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Prospects of Biological Control Agents for Management of Invasive Pest *Tuta Absoluta* (Lepidoptera: Gelechiidae) In Africa

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Abstract

Tuta absoluta (Meyrick) is a devastating agricultural pest of global concern, which has spread widely across continents causing substantial economic losses, particularly in tomato cultivation. In Africa the problem is much severe to the extent that farmers are abandoning the crop. Controlling *T. absoluta* by use of chemical pesticides is profoundly tricky due to development of rapid resistance. Alternative options such as biological controls are either scarce or expensive and only a handful of microbial agents are currently registered for management of *T. absoluta* in Africa. It has been observed that *T. absoluta* causes damage and loss in tomato ranging from 50-100% in South America, Europe and Africa where management options are most limited. Although several synthetic pesticides are registered for management of *T. absoluta* including; chlorantraniliprole spinetoram and emamectin benzoate group, little success are reported in Africa due to various factors including fast resistance development of *T. absoluta*. Commercially available biopesticides such as; *Beauveria bassiana* (Bals.), *Metarhizium anisopliae* (Metschn.), *Bacillus thurungiensis* (Bt), *neem extract* (Azadirachtin) and *Spinosad* (bacteria compound; spinosyn A and spinosyn D) are scarcely distributed in Africa. Although recently there are newly studied biocontrols including *Aspergillus oryzae* (Vuruga Biocide) that is registered in Tanzania, yet not distributed to most farmers across the country. However, some biocontrols have been reported for control *T. absoluta* in Africa including; *Aspergillus flavus* (Ahlb.) and *Aspergillus oryzae* (Ahlb.), they are not commercially available. This review highlights on the utilization and commercialization of various biological control agents for *T. absoluta* management in Africa.

Keywords: Tomato leafminer; *Aspergillus oryzae*; Management strategies; Microbial control agents

Introduction

Tuta absoluta (Meyrick), the tomato leafminer, is an invasive pest from South America that has spread extensively in Europe, Asia and Africa threatening tomato production [1,2,3,4,5].

T. absoluta and other pests, including mealybug and white ly, aphids, cabbage lopper, cutworms, leafminer (*Liriomyza sativa*), tomato fruit worm, and lea beetles are the main threats to tomato producers in Africa and globally except USA where *T. absoluta* has not yet been properly reported [6,7,3,8,9,10,11].

T. absoluta and other lepidopterous pests reduce both the yield and the quality of tomato fruit, thus diminishing its value in the market [12,13,14].

Table 1: Global distribution of Tuta absoluta, host range and damage incidences.

Continent	Confirmed countries	Host	Damage	Invasion period	Reference
South America	Peru, Chile, Ecuador, Argentina, Brazil Bolivia, Colombia, Paraguay, Peru, Uruguay and Venezuela	Tomato, potato, Datura spp, and Nicotiana spp	Damage range from 80-100% Damage range 80-100% tomato damage	1914 - to date; still persisting	Sylla et al., 2019;Desneux et al., 2011;[121] Luna et al., 2015

