2016-11-28

Tomato Leafminer (Tuta absoluta Meyrick 1917): A Threat to Tomato Production in Africa

Zekeya, Never

Journal of Agriculture and Ecology Research International

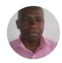
https://doi.org/10.9734/JAERI/2017/28886

Tomato Leafminer (Tuta absoluta Meyrick 1917): A Threat to Tomato Production in Africa

Article · January 2016

DOI: 10.9734/JAERI/2017/28886


Never Zekeya
The Nelson Mandela African Institute of Science and Technology


Musa Chacha
The Nelson Mandela African Institute of Science and Technology


Patrick Ndakidemi
The Nelson Mandela African Institute of Science and Technology


Maneno Yoram Chidege
Tropical Pesticides Research Institute

Journal of Agriculture and Ecology Research International
10(1): 1-10, 2017; Article no.JAERI.28886
ISSN: 2394-1073

SCIENCEDOMAIN *international*
www.sciencedomain.org

Tomato Leafminer (*Tuta absoluta* Meyrick 1917): A Threat to Tomato Production in Africa

Never Zekeya[1*], Musa Chacha[1], Patrick A. Ndakidemi[1], Chris Materu[2], Maneno Chidege[3] and Ernest R. Mbega[1]

[1]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.
[2]Mikocheni Agricultural Research Institute, P.O.Box 6226, Dar es Salaam, Tanzania.
[3]Tropical Pesticide Research Institute, P.O.Box 3024, Arusha, Tanzania.

Authors' contributions

This work was carried out in collaboration between all authors. Author NZ designed the study and wrote the first draft of the manuscript. Author M. Chidege revised the 1st draft. Author CM revised the 2nd draft. Author M. Chacha revised the 3rd draft and managed literature search. Author ERM revised the 4th draft, managed the literature searches and designed the model. Author PAN revised the 5th draft and made conclusion. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAERI/2017/28886
Editor(s):
(1) Claudius Marondedze, Biological and Environmental Sciences and Engineering, King Abdullah University of Science and Technology, Kingdom of Saudi Arabia.
Reviewers:
(1) Anibal Condor Golec, Universidad Nacional Agraria La Molina, Perú.
(2) Gamal Mohamedin Hassan Sahl, Fayoum University, Egypt.
Complete Peer review History: http://www.sciencedomain.org/review-history/17046

Review Article

Received 11th August 2016
Accepted 17th October 2016
Published 28th November 2016

ABSTRACT

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop for income, food and nutrition in Africa. Production of the crop is currently threatened by leaf miner [*Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae)]. Heavy infestation by *T. absoluta* has been reported to cause yield losses ranging from 80-100%. *Tuta absoluta* has high rate of reproduction and short life cycle making it very dominant in the infested tomato fields. Insecticide application for control of the pest is uneconomical for subsistence farming and beyond the earnings of majority of resource-poor farmers in Africa. Use of host resistance and or integrated pest management (IPM) strategies is slightly or not in use thus making the pest reign in the

**Corresponding author: E-mail: neverz@nm-aist.ac.tz;*

majority of African countries. This review discusses how *T. absoluta* threatens production and recommends some focal areas towards addressing this pest problem in the tomato industry in Africa.

Keywords: Tuta absoluta; tomato; Africa; pesticide resistance.

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop for income and nutrition of small-holder farmers in many parts of the world [1,2]. Tomato is cultivated throughout the year and in varied range of environments depending on abiotic factors [3,4]. Tomato fills the hunger gap as farmers usually sell tomato and spend the money obtained to buy cereal and leguminous crops for food during dry seasons. Despite the benefits of tomato, it is in danger of deterioration due to invasion by an exotic insect pest namely tomato leaf miner (*Tuta absoluta*. Meyrick) [5-7].The pest is wide spread in Europe, Asian and Africa [8]. *T. absoluta* is difficult to control due to inability of pesticides to reach the feeding larvae which is usually protected inside the tissue of the tomato plant host [9-12]. Economic losses due to *T. absoluta* infestation in tomato have been reported to be up to 100% in some countries in Africa particularly Sudan, Kenya and Ethiopia [12,13]. In efforts to control the pest, farmers use different options including increased spraying of chemical pesticides, to the levels that are uneconomical and harmful to non-targeted organisms [14,15]. Furthermore, increased chemical application by farmers impends health problems as chemicals persist in human bodies and maginifies pest resistance problems [11,16-18]. Thus, this review discusses the reproduction, epidemiology, strategies for infestation, current and prospective for management of the *T. absoluta* and its potential impact to tomato industry and food security in Africa.

