2017-02-17

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

Zekeya, Never

Academic Journal

https://doi.org/10.5897/AJAR2016.11515

Downloaded from Nelson Mandela-AIST's institutional repository
Full Length Research Paper

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.

Received 3 August, 2016; Accepted 30 November, 2016

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop for income and nutrition of smallholder 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 in 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 losses (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.*

Author(s) agree that this article remain permanently open access under the terms of the Creative Commons Attribution License 4.0 International License.
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 (Goflishu 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 to the fact that contact toxicity does not 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 tolerate dryness, making it flourish well in hot and dry areas (Miranda et al., 1998). T. absoluta larvae feed from mining leaves, stems and fruits. It can attack tomato plants at all developmental stages causing up to 100% loss in tomato fruits, if not controlled (Desneux et al., 2010). It has high reproductive rate within 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 larval feeding strategy 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 acysugar, a substance that was reported to provide resistance against T. absoluta (Resende et al., 2006). However, use of resistant variety is a long term approach for that would take time to attain a suitable one for Sub-Saharan 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 Sub-Saharan Africa.

There are efforts to reduce use of insecticides in tomato fields, including cultural control methods such as controlled irrigation, crop rotation, and biological control (Van Lenteren and Bueno, 2003) and destruction of infested plant material (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 strategy to control this invasive pest in Sub-Saharan 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 (Getin 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 damage (Materu et al., 2016). However, little success has been achieved, 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, benzoyleureas (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; Cherif et 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 (Inanli 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 (Inanli et al., 2012). Other formulations reported to be tested against include that of Metarhizium anisopliae and Beauveria bassiana (Inanli 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 (García-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
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 Gueonaou, 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 Gueonaou, 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 bailed 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 great 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 emit 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 successful 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 signalled 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 achaea*e 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. achaea* is known to be genetically compatible with many pest insects as successful parasitoids (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*, *Pniagio* (Ratzeburgiola) *cristatus* (Ratzeburg), and *Bracconosculator* (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 in order 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 against 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 immediate 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; Mollà et al., 2014) and traps (Michereff et al., 2000) can create an effective IPM (Mollà 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 commercially 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 enemies (Zappala 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.

REFERENCES

Abbes K, Bioni A, Zappalà L, Chermiti B (2014). Fortuitous parasitoids of the invasive tomato leafminer Tuta absoluta in Tunisia. Phytoparasitica 42:85-92.

Abbes K, Chermiti B (2011). Comparison of two marks of sex pheromone dispensers commercialized in Tunisia for their efficiency to monitor and to control by mass-trapping Tuta absoluta under greenhouses. Plant Prot. 6:133-148.

Abbes K, Harbi A, Chermiti B (2012). The tomato leaf miner Tuta absoluta (Meyrick) in Tunisia: current status and management strategies. EPPo Bull. 42:226-233.

Abdel-Reaheem A, Ismail T, Abdel-Rahman S, Abdel-Rhman E, Naglaa F (2015). Efficacy of Three Entomopathogenic Fungi on Tomato leaf miner, Tuta absoluta in Tomato crop in Egypt. Swift J. Agric. Res. 1(2):015-021.

Al-Jboory J, Katbeh-Bader A, Al-Zaide S (2012). First observation and identification of some natural enemies collected from heavily infested tomato by Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae) in Jordan. Med. E. J. Sci. Res. 11:435-438.

Amizadeh M, Hejazi MJ, Niknam N, Arzanlou M (2015). Compatibility and interaction between Bacillus thuringiensis and certain insecticides: perspective in management of Tuta absoluta (Lepidoptera: Gelechiidae). Biocon. Sci. Technol. 25:671-684.

Arnó J, Gabarra R (2011). Side effects of selected insecticides on the Tuta absoluta (Lepidoptera: Gelechiidae) predators Macrolophus pygmaeus and Nesidiocoris tenuis (Hemiptera: Miridae), J. Pest. Sci. 84(4):513-520.