Central/ North America	Canada, Haiti, USA, Mexico, Panama, Costa Rica	Tomato, potato, Datura spp, and Nicotiana spp	damage 30-50%	Present with moderate impact	Desneux et al., 2011; [125,126,128]
Europe	Spain, Italy, Malta, France, Portugal, Germany, Bulgaria, UK, Serbia, Switzaland,Slovenia, Romania, Lithuania, Greece, Cosovo, Azerbaijan,Croatia, Belarus, Netherlands, Belgium, Czech-Republic, Denmark,Georgia, Guernsey,Hungray, North Macedonia,Norway, ukrain,Austria, Montenegro, Cyprus, Bosnia and Herzegovina	Tomato, potato, and Datura spp, Nicotiana spp, Cape gooseberry, bean (Phaseolas vulgaris)	Damage rate range from 50-80%s 50-80% crop damage in protected cultivation	Late 2006 – to date. Continuing to invade new areas and cause damage	[111]; Karadjova et al., 2013; [124]
Asia	Turkey, India, Iran, Japan, China, Rusia, Yemen, Qatar,Bahrain, Kuwait, United Arab Emirate, Bangladesh, Iraq, Syria, Sultanate of Oman, Lebanon, Israel, Palestine, Saudi Arabia, China, Nepal, Afghanstan, Kazakhstan,Tajikistan, Uzbekistan,Pakistan and Burma	Tomato and eggplant	50-100% tomato damage	2010 – onwards; gradually expand its range in the region	Li et al., 2021; [115] Guimapi et al., 2020; Zhang et al., 2020; Han et al., 2019; [106]; [119] Rakha et al., 2017; [131]
Africa	Algeria, Morocco, Libya, Egypt, Senegal, Sudan, Canary island, Eritrea, Nigeria, Ethiopia, Lesotho, Angola, Burundi, Cape Verde, Ghana, Botswana, Benin, Mayotte, Equatorial Guinea, Kenya, Tunisia, Niger, Tanzania, Zambia, Zimbabwe, D R Congo, Somalia, Bukina faso, Namibia, DR Sao Tome and Principe, Togo and Côte d'Ivoire	Tomato, potato, night shade, eggplant,Datura spp, and Nicotiana spp	Up to100% crop damage in open fields	Since 2008 and currently expanding its invasion across the continent	[120,113,134] Sawadogo et al., 2020; Smith et al., 2018; [109] Desneux et al., 2011; Rakha et al., 2017; Tonnang et al., 2015

Australia	Not reported	None reported	Under risk due to high commercial	Expect invasion on tomato	Han et al., 2018; Verheggen et al., 2019

Tuta absoluta has spread globally and is now distributed across various agroecological regions of Africa causing losses tomato as well as other crops such as night shade, eggplant, pepper, and several weeds [15,16] (Table 1). The Tomato leaf miner is also a major impediment in the production of several other solanaceous vegetables in Africa [17,18], It has led to severe damage and yield losses, mainly due to insecticide resistance [19]. Since its arrival in 2014, Tanzanian farmers have experienced massive crop losses [20]. Its control has become a major challenge due to the broad host range and a higher reproductive rate [21,22]. *Tuta absoluta* attacks all developmental crop stages, from seedlings to mature fruits for field and greenhouse-grown solanaceas including *S. tuberosum*, *S. nigrum*, *S. melongena* and wild *Solunum spp* [23-25]. Studies have shown that *Tuta absoluta* larvae and adults prefer the aerial plant parts due to their higher sugar levels [26,27]. This pest is successful due to tolerance under extreme temperature conditions ranging from coldness to high temperature hence surviving in several regions and various seasons [28,29]. Hence, management of this pest is tricky requiring an effective, integrated and affordable biocontrol agent to avert the problem in Africa.

Management of *T. absoluta* in Tanzania and in other African countries rely heavily on application of conventional pesticides [30] without even detection of the pest by using pheromone and colored traps that assist in identification and monitoring of pest population [31]. Despite the popularity of chemical pesticides, studies have revealed the usefulness of using other options including host resistance mechanisms [32]. Generally, there are scarce reports on management options with ability of controlling all stages of *Tuta absoluta*. Biological pesticides including viruses, fungi, bacteria and nematodes have been reported to effectively control *T. absoluta* eggs and larvae [33,34]. However, few of these have undergone screening in Africa despite its widespread invasion.

Natural enemies, particularly Hemipteran predators, are effective against *T. absoluta* and other insect pests [35,36,37]. In addition, entomopathogenic microbes are also gaining popularity in insect pest management worldwide, including Africa [38,39,10,40].