2. IMPORTANT CHARACTERISTICS THAT MAKES *T. absoluta* DEVASTATIVE

2.1 Reproduction of *T. absoluta*

Tuta absoluta has high biotic potential including reproductive rate [19-21]. It is a multivoltine pest producing 250-300 eggs per female leading up to 12 generations per year [22,23]. Once an adult female emerges, it releases a sex pheromone that attracts males towards and this stage is associated with high oviposition rate and consequently high population within short period of time [24-26]. *T. absoluta* has overlapping generations and does not undergo diapauses in presence of food thus thriving over time [26-28]. *T. absoluta* can endure and adapt in harsh conditions such as extreme cold, dry conditions and hot environments [29]. *T. absoluta* has a wide range of alternative host plants including potato, egg plants, african egg plant, black night shade, amaranth and datura species that can harbor it to feed and reproduce in several seasons and at several ecological regions [30-33]. On scarcity of tomato, *T. absoluta* switch on other available host to retain its population and regain when tomato is plenty [34,35]. Hence availability of diversity hosts of *T. absoluta* in different seasons influences selection of the host that favors its reproduction and development [36-39].

2.2 Growth and Infestation Stages of *T. absoluta*

T. absoluta has four main growth stages namely egg, larvae, pupa and adult insect. Each of these growth stages is adaptive and has competitive advantage against chemical control options and environmental hazards. Larvae is the most difficult to control as it mine between the leaflets and tissues thus cannot easily be killed by contact sprays. Pupa pupates in the soil where chemicals and strong heat from the sun cannot easily destroy them and adults hide and lay eggs at undersides of the leaves to veil from predatory birds and unfavorable environmental conditions that can affect its development [40-42]. The infestation stages of *T. absoluta* on host tomato plant are described in Fig. 1. Infestation starts with chemical communication between host plants with the pest. The host plant which has ability to emit attractant chemical compounds and or essential oils compounds or volatile compound producing host (VCP-Host) attracts female *T. absoluta*, then the insect produces hormone that attracts males to mate. After mating, the pest may invade either a non VCP-Host or a VCP-Host. If it invades a non VCP-Host or if it invades the VCP-host and succeeds to lay eggs, but in the presence of a natural enemy (NE) colonization by *T. absoluta* may not

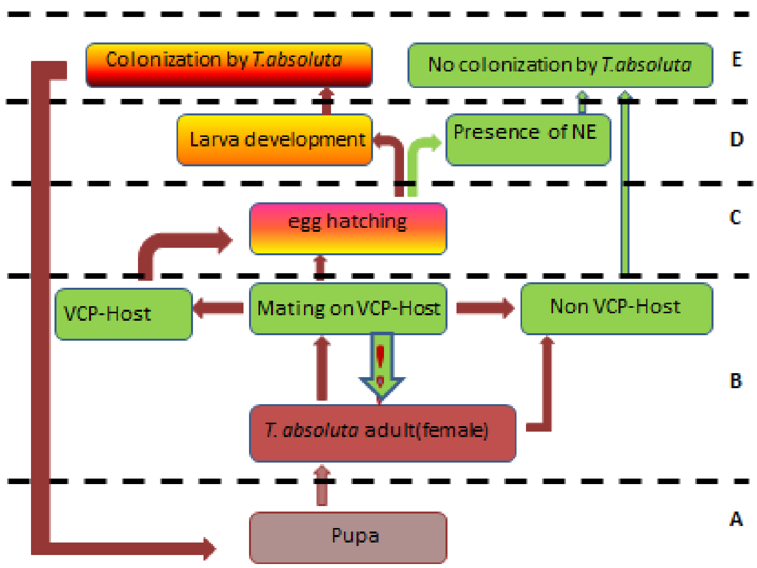


Fig. 1. A model describes infestation stages A to E by *T. absoluta* on host. Infestation starts at stage B. In this stage, a susceptible host or a volatile compound producing host (VCP-Host) emits attractant chemical compounds or essential oils compounds that attract female *T. absoluta*, then the insect produces a sex hormone that attracts males to mate. After mating, the pest may try to invade either a non VCP-Host or a VCP-Host. If it invades a non VCP-Host or if it invades the VCP-host and succeeds to lay eggs (stage C) in the presence of a natural enemy (NE) (stage D), no colonization by *T. absoluta* occurs on host plant (stage E). If it invades a VCP-Host and succeeds to lay eggs (stage C), the eggs will develop into larva (stage D) and the host plant will be totally colonized by *T. absoluta* (stage E). Then the larva exits from the infested plant and drops off the soil where it pupates (stage A) and then erupts into fully developed adult

occurs on host plant. If it invades a VCP-Host and succeeds to lay eggs, the eggs will develop into larva and the host plant will be totally colonized by *T. absoluta*. Then the larva completes its infestation stages by exiting from the infested plant and drops off the soil where it pupates and then erupts into fully developed adult.

2.3 Distribution

Distribution of *T. absoluta* is both triumphant due its ability to drift and spread quickly into a new area, and intercontinental since it is currently found in almost all continents [8]. Its dispersal is mainly attributed by wind [8]. This type of dispersal has advantage on the pest since, as it is moved by wind, its energy becomes available for reproduction [43-45,]. *T. absoluta* can also travel some kilometers by flying and can accidentally be dispersed by humans through local and international trading of unnoticed infested tomato [26,46-48]. South wind is reported to accelerate the spread of *T. absoluta* from South America to Africa [48]. For instance, *T. absoluta* was identified in South America, Peru then moved to Uruguay, Chile, Mexico, Argentina and further East [49-51], from South America east ward to Spain and reached Eurasian countries [52], including India , China and Japan [8]. Spread of *T. absoluta* in Africa has similar trend of southward where swiftly moved from Morocco, Senegal, Sudan, Somalia, Kenya Uganda, Malawi and other Southern Sub-Saharan Africa [53-56]. The pest is still spreading all over the world and is recently threatening tomato market in West Africa, particularly Nigeria [49].