Arnó J, Sorribas R, Prat M, Matas M, Pozo C, Rodríguez D, Perdikis D (2009). Tuta absoluta, a new pest in IPM tomatoes in the northeast of Spain. IOBC/WPRS. Bull. 49:203-208.

Ayalew G (2015). Efficacy of selected insecticides against the South American tomato moth, Tuta absoluta Meyrick (Lepidoptera: Gelechiidae) on tomato in the Central Rift Valley of Ethiopia. Afr. Entomol. 23(2):410-417.

Balzan V, Wäckers L (2013). Flowers to selectively enhance the fitness of a host-feeding parasitoid: adult feeding by Tuta absoluta and its parasitoid Necremnus arynae. Biol. Cont. 67(1):21-31.
Batalla-Carrera L, Morton A, García-del-Pino F (2010). Efficacy of entomopathogenic nematodes against the tomato leafminer \textit{Tuta absoluta} in laboratory and greenhouse conditions. Biol. Cont. 55:523-530.

Bawin T, Dujeu D, De Backer L, Francis C, Verheggen J (2015). Ability of \textit{Tuta absoluta} (Lepidoptera: Gelechiidae) to develop on alternative host plant species. Can. Entomol. pp. 1-9.

Biondi A (2012). Using organic-certified rather than synthetic pesticides may not be safer for biological control agents: selectivity and side effects of 14 pesticides on the predator \textit{Orius laevigatus}. Chemosphere 87(7):803-812.

Biondi A, Zappalà L, Desneux N, Aparo A, Siscaro G, Rapisarda C, Garzia T (2015). Potential toxicity of \(\alpha\)-cypermethrin-treated nets on \textit{Tuta absoluta} (Lepidoptera: Gelechiidae). J. Econ. Entomol. 108:1191-1197.

Braham M (2014a). Role of trap colors and exposure time of pheromone on trapping efficiency of males of the tomato leafminer, \textit{Tuta absoluta} (Meyrick, 1917)(Lepidoptera: Gelechiidae). Afr. J. Colom. 28:2271.

Braham M (2014b). Sex Pheromone Traps for Monitoring the Tomato Leafminer, \textit{Tuta absoluta}: Effect of Colored Traps and Field Weathering of Lure on Male Captures. Res. J. Agric. Environ. Manage. 3(6):290-298.

Braham M, Gilda-Snidez H, Hajji L (2012). Management of the tomato borer, \textit{Tuta absoluta} in Tunisia with novel insecticides and plant extracts. Bull. OEPP/EPPO Bull. 42(2):291-296.

Brevault T, Sylla S, Diatte M, Bernadas G, Diarra K (2014). \textit{Tuta absoluta} Meyrick (Lepidoptera: Gelechiidae): a new threat to tomato production in sub-Saharan Africa: Short communications. Afr. Entomol. 22:441-444.

Brito F, Baldin L, Silva M, Ribeiro P, Vendramim D (2015). Bioactivity of piper extracts on \textit{Tuta absoluta} (Lepidoptera: Gelechiidae) in tomato. Pesqui. Agropecu. Bras. 50:196-202.

Cabello T, Francisco G, Juan F, Francisco G, Garay J (2015). Can interactions between an Omnivorous Hemipteran and an egg Parasitoid limit the level of biological control for the tomato pinworm? Environ. Entomol. 44:12-26.

Calatrava J, Barberá G, Castillo M (2011). Farming practices and policy measures for agricultural soil conservation in semi-and Mediterranean areas: The case of the Guadalentín basin in southeast Spain. Land Degrad. Dev. 22:55-69.

Campos R, Rodrigues S, Silva M, Silva M, Silva F, Guedes C, Siqueira A (2014). Spinosad and the tomato borer \textit{Tuta absoluta}: a bioinsecticide, an invasive pest threat, and high insecticide resistance. PloS one 9:e103235.

Campos MR, Silva TB, Silva WM, Silva JE, Siqueira HA (2015). Spinosyn resistance in the tomato borer \textit{Tuta absoluta} (Meyrick) (Lepidoptera: Gelechiidae). J. Pest Sci. 88(2):405-412.