The alternate use of different active ingredients biocontrol agents such as; predators, parasitoids, botanicals and microbials showed high efficacy with low or no rate resistance on the pest [8,41]. However, use of an integated pest management including use of botanicals such as neem extract, microbial pesticide and minimal chemical pesticides is highly recommended for effective synegetic effects and safety with natural enemies [42,43,35]. Microbial controls including fungi, bacteria and virus have high potential to be used as biocontrol agents for management of insect pests for crop protection [33,44]. Bacteria especially Bacillus spp have proven to be effective for controlling *Tuta absoluta* in many areas [45]. Several reports have proved the efficacy of entomopathogenic bacteria; B. thuringesis for the control of *T. absoluta* larvae in Africa [40,46]. However, the effectiveness and accessibility of these biopesticides vary with pest species and geographical areas whereas little success has been reported in controlling *T. absoluta* in Tanzania [47]. Entomopathogenic fungi have been highly used as foliar sprays/drenches directly on plant or as endophytes for controlling insect pests compared to the rest of microbial controls [48,49]. Beauveria bassiana is widely used as epiphyte or endophyte for pest control worldwide [48,50] with high efficacy as both an endophyte and a foliar spray. Other entomopathogenic fungi including Metarhizium anisopliae have been reported to be highly effective against different pests including *T. absoluta* [51]. On other hand, Aspergillus spp. have been screened and evaluated in laboratory with high efficacy against larvae, pupae and adults of *T. absoluta* in Algeria and Tanzania [52,47]. In Africa, entomopathogenic microbes have been introduced for pest management with few record of registed products [53].

Since the management of insect pests is shifting from reliance on chemicals to integrated approaches of biocontrols including pathogenic nematodes, bacteria, fungus and virus [54,55,56,53], it is evident that biopesticides will increasingly be adopted in many regions especially in Africa where the pest is recently invading abruptly. Hence, native microbial controls including Aspergillus species could be a potential biopesticide for control of *T. absoluta* as it has been revealed with promising results on T.absoluta in Africa [52,47]. This review highlights the global trends of *T. absoluta*, available and registered management options for controlling *T. Absoluta*. It also provides prospects for screening and registration of novel biopesticide from local context for effective management of *T. absoluta* in Africa where the pest available managent options are unaffordable by most farmers.

Current management strategies for controlling Tuta absoluta

Conventional pesticides

Synthetic chemical pesticides have been used worldwide with low success due to resistance in most regions [51,57]. Management of *T. absoluta* by single approach cannot suppress the pest below economic injury level due to the fact that there is no single option that can 100% control all stages [58]. Several studies reported the failure of chemical pesticides including Chlorantraniliprole and Amamectin benzoate for controlling *T. absoluta* [19,59]. Chemical pesticides are imported in Africa in which their effectiveness might be compromised during shipping and misused by farmers due pest panic as well as limited training on application of pesticides [47]. Additionally, synthetic pesticides are environmentally and economically unaffordable in most African countries with limited financial resources. However, proper use with integration with environmentally safe strategies including traps and biological agents should be promoted to enhance management of *T. absoluta*.

Pheromone traps

Pheromones and other semiochemicals are widely applied for controlling insect pests in integrated pest management (IPM) programs including monitoring, mass trapping, rule and killing (attact-inhilate) and mating disruption [32]. Studies show that pheromone traps are effective in controlling *T. absoluta* under protected cultivation [60]. However, although traps are useful for attracting mainly adult male moth and often for population monitoring [5], they are expensive, and are rarely used by farmers to control *T. absoluta* in Africa. Studies show that pheromone traps cannot be effective when used merely for control of pests because they are designed to disrupt mating and not killing [61]. However, other studies have revealed that incorporation of semiochemicals; attractants of different colors in pheromone traps in early growing season help detect pests and monitor population and gradually minimize pest impact in the field [32,5]. Proper selection and application of traps could be effective when integrated with biological controls to safely protect tomato and other vegetable crops against *T. absoluta*.