2.4 Challenges with Chemical Pesticides

Conventional pesticides are commonly applied to control insect pests including *T. absoluta*. Some reports show the effect of chemical sprayers mainly harming untargeted organisms as well as environment and not the *T. absoluta* [57-59]. The nature of infestation especially by the *T. absoluta* larvae hiding inside protected tomato plant tissue and resistance to different chemicals limit control efforts [60-62]. Common chemicals that *T. absoluta* has been reported to develop resistance are Cartap [62], pyrethroids [63], organophosphates, spinosad, Emamectin benzoate and Abamectin [64], chloride channel activators, benzoylureas [65] and diamide [66]. Pest resistance has been reported to cause increased use of chemical pesticides applications against *T. absoluta* in many parts of the world [67]. In Spain, about 15 applications and in Brazil up to 30 applications have been reported [68,69]. Resistance of *T. absoluta* against spinosad chemical was reported to reach up to 180,000 folds within seven further generations in Brazil [64]. In countries such as Tunisia, more than 18 chemicals were introduced during 2009-2011 for the control of *T. absoluta* but none of them seemed efficient in solving the pest problem [70]. However, chemical pesticides are very expensive and are applied frequently to the extent that most small-holder farmers in Africa cannot afford to purchase regularly.

2.5 Scarcity of Host Resistant Tomato Varieties

Production of resistance varieties of tomato has gained more attention in some parts of the world such as South America where the pest originated [33,39,63,71-73]. However to-date, there seems limited or no clear information as whether there are successful tomato varieties which are resistant to *T. absoluta* [74-76]. Efforts to develop resistant varieties are going on in different parts of the world, but the pest seems to change rapidly and this may need more research efforts to identify the adaptation mechanisms and areas of weakness for effective control [12].

2.6 Yield Loss Due to *T. absoluta*

Insect pests including *T. absoluta* are reported to be accountable for destroying one fifth of the world's total crop production annually [77]. This is because most insects are herbivores and ecologically successful [78]. Insect pests have a high ability to manipulate environments and select suitable hosts [79,80]. Insect pests including *T. absoluta* are capable of evolving to biotypes that can adapt to new situations, such as overcoming the effect of toxic materials, some of which human beings use to control insect pests [81]. In Africa as in other parts of the world, insect associated losses has been reported to be as high as 80-100% in vegetables particularly tomato [58,62,82-86].

2.7 Potential Impact of *T. absoluta* on Tomato Production in Africa

Tomato industry is in danger of deterioration due to effect by *T. absoluta* if not controlled. Several authors [87-99] have consistently reported that, no effective control including use of chemicals is available for farmers. Parolin et al. [100] furthermore reported that without any practical solution to farmers, growers will lose all benefits that could be earned from tomato production. Though most farmers depend on tomato production for their livelihood, there is a risk that most farmers will switch to other crops due to massive losses due to *T. absoluta* that farmers experience in growing tomato [11]. Abandonment of tomato production can be due to yield loss and high costs of pest control above the threshold level that farmers would not afford [101,102]. This will have great impact to the economy of African countries and people who depend on tomatoes for income [103,104].

2.8 Management Prospective

Tomato growing farmers in Africa are currently stranded due to lack of effective control options as even under increased spay cycles, they experience massive losses due to *T. absoluta* [12,105]. This however has opened a new window for research and development of new and alternative control measures. The most recommended and promising approaches include application of biological control options such as parasitoids and nematodes [106-109], entomopathogenic fungi and bacteria [97], and pheromone traps for monitoring population as well as detection of their presence [107,110,111]. Screening and breeding for resistant of host tomato plants is considered effective in overcoming the pest and efforts are going on [112-115]. As these may be long time strategies which may not be readily available for Africa, there is need for multidisciplinary efforts involving research scientists, agricultural extensions, economists, policy makers, politicians and farmers to build a united priority in developing appropriate management options to rescue tomato industry which is currently in danger of deterioration in Africa. Moreover, molecular characterization of *T. absoluta* is of great importance for confirmation of the pest as it moved in different regions with various conditions that might affect the genetic aspect of the pest.

3. CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

T. absoluta is an impending threat to tomato in Africa. There is currently no single control option that has proven to be effective against *T. absoluta*. Use of host resistance and or integrated pest management (IPM) strategies is slightly or not in use thus making the pest reign in the majority of African countries. Thus, there is need for multidisciplinary efforts involving research scientists to find out genetic mechanisms and strategies that will halt further colonization of *T. absoluta* in Africa; agricultural extensions to communicate practical agricultural solutions to farmers; policy makers to establish appropriate policies; and farmers to apply developed/recommended solutions for sustainable tomato production in Africa.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Cetin B, Vardar A. An economic analysis of energy requirements and input costs for tomato production in Turkey. Renewable Energy. 2008;33:428-433.
2. Oerke EC, Dehne HW Schönbeck F, Weber A. Crop production and crop protection*:* Estimated losses in major food and cash crops. Elsevier; 2012.
3. Calatrava J, Barberá GG, Castillo VM. Farming practices and policy measures for agricultural soil conservation in semi-arid Mediterranean areas: The case of the Guadalentín basin in southeast Spain. Land Degradation & Development. 2011;22:58-69.
4. Laube W, Schraven B, Awo M. Smallholder adaptation to climate change: Dynamics and limits in Northern Ghana. Climatic Change. 2012;111:753-774.
5. Cifuentes D, Chynoweth R, Bielza P. Genetic study of Mediterranean and South American populations of tomato leaf miner *Tuta absoluta* (Povolny, 1994) (Lepidoptera: Gelechiidae) using ribosomal and mitochondrial markers. Pest Management Science. 2011;67:1155-1162.
6. Chailleux A, Desneux N, Seguret J, Khanh HD, Maignet P, Tabone E. Assessing European egg parasitoids as a mean of controlling the invasive South American tomato pinworm *Tuta absoluta*. PLoS One. 2012;7:e48068.
7. Retta AN, Berhe DH. Tomato leaf miner– *Tuta absoluta* (Meyrick), a devastating pest of tomatoes in the highlands of Northern Ethiopia: A call for attention and action. Research Journal of Agriculture and Environmental Management. 2015; 4:264-269.
8. Desneux N, Luna MG, Guillemaud T, Urbaneja A. The invasive South American tomato pinworm, *Tuta absoluta*, continues to spread in Afro-Eurasia and beyond: The new threat to tomato world production. Journal of Pest Science. 2011;84:403-408.
9. Silva GA, Picanço MC, Bacci L, Crespo AL, Rosado JF, Guedes RN. Control failure likelihood and spatial dependence of insecticide resistance in the tomato pinworm, *Tuta absoluta*. Pest Management Science. 2011;67:913-920.
10. Cuthbertson AG, Mathers JJ, Blackburn LF, Korycinska A, Luo W, Jacobson RJ, Northing P. Population development of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) under simulated UK glasshouse conditions. Insects. 2013; 4:185-197.
11. Brevault T, Sylla S, Diatte M, Bernadas G, Diarra K. *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae): A new threat to tomato production in Sub-Saharan Africa. African Entomology. 2014;22:441-444.
12. Tonnang HE, Mohamed SF, Khamis F, Ekesi S. Identification and risk assessment for worldwide invasion and spread of *Tuta absoluta* with a focus on Sub-Saharan Africa: Implications for phytosanitary measures and management. *PloS One*. 2015;10:e0135283.
13. Ayalew G. Efficacy of selected insecticides against the South American tomato moth, *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) on tomato in the Central Rift valley of Ethiopia. African Entomology. 2015;23:410-417.
14. Pimentel D. Environmental and economic costs of the application of pesticides primarily in the United States. Environment, Development and Sustainability. 2005;7: 229-252.
15. Khot LR, Sankaran S, Maja JM, Ehsani R, Schuster EW. Applications of nanomaterials in agricultural production

