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Zekeya, Never

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Tomato Leafminer, *Tuta absoluta* (Meyrick 1917), an emerging agricultural pest in Sub-Saharan Africa: Current and prospective management strategies

Never Zekeya*, Patrick A. Ndakidemi, Musa Chacha and Ernest Mbega

Department of Sustainable Agriculture and Biodiversity Conservation, School of Life Science and Bioengineering, The Nelson Mandela African Institution of Science and Technology P. O. Box 447, Arusha, Tanzania.

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Tomato (*Solanum lycopersicum* L.) is an important vegetable crop for income and nutrition of small-holder farmers in sub-Saharan Africa. However, it is attacked by many insect pests that cause high economic losses. This review focuses on one insect pest, namely *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae). Many studies have shown that chemical pesticides have failed to control tomato leafminer in many parts of the world including America, Europe, Asian and Sub-Saharan Africa, where the pest is impacting significantly the tomato value chains as farmers were unaware of the pest and unprepared to control it. The review has also evaluated current approaches used to manage *T. absoluta* in different countries and proposes areas for future investment in research for effective and affordable management to prevent further losses caused by *T. absoluta* in tomato production is Sub-Saharan Africa.

Key words: *Tuta absoluta*, agricultural pest, pesticides resistance, pheromone trap, biocontrols

INTRODUCTION

Tomato leaf miner, *Tuta absoluta* (Meyrick, 1917; Lepidoptera: Gelechiidae) is a devastating pest of tomato and other Solanaceous crops in many areas of the world causing severe damage and yield loss (Cifuentes et al., 2011; Zappala et al., 2012, 2013; El-Arnaouty et al., 2014; Tonnang et al., 2015; Bawin et al., 2015). It is a native of South America and known to cause substantial loses (Urbaneja et al., 2013; Zucchi et al., 2009). *T. absoluta* has been–reported to be common in tomatoes growing in altitudes not exceeding 1000 m above sea level (Tonnang et al., 2015). It spreads mainly by natural dispersal means, such as through winds (Gontijo et al., 2013; Sridhar et al., 2014). Tomato leafminer was recorded first in 1917 and as tomato pest in 1960s in Peru (Seplyarsky et al., 2010; Guedes and Picanço, 2012). Then, it crossed borders to Europe, where for the first time it was reported in 2006 in Spain (Desneux et al., 2011). Later on, the pest extended its invasion to France, Italy, Greece, Malta and Bulgaria (Harizanova et al., 2009; Roditakis et al., 2010; Braham et al., 2012). In Africa, *T. absoluta* was reported first in Algeria and Morocco in 2008 and in 2009, it was reported in Libya

*Corresponding author. Email: neverz@nm-aist.ac.tz.

(Harbi et al., 2012). *T. absoluta* continued to spread in Africa and invaded Egypt in 2010 (Moussa et al., 2013) then reached Sudan and South Sudan in 2011 (Pfeiffer et al., 2013; Brevault et al., 2014), then Ethiopia in 2012 (Goftishu et al., 2014). Other countries in Africa reported to be invaded by tomato leafminer are Kenya (2013) *(*Mohamed et al., 2015*),* Tanzania (2014) (Biondi et al., 2015) and Senegal (2014) (Tonnang et al., 2015). *T. absoluta* cannot easily be controlled by chemical sprays due tothe fact that coontact toxicity annot reach larvae inside the leaves (Ayalew, 2015). The pest has a physiological ability to adapt and survive in harsh environments such as cold temperate and hot tropical regions (Cuthbertson et al., 2013; Ponti et al., 2015). Tonnang et al. (2015) reported that the pest can survive temperature as high as 49°C in summer in Sudan. In another report by Van Damme et al. (2015), *T. absoluta* adults have been reported to survive at temperatures below 5°C. The pest can also tolerant dryness, making it flourish well in hot and dry areas (Miranda et al., 1998). *T. absoluta* larvae feedby mining leaves, stems and fruits. It can attack tomato plants at all developmental stage causing up to 100% loss in tomato fruits, if not controlled (Desneux et al., 2010). It has high reproductive ratewithin a short period of time and capable of producing up to 12 generations per year at favorable temperature (Mollá et al., 2011).

