International Journal of Applied Agricultural Sciences
2024; Vol. 10, No. 3, pp. 100-112
https://doi.org/10.11648/j.ijaas.20241003.13

Review Article

Review on Status of Tomato Leaf Miner and It's Management Practices

Zalalem Tesso*

Department of Horticulture, College of Agriculture and Natural Resource, Dambi Dollo University, Dambi Dollo, Oromia

Abstract

Tomato (Lycopersicon esculentum Mill.) is one of the most important edible and nutritious vegetable crops of the world. It is consumed as fresh table tomato and as raw material for food processing industries It grows both on a small and commercial large scale as cash crop. Tomato production is highly constrained by several factors including insect pests and disease. The most important insect pest that is constraining tomato production tomato leaf miner- Tuta absoluta (Meyrick). Tuta absoluta is one of the most devastating tomato leaf miner and it spreads extensively in almost all parts of the world. Tomato leaf miner is a pest of other Solanaceous crops in many vegetable crop growing areas around the world. It is a serious threat for tomato production and it results in highest damage. *T. absoluta* has fast growth rate with developmental stages of egg, larvae, pupa, and adult and it adapts to different environmental conditions. A larva is the most destructive one that consumes preferably leaves stems and fruits of the tomato plant on which they develop creating mines and galleries. by hiding within mesophyll of the plant tissues. To control tuta absoluta focused on different environmental friendly approaches that inclusively termed as IPM strategies. These are cultural practices, biopesticides, and biological using parasitoids, predators, inheritance sterility development in insect and pest resistant plant cultivar production are considered as promising alternatives to control *T. absoluta*. Therefore, this review briefly describes the current status of these methods used to design suitable and sustainable management strategies against *T. absoluta*. The aim of this review paper is describing the status of the pest and its control methods.

Keywords

Parasitoids, Predators, Galleries

1. Introduction

Tomato (*Solanum lycopersicum* Mill.), which belongs to the nightshade family *Solanaceae* is one of the most widely cultivated and consumed food crops among vegetables in the world. Tomato is the world largest vegetable crop after sweet potato [58].

Tomato is considered one of the vital vegetable crops of the world and its has nutritional values which could either be consumed fresh or raw material for food processing industries [28].

Tomato is one of the most important vegetable crops in Ethiopia grown for fresh market and processing. It grows under irrigated and non-irrigated areas in small and large scale farming system. The crop is a warm season crop sensitive to freezing temperature and frost. Tomato can be produced un-

*Corresponding author: tessozalalem6@gmail.com (Zalalem Tesso)

Received: 5 January 2024; **Accepted:** 26 January 2024; **Published:** 6 June 2024

der open fields and green house condition. The crop is rich in nutrients such as vitamin, minerals and antioxidants which are essential to well-balanced human diet [72].

It is an important ingredient in most diets and a very cheap and very good source of vitamins A, C and E and minerals that are very good for body and protect the body against diseases [73]. It also contains a large quantity of water (75%) and calcium (20%) all of which are of great importance in the metabolic activities of man. Dietary intake of tomatoes and tomato products containing lycopene has been shown to be associated with a decreased risk of chronic diseases, such as cancer and cardiovascular disease [3].

Tomato production has been facing many biotic and environmental constraints. such constraints are pests and diseases which reduce yields and the quality of marketable fruits. Many insect pests are associated directly with tomato damage and yield losses. *Tuta absoluta* (Meyrick) is considered as one of the most important and devastating tomato insect pest [59].

Tomato leaf miner was first found in Ethiopia in 2012 infesting open-field tomato plants [57]. Afterwards of its introduction, the insect has spread quickly and it is currently considered a key challenge on tomato production. It is believed to have been introduced through the northern part of the country from Yemen or Sudan. The rapidly growing regional, national and international travel and trade drastically increase the potential for moving noxious pest species to new geographic regions and locations. The packing materials for import of tomatoes, peppers and eggplants, as well as imported planting material as the most likely entry, establishment and spread means for the pest [43]).

T. absoluta is a nocturnal moth of the *Gelechiidae* family under the order Lepidoptera. Is currently recognized as a major threat to tomato production in both greenhouse and open field conditions. The moth originates from South America and was spread to Europe, North Africa, Asia and recently in the Middle East over the past ten years [76]. It was experimented that a female *Tuta Absoluta* lays up to 260 eggs individually on the tender leaves during its life time. Their larvae damage leaves, fruits, and stems, causing considerable losses on tomato yield. Losses of 50-100% have been reported on tomato [27].

Tomato leaf miner has a high reproductive potential in favorable conditions, the insect can complete about 10-12 generations in a year [57]. Tomato leaf miner is difficult to control because the larvae feed inside the plant [36].

The use of chemical pesticides as its control measure is highly sought and the most effective method to reduce *T. absoluta* treat level. However, the need for alternative control methods is encouraged, considering that, the pest has developed resistance to dozens of the pesticides and the negative side effects of pesticides over-use to the environment and beneficial arthropods. Control using sex- based pheromone to prevent mating has been developed; however, the ability of female *T. absoluta* to reproduce parthenogenetically weakened any of these pheromone-based controls [7].

Some insects may be the best controlled by a combination of practices that are not fully effective when used alone, *T. absoluta* is one of them. To control those pests effectively, it is critical to combine all available control measures including cultural methods, biological control agents and the correct use of registered pesticides [35].