and crop protection: A review. Crop Protection. 2012;35:64-70.
16. Moreno SC, Carvalho GA, Picanço MC, Morais EG, Pereira RM. Bioactivity of compounds from *Acmellaoleracea* against *Tuta absoluta* (Meyrick)(Lepidoptera: Gelechiidae) and selectivity to two non-target species. Pest Management Science. 2012;68:386-393.
17. Biondi, Zappalà L, Desneux N, Aparo A, Siscaro G, Rapisarda C, Garzia GT. Potential toxicity of α-cypermethrin-treated nets on *Tuta absoluta* (Lepidoptera: Gelechiidae). Journal of Economic Entomology. 2015;108:1191-1197.
18. Muniappan R, Heinrichs EA. Feed the Future IPM innovation lab: A critical role in global food security. Outlooks on Pest Management. 2015;26:148-151.
19. Pratissoli D, Parra JR. Fertility life table of *Trichogramma pretiosum* (Hym., Trichogrammatidae) in eggs of *Tuta absoluta* and *Phthorimaeao perculella* (Lep., Gelechiidae) at different temperatures. Journal of Applied Entomology. 2000;124:339-342.
20. Abbes K, Chermiti B. Propensity of three Tunisian populations of the tomato leafminer *Tuta absoluta* (Lepidoptera: Gelechiidae) for deuterotokous parthenogenetic reproduction. African Entomology. 2014;22:538-544.
21. Savino V, Coviella CE, Luna MG. Reproductive biology and functional response of *Dineulophusphtorimaeae*, a natural enemy of the tomato moth, *Tuta absoluta*. Journal of Insect Science. 2012;12:153.
22. Doğanlar M, Yiğit A. Parasitoids. Complex of the tomato leaf miner, *Tuta absoluta* (Meyrick 1917), (Lepidoptera: Gelechiidae) in Hatay Turkey. Kahramanmaras Sutcu Imam University Journal of Natural Sciences. 2011;14:28-37.
23. Sridhar V, Chakravarthy AK, Asokan R. New record of the invasive South American tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in India. Pest Management in Horticultural Ecosystems. 2014;20:148-154.
24. Ferrara FA, Vilela EF, Jham GN, Eiras ÁE, Picanço MC, Attygalle AB, Meinwald J. Evaluation of the synthetic major component of the sex pheromone of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Journal of Chemical Ecology. 2001;27:907-917.
25. Megido RC, Haubruge E, Verheggen FJ. First evidence of deuterotokous parthenogenesis in the tomato leafminer, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Journal of Pest Science. 2011;85:409-412.
26. Tropea GG, Siscaro G, Biondi A, Zappalà L. *Tuta absoluta*, a South American pest of tomato now in the EPPO region: Biology, distribution and damage. EPPO Bulletin. 2012;42:205-210.
27. Speranza S, Sannino L. The current status of *Tuta absoluta* in Italy. EPPO Bulletin. 2012;42:328-332.
28. Polat B, Özpınar A, Şahin AK. Studies of selected biological parameters of tomato leaf miner *Tuta absoluta* (Meyrick), (Lepidoptera: Gelechiidae) under natural conditions. Phytoparasitica. 2016;1-8.
29. Kılıç T, First record of *Tuta absoluta* in Turkey. Phytoparasitica. 2010;38:243-244.
30. Megido RC, Brostaux Y, Haubruge E, Verheggen FJ. Propensity of the tomato leafminer, *Tuta absoluta* (Lepidoptera: Gelechiidae), to develop on four potato plant varieties. American Journal of Potato Research. 2013;90(3):255-260.
31. Bawin T, Dujeu D, De Backer L, Francis F, Verheggen FJ. Ability of *Tuta absoluta* (Lepidoptera: Gelechiidae) to develop on alternative host plant species. The Canadian Entomologist. 2015;1-9.
32. Omer IM. Survey of summer tomato pests in Khartoum State, with special reference to biology and natural control of *Tuta absoluta* (Doctoral dissertation, Sudan University of Science and Technology; 2015.
33. Portakaldali M, Öztemiz S, Kütük H. A new host plant for *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in Turkey. Journal of the Entomological Research Society. 2013;15:21.
34. Pereyra PC, Sánchez NE. Effect of two solanaceous plants on developmental and population parameters of the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Neotropical Entomology. 2006;35:671-676.
35. Rehman A, Saeed AM, Khan AM, Rafique A, Ashraf M. Potato: A new host plant of *Tuta absoluta* Povolny (Lepidoptera: Gelechiidae) in Turkey. Pakistan J. Zool. 2012;44:1183-1184.
36. Wist TJ, Evenden ML. Host plant preference and offspring performance of a leaf-mining moth, *Caloptilia fraxinella*, on

two *Fraxinus* species. Entomologia Experimentalis et Applicata. 2016;159:311-326.

