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Tomato Leafminer (*Tuta absoluta)* an emerging agricultural pest: Control and management strategies: A Review

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop for income of small-holder farmers. However, it is attacked by many insect pests that cause high economic losses. More than sixty five research technical papers were reviewed focus on control and management strategies of *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae). The aim of this review paper is to call for attentions and concerted actions of concerned sectors by describing the potential damage of the pest, its entry, pathways and its control methods. The pest is becoming one of the major key pests of tomato which account for its production loss of up to 80 to 100% if left unchecked. The pest have developed resistance to dozens of pesticides and therefore the (IPM) strategy that employs bio-chemical, biological, physical and cultural methods is the only best option we had at time. Therefore, a brief outlook of the future research and applications of indigenous *T. absoluta* biological control agents are widely discussed.

***Keywords*:** Tomato, *Tuta absoluta*, Integrated Pest Management (IPM), Pest control, Botanicals etc.

1. INTRODUCTION

The tomato leaf miner, *Tuta absoluta* [1] (Lepidoptera: Gelechiidae) is a major nocturnal pest of tomato, *Lycopersicon esculentum* [2-3] as well as other solanaceous crops [4]. It is one

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of the serious pest and invasive species originating from South America [5] and also known as South American tomato moth, tomato borer, American tomato pinworm. It has been mentioned that the pest has ability to infest not only cultivated species of the genus *Solanum* but also wild species [6]. Tomato trade and, to a lesser degree, active flight or passive movement on wind currents are the main mechanisms of current spread of this pest [7].

The pest has been considered as the most important constraints to tomato production both under plastic greenhouse and open field tomatoes. It is reported to attack in potato (*Solanum tuberosum* L.), eggplant (*Solanum melongena* L.), pepper (*Capsicum annum* L.), some weeds (*Datura stramonium* L., *Nicotiana glauca* G.) [8] and some other non-solanaceous crop plant like green beans (*Phaseolus vulgaris* L.) [9] or Malva spp. [10]. Thus, the pest has the widest range of host plants.

Tuta absoluta has higher rate of reproduction. Adults of *T. absoluta* usually lay eggs on the underside of leaves and on stems. The leaf miner goes through six stages, namely egg, three larval stages, pupa and adult. The adult leaf miners are small, yellow and black colored flies. The larvae form mines in the leaves of plants. Pupation takes place mostly in the soil. Overwintering can take place during egg, pupa or adult moth but not in lava stage [11]. It can complete between 10 – 20 generations in a year depending on environmental conditions, its minimum action temperature being 9 °C [11]. At 14°C, it takes 76 days while at temperatures above 20 °C; it takes 24 days [12]. The pest has also has higher areas of the adaptation. The pest can survive temperature as high as 49 °C in summer and also survive at temperatures below 5 °C. The pests can also tolerant dryness, making it flourish well in hot and dry areas [13].

The larva feeds voraciously upon tomato plants, producing large galleries in leaves, burrowing in stalks, and consuming apical buds and green and ripe fruits. It is capable of causing a yield loss of 50% to 100% [2], [14] and [7]. The species can overwinter in the egg, pupa, or adult stage [11].

Tomato leaf miner infest various plant parts including seedlings, flowers, tomato fruits and unsold fresh tomato fruits [15]. Larvae can damage tomato plants during all growth stages, producing large galleries in their leaves, burrowing the stalks, apical buds, green and ripe fruits [16]. It has been nicknamed the tomato 'Al–Shabaab' as it destroys the whole plant [16-17].

It can cause important yield losses in different production regions and under diverse production systems [18]. When *T. absoluta* invades a farm, either open field, screened house or green house, the damage is irreversible. *T. absoluta* leaves an unimaginable loss after attacking cultivated tomato crop. In some regions, the cost of producing tomatoes increased 15 times per season after infestation of *T. absoluta*. It is estimated that when this pest invades tomato growing regions of the world, its management cost may go up by about $500 million per year [12].

Yield and fruit quality are both significantly impacted by direct feeding of the leaf miner as well as secondary pathogens entering host plants through wounds made by the pest. Tomato plants may be attacked at any developmental stage. Larvae penetrate the fruit, leaves, or stems of host plants, creating conspicuous mines and galleries and also allowing for invasion by secondary pathogens which may lead to fruit rot [11].

Some insects may be the best controlled by a combination of practices that are not fully effective when used alone and *T. absoluta* is one of them. It is critical to combine all available control measures including cultural methods, biological control agents and the correct use of registered pesticides to control those pests effectively [19].

Farmer uses various pesticides as a quick and adopted control measure of the pest [20]. The use of chemical pesticides as its control measure is highly sought and the most effective method to reduce *T. absoluta* treat level. Uncontrolled application of any agro-chemical leads to high level of residues on the tomato fruits, thus putting the lives of consumers and the general ecology at risk. Applications of non-selective insecticides have also interfered with biological control methods for other insect pests like aphids, thrips and white flies [21-22]. 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 [2].