Objective: Review on the status of tomato leaf mine/ Tuta absoluta (Meyrick) and it's manage mental practices.

2. Status of Tomato Leaf Miner and It's Management

2.1. Origin and Distribution of *T. Absoluta*

The species is thought to originate from Chile and to have spread to South America, Europe then to South East Asia and is now moving south from the lower Mediterranean shores into Africa on different solanaceous crops after developing resistance to the commonly used plant protection products [5].

The rapid distribution of *T. absolutes* over wide geographic areas may be a result of various factors such as high biotic potential, the large range of host plants, the intra-continental dispersal facilitation due to human transportation and the artificial selection of insecticide-resistant populations, the absence of co-evolved natural enemies may explain why the pest population dynamics in the newly invaded areas are faster than in the native area, where natural enemies are more frequent [69]. The spread of this pest has hit almost all the continents. Below is the highlight of the major areas where this pest has been discovered and appeared prevalent.

Table 1. *The world's geographical distribution of tomato leaf miner/Tuta absoluta.*

S/N0	Region	Country	Year Introduced	Reference
1	South America	Brazil (Peru)	Native	[19]
2	South America	Argentina	Declared pest 1964	[19]
3	Europe	Spain	2006	[19]
4	North Africa	Algeria	2008	[57]
5	North Africa	Morocco	2009	[57]

S/N0	Region	Country	Year Introduced	Reference
6	North Africa	Egypt	2010	[57]
7	West Africa	Sudan/Southern Sudan	2011	[54]
8	East Africa	Ethiopia	2012	[53]
9	East Africa	Kenya	2013	[53]
10	East Africa	Tanzania	2014	[75]
11	West Africa	Senegal	2014	[57]
12	West Africa	Nigeria	2015	[57]
13	West Africa	Niger Republic	2016	[57]

Source: [65]

2.2. Biology and Life Cycle

Tuta absoluta is an important invasive pest of tomato and always active at night. It mates and lays eggs during the night period. Adults are spackle brown or silver-colored with black spotted wings with length of 8-10 mm and 5-7 mm long, *T. absoluta* is a holometabolous with high reproduction rate. Adult lifespan ranges between 10 and 15 days for females and 6–7 days for males. The female lays the eggs mainly on the leaves, although they can also be found on stems and sepals. The number of eggs per female is usually between 40 and 50 and may reach 260 before completing the life cycle [19].

Eggs are laid isolated, facilitating their distribution on the crop. Eggs are small cylindrical, creamy white to yellow 0.35 mm long. Egg hatching takes place 4- 6 days after egg lying; eggs are hatched into larvae, which develop in to four larval stages called instars. Females can lay up to 260 - 300 eggs leading to 12 generations per year depending on environmental conditions [19].

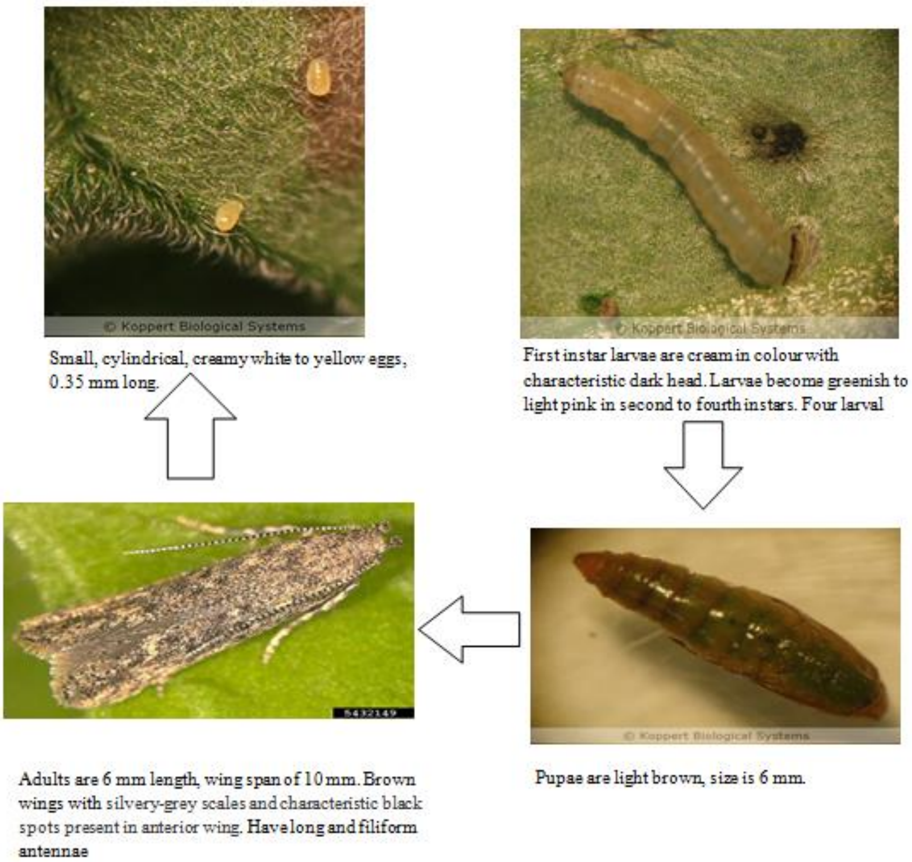

Figure 1. *Life cycle of leaf miner Source: [8].*

They undergo complete metamorphosis involving four developmental stages which larva, pupa and adult stages that are completed within 24-30 days at favorable environmental conditions. The newly emerged female adults release sex pheromone that attracts the male during mating. Females usually deposit their eggs on tomato leaves within 7 days of mating. The egg color varies from creamy white to bright yellow. The emerging larvae burrow into the leaves where they feed on the mesophyll tissues and develop within days [8].