37. Nava DE, Gomez-Torres ML, Rodrigues MD, Bento JM, Haddad ML, Parra JR. The effects of host, geographic origin, and gender on the thermal requirements of Diaphorinacitri (Hemiptera: Psyllidae). Environmental Entomology. 2010;39:678-684.
38. Bawin T, Dujeu D, De Backer L, Fauconnier ML, Lognay G, Delaplace P, Verheggen FJ. Could alternative solanaceous hosts act as refuges for the tomato leafminer, *Tuta absoluta*?. Arthropod-Plant Interactions. 2015;425-435.
39. Megido RC, De Backer L, Ettaïb R, Brostaux Y, Fauconnier ML, Delaplace P, Verheggen FJ. Role of larval host plant experience and solanaceous plant volatile emissions in *Tuta absoluta* (Lepidoptera: Gelechiidae) host finding behavior. Arthropod-Plant Interactions. 2014;8:293-304.
40. Sinclair RJ, Hughes L. Leaf miners: The hidden herbivores. Austral Ecology. 2010;35:300-313.
41. Steiner M, Goodwin. *Tuta absoluta*: Coming soon to a tomato crop near you... Practical Hydroponics and Greenhouses. 2009;108:44.
42. Balzan MV Moonen AC. Management strategies for the control of *Tuta absoluta* (Lepidoptera: Gelechiidae) damage in open-field cultivations of processing tomato in Tuscany (Italy). EPPO Bulletin. 2015;42:217-225.
43. Gontijo PC, Picanço MC, Pereira EJ, Martins JC, Chediak M, Guedes RN. Spatial and temporal variation in the control failure likelihood of the tomato leaf miner, *Tuta absoluta*. Annals of Applied Biology. 2013;162:50-59.
44. Ponti LU, Gutierrez A, Altieri MA. Holistic management of invasive species: The case study of *Tuta absoluta* (Meyrick) (Lepidoptera, Gelechiidae). Atti Accademia Nazionale Italiana di Entomologia. 2013; 125-136.
45. Cascone P, Carpenito S, Slotsbo S, Iodice L, Sørensen JG, Holmstrup M, Guerrieri E. Improving the efficiency of *Trichogramma achaeae* to control *Tuta absoluta*. Bio Control. 2015;60:761-771.
46. Bayram Y, Büyük M, Özaslan C, Bektaş Ö, Bayram N, Mutlu Ç, Bükün B. New host plants of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in Turkey. Journal of Tekirdag Agricultural Faculty. 2015;12.
47. Oztemiz S. *Tuta absoluta* povolny (Lepidoptera: Gelechiidae), the exotic pest in Turkey. Romanian Journal of Biology. 2014;59:47–58.
48. Bettaïbi A, Mezghani-Khemakhem M, Bouktila D, Makni H, Makni M. Genetic variability of the tomato leaf miner (*Tuta absoluta* Meyrick; Lepidoptera: Gelechiidae), in Tunisia, inferred from RAPD-PCR. Chilean Journal of Agricultural Research. 2012;72:212.
49. Steiner M, Goodwin S. *Tuta absoluta*. Practical Hydroponics and Greenhouses. 2015;153:38.
50. Cocco A, Deliperi S, Delrio G. Control of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in greenhouse tomato crops using the mating disruption technique. Journal of Applied Entomology. 2013; 137:16-28.
51. Duric Z, Delic D, Hrncic S, Radonjic S. Distribution and molecular identification of *Tuta absoluta* (Meyrick, 1917) (Lepidoptera, Gelechiidae) populations in Bosnia and Herzegovina and Montenegro. Polish Journal of Entomology. 2014;83:121.
52. Shashank PR, Chandrashekar K, Meshram NM, Sreedevi K. Occurrence of *Tuta absoluta* (Lepidoptera: Gelechiidae) An invasive pest from India. Indian Journal of Entomology. 2015;77:323-329.
53. Satti AA, Alien insect species affecting agriculture and natural resources in Sudan. Agriculture and Biology Journal of North America Issn Print. 2011;2151-7517.
54. Pfeiffer DG, Muniappan R, Sall D, Diatta P, Diongue A, Dieng EO. First record of *Tuta absoluta* (Lepidoptera: Gelechiidae) in Senegal. Florida Entomologist. 2013; 96:661-662.
55. ICIPE, Development and implementation of a sustainable IPM and surveillance program for the invasive tomato leafminer, *Tuta absoluta* (Meyrick), in North and sub-Saharan Africa, GIZ; 2015.
56. Mohamed ES, Mohamed ME, Gamiel SA. First record of the tomato leafminer, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in Sudan. EPPO Bulletin. 2012;42:325-327.
57. Klieber J, Reineke A. The entomopathogen *Beauveria bassiana* has epiphytic and endophytic activity against the tomato leaf

miner *Tuta absoluta*. Journal of Applied Entomology; 2015.
58. Zappalà L, Siscaro G, Biondi A, Mollá O, González-Cabrera J, Urbaneja A. Efficacy of sulphur on *Tuta absoluta* and its side effects on the predator *Nesidiocoris tenuis*. Journal of Applied Entomology. 2012; 136:401-409.
59. Roubos CR, Rodriguez-Saona C, Isaacs R. Mitigating the effects of insecticides on arthropod biological control at field and landscape scales. Biological Control. 2014;75:28-38.
60. Terzidis AN, Wilcockson S, Leifert C. The tomato leaf miner (*Tuta absoluta*): Conventional pest problem, organic management solutions? Organic Agriculture. 2014;4:43-61.
61. Urbaneja A, Desneux N, Gabarra R, Arnó J, González-Cabrera J, Mafra NA, Peña JE. Biology, ecology and management of the South American tomato pinworm, *Tuta absoluta*. Potential Invasive Pests of Agriculturalcrops. 2013;3:98.
62. Siqueira HA, Guedes RN, Picanco MC. Cartap resistance and synergism in populations of *Tuta absoluta* (Lep., Gelechiidae). Journal of Applied Entomology. 2000;124:233-238.
63. Siqueira HA, Guedes RN, Fragoso DB, Magalhaes LC. Abamectin resistance and synergism in Brazilian populations of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). International Journal of Pest Management. 2001;47:247-251.
64. Guedes RN, Picanço MC. The tomato borer *Tuta absoluta* in South America: pest status, management and insecticide resistance. EPPO Bulletin. 2012;42:211-216.
65. Campos MR, Rodrigues RS, Silva WM, Silva TM, Silva VF, Guedes RN, Siqueira HA.Spinosad and the tomato borer *Tuta absoluta*: A bioinsecticide, an invasive pest threat, and high insecticide resistance. PloS One. 2014;9(8):e103235.
66. Haddi K, Studies on insecticide resistance in *Tuta absoluta* (Meyrick), with special emphasis on characterization of two target site mechanisms; 2012.
67. Roditakis EV, Emmanouil G, Maria S, Marianna N, Ralf GM, Bassi A. First report of *Tuta absoluta* resistance to diamide insecticides. Journal of Pest Science. 2015;88:9-16.
68. Campos MR, Silva T, Silva WM, Silva JE, Siqueira HA. Susceptibility of *Tuta absoluta* (Lepidoptera: Gelechiidae) Brazilian populations to ryanodine receptor modulators. Pest Management Science. 2015;71:537-544.
69. Consoli FL, Parra JR, Hassan SA. Side-effects of insecticides used in tomato fields on the egg parasitoid *Trichogramma pretiosum* Riley (Hym.,Trichogrammatidae), a natural enemy of *Tuta absoluta* (Meyrick) (Lep., Gelechiidae). Journal of Applied Entomology. 1998;122:43-47.
70. Abbes K, Harbi A, Chermiti B. The tomato leafminer *Tuta absoluta* (Meyrick) in Tunisia: current status and management strategies. EPPO Bulletin. 2012;42:226-233.
71. Mohamed ES, Mahmoud ME, Elhaj MA, Mohamed SA, Ekesi S. Host plants record for tomato leaf miner *Tuta absoluta* (Meyrick) in Sudan. EPPO Bulletin. 2015;45:108-111.
72. Karut K, Kazak C, Döker İ, Ulusoy MR. Pest status and prevalence of tomato moth *Tuta absoluta* (Meyrick 1917) (Lepidoptera: Gelechiidae) in tomato growing greenhouses of Mersin. Türkiye Entomoloji Dergisi. 2011;35:339-347.
73. Proffit M, Birgersson G, Bengtsson M, Reis JrR, Witzgall P, Lima E. Attraction and oviposition of *Tuta absoluta* females in response to tomato leaf volatiles. Journal of Chemical Ecology. 2011;37:565-574.
74. Nombela G, Beitia F, Muñiz MA. Differential interaction study of *Bemisia tabaci* Q-biotype on commercial tomato varieties with or without the Mi resistance gene, and comparative host responses with the B-biotype. Entomologia Experimentaliset Applicata. 2001;98:339-344.
75. Chu D, You-Jun Z, Judith K, Brown, C, Bao-Yun X, Qing-Jun W, Guo-Ren Z. The introduction of the exotic Q biotype of *Bemisia tabaci* from the Mediterranean region into China on ornamental crops. Florida Entomologist. 2006;89:168-174.
76. Rakha M, Bouba N, Ramasamy S, Regnard JL, Hanson P. Evaluation of wild tomato accessions (*Solanum* spp.) for resistance to two-spotted spider mite (Tetranychusurticae Koch) based on trichome type and acyl sugar content. Genetic Resources and Crop Evolution. 2016;1-12.
77. Dhaliwal GS, Jindal V, Mohindru B. Crop losses due to insect pests: Global and