Castillo E, Jiménez J, Delgado A (2010). Secondary metabolites of the Annonaceae, Solanaceae and Meliaceae families used as biological control agents against \textit{Tuta absoluta} (Meyrick)(Lepidoptera: Gelechiidae) under simulated UK glasshouse conditions. Insects 4:185-197.

da Silva H, Abreu B, Caliman B, Antonio C, Patel B (2008). Tomatoes: Origin, Cultivation Techniques and Germplasm Resources. In: Tomatoes and tomato products - Nutritional, medicinal and therapeutic properties. Eds: Preedy, V.R. and Watson, R.R., Science Press, Enfield, New Hampshire, USA, pp. 365-380.

De Backer L, Megido C, Fauconnier M, Brostaux Y, Francis F, Verheggen F (2015). \textit{Tuta absoluta}-induced plant volatiles: attractiveness towards the generalist predator \textit{Macrolophus pygmaeus}. Arthr. Plant Int. 9:465-476.

Desneux N, Luna G, Guillemaud T, Urbaneja A (2011). The invasive South American tomato pinworm, \textit{Tuta absoluta}, continues to spread in Afro-Eurasia and Europe, becoming the new threat to tomato world production. J. Pest Sci. 84:403-408.

Desneux N, Wajnberg E, Wyckhuys KA, Burgio G, Arpaia S, Narváez-Vasquez CA, González JC, Rioscas DC, Tabone E, Frandon J, Pizzol J (2010). Biological invasion of European tomato crops by \textit{Tuta absoluta}: ecology, geographic expansion and prospects for biological control. J. Pest Sci. 83:197-215.

Do T, Cerveja A, Tomateiro T (2009). Sources of resistance to tomato leafminer in cherry tomato. Sci. Agrar. 10:327-330.

Durmusoglu E, Hatipoglu A, Balci H (2011). Efficiency of some plant extracts against \textit{Tuta absoluta} (Meyrick, 1917) (Lepidoptera: Gelechiidae) under laboratory conditions. Turk. Entomol. Dergisi-Turkish J. Entomol. 35:651-663.

El-Arnaouty A, Pizzol J, Galal H, Kortam N, Alfi I, Beysvat S, Heikal H (2014). Assessment of two Trichogramma species for the control of \textit{Tuta absoluta} in North African tomato greenhouses. Afr. Entomol. 22:801-809.

Ferracini C, Ingegno B, Letizia N, Paolo F, Ester M, Marco L, Alma A (2012). Adaptation of indigenous larval parasitoids to \textit{Tuta absoluta} (Lepidoptera: Gelechiidae) in Italy. J. Econ. Entomol. 105:1311-1319.

Gacemi A, Guenao Y (2012). Efficacy of emamectin benzoate on \textit{Tuta absoluta} Meyrick (Lepidoptera: Gelechiidae) inverting a protected environment. J. Pest Sci. 2:52-57.

García-del-Pino F, Alabern X, Morton A (2013). Efficacy of soil treatments of entomopathogenic nematodes against the larvae, pupae and adults of \textit{Tuta absoluta} and their interaction with the insecticides used against this insect. BioCon 58:723-731.

Ghoneim K (2014). Predatory insects and arachnids as potential biological control agents against the invasive tomato leafminer, \textit{Tuta absoluta} Meyrick (Lepidoptera: Gelechiidae), in perspective and prospective. J. Entomol. Zool. Stud. 2(2):52-71.

Ghoneim K (2014a). Parasitic insects and mites as potential biocontrol agents for a devastative pest of tomato, \textit{Tuta absoluta} Meyrick (Lepidoptera: Gelechiidae) in the world: a review. Int. J. 2:81-115.

Goftishu M, Seid A, Dechassa N (2014). Occurrence and population dynamics of tomato leaf miner \textit{Tuta absoluta} (Meyrick), Lepidoptera: Gelechiidae. J. Econ. Entomol. 8:59-64.

