Agro-ecological regions within the country are diverse and different regions possess environmental advantages in terms of optimum climatic and soil adaptability for the production of specific crops. The Northern regions are the main producers of tomatoes [2,3]. 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 [1]. The production is beset with many biotic and abiotic stresses such as diseases, nematode and insect pests, thus resulting in reduced yield. 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 losses, poor handling and lack of modern storage and processing facilities [4]. In 2014 for instance, Nigerian farmers averagely generated a significantly lowest yield of 4.0 m tons/ha of tomato as compared to the quantity produced by Egypt (38.7 m tons/ha) and South Africa (78.7 m tons/ha) [2].

1.1 Invasive/Introduced Species

The invasive species are non-native that significantly modify or disrupt new ecosystems colonized. They may arrive in new areas through natural migration but are often introduced by human activities and/or other species [3]. In 2016, a sporadic attack by an invasive tomato leaf miner, *T. absoluta* was reported to cause more than 80% yield loss in Nigeria [3]. This had caused price hikes of up to 400% in three months as *T. absoluta* destroyed the annual harvest affecting entire tomato farms across northern states in the country (Fig. 1) (5). The incident resulted in tomato shortage to the then newly commissioned Africa largest tomato processing company (Dangote Farms Tomato Processing Factory in Kano, Nigeria). Nonetheless, *Tuta absoluta* was resurfaced in 2017 and spreads to the north Eastern states especially Gombe state [6].

According to the Federal Ministry of Agriculture and Rural Development (FMARD) Nigeria currently produces 1.8 million tons annually, signifying that the output lost from the pest invasion is equivalent to 720, 000 metric tons (MT). However, the root cause of *T. absoluta* introduction to Nigeria is unknown and had become the most devastating pest with severe destructions in tomato producing areas [6]. Huge economic losses and rapid spread of the devastating pest had been recorded in recent years. Complete eradication of the pest might be possible by the adoption of Integrated Pest Management (IPM) strategies. These involve the use of modern methods such as Tray Trap Technology (TTT) and biological control methods such as use of parasitoids and predators as well as minimized synthetic chemicals usage. Recently, National Horticultural Research Institute, Nigeria (NIHORT) developed and tested the efficacy of three bio-pesticides techniques: NIHORT-Raktin, NIHORT-Lyptol, and O-Ruptur [7]. Similarly, gene silencing methods using RNA

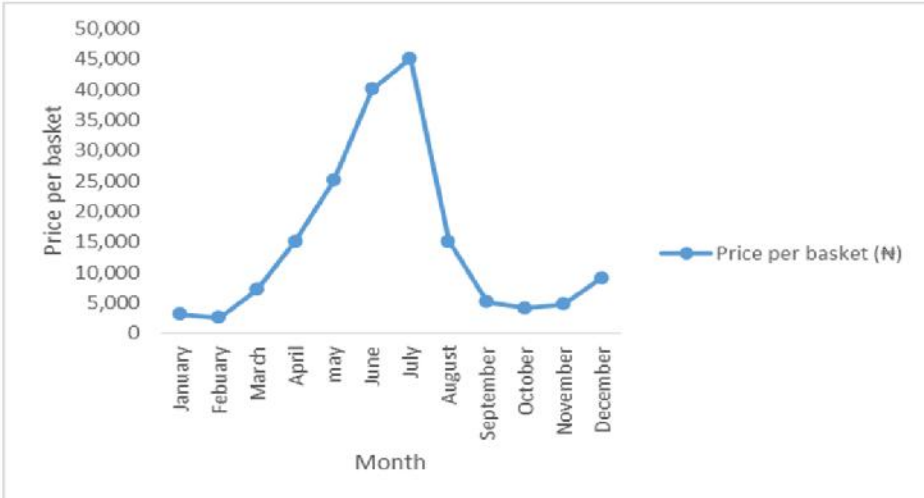

Fig. 1. Change in Tomato price during 2015 *Tuta absoluta* outbreak in Nigeria (Naira per basket)

Source: Sanda et al. [5]

interference (RNAi) technology had also demonstrated potentials in controlling insect pests [8]. The present study had reviewed the ecology; biology and potential management strategies of *T. absoluta* for the implementation of efficient, effective and sustainable IPM strategies in Nigeria and elsewhere.