Several chemical pesticides are used to control the pest, but none is suitably adapted for control of the tomato borer due to larvare feeding stratergy inside plant tissues and foliar spray easily washed out by wind and rain (Abbes and Chermiti, 2011; Guedes and Picanço, 2012; Guedes and Siqueira, 2013). Additionally, most chemical pesticides have adverse impacts to both humans, non targeted organisms and environment as well (Abdel-Raheem et al., 2015). It is always agreed that, pest control using resistant tomato varieties is the best and sustainable option (Oliveira et al., 2012). Many accessions have been reported to be good source of germplasm resistant to pests including *T. absoluta* (Rodrigues et al., 2011). The resistance by host tomato plant can be attributed to acylysugar, a substance that was reported to provide resistance against *T. absoluta* (Resende et al., 2006). However, use of resitant variety is a long term approach for that would take time to attain a suitable one for SubSaharan Africa. Hence there is a need to develop a short and long term pest control strategies that will avert losses caused by *T. absoluta* in SubSaharan Africa.

There are efforts to reduce use of insecticides in tomato fields, including cultural control methods such as controlled irrigation, crop rotation argumentative biological control (Van Lenteren and Bueno, 2003) and destruction of infested plant material the environment (Abbes et al., 2012). Cultivation of resistance tomato varieties has been reported in other countries (Guedes and Siqueira, 2013).but not common to Sub-Saharan Africa. Other methods include biological control, such as use of natural enemies including parasitoids predators and entomopathogenic microbes (Guedes and Picanço, 2012). Abbes and Chermiti (2011) reported that use of insect's sex pheromones to control *T. absoluta* in open fields. Similarly, the pheromones are reported to perform well in greenhouses (Cocco et al., 2013). Although these methods are applied, they are not guaranteed to reduce this pest and may be costly and not readily available, especially for small holder tomato farmers in sub-Saharan Africa. There is need to propose a systematic, sustainable and integrated pest management stratergy to control this invasive pest in Subsahan Africa. Therefore, this review comprehensively describes the economic importance of *T. absoluta*, control methods that exist and finally proposes an IPM strategy that can be applied to manage the pest in Sub-Saharan Africa.

Economic importance of *Tuta absoluta*

Tomato is the major horticultural crop in Tanzania where it is estimated that 17.5 Mt/ha is produced per year (Materu et al., 2016). However, invasion of tomato borer has declined production by 50% (Materu et al., 2016). *T.absoluta* is a new pest in sub-Saharan Africa. It is greatly damaging tomato crop to levels that farmers are giving up production due to costs and losses it causes in tomato production (Muniappan and Heinrichs, 2015). It is well known that small-holder farmers rely on tomato for income in many parts of sub-Saharan Africa (Oerke et al., 2012), due to its high nutritive value and role in small-scale trade (Cetin and Vardar, 2008). Tomato is cultivated throughout the year in varied range of environments from valley, mountains, in arid and semiarid areas as long as environmental conditions favors (Calatrava et al., 2011; Laube and Awo, 2012). During rainy season, farmers work out to control diseases whereas dry season is highly susceptible to pest including tomato borer. The two varying seasons increases infestation pressure to the pest causing economic losses of to up to 100% in some countries in sub-Saharan Africa (Ayalew, 2015). It has been reported that, farmers in Tanzania increase pesticides use by misusing, doubling doses and wrong application for the purpose of protecting their crops from demage (Materu et al., 2016). However, little succes has been archieved, but would increase the problem such as development resistance among pest populations (Muniappan and Heinrichs, 2015). Moreover, in Tanzania where the pest was noticed in farmers' fields recently, it seemed doubtlessly that tomato growers were not prepared for the pest thus they never had any appropriate control against it (Materu et al., 2016). Considering time of entry to Africa of *T .absoluta* being less than ten years, it is again probably that tomato growers in the sub-Saharan Africa are unable to grow the crop due to fear of loses. There is need therefore to impose immediate attention and practical solutions in favor of tomato production within its value chain in sub-Saharan Africa.

Use of chemical pesticide

Chemical pesticides are common in pest control. Common chemicals are pyrethroids (Guedes and Picanço, 2012), organophosphates, spinosad, emamectin benzoate and abamectin (Campos et al.,2014), chloride channel activators, benzoylureas (Haddi 2012) and diamide (Roditakis et al., 2015). Application of these chemicals against *T. absoluta* has been reported with little success, mainly because of pest resistance and to some point could be utilized by plant as well (Siqueira et al., 2000). Tomato borer resistance has been reported widely used chemicals such as spinosad Cartap and Abamectin, creating further threat to farmers (Siqueira et al., 2000; Reyes et al., 2011; Haddi et al., 2012; Campos et al., 2015; Guedes and Siqueira, 2013).