Microbial control agents against *T. absoluta*

Microbial controls for pest management are becoming popular worldwide as effective and affordable control options against various insect pests on various crops [38]. In Europe and America, the application of microbial controls for crop protection has been commercialized and used intensively [62] whereas it has only been recently introduced in Africa. Microbes play a major role in balancing nutrients and proper utilization in agriculture [63]. A study by Buragohain et al. 2021 reported the effectiveness of integrating *B. thuringiensis var kurstaki, B. bassiana* and neem extract for management of *T. absoluta* under ield conditions in India. This reveals that native biocontrol agents are potential for effective management of various insect pests [64,65,66]. Other microbial controls including viruses, bacteria and nematodes have been reported to be effective against eggs and larvae of T. absoluta under laboratory conditions [33,34] but their further validation is needed. Despite the fact that T. absoluta is widespread in Africa, few microbial controls have been registered and commercialized [47,67]. The commercially available bgacterial biopesticides are *B. thuringiesis* and *B. sub ilis* [55,68,65,69,70]. Recently, entomopathogenic fungi are increasingly studied and reported to be effective pest controls [71,72,73]. Some fungi species including *B. bassiana* are reported as plant endophytes enhancing pest control [48,6], and also produce toxic metabolites for pest control [74,75]. On the other hand, *M. anisopliae, B. bassiana, A. lavus* and *A. clavatus* have shown high efficacy against several agricultural insect pests [76]. It has also been observed that most entomopathogenic fungi are effective in controlling lower stages of pests and some crop diseases when combined with chemical pesticides [77]. However, improving access, training on application and handling of available biopesticides particularly *M. anisopliae*, *B. bassiana* and *B. thuringiensis* and proper integration with other pesticides are critical, which could ensure potential market in Tanzania and Africa at large [78]. Since microbial control options for insect pest management are becoming popular globally, it is high time to embark on their commercialization in Africa.

Table 2: Current management strategies for controlling Tuta absoluta in invaded regions.

Type	Commercial name/ ingredients & source	Efficacy	Accessibility	Reference
Synthetic pesticides	Chlorantraniliprole (Coragen, E.I. DuPont de Nemours and Company, New York, USA); Emamectin benzoate (Wiltigo, King Quenson Group, Shenzhen, China); spinetoram (Radiant, Dow Agrosciences, Indianapolis, USA); S	For controlling, eggs, larvae and pupae, but with high pest resistance within short time	Low application in America, Europe, Asia, recently introduced and misused in Africa with little success	[107,114]; Guedes & Picanço, 2012; [121,129]
Traps	Pheromone traps (*Tuta absoluta*-Optima), Russell IPM Company (London, UK)	Contain 0.5 mg lure (TDTA and TDDA)/trap for trapping adults	America, Europe, Asia, Africa (limited access) mainly for monitoring	Desneux et al., 2010; [122] Ostrauskas & Ivinskis, 2010
Botanicals	*Azadirachta indica*	Eggs and larvae	Africa, America, Asia	Kona et al.,2014
Microbial control	*Metarhizium anisopliae, Beauveria bassiana,* *Bacillus thuringiensis* (Bt)	Larvae, eggs, pupae	Canada, USA, Australia, Spain, Mexico, Colombia, South Africa,	Fite et al., 2020;[102]; Contreras et al., 2014; Sabbour & Nayera, 2014; [130]

	Aspergillus oryzae (Vuruga Biocide)		Kenya, Egypt, and Tanzania	
Nematodes	*Steinernema carpocapsae*, *Steinernema feltiae*, *Heterorhabditis bacteriophora*	Larvae, pupa and adults	No commercialization information, no access in developing countries	Batalla-Carrera et al., 2010
Predator	Nabis pseudoperous Blaptostethus pallescens Poppius la	Larvae, larvae and eggs (under laboratory)	Spain	[104,117]
Parasitoids	*Trichogramma achaeae, T. pretiosum, Neochrysocharis formosa, Necremnus tutae, Necremnus near artynes* and *Necremnus near tidius*	*Eggs and larvae*	Europe and America, Argentina	de Campos et al., 2020; Ballal et al., 2016;Biondi et al., 2013; [108]; Ferracini et al., 2012; Luna et al., 2011; Pratissoli & Parra, 2000
Resistant tomato varieties	*Unappealing leaf surface, trichome, repellant cues*	*Egg, larvae, adult repellant*	None are commercially adopted	[123] Rakha et al., 2017; [132]
Protected cultivation	*Application of green/net houses*	*Preventing pest attack physically*	America, Europe, Asia but less adopted in African countries	Cocco, Deliperi, & Delrio, 2013; [112];Ostrauskas & Ivinskis, 2010