2. RESULTS AND DISCUSSION

2.1 Geographical Distributions

The Tomato leafminer, *T. absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is native to South America (Peru) and was declared a major pest of tomato in 1964 in Argentina [9,10]. It was first noticed in Spain in 2006; since then, *T. absoluta* spread across Europe, Middle East and continues to spread rapidly across African countries and is found everywhere across the world including Nigeria. In Nigeria, it is commonly called "tomato Ebola or Sharon" (Table 1) [8].

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. 3) [22]. Tomato leafminer had become widespread and an important pest throughout the regions [23]. According to the Ministry of Agriculture and Rural Development of the Federal republic of Nigeria six tomato producing states inclusive of Kano, Katsina, Jigawa, Gombe, Plateau and Abuja had been adversely affected by the pest in 2017 [Channels TV news station on 24 May 2016] [21].

Table 1. The world's geographical distribution of *Tuta absoluta*

S/N0	Region	Country	Year Introduced	Reference
1	South America	Brazil (Peru)	Native	[9,10]
2	South America	Argentina	Declared pest 1964	[9,10]
3	Europe	Spain	2006	[11]
4	North Africa	Algeria	2008	[12,13]
5	North Africa	Morocco	2009	[12,13]
6	North Africa	Egypt	2010	[14]
7	West Africa	Sudan/Southern Sudan	2011	[15,16]
8	East Africa	Ethiopia	2012	[17]
9	East Africa	Kenya	2013	[18]
10	East Africa	Tanzania	2014	[19]
11	West Africa	Senegal	2014	[20]
12	West Africa	Nigeria	2015	[21]
13	West Africa	Niger Republic	2016	[22]

3. BIOLOGY AND LIFE CYCLE

Tuta absoluta is an important invasive pest of tomato and a noctuid moth that is almost always active at night. It mates and lays eggs during the night period. Adults (Fig. 2a) 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 [10,4].

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 [24]. The newly emerged female adults release sex pheromone that attracts the male during mating [25,26]. 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

Fig. 2. (A) Adult of *Tuta absoluta* (B) *Tuta absoluta* larvae damaging tomato fruit
Source: [24,26]

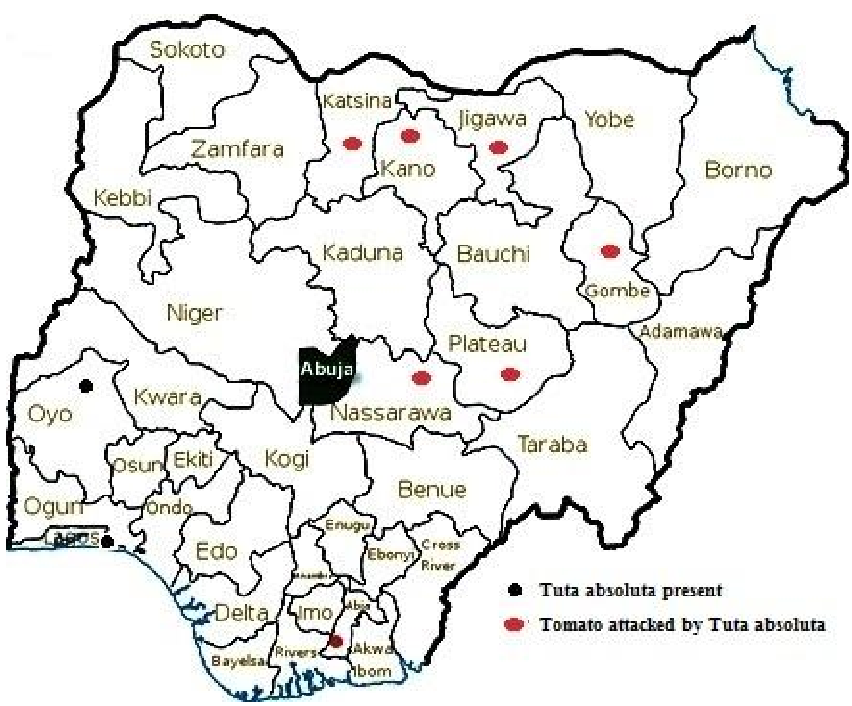

Fig. 3. Presence of *Tuta absoluta* and areas attacked in tomato growing zones of Nigeria
Source: [3,27,28]

days [29]. The larvae (caterpillars) (Fig. 2b) 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 [26]. The caterpillars possess two narrow black bands on the head, one lateral and the other ventral. The pupa (Chrysalis) measures 4mm to 5mm in size and is initially green in color before turning brown. Pupation lasts for 10-11 days in soil to get rid of chemicals and strong heat. However, *T. absoluta* was reported to exhibit different pupation behaviors depending on the environment and can survive the winter as egg, larva or adult depending on the environmental conditions [26].