Indian Scenario. Indian Journal of Entomology. 2015;77:165-168.

78. Alamalakala L, Parimi S, Dangat S, Char BR. Non-Bt soil microbe-derived insecticidal proteins. In Biocontrol of Lepidopteran Pests. Springer International Publishing. 2015;89-121.
79. Coppel HC, Mertins JW. Biological insect pest suppression. Springer Science & Business Media. 2012;4.
80. Bernays EA, Chapman RF. Host-plant selection by phytophagous insects. *Springer* Science & Business Media. 2007;2.
81. Oerke EC. Crop losses to pests. The Journal of Agricultural Science. 2006;144: 31-43.
82. Gressel J, Hanafi A, Head G, Marasas W, Obilana AB, Ochanda J, Tzotzos G. Major heretofore intractable biotic constraints to African food security that may be amenable to novel biotechnological solutions. Crop Protection. 2004;23:661-689.
83. Laube W, Schraven B, Awo M. Smallholder adaptation to climate change: Dynamics and limits in Northern Ghana. Climatic Change*.* 2012;111:753-774.
84. Arah IK, Kumah EK, Anku EK, Amaglo H. An overview of post-harvest losses in tomato production in Africa: Causes and possible prevention strategies. Journal of Biology, Agriculture and Healthcare. 2015;5:78-88.
85. Oliveira CM, Auad AM, Mendes SM, Frizzas MR. Economic impact of exotic insect pests in Brazilian agriculture. Journal of Applied Entomology. 2013; 137:1-15.
86. Moawad SS, Ebadah IA, Mahmoud YA. Biological and histological studies on the efficacy of some botanical and commercial oils on *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae). Egyptian Journal of Biological Pest Control. 2013;23:301.
87. Reyes M, Rocha K, Alarcón L, Siegwart M, Sauphanor B. Metabolic mechanisms involved in the resistance of field populations of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) to spinosad. Pesticide Biochemistry and Physiology. 2012;102:45-5.
88. Biondi A, Chailleux A, Lambion J, Han P, Zappalà L, Desneux N. Indigenous natural enemies attacking *Tuta absoluta* (Lepidoptera: Gelechiidae) in Southern France. Egyptian Journal of Biological Pest Control. 2013;23:117.
89. Horrigan L, Robert SL, Polly W. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environmental Health Perspectives. 2002;110:445.
90. Opara LU. Traceability in agriculture and food supply chain: A review of basic concepts, technological implications, and future prospects. Journal of Food Agriculture and Environment. 2003;1:101-106.
91. Atreya K. Pesticide use knowledge and practices: A gender differences in Nepal. Environmental Research. 2007;104:305-311.
92. Gold LS, Stern BR, Slone TH, Brown JP, Manley NB, Ames BN. Pesticide residues in food: investigation of disparities in cancer risk estimates. Cancer Letters. 1997;117:195-207.
93. Matsumura F. Toxicology of insecticides. Springer Science & Business Media; 2012.
94. Hamilton AJ, Stagnitti F, Premier R, Boland AM, Hale G. Quantitative microbial risk assessment models for consumption of raw vegetables irrigated with reclaimed water. Applied and Environmental Microbiology. 2006;72:3284-3290.
95. Hernández R, Reardon T, Berdegué J. Supermarkets, wholesalers and tomato growers in Guatemala. Agricultural Economics. 2007;36:281-290.
96. Fogarty AM, Tuovinen OH. Microbiological degradation of pesticides in yard waste composting. Microbiological Reviews. 1991;55:225-233.
97. Keikotlhaile BM, Spanoghe P, Steurbaut W. Effects of food processing on pesticide residues in fruits and vegetables: A meta-analysis approach. Food and Chemical Toxicology. 2010;48:1-6.
98. Probst L, Houedjofonon E, Ayerakwa HM, Haas R. Will they buy it? The potential for marketing organic vegetables in the food vending sector to strengthen vegetable safety: A choice experiment study in three West African cities. Food Policy. 2012; 37:296-308.
99. Kariathi V, Kassim N, Kimanya M. Pesticide exposure from fresh tomatoes and its relationship with pesticide application practices in Meru district. Cogent Food & Agriculture. 2016; 2:1196808.