Gontijo C, Picano C, Pereira G, Martins C, Chediak M, Guedes C (2013). Spatial and temporal variation in the control failure likelihood of the tomato leaf miner, \textit{Tuta absoluta}. Ann. Appl. Biol. 162:50-59.
González-Cabrera J, Mollá O, Montón H, Urbaneja A (2011). Efficacy of Bacillus thuringiensis (Berliner) in controlling the tomato borer, Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae). BioControl 56:71-80.

Guedes C, Picanço C (2012). The tomato borer Tuta absoluta in South America: pest status, management and insecticide resistance. EPPO Bull. 42:211-216.

Guedes C, Siqueira A (2013). The tomato borer Tuta absoluta: insecticide resistance and control failure. Plant Sci. 7 (005):1-7.

Haddi K (2012). Studies on insecticide resistance in Tuta absoluta (Meyrick), with special emphasis on characterisation of two target site mechanisms. http://archivio.uni.it/handle/10761/1229.

Harbi A, Abbas K, Chemiti B (2012). Evaluation of two methods for the protection of tomato crops against the tomato leaffminer Tuta absoluta (Meyrick) under greenhouses in Tunisia. EPPO Bull. 42:317-321.

Harizanova V, Stoeva A, Mohamedova M (2009). Tomato leaf miner, Tuta absoluta (Povolny) (Lepidoptera: Gelechiidae)—first record in Bulgaria. Agric. Sci. Technol. 1:95-98.

Hartman B, St. Clair A (1998). Variation for insect resistance and absolute algal populations and their cross populations derived from Lycopersicon perennis. Crop Sci. 38:1501-1508.

Ianni C, Yoldas Z, Birgúcü K (2012). Effects of entomopathogenic fungi, Beauveria bassiana (Bals.) and Metarhizium anisopliae (Metsch.) on larvae and egg stages of Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae). Ege Üni Zir Fak Der 49:239-242.

Isman MB (2006). Botanical insecticides, deterrents, and repellents in specialty and high value vegetable crops. Florida Entomol. 89:107-123.

Jervis MA, Ellers J, Harvey JA (2008). Resource acquisition, allocation, and utilization in parasitoid reproductive strategies. Ann. Rev. Entomol. 53:361-385.

Kaoud A (2014). Alternative methods for the control of Tuta absoluta (Lepidoptera: Gelechiidae) grown accessions of Lycopersicon esculentum (L.) in tunisia. Jpn. J. Mar. Sci. Technol. 41:41-46.

Kılıç T (2010). First record of Tuta absoluta in Turkey. Phytotrapas 38:243-244.

Lietti M, Botto E, Alzogaray A (2005). Insecticide resistance in argentine populations of Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae). Neotrop. Entomol. 34:113-119.

Lobos E, Occhionero M, Wenentitzky D, Fernandez J, Gonzalez M, Rodriguez C, Oethschlager C (2013). Optimization of a trap for Tuta absoluta algal populations and its effectiveness in mass trapping. Neotrop. Entomol. 42:448-457.

Luna G, Pereyra C, Cielli E, Nieves E, Nadia S, Sánchez E (2015). Potential of biological control agents against, Tuta absoluta (Lepidoptera: Gelechiidae): current knowledge in Argentina. Florida Entomol. 98:489-494.

Malfer-Neyrart D, Stéphane FM, Bettig CJ, Munson AS, Perring TM, Stelkenius LL, Vargas RI (2013). Manipulation of insect behavior with specialized pheromone and lure application technology (SPLAT®). Pest Manage. Nat. Prod. 114:31-58.

Maluf R, de Fátima Silva V, das Graças C, Maria G, Luiz Antonio A, Neto C, Gonçalves M, Nizio C (2010). Resistance to the South American tomato pinworm, Tuta absoluta in high acylsucan and or high zigiborone tomato genotypes. Euphytica 176:113-123.

Materu CL, Shao EA, Losusaki E, Chidgee M, Mwambela N (2016). Gardner’s perception knowledge and practices on management of Tuta Absoluta Meyerick (Lepidoptera Gelechiidae) in tomato growing areas in Tanzania. Int. J. Res. Agric. For. 3(2):1-5.