Pest resistance has been reported to cause increased use of chemical pesticides applications against *T. absoluta* in many parts of the world (Consoli et al., 1998; Siqueira et al., 2000; Lietti et al., 2005). In Spain, about 15 applications and in Brazil up to 30 applications have been reported (Guedes and Picanço, 2012; Silva et al., 2011). The pest resistance against spinosad chemical reached up to 180,000 resistances within seven further generations in Brazil (Campos et al., 2014). In countries such as Tunisia, more than 18 chemicals were introduced during 2009-2011 for the control of tomato borer but none of them seemed efficient in solving the pest problem (Abbes et al., 2012). Failure of these chemicals in controlling *T. absoluta* opened a new window for development of other methods including biopesticides, pheromone traps, and parasitoids (Regnault-Roger, 2012; Cherifet al., 2013; Zappala et al., 2013). Though chemical pesticides are economically and environmentally unaffordable, farmers still seek them for their agricultural uses because is the only easily accessible option. Thus introduction of IPM strategies in Sub-Saharan Africa will promote sustainable horticultural farming.

Bioactive compounds from plant against *T. absoluta*

Botanicals have been reported to play a great role in controlling pests (Isman, 2006; Sharma and Bhandari, 2014; Zekeya et al., 2014). Many laboratory studies revealed the efficacy of plant compounds against insect pests including *T. absoluta* (Castillo et al., 2010; Senthil-Nathan, 2013). For instance, extracts from neem plants were reported to be efficient against *T. absoluta* under laboratory condition (Durmusoglu et al., 2011). Valchev and Markova (2014) reported that Neem plant contains a number of active metabolites such as alkaloids which can control insect pests. These compounds have been reported to have control efficacy against tomato borer (Yankova et al., 2014). Other plants which are promising in management of *T. absoluta* include Piper (Brito et al., 2015) whereas compounds from *Acmella oleracea* were revealed to be active against *Tuta absoluta* (Moreno et al., 2012). Though biochemical pesticides have been cited as promising for pest control, their application in the sub-Saharan Africa is limited and none of the compounds have been registered commercially to help farmers. Hence more researches and validation of these natural resources is highly demanded to protect crop damage and loss including those by *T. absoluta* (Cork et al., 2009). Plant based pesticides have been documented to be better than synthetic chemical pesticides as they are biodegradable, naturally available and environmentally friend to none targeted organisms.

Management *T. absoluta* by entomopathogenic microbes

Use of microorganism as biopesticides for management of pests has increasingly gained popularity in recent years (Mollá et al., 2011). Bacteria and fungi have been used for a long time in management of tomato borer in America and Europe (Trottin-Caudal et al., 2012; Parra, 2009). The microbes have been reported to attack pests by their pathogenic effects (İnanli et al., 2012; Pires et al., 2009). Currently there are many commercially available bacterial and fungal formulations for controlling pests including *T. absoluta* in America and Europe (Sabbour, 2014). The formulations are either by foliar spray or by drenching the roots (Amizadeh et al., 2015). One of the best and successful formulations was that of *Metarhizium anisopliae* (fungus) and *Bacillus subtilis* (bacteria) which have been reported to reduce the population of *T. absoluta* on tomato at all developmental stages in America and Europe (İnanli et al., 2012). Other formulations reported to be tested against include that of *Metarhizium anisopliae* and *Beauveria bassiana* (İnanli et al., 2012; Kaoud, 2014). Most of these reports however were all based on screen house studies (González-Cabrera et al., 2011; Sabbour and Nayera, 2014) and only a few have been tested on field conditions and thus they may not be readily available for small-holder farmers. Nematodes have been reported as biocontrols of *T. absoluta* in some countries and depicted high insect mortality (Batalla-Carrera et al., 2010). The nematodes were reported to be effective against larvae, pupae and adult *T. absoluta* (Garcia-del-Pino et al., 2013). Unfortunately, none of these strategies have been reported to be effective in Sub-Saharan Africa, thus this review highlight the potential of native entomopathogens and endophytes in management of *T. absoluta* with respect to environmental conservation in Sub-Saharan Africa.