The larvae start feeding on stem, leaves, buds and fruits. Young larvae are cream in color with dark head. As they develop, the larvae become greener and slightly pink in the last instar. The larvae (caterpillars) appear creamy in the first stage before turning greenish and pinkish in the final stage. They measure from 0.6mm to 0.8mm in length in their first larval stage and 7.3mm to 8mm in the fourth stage. Adults are nocturnal and hide between leaves during the day time. Their activity is concentrated in the early morning and evening; during the rest of the day, they remain hidden among the leaves [79]. *Tuta absoluta* can overwinter as eggs, pupae or adults depending on environmental conditions. Moths are active during the night and hide between leaves during the day (Figure 1).

2.3. Economic Importance and Damage

T. absoluta is a major pest of both field and greenhouse tomato productions. The pest has been responsible for losses of 80-100% in tomato plantations in both protected cultivation and open fields [57]. Yield and fruit quality are both considerably impacted by direct feeding of the pest as well as secondary pathogens entering host plants through wounds made by the pest Feeding damage is caused by all larval instars and throughout the entire crop cycle [42].

After hatching, larvae penetrate apical buds, flowers, new fruit, leaves, or stems. On leaves, the larvae feed on the mesophyll tissue, forming irregular leaf mines which may later become necrotic. Larvae can form extensive galleries in the stems which alter the general development of the plants. Fruits are also attacked by the larvae, forming galleries which represent open areas for invasion by secondary pathogens, leading to fruit rot [77].

Plants can be attacked at any developmental stage, with females ovipositing preferentially on leaves, and to lesser extent on leaf veins and stem margins, sepals or green fruits. Oviposition was found possible on unripe tomatoes only [25]. The pest damage at the larval stage and it entirely attacks the tomato plant thus damaging all of the productive parts [6].

Specifically, the larvae penetrate the apical buds, flowers, fruits, leaves and/or stems immediately after hatching [38]. T. absoluta feeds on both green and mature tomato fruits and can destroy the entire tomato vegetation within two days (Figure 2) and the damage is always severe especially in young plants The pest affects tomatoes destined to fresh market as well as to processing [56].

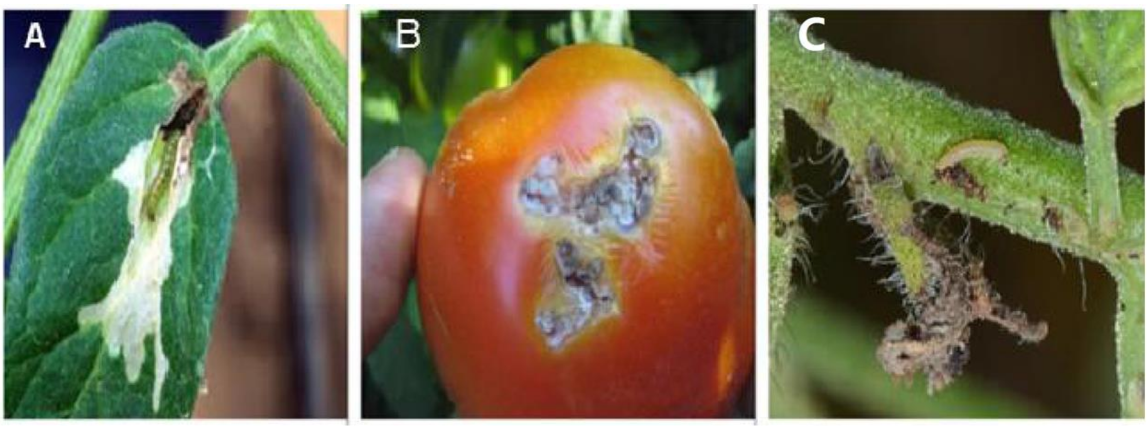

Figure 2. *Symptoms of Tuta absoluta damage on; - A) leaf B) fruit C) stem of tomato Source: [27].*

According to [2] cited (Personal Communication), Tuta absoluta is the pest caused serious economic damage in Ethiopia and Kenya. The economic impact is reflected by an increase in the cost of tomato production and yield loss /lower marketable production, as well as potential loss of markets if it were to become established.

In 2016, a sporadic attack by an invasive tomato leaf miner, cause more than 80% yield loss in Nigeria. This had caused price up to 400% in three months as *T. absoluta* destroyed the annual harvest affecting entire tomato farms (Figure 3). Huge economic losses and rapid spread of the devastating pest had been recorded in recent years [12].