Megido C, De Backer L, Etaalb R, Brostaux Y, Fauconni M-L, Delaplace P, Francis F (2014). Role of larval host plant experience and solanaceous plant volatile emissions in Tuta absoluta (Lepidoptera: Gelechiidae) host finding behavior. Annu. Plant Int. 8:293-304.

Megido C, Haubruege E, Verheggen J (2013). Phenorembased management strategies to control the tomato leaffminer, Tuta absoluta (Lepidoptera: Gelechiidae). A review Synthèse bibliographique: les stratégies de lutte phénomérale utilisées pour contrôler la mineuse de la tomate. Tuta absoluta (Lepidoptera: Gelechiidae). Biotechnol. Agron. Soc. Environ. 17:475.

Michel-Salzat A, Whitfield B (2004). Preliminary evolutionary relationships within the parasitoid wasp genus Cotesia (Hymenoptera: Braconidae: Microgastrinae): combined analysis of four genes. Syst. Entomol. 29:371-382.

Miranda M, Picanço C, Zununco C, Bacci L, Silva D (2005) Impact of integrated pest management on the population of leafminers, fruit borers, and natural enemies in tomato. Ciênc. Rural 35:204-208.

Miranda M, Picanço C, Zununco C, Guedes (1998) Ecological life table of tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae). Biocontrol Sci. Technol. 8:597-606.

Mohamed I, Mahmoud E, Elhaj M, Mohamed A, Elhesi S (2015). Host plants record for tomato leaf miner Tuta absoluta (Meyrick) in Sudan. EPPO Bull. 45:108-111.

Mollá O, Biondi A, Alonso-Valiente M, Urbaneja A (2014). A comparative life history study of two mirid bugs preying on Tuta absoluta and Euprostemon kuehnelli eggs on tomato crops: implications for biological control. BioControl 59:175-183.

Mollár O, González-Cabrera J, Urbaneja A (2011). The combined use of Bacillus thuringiensis and Nesiocoris tenuis against the tomato borer, Tuta absoluta. BioControl 56:883-891.

Moreno, Shaiene C, Carvalho, Geraldo A, Picanço, Marcelo C, Morais, Eliassengel GF, Pereira RM (2012). Bioactivity of compounds from Acromeltus laevorescens against Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae) and selectivity to two non-target species. Pest Manage. Sci. 68:386-393.

Moussa A, Baiomy F, El-Adi E (2013). The status of tomato leafminer; Tuta absoluta (Meyrick)(Lepidoptera: Gelechiidae) in Egypt and potential effective Pesticides. Acad. J. Entomol. 6:110-115.

Muniappan R, Heinrichs A (2015). Feed the Future IPM Innovation Lab: A Critical Role in Global Food Security. Outl. Pest Manage. 26:148-151.

Mwangi F (2015). Evaluation of botanical pesticides and coloured sticky insect traps For Management of Insect pests (Thrips, Whiteflies And Aphids) In French Beans (Phaseolus vulgaris L.). University of Nairobi.

Oerke C, Dehne W, Schönbeck F, Weber A (2012). Crop production and crop protection: estimated losses in major food and cash crops: 1961-2006. In: Crop production and crop protection, 2nd edn. Wallingford, Oxfordshire, UK: CAB International, 801-826.

Oliveira A, da Silva H, Leite, D, Jham G, Picanço M (2009). Resistance of 57 greenhouse-grown accessions of Lycopersicon esculentum and three cultivars to Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae). Sci. Hortic. 119:182-187.

Parrar JR (2009). Egg parasitoids commercialization in the new world. In Egg parasitoids in agroecosystems with emphasis on Trichogramma. Springer, Netherlands. pp. 373-382.

Pfleffer G, Muniappan R, Sall D, Diatta P, Diongue A, Dieng O (2013). First record of Tuta absoluta (Lepidoptera: Gelechiidae) in Senegal. Flo. Entomol. 96:661-662.