4. IMPACTS OF *Tuta absoluta* ON TOMATO PRODUCTION IN NIGERIA

In Nigeria, *T. absoluta* was first reported in 2015 in the Arumeru district and later discovered in Kadawa irrigation valley of Kano state, the major tomato producing area in the country and where the famous Dangote's Dansa Tomato Company is sited. The pest inflict its damage at the larval instar stage and it entirely attacks the tomato plant thus damaging all of the productive plant parts [29] (Fig. 4). Specifically, the larvae penetrate the apical buds, flowers, fruits, leaves and/or stems immediately after hatching. Leaf damages are often due to the feeding habit on the mesophyll tissue which forms irregular mines on leaf surfaces and later become necrotic. Moreover, sometimes the larvae form large galleries on the stem and fruits which alter plants' general development and it also develop open wounds that serve as entry points of pathogens leading secondary infections [30]. *T. absoluta* feeds on both green and mature tomato fruits and can destroy the entire tomato vegetation within two days (Fig. 3) and the damage is always severe especially in young plants. Tomato is considered the primary host for *T. absoluta*; however, it also attacks eggplants, peppers, potatoes, beans and tobacco, hence the pest remains persistent in both cultivated and uncultivated areas for long time.

5. MANAGEMENT STRATEGIES OF *TUTA ABSOLUTA*

Considering the vicious nature and crop destruction potential of *T. absoluta* in the invaded regions, there exist no feasible, effective, efficient and sustainable control method(s) that can effectively be used by resource poor farmers to manage pest in Nigeria. However, there various control strategies which if properly and effectively implemented can help manage *T. absoluta* in the country and beyond [7]. According to the NIHORT, the integrated pest management of *T. absoluta* must focused on realizing the following national goals: 1) to contain the economic damage of leafminer, 2) to prevent the development of resistant strains of *T. absoluta* and 3) to prevent the accumulation of insecticide residues in the food chain. Therefore, these management strategies can be categorized as follows; i) Chemical control ii) The use of pheromone traps and mass trapping (Tuta trap tray) ii) Cultural control iv) Biological control v) Resistant varieties and vi) 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.

Fig. 4. Symptoms of *Tuta absoluta* damage on; - A) leaf B) fruit C) stem of tomato
Source: Sanda et al. [9]

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 by *T. absoluta* to it and is known to be compatible with other natural enemies. Although a number of pesticides had 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 [31, 32,33].

5.2 Pheromone

Sex pheromones are powerful chemicals secreted by female insect 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 but also elicit courtship behavior [33]. The female sex pheromone of *T. absoluta* for instance, 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 [34]. Sex pheromones have been widely used to monitor, forecast or control populations of moth pests [35]. The most widespread and successful application of sex pheromones is that used in the detection and population monitoring [36]. The insect populations could be controlled or monitored by two main techniques; the mass annihilation and mating disruption techniques [35]. Sex pheromones management strategies are based on the sexual reproduction of the targeted pest. However, a study by [37,38,39] 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 pheromones management strategies and must be considered imperative for further studies especially in *T. absoluta* management [38,39]. 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 [40]. According to [41] virgin females could be used 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 [38]. 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 Lepidopterans [41]. To monitor *T. absoluta*, pheromone lures are principally coupled with Delta traps [42,43]. Various companies such as ISCA Technologies (United States), Russell IPM Ltd. (United Kingdom), Koppert Biological Systems (The Netherlands), and PRI Pherobank (The Netherlands) had manufactured different kind of these traps for *T. absoluta* management [30].

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 and high capture rates were achieved [44], however, 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 ones placed at 1m above the ground. Interestingly, the traps do not attract predators of the *T. absoluta* such as *Nesidiocoris spp* [44]. Similarly, the NIHORT developed simple, effective, efficient and sustainable technology known as Tray Trap Technology (TTT) that can attract, trap and kill more than five thousand adults per tray [7]. It was the only control measure employed and recorded massive successes in curtailing the menace of leafminer pest in Nigeria. The tool is sold to local farmers at affordable rates within the outbreak areas. Moreover, the technology consists of 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. 5). The whole system is placed in the farm but away from canopies and the lamp attracts adult *T. absoluta* pests during nights. The adults flap around the

Fig. 5. Tray Trap Technique (TTT) in Nigeria A) Installed TTT System B) Dead Tuta adults captured on TTT C) TTT Distributed to Tomato Famers by NIHORT
Source: National Horticultural Research Institute, Ibadan, Nigeria (NIHORT) [5,7]

light and suddenly fall into the solution and remain captive.