Microbial pesticide potential for commercialization

Aspergillus species particularly *A. oryzae* have been revealed to infect several insect life stages [47] registered (BCA/IN0005) for controlling *Spodoptera frugiperda* (fall armyworm) and *T. absoluta* in Tanzania. This novel microbial control agent could further be evaluated in other African counties as biocontrol of *T. absoluta* and other pests. Other fungal species such as Aspergillus species have been reported to control various pests in tropical countries [52,79], hence should be further evaluated and commercialized for control of T. absoluta in Africa. This review informs researchers to screen and commercialize new microbial control agents including A. oryzae that is reported to control different stages of T. absoluta including adult females to effective control crop damage in the ield (Table 3).

Table 3: List of potential microbial control agents for controlling T. absoluta.

Name	Target	Active ingredient/utility	Application	Reference
Bacillus thuringesis, Bacillus sublilis	Eggs, larvae	Spore/colony forming units commercially available in America, Europe, Asia and Africa	Foliar sprays and seed coats for seed and seedling protection	Abdullah, 2020; Kamal et al., 2019; Gowtham et al., 2018; Sabbour, 2014; Abd El-Ghany et al. 2016b
Metarhizium anisopliae	Eggs, larvae	Conidia/metabolites commercialized in America and Europe	Applied as direct foliar spray, root endophytes of conidia	[127] Contreras et al., 2014)
Beauveria bassiana	Eggs, larvae and pupae	Conidial formulations commercialized in developed countries	Endophytes and foliar spray of formulated conidia	[116], Inanli, Yoldaș, & Birgücü, 2012; Urbaneja et al., 2012; Abd El-Ghany et al. 2016b
Trichoderma album, Trichoderma harzianum	Eggs, larvae and adults	Conidia of T. album and T. harzianum in a neem	Laboratory tested but not commercialized	Kaoud, 2014; [118,135-137]

		blend no commercial product for T. absoluta		
Aspergillus flavus, Aspergillus oryzae (BCA/IN/0005)	Eggs, larvae, pupae and adult	Infective conidia of A. flavus reported in laboratory where A. oryzae- registered in Tanzania for controlling lepidopterous pests	With broad application as biopesticide and potential endophyte of crops in Africa	[110,138,139]; Lakhdari et al., 2016; Zekeya et al., 2019; FAO-highlights, 2020

Natural enemies

Parasitoids and predators including Macrolophus pygmaeus and Hymenopteran, respectively, are effective in controlling *T. absoluta* eggs and larvae and several insect pests helping to reduce damage and suppress population [80-83]. Table 2 shows a list of parasitoids with their revealed efficacy in developed countries [27] few parasitoids are reported for controlling *T. absoluta* in Africa [80]. However, lack of expertise on parasitoids rearing and parasitism efficacy could be one of the obstacles of utilizing this approach for controlling insect pests in Africa. Hence there is a need for screening and registration of parasitoids as natural controls of *T. absoluta* in the region.

Botanical extracts

Botanical extracts have been and are currently used for controlling insect pest although only few exist commercially [84,85]. Neem extract has been widely used for the management of crop pests with efficacy against *T. absoluta* eggs, larvae and pupae [1]. Another study by [103] revealed the potential of using piper extracts for control of *T. absoluta* on tomato. Studies revealed that botanical extracts are potential sources of active ingredients for controlling pests, particularly *T. absoluta* and can have enhanced activity when combined with synthetic pesticides [86]. A study by [105] revealed that Orange peel oil have high insecticidal activity against larvae of *T. absoluta*. Again, other studies revealed that plant extracts are potential larvicides of *T. absoluta* when prepared and applied appropriately. However, botanical pesticides should be careful handled as they might have side effects as synthetic chemical pesticides in some circumstances [87-89]. Hence, this review highlights potential biological pesticides due to high efficacy, potential for commercialization and safety for sustainable crop production.