Pires M, Marques J, Wanderley-Texeira T, Álvaro C, Alves C, Alves B (2009). Ultrastructural of Tuta absoluta parasitized eggs and the reproductive potential of females after parasitism by Metarthius flavipes. J. Invertebr. Pathol. 99:136-142.

Ponti L, Gilioli G, Biondi A, Desneux N, Gutierrez P, Gilioli G, Biondi A, Desneux N, Gutierrez P, Pires M, Marques J, Wanderley-Texeira T, Álvaro C, Alves C, Alves B (2009). Ultrastructural of Tuta absoluta parasitized eggs and the reproductive potential of females after parasitism by Metarthius flavipes. J. Invertebr. Pathol. 99:136-142.

Pires M, Marques J, Wanderley-Texeira T, Álvaro C, Alves C, Alves B (2009). Ultrastructural of Tuta absoluta parasitized eggs and the reproductive potential of females after parasitism by Metarthius flavipes. J. Invertebr. Pathol. 99:136-142.

Pires M, Marques J, Wanderley-Texeira T, Álvaro C, Alves C, Alves B (2009). Ultrastructural of Tuta absoluta parasitized eggs and the reproductive potential of females after parasitism by Metarthius flavipes. J. Invertebr. Pathol. 99:136-142.

Pires M, Marques J, Wanderley-Texeira T, Álvaro C, Alves C, Alves B (2009). Ultrastructural of Tuta absoluta parasitized eggs and the reproductive potential of females after parasitism by Metarthius flavipes. J. Invertebr. Pathol. 99:136-142.
Roditakis E, Vasakis E, Grispou M, Stavrakaki M, Nauen R, Gravouil M, Bassi A (2015). First report of *Tuta absoluta* resistance to diamide insecticides. J. Pest Sci. 88:9-16.

Rodrigues B, Elsayed Y, da Silva H (2011). Genetic variability by ISSR markers in tomato (*Solanum lycopersicon* Mill.). Rev. Bras. Citênc. Agríc. 6:243-252.

Sabbour M (2014). Biocontrol of the tomato pinworm *Tuta absoluta* (Meyrick)(Lepidoptera: Gelechiidae) in Egypt. Md East J Agric Res 3: 499-503.

Sabbour M, Nayera S (2014). Evaluations of three *Bacillus thuringiensis* against *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in Egypt. Int. J. Sci. Res. 3(8):2319-7054.

Sánchez NE, Pereyra, Patricia CL, Maria G (2009). Spatial patterns of parasitism of the solitary parasitoid *Pseudapanteles dignus* (Hymenoptera: Braconidae) on *Tuta absoluta* (Lepidoptera: Gelechiidae). Environ. Entomol. 38(2):365-374.

Senthil-Nathan S (2013). Physiological and biochemical effect of neem and other Meliaceae plants secondary metabolites against *Lepidopteran* insects. Front. Physiol. 4:359.

Seplyarsky V, Weiss M, Haberman A (2010). *Tuta absoluta* Povolny (Lepidoptera: Gelechiidae), a new invasive species in Israel. Phytoparasitica 38:445-446.

Sharma N, Bhandari S (2014). Management of pathogens of stored cereal grains. Sustainable Agric Rev (pp. 87-107): Springer.

Silva A, Picanço C, Bacci L, Crespo B, Rosado F, Guedes C (2011). Control failure likelihood and spatial dependence of insecticide resistance in the tomato pinworm, *Tuta absoluta*. Pest Manage. Sci. 67:913-920.

Siqueira A, Guedes C, Picanço C (2000). Insecticide resistance in populations of *Tuta absoluta* (Lepidoptera: Gelechiidae). Agric. For. Entomol. 2:147-153.

Soliman A, Hegazi M, Attaia M, Imam I (2013). Evaluating the role of sex pheromone in monitoring and controlling tomato leaf miner, *Tuta absoluta* (Meyrick), under the Egyptian north western coast conditions. Egypt. J. Biol. Pest Cont. 23:169.