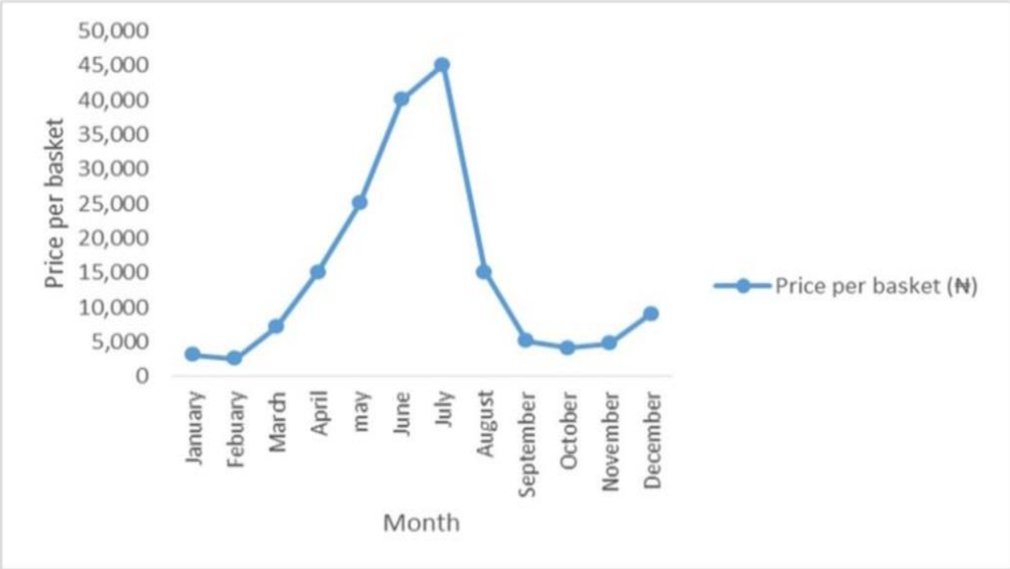

Figure 3. *Change in Tomato price during 2015 Tuta absoluta outbreak in Nigeria (Naira per basket) Source: [65].*

2.4. Host Plants of *T. absoluta*

T. absoluta has major host, minor host and wild host. Tomato is the main host plant for *T. absoluta.* They attacks other species of cultivated Solanaceae: potatoes, eggplants, peppers and wild Solanaceae such as *S. americanum, S. nigrum, Datura stramonium, D. ferox and Nicotiana glauca* [75]. On potato only attacks aerial parts, thereby not directly impeding tuber development. Nevertheless, leaf feeding may indirectly lower potato yield and under appropriate climatic conditions, [60]. *T. absoluta* has also occasionally been found on several species of plants, such as the sweet pepper, tobacco, bean, cape gooseberry *and* green beans [52].

The larvae of *T. absoluta* can also be found on wild hosts such as *D. stramonium* L., *Daturaferox*L., *Lycium chilense* [62]. Different plant species have been alternative hosts of this insect, this indicates that *T. absoluta* shows a high propensity to use various plants as secondary hosts [35].

3. Management of Tomato Leaf Miner

3.1. Cultural Methods

3.1.1. Good Agricultural Practices

Good agricultural practices for the control of *Tuta absoluta* include crop rotation with non-solanaceous crops ploughing, adequate irrigation and fertilization, removal of infested plants and complete removal of post-harvest plant debris and fruit. The removal of wild solanaceous host plants near the growing area is also encouraged, as these can host all stages of the pest, which can then re-infect the growing crop [77].

According to [2] cited Anonymous (2009) detected fruit stalks that damaged by larvae of *T. absoluta*, there will be an overhaul of the whole plot, the process of withdrawal and destroyed securely to prevent the pest completes its cycle and continue to spread. The wild host plants should also be removed to prevent the further build up of a potential population [2].

The removal of infested fruits and destruction of alternative hosts are frequent recommendations against T. absoluta, but are not always feasible or effective. Fruit removal is routine in tomato fields, but the destruction of damaged fruits should be done more frequently as it improves control of T. absoluta. However, borer attack is not limited to the fruits, and their removal does not solve the problem destruction of the whole plant is necessary [2].

3.1.2. Management of Plant Material

According to [62] the use of transplants free of pests may be useful in control of *T. absoluta*. When the pest damage is low, it is important to remove any of symptomatic leaves, stems and fruits affected by the presence of larvae or pupae and place them in plastic bags to destroy. Remove weeds that may be host to the pest within the area of vicinity. To prevent population build up one should not leave infested plant material on the ground, as the larvae will quickly leave them and colonize new plants.

3.1.3. Destruction of Crop Residues

The crop residue after the harvest of tomato, potatoes, eggplants and peppers should be destroyed as soon as possible. They can be destroyed by either burning, buried or covered with transparent plastic film to ferment them. Soil solarization may be useful in warm climates to kill pupae that remain in the soil. Leave a minimum of six weeks between successive susceptible crops [40].

3.2. Resistance Varieties

Breeding host plants resistant to *T. absoluta* remains an intensively pursued management tactic, particularly since the 1990s [37]. The cultivated tomato is highly vulnerable to *T. absoluta*. Although genetic sources of resistance to *T. absoluta* were detected among germplasm bank accessions of *S. lycopersicum.* The most promising genetic sources of resistance are from wild tomato [31].

Constitutive tomato resistance to *T. absoluta* has been the focus of attention in breeding programs relying on resistance related to leaf allelochemicals or trichome density. These compounds impair egg laying and larva feeding, leading to antixenosis, and larval toxicity, leading to antibiosis [10].

Induced resistance mechanisms in tomato are being considered. As a chewing insect, *T. absoluta* triggers the jasmonic acid (JA) pathway, potentially enhancing plant defenses against various pests as a result of cross-effects between distinct plant defense pathways. This induction are Constitutively expressed defensive allelochemicals toxic to pests, The release of volatile organic compounds (VOCs) that attract natural enemies and Preventing the release of volatiles necessary for host-plant finding by *T. absoluta* [20].