Pheromone traps for scheming *T. absoluta*

Sex pheromone traps have been cited as among environmentally accepted pest management strategy (Kılıç, 2010; Witzgall et al., 2010; Gacemi and Guenaoui, 2012). They have been reported to play a significant role in monitoring *T. absoluta* abundance (Harizanova et al., 2009; Reddy and Guerrero, 2010; Van der Straten et al., 2011). The traps are used prior to other control strategies so as to determine the presence and abundance of insects so as to decide on appropriate control measure to apply (Cocco et al., 2013; Witzgall and Cork, 2010). Although these traps are designed to control only adult male moth, they have been reported to be effective in managing tomato borer (Cocco et al., 2013; Reddy and Guerrero, 2010; Braham, 2014b; Cocco et al., 2012; Vacas et al., 2011). For effective application in the field, the sex pheromone traps are to be properly hanged at right positions depending on the height of tomato varieties and wind direction (Kılıç, 2010; Soliman et al., 2013). Another factor reported to be important is the color of the trap which, affects and influences the movement of the pest towards it, thus enhancing trapping efficiency (Braham, 2014a; Megido et al., 2013; Mwangi, 2015). Shining colors especially red has been reported to be the most attractive to *T. absoluta* (Taha et al., 2012). Combination of these factors have been reported to improve traps efficiency in the field (Kılıç, 2010; Lobos et al., 2013; Speranza and Sannino, 2012), especially when they are combined with insect killing ingredients. Use of killing agent in combination with sex pheromones is has minor effect however when the pheromone traps used are only for disrupting mating system (Mafra-Neto et al., 2013; Gacemi and Guenaoui, 2012).

Although pheromone traps in combination with active insect killing agent is reported to be used against *T.absoluta*, no study has reported the efficacy of pheromone traps when synergized by active plant compounds. Due to the current *T. absoluta* situation in sub-Saharan Africa, in particular Tanzania, it is evident that a pheromone trap baited with active compound could be developed and deployed in fields to improve monitoring and control of *T. absoluta.*

Parasitoids for management of *T. absoluta*

Natural enemies play a geat ecological role in controlling pests in natural settings (Chailleux et al., 2013; Ferracini et al., 2012; Sánchez et al., 2009; Ghoneim, 2014). A study by Megido et al. (2014) showed that the larvae of *T. absoluta* search for and acquires some biological characteristics and thermal requirements from host plants that can attract a parasitoid as well. *T. absoluta* host plants have ability to emmit volatile compounds that attract either pest predator or parasitoid toward it that also favor the parasitoid indirectly (Proffit et al., 2011; De Backer et al., 2015). One of suscessiful used parasitoids include *Trichogramma pretiosum* which, can parasitise a number of species including *T. absoluta* (Abbes et al., 2014; Zappala, 2012).

Other reports showing application of parasitoid principles in controlling *T.absoluta* are for instance from oder Hymenoptera (Balzan and Wäckers, 2013; Ferracini et al., 2012). The most important *T. absoluta* egg parasitoids are originated in the family Trichogrammatidae, Encyrtidae and Eupelmidae. Several Trichogrammatid species parasitizes eggs of different insects orders, especially Hymenoptera, Neuroptera, Diptera and *Trichogramma* (Ghoneim2014a). There are about 210 species of *Trichogramma* that have been signaled as natural enemies of a variety of agricultural and forest pests in many regions of the world and some species are used commercially in biological control programs (Ghoneim, 2014a; Zouba et al., 2013). This is due to their good records in controlling pests and ability to be produced quickly and affordably relative to other parasitoids (Zouba et al., 2013). Of practical use, *Trichogramma achaeae* Nagaraja and Nagarkatti, has a worldwide distribution and was reported to parasitize on *T. absoluta* eggs (Chailleux et al., 2012; Steiner and Goodwin, 2015). This parasitoid especially female has high ability in parasitising both eggs and larvae of the pests (Jervis et al., 2008). *T. achaeae* is known to be genetically compatibile with many pest insects as successful partasitoids (Michel and Whitfield, 2004). Further investigation on use of *Trichogramma* parasitoids in insect pest management is drawing an attention of some authors for other insect pests to date (Cabello et al., 2015; Luna et al., 2015). One of other successful parasitoid in the literature include; *Pseudapanteles dignus* (Hymenoptera) which, has been reported have ability to parasitize *T. absoluta* larvae (Sánchez et al., 2009). Larvae of other species reported to parasitize *T. absoluta* include *Neochrysocharis Formosa*, *Pnigalio* (Ratzeburgiola) *cristatus* (Ratzeburg), and *Braconosculator* (Ferracini et al., 2012). However little or none of native microbes have been used for management of the pest in the region. Hence screening and application natural enemies such as microbial parasitoids could be a potential management strategy in Sub-Saharan Africa.