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 leafminer moths inflict damage on the crop and to begin to lay 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.

Nonetheless, to tackle this problem, predators could be reared in mass and released prior to domination by the destructive pests. Several scientific reports [45,46,47] had established the importance of the control agents in the management of the epidemics invasive species to a significantly lower threshold levels. However these control agents might be severely affected with improper planning especially when chemical control methods are the ultimate options. Pyrethroids (e.g. Alphacypermethrin, deltamethrin, cypermethrin etc.) can kill up to 75% of the population of 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 are feasible, cost effective and environmentally friendly. There are several bio-agents that are currently used for the control of *T. absoluta* among which are: a) *Trichogramma achaeae b) Amblyseius spp. c) Nesidiocoris tenuis d) Macrolophus pygmaeus e) Bacillus thuringiensis f) Entomopathogenic Nematodes (EPN) and fungi Nabis pseudoferus.*

5.4.1 *Trichogramma achaeae*

In South American the egg parasitoid wasp, *Trichogramma achaeae* had been identified as agent for biological control of the Tomato Pinworm, *T. absoluta*. In a greenhouse research, higher 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 [45]. Moreover, biological control of *T. absoluta* using the damsel bug, *Nabis pseudoferus*, has also been conducted in Spanish greenhouses [45]; while two semi field bioassays on tomato plants under controlled conditions had 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 [46]. 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 spray programmes that are carefully designed to conserve Trichogramma parasitoids. Moreover, Trichogramma parasitoids can be used in combination with *M. pygmaeus* for effective biological control of *T. absoluta* on tomatoes.

5.4.2 *Amblyseius spp*

Amblyseius swirskii is a beneficial predatory mite endemic to the Eastern Mediterranean regions. This species is considered generalized predator and readily predates 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 [47,48]. Both

Amblyseius swirskii and *A. cucumeris* had been observed feeding on very young *T. absoluta* caterpillars. In laboratory studies, these and other predatory mites had been observed feeding on the eggs of *T. absoluta*, though they could not complete their life cycle on leaf miner eggs alone [48,49,50,51].

5.4.3 *Nesidiocoris spp*

Nesidiocoris tenuis (Reuter) (Hemiptera: Miridae) is an effective predator of pests of tomato crops and a promising bio-control agent of *T. absoluta* in the Mediterranean. *N. tenuis* has catholic habits, feeding on almost every small arthropod dwelling on tomato plants [52]. This bug is indigenous to Kenya and is commercially reared and has been widely used in Spain against *T. absoluta* in tomato farms [52]. It has also been tested in south eastern Algeria. However, one should be cautious when using them as bio-control 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 bugs as compared to their artificially large inundatory release.

5.4.4 *Macrolophus spp*

Macrolophus pygmaeus and *M. caliginosus* had been reported feeding on young leafminer caterpillars. *Macrolophus* can be a common insect in natural vegetation and has been recorded as becoming established inside tomato greenhouses in Northern Europe [51]. Moreover, both *Nesidiocoris* and *Macrolophus* had been observed to prey on *T. absoluta* immediately after its detection in the Spanish Mediterranean coastal region [53,54]. *M. pygmaeus* and *N. tenuis* have already been tested under laboratory conditions to assess their suitability as *T. absoluta* predators [55]. Adults 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 that of *N. tenuis* [54]. Furthermore, both species prey on the larvae at all larval stages with greater preference for first- instar larvae [46,56], although the number of larvae preyed upon was significantly lower than that of eggs. Also [46] reported 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. The bacterium ingest a lot of leafminer larva to a lethal dose while 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 [55]. [56] 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 [57,58]. *B. thuringiensis* is proved to be highly efficient in reducing the damage produced by the first, second, and third *T. absoluta* larval instars with statistically significant differences between controls and treated plants in all cases [59].