Breeding tomatoes for *T. absoluta* resistance had been unsuccessful and so there are no commercial tomato hybrids available that have an acceptable degree of resistance to *T. absoluta* [36]. This is thought to be due to a lack of genetic variability for this trait within the gene pool used for domestic tomato production, resulting from long periods of breeding/selection for other traits. However, to date no clear information as whether there are successful tomato varieties which are resistant to *T. absoluta*. Efforts to develop resistant varieties are going on in different parts of the world and this may need more research efforts to identify the adaptation mechanisms and areas of weakness for effective control [11].

Insect resistant cultivar development is considered as one of alternative approach than chemical pesticides for obtaining cost-benefit ratio for pest control. In Brazil, tomato improvement was practiced to obtain pest-resistant cultivars by incorporating the alleles for resistance present in wild plants for commercialization and produce the allele-chemicals associated with resistance. Three types of allele-chemicals (acyl-sugars, zingiberene, and 2-tridecanone) have been associated as resistant to *T. absoluta* [33]. The resistance of tomato strains rich in 2-tridecanone (2-TD), zingiberene (ZGB), and acyl sugars (AA) to the tomato moth, *T. absoluta* showed significant reduction on evaluated characteristics, such as oviposition rate, severity of damage to the plants, injuries to the leaflets, and the percentage of leaflets attacked [22].

The oviposition rate reduction of *T. absoluta* was directly associated with high concentrations of 2-TD, ZGB, and AA in the tomato cultivars. This is a very important strategy to prevent the tomato plant from insect attack. These three allele-chemicals had equivalent effects on oviposition, which was consistently lower on these strains than on the susceptible controls [70].

3.3. Biological Methods

It has been used against crop pest insects belonging to the orders Homoptera, Diptera, Hymenoptera, Coleoptera and Lepidoptera, among others [66]. The biological control agents are considered as one possible solution of the *T. absoluta* crisis. This strategy offers a more sustainable and less expensive alternative to chemicals [59].

Biological control has also received attention as a potential to against T. absoluta. The initial focus of attention was predatory stinkbugs and subsequently egg parasitoids. The basic strategy was the release of these natural enemies to contain the pest population [74]. However, the use of predatory stink bugs was limited to experimental releases due to their low incidence in tomato fields, dubious efficacy and higher cost than current control methods for practical use. This was further limited by field parasitism of the predator and the negative impact of insecticides on the predator population [8].

According to [23] the following areas need to be considered in developing feasible biological control, Detailed survey and works need to be conducted on the nature of the endemic natural enemy complex associated with T. absoluta in tomato production regions, Assess the potential of native natural enemies to control the pest, Define economical thresholds and intervention levels for T. absoluta that account for biological control and Carefully balance costs and benefits of classical biological control.

Bacillus thuringiensis high efficacy in reducing the damage caused by T. absoluta at high infestation levels when compared with non-treated controls. *B. thuringiensis* are highly efficient reducing the damage produced by first, second, and third *T. absoluta* larval instars. The species from the mite group of arthropods feeding on caterpillars and adults of tomato leaf miner, with one or more mites per host. They observed that larvae and adults of Tuta absoluta being paralyzed by the toxins and made sound recommendation for Pyemotes sp [34].

Biological control occupies a central position in integrated pest management programmes. This is because have enormous and unique advantages such as safe, permanent and economical [49].

3.3.1. Predators

These enemies of *T. absoluta* are commercially available and can be used in its control. These may include Predatory bugs such as *Mesoglossus pygmaeus* and *Nesidiocoristenuis* have been identified as the most promising natural enemies of *T. absoluta* they are large consumers of eggs of the pest [61].

Nesidiocoris tenuis regulates *T. absoluta* population due to its ability to prey efficiently on eggs This predator species was able to prey on more than 100 eggs per individual per day [55].

Mesoglossus pygmaeus and *N. tenuis* also reduced leaflet infestations up to 75 and 97% and fruit infestations up to 56 and 100%, respectively. Though, preying on the egg and larvae of *T. absoluta.* In Mediterranean region using *Nesidiocoristenuis*,, highly effectiveness of predator use when combined with other methods in controlling *T. absoluta* [64].

3.3.2. Parasitoids

These are one of natural enemies that can be used to control population growth of t. absoluta in both greenhouses and open field tomato farms. They are the most widely used natural enemies of *T. absoluta* in South America. *Trichogrammatoidea bactrae* and *Trichogramma pretiosum* are egg parasitoids of *T. absoluta* [48].

However, the endoparasitoid, P. dignus, and the ectoparasitoid, D. phtorimaeae formed more than 50% of natural parasitism in the larval stage of T. absoluta. However, until now there are no any reports that indicate the existence of adult parasitoids of *T. absoluta* [32].

The most important *T. absoluta* egg parasitoids are found in the families of Trichogrammatidae, Encyrtidae and Eupelmidae. *Trichogramma pretiosum* and *Trichogramma exiguum* are egg parasitoids under the family Trichogrammatidae and the most extensively used to control tomato leaf miner *T. absoluta.* Regarding parasitoids of *T. absoluta* eggs, *Trichogrammaacheae* has been identified as a potential biological control agent of the pest and is currently being released in commercial tomato greenhouses [78].