Chemical control has been the main method of control used against *T. absoluta* and growers normally choose the insecticide in a diversity of options officially registered and recommended. The principal method for *T. absoluta* control is blanket spraying with insecticides that are harmful to both humans and the environment [23-24]. Moreover, effectiveness of chemical control is limited due to the insect's nature of damage as well as its capability of rapidly developing insecticide resistant strains [25-26].

Tuta absoluta is a difficult pest to control because it is potentially very damaging and it has the ability to develop resistance to several insecticides [26]. The effectiveness of insecticides alone might be sometimes impaired because of the mine-feeding behavior of larvae or deficient spraying technology. Usually, several sprayings are required per growing season and it is noted a decrease of the efficacy of products used against *T. absoluta* since the 1980s in tomato crops. Resistance to some active ingredients has been reported in several countries, for example to abamectin, cartap and permethrin in Brazil. Recently, a South American population of the tomato leaf miner has been found to be resistant to spinosad, a new-generation insecticide [27]. Similarly, resistance to organophosphates and pyrethroid insecticides has been reported in Chile [28-29].

Different strategies might be applied in an Integrated Pest Management (IPM) program to control *T. absoluta* outbreaks including insecticides and biological control and the association of both. Studies have being done on the use of synthetic sex pheromones in order to monitor population levels and trigger applications of chemicals on the right [18] and [30].

Sex based pheromones are developed to prevent the mating are also developed to control the pest, the ability of female to reproduce parthenogenetically has weakened these pheromone based control [2] and [30]. Prophylaxis is one of the most effective and cheapest ways of reducing pest infestation [31].

2. MATERIALS AND METHODS

This paper was prepared by collecting the information from all available resources i.e. books, journals, annual reports, proceedings etc published by different Authors, Researchers, Professors as well as research centers and stations. A total of sixty five research papers were collected and intensive review was made. Collected information's were systematically arranged into different subheadings namely; cultural methods, chemical methods, biological methods (parasites, parasitoids, entomopathogens, botanicals extracts and finally Integrated pest management.

3. DISCUSSIONS

Environmental friendly controlling strategies have been developed for protection from *T. absoluta*. This includes, cultural control measures (crop rotation, selective removal and destruction of infected plant material) [8], using natural enemies (parasitoids, predators, entomopathogens and nematodes) [7], botanicals and production of resistant tomato cultivar varieties. The integration of these methods with each other and minimum use of less environmental hazardous insecticides are important to control of *T. absoluta* without disturbing ecological and biological world. Botanicals, natural enemies and microbial cells with their products are especially considered as promising alternatives than using synthetic pesticides.

3. 1. Cultural Methods

Prophylaxis is the cheapest and the effective ways of the reducing the pest infestation [31]. It is the aim of the most of the cultural practices recommended for the *T. absoluta* control. The adoption of prophylactic methods could be the key to success in controlling the pest, particularly in greenhouses [21].

The cultural methods involves physical removal of the pest and the infested parts of the crop or the whole crop and either burning it or burying it deep in the soil, effective weed control before and during crop season especially of all other alternative host plants such as black nightshades, potatoes, datura, solanum and nicotiana [16], crop rotations with non-host crops help manage the pest [32], remove the crop and close it to avoid the adults from migrating from the open field in case of the green house conditions and ploughing, over–head irrigation, soil solarisation, use of pest free seedlings and manuring [33-34].

Covering crop residues with plastic for no less than three weeks reportedly reduced the number of adult *T. absoluta* by 94% during the fall. Crop residues can also be eliminated by burning or grinding combined with insecticide sprays. Crop rotation with non-host crops is also imperative [35]. Soil solarisation has been advised in warm climates to kill pupae that remain in the soil after harvest [33]. The use of genetic resistance may be also an alternative to control this pest since some sources of resistance to *T. absoluta* have been reported in some species of wild Tomato. The two mechanisms of resistance detected so far have been the antixenosis and antibiosis [36].

3. 2. Chemical Methods

Several chemical pesticides are used to control the pest, but none is suitably adapted for control of the tomato borer due to larvae feeding stratergy inside plant tissues and foliar spray easily washed out by wind and rain [37-38]. Insecticides recommended for the management of *T. absoluta* are of low to moderate effectiveness due to the cryptic nature of the larvae and the high biotic potential of the insect. They include pyrethrin, carbaryl, deltamethrin, spinosin, indoxacarb, abemectin, emamectin benzoate and cyromazin. Cases of insecticide resistance have been reported on organophosphates, pyrethroids, abamectin, cartap, permethrin and spinosad [16] and [39] and [40]. Additionally, most chemical pesticides have adverse impacts to both humans, non-targeted organisms and environment as well [41]. Chemical control has been the main method of control used against *T. absoluta.* Farmers normally choose the insecticide in a diversity of options officially registered and recommended. The effectiveness of insecticides alone might be sometimes impaired because of the mine-feeding behavior of larvae or deficient spraying technology.