Although parasitoids are very promising in management of pest, there are no any parasitoids of *T. absoluta* that have been reported from Sub-Saharan African countries including Tanzania. Hence, there is an urgent need to identify and assess parasitism rate in sub-Saharan Africa and include in IPM programs.

Cultivation of resistant tomato varieties

Plant and herbivore pests have coexisted since ancient time and each part played a role in development of resistance inorder to survive (VanDoorn and de Vos, 2013). Plant resistance to pests is influenced by genetic and phenotypic traits such as morphological and chemicals released (Antonio et al., 2011). Tomato is known to have narrow genetic base due severe breeding and domestication of wild varieties (Do et al., 2009; Melo et al., 2008; Gharekhani and Salek-Ebrahimi, 2014). However, its variation has a role to play in resistance against pests (Hartman and St Clair, 1998). The source of resistance against *T. absoluta* has been reported (Resende et al., 2006; da Silva et al., 2008; Rodrigues et al., 2011). The role of tomato chemical including acyl sugars in resistance againt *T. absoluta* have been documented (Oliveira et al., 2012). Maluf et al. (2010) revealed the importance of tomato resistance against T. absoluta. However, these sources have not been exploited yet in sub-saharan Africa, also calling for imediate managerial strategy *T. absoluta*.

Several studies recommend use of Integrated Pest Management (IPM) strategy for effective management of *T. absoluta* (Miranda et al., 2005; Arnó et al., 2009). A combination of physical and biological agents such as parasitoids, predators (Chailleux et al., 2013; Mollá et al., 2014) and traps (Michereff et al., 2000) can create an effective IPM (Mollá et al., 2011). The use of pheromone traps together with entomopathogenic fungi and bacteria is common in IPM programs (Abbes et al., 2012). Parasitoids and predators have been used and are commecially available as part of IPM programs in America and Europe (Abes et al., 2014; Al-Jboory et al., 2012; Cely et al., 2010; Zappala et al., 2013).On other hand, chemical pesticides are common in management of pest, but are not suitable when integrated with other management strategies especially biological ones (Arnó et al., 2009). Chemical pesticides have been reported to cause severe side effects to natural enermies (Zappalà et al., 2012), thus ad. Arnó and Gabarra (2011) reported that conventional pesticides have great effects on natural enemies of parasitoids whereas the use of organic pesticides is also uncertainty (Biondi, 2012).Thus coming up with an effective IPM strategy is challenging but not impossible. Hence development of sustainable and affordable IPM is crucial to rescue tomato production as well as raising income of farmers in Sub-Saharan Africa.

Potential management strategy in Sub Saharan Africa

Tomato is one of the major horticultural crops for income of small holder farmers in Africa. Invasion of tomato borer has led to decline of tomato market. Hence this paper reviews current managerial options against tomato leafminer in tomato growing in sub-Saharan Africa so as to highlight the current situation and future prospects. Pheromone traps are important and best for detection and monitoring of insect population but could not be used as management option. Use of chemical pesticides is common in Sub-Saharan Africa; however, alternation of classes of compound would reduce the problem of insect resistance to pesticides. On the other hand, entomopathogenic fungi and bacteria such as *Metarhizium anisopliae* and *Bacillus subtilis* are commercially available in the region, validated to be used at early stage of plant development for control of the pest. Conversely, none of parasitoid and resistant tomato variety has been identified for management of *T. absoluta* in Sub-Saharan Africa. This calls for researches to search for best option suitable for the region. However, no single control method or approach has been reported for sub-Saharan Africa, thus this review highlighted potentials strategies that would be adopted immediately to sustainably control *T. absoluta* in sub-Saharan Africa, where cultivation is solely rely on open fields making it more susceptible to pest. The prospective IPM strategy based on native microbial biocontrols, pheromone trap, compounds from plants and some moderate synthetic pesticides would be relevant and environmentally affordable solution for small holder farmers in Sub-Saharan Africa.

Conflict of Interests

The authors have not declared any conflict of interests.

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