Finally, spiders, predatory mites, thrips, lacewings, earwigs ground beetles, ladybugs, and ants feeding occasionally on *T. absoluta*, but no biocontrol activity has been quantified thoroughly [8] (Figure 4).

Egg parasitoids, notably species of *Trichogramma*, are found in association with *T. absoluta*, but natural parasitism appears low, possibly owing to the poor egg quality for *Trichogramma* offspring development [17].

Lines with circles show negative effects in the direction of the circles and lines with arrows show positive effects in the direction of the arrows. Solid lines show direct interactions, and dashed lines show indirect interactions (mediated by another component of the system; green and red indicate plant- and natural enemy–mediated indirect interactions, respectively). Thickness of lines and size of circles/arrowheads are proportional to the known or estimated strength of the interactions.

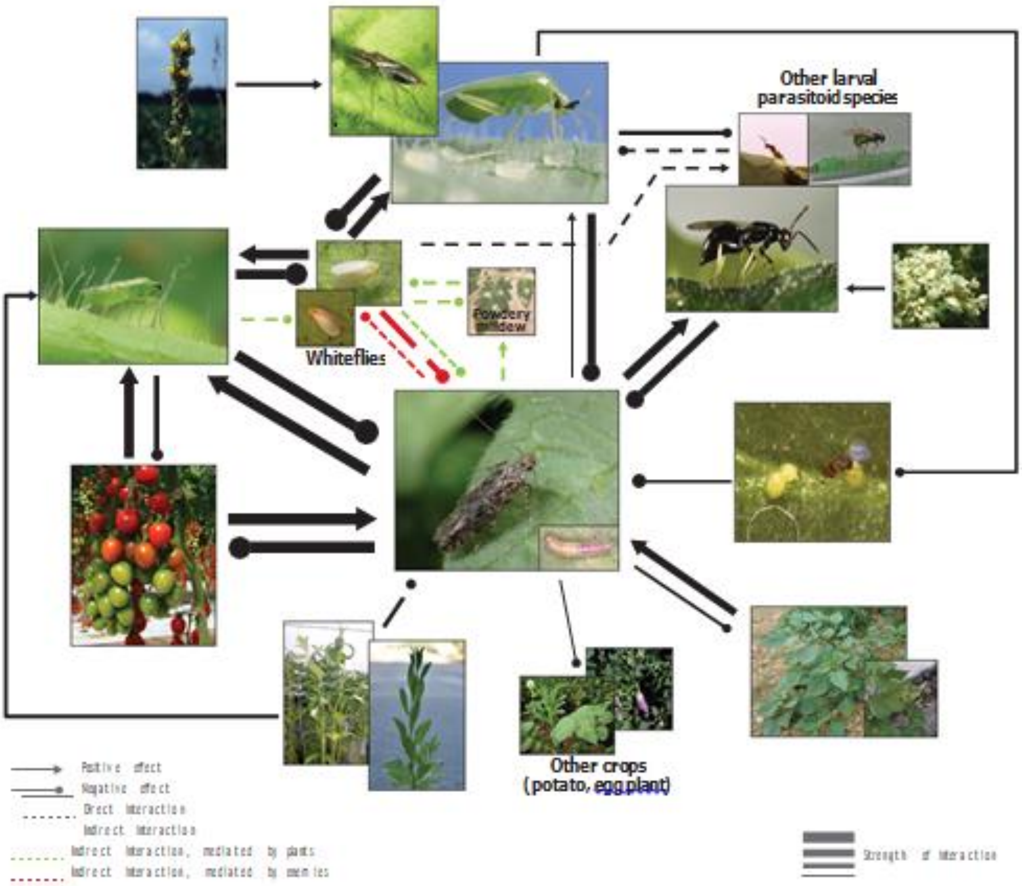

Figure 4. *Biotic interactions and linkages between Tuta absoluta and other components of the tomato agro-ecosystem and neighboring systems. Source: [8].*

3.3.3. Entomopathogens

Effectiveness of entomopathogens controlling *T. absoluta* with the exception of *Bacillus thuringiensis* var. kurstaki. *Bacillus thuringiensis*, an entomopathogenic bacterium has been used in the control of tomato plant pests and very effective bio-insecticide [8]. *Bacillus thuringiensis* do not raise any environmental concern as they are environmentally. In addition, the entomopathogenic nematodes *Steinernema carpocapsae* friendly *Steinernemafeltiae* and *Heterorhabditisbacteriophora* have proved to be capable of infecting late larval instars of *T. absoluta* [50]). In the leaf bioassay, a high level of larval parasitization (77 to 92%) was recorded revealing the nematode's capacity to kill the larvae inside the galleries. These indicated that nematode treatment reduced insect infection of tomato plants by 87 to 95% [6].

3.4. Botanicals

Botanicals are very important natural resources used to control different agricultural pests for long period of time. Crude extracts from seeds, leaves, bark, bulbs, and fruits of the different plant species have been extensively tested on agricultural pests for bioactivity worldwide [41].

The phytochemical products, especially extracts or essential oils are suggested as potential alternatives than synthetic pesticides to control insect pests. Ethanolic leaf extract obtained from *Piper amalago* var. *medium*, for instance, caused 70% larval and pupal mortality in two-day exposure through exhibiting acute toxicity at the concentration of 2,000 mg L^{-1} [21].