100. Parolin P, Bresch C, Poncet C, Desneux N. Introducing the term 'Biocontrol Plants' for integrated pest management. Scientia Agricola. 2014;71:77-80.
101. Michereff FM, Vilela EF, Jham, GN, Attygalle A, Svatos A, Meinwald J. Initial studies of mating disruption of the tomato moth, *Tuta absoluta* (Lepidoptera: Gelechiidae) using synthetic sex pheromone. Journal of the Brazilian Chemical Society. 2000;11:621-628.
102. Hussien AM. Biology, major hosts and preference of the African bollworm, *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae) to Three Tomato Cultivars at New Halfa. Agricultural Scheme (Doctoral Dissertation; 2015).
103. Bentley JW, Robson M, Sibale BB, Nkhulungo E, Tembo Y, Munthali F. Travelling companions: Emerging diseases of people, animals and plants along the Malawi-Mozambique border. Human Ecology. 2012;40:557-569.
104. Chadha ML, Oluoch MO. Home-based vegetable gardens and other strategies to overcome micronutrient malnutrition in developing countries. Food Nutrition and Agriculture. 2003;32:17-23.
105. de Bon H, Huat J, Parrot L, Sinzogan A, Martin T, Malézieux E, Vayssières JF. Pesticide risks from fruit and vegetable pest management by small farmers in sub-Saharan Africa. A review. Agronomy for Sustainable Development. 2014;34:723-736.
106. El-Arnaouty SA, Pizzol J, Galal HH, Kortam MN, Afifi AI, Beyssat V, Heikal IH. Assessment of two *Trichogramma* species for the control of *Tuta absoluta* in North African tomato greenhouses. African Entomology. 2014;22:801-809.
107. González-Cabrera J, Mollá, O, Montón H, Urbaneja A. Efficacy of *Bacillus thuringiensis* (Berliner) in controlling the tomato borer, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Bio Control. 2011;56:71-80.
108. Batalla-Carrera L, Morton A, García-del-Pino F. Efficacy of entomopathogenic nematodes against the tomato leafminer *Tuta absoluta* in laboratory and greenhouse conditions. *Bio Control*. 2010;55:523-530.
109. Garcia-del-Pino F, Alabern X, Morton A. Efficacy of soil treatments of entomopathogenic nematodes against the larvae, pupae and adults of *Tuta absoluta* and their interaction with the insecticides used against this insect. Bio Control. 2013;58:723-731.
110. Chermiti B, Abbes K. Comparison of pheromone lures used in mass trapping to control the tomato leafminer *Tuta absoluta* (Meyrick, 1917) in industrial tomato crops in Kairouan (Tunisia). EPPO Bulletin. 2012;42:241-248.
111. Cocco A, Deliperi S, Delrio G. Potential of mass trapping for *Tuta absoluta* management in greenhouse tomato crops using light and pheromone traps. IOBC-WPRS Bull. 2012;80:319-324.
112. Jeschke P. Progress of modern agricultural chemistry and future prospects. Pest Management Science; 2015.
113. Leite GD, Picanço M, Guedes RN, Zanuncio JC. Role of plant age in the resistance of *Lycopersicon hirsutum* f. glabratum to the tomato leafminer *Tuta absoluta* (Lepidoptera: Gelechiidae). Scientia Horticulturae. 2001;89:103-113.
114. Zappala L, Bernardo U, BiondiA, Cocco A, Deliperi S, Delrio G, Siscaro G. Recruitment of native parasitoids by the exotic pest *Tuta absoluta* in Southern Italy. Bull Insectol. 2012;65:51-61.
115. Rakha M, Hanson P, Ramasamy S. Identification of resistance to *Bemisia tabaci* Genn. In closely related wild relatives of cultivated tomato based on trichome type analysis and choice and no-choice assays. Genetic Resources and Crop Evolution. 2016;1-14.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/17046