5.4.6 Entomopathogenic Nematodes (EPN) and fungi

Insect killing nematodes are massively and commercially produced 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 experiments had revealed high larval mortality (78.6-100%). However, low pupal mortality (10%) had been recorded when *Steinernema feltiae* was evaluated against the pest [29,60]. The efficiency of Entomopathogenic fungi on *T. absoluta* has not been widely investigated although, several fungal species including *Metarhizium anisopliae* and *Beauveria bassiana* were reported to attack the eggs, larvae and adults of the Leafminer. Studies revealed up to 54% mortality of *T. absoluta* adults by *M. anisopliae* [61] while the Entomopathogenic fungus *M. anisopliae* could result in female mortality of up to 37.14%. Laboratory studies indicated *B. bassiana* caused 68% larval mortality [61]. It was reported that complete control of *T. absoluta* pupae in laboratory bioassays with another commercial

Metarhizium have been achieved [62]. Moreover, in Algeria similar results were reported [62,63] that the eggs and early instars of *T. absoluta* were also readily infected and destroyed by *M. anisopliae*. According to reports from 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 leafminer in integrated pest management programs.

5.4.7 Bio - pesticidal control

Azadirachtin is a complex of Tetranortri-terpenoidlimonoid from Neem seeds and is a 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 were also found in other parts of the tree (leaves, flowers, bark and roots) [62]. The Neem seed extract, Azadirachtin acts as a contact and systemic insecticide against *T. absoluta*. A soil application caused 48.9-100% larval mortality [63]. 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 [64]. Azadirachtin has a knockdown action on *T. absoluta* larvae while in a laboratory test; aqueous Neem seed extract induced high larval mortality by both systemic and trans-laminar actions [65]. It prevents oviposition by inhibiting oogenesis and synthesis of ovarian ecdysteroid. In males, Azadirachtin interrupts the meiotic process responsible for sperm production [66]. Nonetheless, a laboratory study reported that isolates of *B. bassiana* high mortality to tomato leafminer eggs and larvae [60,61] where the eggs appeared more susceptible than the first instars larvae [58]. Thus, the use of Azadirachtin significantly reduces *T. absoluta* population on tomato plants in the field. It is much more effective on first and second instar larvae compared to the third and fourth instars.

Generally the efficacy in Azadirachtin is low during the first few days of application and later suddenly increases until the 14^{th}day, during which it exerts its maximum efficacy [65]. Recently, the NIHORT developed three new bio-pesticides for the control of *T. absoluta* at different stages (Fig. 6). These are the NIHORT-Raktin, NIHORT-Lyptol and O-Ruptur. The 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 such insects as *T. absoluta,* army worm, aphids, biting and sucking insects. The 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 [7]. O-Ruptur is a wettable concentrate containing the active ingredient Tropine. It has contact poison against tomato leafminer 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

Preventive approaches are best techniques to counter leafminer epidemic as the pest is very difficult to control. Sound farm sanitation reduces the pest survival rate since most eggs and larvae are being destroyed. The selective removal and destruction of infested plant parts and the total destruction of plants after harvest [66] as well as 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* [55].

5.6 Resistant Varieties

Breeding tomatoes for *T. absoluta* resistance had so far been unsuccessful and so there are no commercial tomato hybrids available that have an acceptable degree of resistance to *T. absoluta* [67,68]. 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

Fig. 6. Bio-pesticides for *T. absoluta* control developed by NIHORT A) NIHORT-Raktin B) NIHORT-Lyptol C) O-Ruptur

Source: National Horticultural Research Institute, Ibadan, Nigeria (NIHORT) [5,7]

more research efforts to identify the adaptation mechanisms and areas of weakness for effective control [21].

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 insect RNA transcripts using RNAi may lead to total death of the pests. [8] reported the possibility of using RNAi as an alternative method for controlling the tomato leafminer. 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 [67]. 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. CONCLUSIONS

Currently, *T. absoluta* is present everywhere in Africa and Nigeria where tomato is grown; the pest is a potential impending threat to tomato production that spreads across Africa. Moreover, with all its damaging impacts on tomato production, there exist no effective, efficient and sustainable management options that will help eradicate the pest. Multilateral measures are proposed in controlling tomato leafminer which consider combination of biological control methods, massive trapping and chemical or microbiological applications. Others include legislative and agricultural extension approaches to convey practical agricultural solutions to farmers; policy makers to establish appropriate control policies; and farmers to adopt new innovations towards sustainable tomato production in Africa. The use of breeding and molecular approaches in order to bring forward resistant varieties could be the most sustainable control strategy. Moreover, the bio-pesticides (NIHORT-Raktin, NIHORT-Lyptol and O-Ruptur. NIHORT-Raktin) of the NIHORT should be given wider spread and be cost effective. Therefore, there is need for more collaborative efforts of the European and African research scientists and the management specialists as well as tomato growers to tackle *T. absoluta* menace in Nigeria and beyond.

COMPETING INTERESTS

All authors have declared that no competing interests exist.

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