The allelochemicals found in Piperaceae are diverse with insecticidal/insectistatic properties from allelochemicals, piperamides are the major classes of compounds found in species of the genus *Piper* that exhibits dual biological activity on insects, neurotoxic and affect lipid metabolism and promising to manage chemical resistant insect populations [67].

The ethanolic extract of Neem results in 24.5% egg and 86.7 to 100% larval mortality of *T. absoluta* at different concentration. In the same way, the petroleum ether extract obtained from *Jatropha* also achieved 18 to 25% egg and 87 to 100% larval death on *T. absoluta* after being exposed for 4 days in different concentration [45]. The extracts obtained from jojoba seed at 100% concentration resulted in 75% mortality on 2^{nd} larval instars of *T. absoluta* [1].

The aqueous extracts obtained from five different plant species showed moderate to high mortality on *T. absoluta* developmental stages. These extracts are from chinaberry leaves and fruit caused (91%), geranium (87%), garlic (85%), onion (80%), basil flower (74%) and leaves (54%) mortalities on 2nd instars larvae at 6% concentration after 5 days exposure [30].

Garlic also acts as a repellant for larvae in 37.5% and caused weight loss on first larval instars of *T. absoluta and* 78% 1st instars larval mortality after 4 days of exposure to 2000 ppm oil extract concentration. Clover and *Eucalyptu*s oil extract also caused moderate (67 and 63%) mortality of 1st instars larvae at the highest (2000 ppm) concentration after 6 days exposure [63].

Furthermore, crude extracts of three plant *A. indica* seed, *Cymbopogon citrates*, and *A. sativum* also caused 98, 97 and 95% mortality at larval stage of *T. absoluta*, respectively in 7 days of exposure in Ethiopia [68].

3.5. Sterile Insect Technique (SIT)

Inherited sterility techniques are commonly practiced to control different agricultural insect pests [13]. It does not any effect on the environment and important approach to control especially invasive pest in an agricultural system like *T. absoluta* [14]. The radiation sterilization of insects and sterile male insect release into a wild population of the same species was expected to prevent the reproduction of wild females and practiced for pest control [44].

The inheritance sterilization works in the way that the irradiated male insect is released into the natural population and mate with an untreated female to produce abnormality in offspring. In this case, most radiation-induced chromosomal breaks will not lead to the loss of chromosome fragments and remains stable during both mitosis and meiosis and can be transmitted through germ cells to the next generation [15].

The optimum dose of X-radiation to make male moth sterile is between 200 and 250 Gy [15]. In the first generation, the egg hatching is reduced and the produced offspring becomes highly sterile and most are male. Adult emergence decreased at doses of X-radiation increased the results into formation of malformed wings and bent legs. This inherited sterility way of pest management is compatible with the use of other [15].

3.6. Physical Controls

According to [79] *T. absloluta* and other flying pests like bollworm, thrips and whitefly can be physically excluded from tomatoes grown inside the greenhouses using different methods. This may include screening of vents in the roof and sides of greenhouses and the disciplined use of double entry doors can reduce migration of pests into the greenhouse. Outward facing fans inside the double entry porch can blow back any flying insect pests. Greenhouses should be fitted with insect exclusion nets throughout and all doors capable of being sealed tightly. To prevent the entry of the pest, nets with a minimum density of 9 x 6 threads/cm^2 have to be used [52].

Any openings or gaps in the structure should be avoided. Human movement from infested to non infested greenhouses should be avoided and growers should make sure that live adult moths are not present on their person before entering greenhouses [62].

This method may be a useful measure to exclude *T. absoluta* adults. It has to be taken into account that screening the greenhouse will also reduce natural colonization by parasitoids and predators, thus biological control based on the conservation of beneficial insects may be hampered. Nets also reduce greenhouse ventilation, so measures to encourage air movement have to be implemented [52].

3.7. Chemical Methods

Chemical control is the primary method to manage the pest, but it has serious drawbacks, including reduced profits from high insecticide costs, destruction of natural enemy populations, buildup of insecticide residues on tomato fruits and in the environment and fundamentally the rapid development of insecticide resistance. Besides, the efficiency of chemical control of tomato leaf miner infestations has been poor because of the endophytic habit of its larvae, which are protected in the leaf mesophyll or inside fruits and pest resistance against a number of applied insecticides [19]. Chemical control is difficult because the pests high reproductive capacity and very short generations have an increased risk of developing resistance [46].

According [71], the pesticide demonstrated control failure against leaf miners. To control the pest effectively it is critical to combine all the control measures available and not to rely only on insecticide sprays. It is very important to pay attention to the side effects of pesticides on natural enemies, especially predatory bugs. The insecticide should be selected carefully, especially in the early growth stages of the crop.

Chemical pesticides continue to be an important component of insect pest management even with the development of other control methods. Chemical applications play a crucial role in controlling *T. absoluta* infestation. [39] investigated the efficacy of three bio-insecticides (Spinetoram, Spinosad and Emamectin) and four chemical insecticides (Pyridalyl, Indoxcarb, Coragen and Chlorfenapyr) in the control of tomato leaf miner under a field condition. The bio insecticides were more effective in the control of *T. absoluta* than the selected chemical insecticides. The organophosphates chlorpyrifos, methamidophos and the pyrethroid deltamethrin are broad spectrum insecticides effective against a wide range of pests. In the United States, methamidophos and deltamethrin are registered for control of tomato pinworm on tomato. However, most organophosphates and pyrethroids are highly toxic to bees and beneficial insects [77].