Speranza S, Sannino L (2012). The current status of *Tuta absoluta* in Italy. EPPO. Bull. 42:328-332.

Sridhar V, Chakravarthy K, Asokan R (2014). New record of the invasive South American tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in India. Pest Manage. Hortic. Ecosyst. 7:148-154.

Steiner M, Goodwin S (2015). *Tuta absoluta*: Coming soon to a tomato crop near you. Pract. Hydroponics Greenhouses 108:44-49.

Taha M, Homam H, Afsah E, EL-Sharkawy M (2012). Effect of trap color on captures of *Tuta absoluta* moths (Lepidoptera: Gelechiidae). Int. J. Environ. Sci. Eng. 3:43-48.

Tonnang Z, Mohamed F, Khamsi F, Ekesi S (2015). Identification and risk assessment for worldwide invasion and spread of *Tuta absoluta* with a focus on sub-saharan Africa: Impl. Phyto Meas Manage. PloS one 10:e0135283.

Trottin-Caudal Y, Balfert V, Leyre M, Hulas N (2012). Experimental studies on *Tuta absoluta* (Meyrick) in protected tomato crops in France: biological control and integrated crop protection. EPPO. Bull. 42:234-240.

Urbañez A, Desneux N, Gabarra R, Arnó J, González-Cabrera J, Mafra Neto A, Peña JE (2013). Biology, ecology and management of the South American tomato pinworm, *Tuta absoluta*. Potent. Invas. Pests Agric. Crops pp. 98-125.

Vacas S, Alfaro C, Primo J, Navarro-Llopis V (2011). Studies on the development of a mating disruption system to control the tomato leafminer, *Tuta absoluta* Povolny (Lepidoptera: Gelechiidae). Pest Manage. Sci. 67:1473-1480.

Van Damme V, Berkvens N, Moerkens R, Berckmoes E, Wittemans L, De Vis R, De Clercq P (2015) Overwintering potential of the invasive leafminer *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) as a pest in greenhouse tomato production in Western Europe. J. Pest Sci. 88:533-541.

Van Lenteren C, Bueno P (2003). Augmentative biological control of arthropods in Latin America. BioCont 48:123-139.

VanDoorn A, de Vos M (2013). Resistance to sap-sucking insects in modern-day agriculture. Front. Plant Sci. 4:222.

Witzgall P, Kirsch P, Cork A (2010). Sex pheromones and their impact on pest management. J. Chem. Ecol. 36:80-100.

Yankova V, Valchev N, Markova D (2014). Effectiveness of phytopesticide Ne m Azal T/S® against tomato leaf miner *Tuta absoluta* Meyrick in greenhouse tomato. Bul. J. Agric. Sci. 20 (5):1116-1118.

Zappala L, Bernardo U, Biondi A, Cocca A, Delipieri S, Delrio G, Garzia T (2012). Recruitment of native parasitoids by the exotic pest *Tuta absoluta* in Southern Italy. Bull. Insectol. 65:51-61.

Zappala L, Biondi A, Alma A, Al-Jbooy J, Arro J, Bayram A, Guenaoui Y (2013). Natural enemies of the South American moth, *Tuta absoluta*, in Europe, North Africa and Middle East, and their potential use in pest control strategies. J. Pest Sci. 86:635-647.

Zekeya NM, Shahada F, Chacha M (2014). Bioefficacy of *Bersama abyssinica* extracts against cowpea beetle; *Callosobruchus maculatus* in Storage. Int. J. Innov. Res. Dev. 3:8.

Zoubia A, Chemili B, Kadri K, Fatouch S (2013). Molecular characterization of *Trichogramma bourarachae* strains (Hymenoptera: Trichogrammatidae) from open field tomato crops in the South West of Tunisia. Biomirror 4:05-11.

Zucchi A, Querino B, Monteiro C (2009). Diversity and hosts of *trichogramma* in the new world, with emphasis in South America. In Egg parasitoids in agroecosystems with emphasis on *Trichogramma*. Springer Netherlands. pp. 219-236.