Future outlook for controlling *Tuta absoluta* in Africa

Integrated pest management approach could be effective for sustainable control of *Tuta absoluta* [90]. Biopesticides from *B. bassiana, M. anisoplia B. subtilis* and *B. thuringiensis* have promising results for controlling a broad range of pests [38,91,66]. However, their effectiveness on host pests is diminutive,due context variations compared to native strains that have shown high efficiency on *T. absoluta* [66].

Thus, there is an urgent need for screening for effective alternative options available in local contexts. Figure 1 summarizes the potential applicability of genus *Aspergillus* as a biocontrol agent and shows how *Aspergillus* species can promote plant growth through production of growth hormones such as gibberellins [63,92].

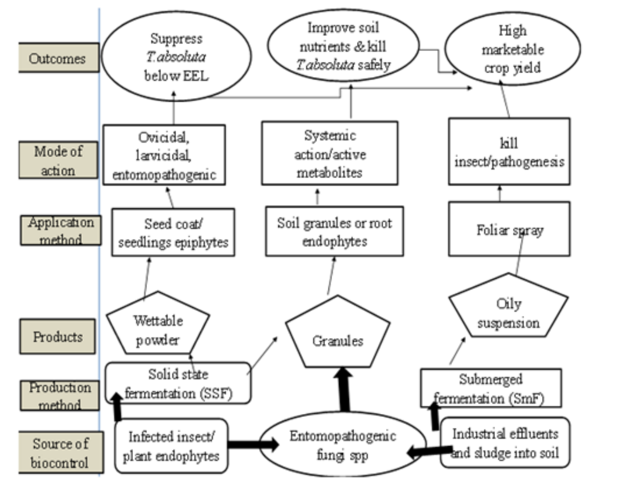

Figure 1: The potential for formulation of novel biopesticide and various modes of application of Aspergillus species as endophyte/epiphyte enriching plant nutrient levels (NL), in soil upon saprophytic activity and pest control via foliar application to kill eggs, larvae, pupae and moth suppressing pest below economic injury level (EEL) in fields.

It also shows that *Aspergillus spp* produces phytohormones and has insecticidal activities against agricultural pests [76] and can act as bio-fertilizers by decomposing organic materials [101]. *Aspergillus* species has a good record in nutrient enhancement and promotion of healthy plant growth [93] whereas *A. flavus* and *A. awamori* act upon industrial waste water and heavy metals, providing nutrients and minerals and crop protection [94-96]. *A. fumigatus* and *A. parasiticus* are reported to have endophytic activity in plants through production of essential minerals and metabolites [97]; *A. oryzae* has been reported as a marine endophyte that produces protective metabolites against pests [98]. *Aspergillus* species are also known for producing metabolites that enhance plant defense against pests and diseases (Sun et al., 2018) and act as a source of metabolites in various environments [99]. Furthermore, [79] have reported activity of *A. oryzae* against locusts and, more recently, A. flavus has shown significant activity against *T. absoluta* in Algeria [52]. Locally available entomopathogenic fungi could be potential suppressers of all life stages of *T. absoluta* including adult moths, and reduce its impact in Africa [47]. However, integrated pest management and biological control are essential for enhancing efficacy [100]. Hence an *Aspergillus*-based biopesticide could have multiple and integrated applications with other biological control agents. It could be incorporated in irrigation systems, foliar sprays and drenching applications to maximize pest control efforts

Conclusion

Tuta absoluta is a tricky pest to be controlled by a single strategy. Various management options are available in other regions but with little success in Africa. Besides a wider use of synthetic pesticides for management of *T. absoluta* in most regions, their effectiveness is context based due to varied agroecological conditions leading to failures and increasing cultivation cost. Due to these shortcomings of the available pest management options, this review recommends for commercialization of locally available biocontrol agents in Africa. However, screening for novel microbial agents should be funded and promoted to enhance efficacy, accessibility and applicability for effective management of destructive pest, *T. absoluta* in Africa.

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