Pheromone Sex

Pheromones are powerful chemicals secreted by female insect to attract the male counterparts for mating. They can either be natural or synthetic. These chemicals are detected by the males, assisting them in locating the females for mating. Is chemical secretion released in the form of fluid that triggers the opposite sexual interest [40].

Many pheromones from different species have been identified and are synthetically produced for use in insect pest management. The majority of female sex pheromones identified in Lepidoptera consist of a mixture of two or more compounds which not only evoke long-range male attraction but also elicit courtship behavior. The main methods for utilizing an understanding of pheromones to control pests are monitoring, mating disruption, mass trapping and other manipulations of pest behavior [51].

The large numbers of male individuals caught in pheromone traps as high as 14000 males per trap per day under greenhouse condition. Pheromone is serving as alternative to monitor male moth population through trapping. Mostly male moths are attracted to the secreted pheromone. Therefore, mass trapping of male moths is encouraged by using pheromone and imperative to early warning of pest abundance and monitor insect population [32].

The trapped insects can be damaged mechanically or by applying chemical. These techniques have been successfully applied in controlling leaf miners on both greenhouses and open field. The most widespread and successful application of sex pheromones is that used in the detection and population monitoring [24].

Asexual reproduction as well as the polygenic nature of *T. absoluta* males could have strong implications on the efficiency of sex pheromones management strategies and must be considered imperative for further studies especially in *T. absoluta* management [16]. To monitor *T. absoluta*, pheromone lures are principally coupled with Delta traps [39].

3.8. Integrated Pest Management Strategies

Tuta absoluta has the ability to develop resistance to any control measure used singly [54] and requires an integrated approach. Therefore, integrated pest management programs are being developed in several countries to manage infestations of *T. absoluta* [35]. Appropriate measures that discourage the development of pest populations. That are economically justified and reduce or minimize risks to human health, the environment and encourages natural pest control mechanisms [26].

To control the pest effectively it is critical to combine all available control measures including cultural methods and the correct use of registered pesticides, using natural enemies, botanicals and production of resistant tomato cultivar varieties [22, 76].

Crop rotation with non-solanaceous crops is important as this will help in breaking the life-cycle of *Tuta absoluta*. *Tuta absoluta* has a wide host range and removing wild relatives from the vicinity of tomato is important as this will eliminate alternative hosts, limiting the chances of the pest developing and moving to the next generation. Destroying infested plants and plant parts helps to controlling the pest population. Also, inspection of the packaging equipment to ensure there are no eggs, larvae or pupae that might develop and spread is important [62].

Fruits coming from foreign countries should be accompanied with a phytosanitary certificate. Proper fertilization provides the required nutrients to the plant and this gives the plant a competitive ability to tolerate pest damage. *Tuta absoluta* takes longer to develop in fertilized soils, Irrigation not only provides an optimum environment for plant growth but also drowns the pest, which is useful in bring in down its population [54].

4. Summary and Conclusion

Tomato is one of the most important edible and nutritious vegetable crops grown on both greenhouses and open field. The average yield of tomato decrease due to several factors including pest and diseases. The most important pest of tomato production is tomato leaf miner -*Tuta absoluta* (Meyrick). Tomato leaf miner enters into new areas through tomato fruits from infested areas, containers and packaging equipment and transportation vehicles. This pest attacks many crops in the nightshade family. The pest attacks the aerial part of the plant (stem, leaves, and fruit) in all stages of tomato growth, thus capable of causing production loss of up to 80 to 100%. The rapid distribution of *T. absolutes* by high biotic potential, large range of host plants and the intra-continental dispersal facilitation due to human transportation. To control establish a *T. absoluta use* monitoring program, establish international, national and regional quarantine regulations. When *T. absoluta* established there is a need to conduct survey of local natural enemies by identify effective ones. In areas that have not yet been invaded by the pest, it is essential to monitor ports of entry and borders adjoining infested countries with pheromone traps, inform the public about the impending danger of *T. absoluta* invasion via mass media.

A pesticide is better control than other management methods However, the use of pesticides should not be considered the main substitute for the judicious management of this pest. The continuous use of some products is prone to result in insecticide-resistant populations, with farmers coping by using a cocktail of products. The highest and most widespread pesticide risks, including both acute and chronic human health, the negative impacts on natural enemies of this pest and pollinators. Biological control is one of IPM and potential to mitigate insect pests from farming system. The IPM strategy is very important and has dual purpose, environmental friendly and effective to manage the pests.

5. Future Line Work

Tuta absoluta will undoubtedly continue to be an important pest of tomatoes and other Solanaceae. For the moment, the management of the pest relies nearly exclusively on the intensive use chemical insecticides, some of which are highly toxic. Awareness should be raised on the dangers of these pesticides, for farmers, consumers and the environment. Such practices will also undoubtedly result in insecticide resistance. To avoid side effects of the intensive use of pesticides and to lower the risk of insecticide resistance, sustainable IPM strategies based on biological control urgently need to be developed.

Abbreviations

2-TD	2-Tridecanone
AA	Acyl Sugars
C/M2	Centimeter Per Meter Square
IPM	Integrated Pest Management
JA	Jasmonic Acid
PPM	Part Per Million
VOCs	Volatile Organic Compounds
ZGB	Zingiberene
SIT	Sterile Insect Technique

Author Contributions

Zalalem Tesso is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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