The use of Neem oil (Azadiractin) acts as a contact and systemic insecticide against low infestations of *Tuta absoluta* larva when used on the tomato plant. The use of *Bacillus thuringensis* is recommended at low-medium infestation levels in conjunction with Azadiractin. The application of dustable sulphur can also have a repellent effect on oviposition, and therefore can be used as a non-chemical preventive measure.

Pest resistance has been reported to cause increased use of chemical pesticides applications against *T. absoluta* in many parts of the world [26] and [42]. About 15 applications in Spain and up to 30 applications have been reported in Brazil [24] and [43]. Moreover, the pest resistance against spinosad chemical reached up to 180,000 resistances within seven further generations in Brazil. More than 18 chemicals were introduced during 2009-2011 for the control of tomato borer but none of them seemed efficient in solving the pest problem in countries such as Tunisia, [25].

Failure of these chemicals in controlling *T. absoluta* opened a new window for development of other methods including bio-pesticides, pheromone traps, and parasitoids. Though chemical pesticides are economically and environmentally unaffordable, farmers still seek them for their agricultural uses because is the only easily accessible option. Thus introduction of IPM strategies will promote sustainable horticultural farming.

3. 3. Biological Methods

Predators of *T. absoluta* include mired bugs (*Nesidiocoris tenuis*) and *Macrolophus pygmaeus*. They are commercially available and widely used in Europe and North Africa [33]. Insecticide formulations based on *Bacillus thuringiensis*is are used in control of *T. absoluta* in their native and invaded fields. They are mostly used in control of the first – instar larvae and has no side effects on beneficial arthropods. Neem formulations are also effective in controlling *T. absoluta*. It acts as both systemic and contact insecticide for *T. absoluta* [44]. *Metarhizium anisopliae* and *Beauveria bassiana* are amongst fungal species that have been reported to attack the eggs, larvae and adults of *T.absoluta* [45-46]. Natural enemies of *T. absoluta* moth include *T. exiguum*, *Trichogramma pretiosum*, *Pristomerus*, *Dineulophus phthorimaeae*, *Cremastus*, *Copidosoma* and *Apanteles* [47-48]. These are used as parasitoids. Predators of the moths include *Chilocorus* [49] spiders, carabids, earwigs, hemipterans, wasps, ants, lace wings and *Steinernema carpocapsae.* Predators have not been identified yet due to excess use of insecticides [16] and [34].

This implies that *T. absoluta* monitoring programs must be established where local natural enemies survey will be conducted and the effective ones identified.

a. Predators

The natural enemies for *T. absoluta* have been reported from their place of origin (South America). The enemies of *T. absoluta* are commercially available and can be used in its control. Predatory bugs such as *Macrolophus pygmaeus* (commercially available as *Macrolophus caliginosus*) and *Nesidio coristenuis* have been identified as the most promising natural enemies of *T. absoluta* in Europe as they are large consumers of eggs of the pest [50]. In the Mediterranean production areas, these two species naturally colonize tomato crops not sprayed with broad-spectrum insecticides and they are released for biological control in greenhouse tomato crops. Other identified predators of *T. absoluta* are the mirid *Dicyphus maroccanus*, the nabid *Nabis pseudoferusibericu.* In the Mediterranean region using *Nesidio coristenuis,* showed highly promising results and effectiveness of predator use when combined with other methods in controlling *T. absoluta*.

b. 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, where the pest originated. In Europe, parasitoids have been found parasitizing *T. absoluta* larvae in the Mediterranean area. *Stenomesius* spp. and other undetermined species (mainly Braconidae) occur spontaneously in infected tomato plots in Spain, indicating that native parasitoids are adapting to the new host. Regarding parasitoids of *T. absoluta* eggs, *Trichogramma acheae* has been identified as a potential biological control agent of the pest and is currently being released in commercial tomato greenhouses [50-51].

c. Entomopathogens

Bacillus thuringiensis, an entomopathogenic bacterium has been used in the control of tomato plant pests as very effective bio-insecticide [52-53]. It has used extensively to control the pest in crops where IPM programs based on biological control are applied. Bio-insecticides like *Bacillus thuringiensis* do not raise any environmental concern as they are environmentally friendly.

3. 4. Semiochemicals Methods

Sex pheromones have widely been used to forecast, monitor and/or control moth pest populations [54]. They are chemical signals released by mostly female adult organisms to attract the same species of the opposite sex for mating [17] and [51]. Before 1995, virgin *T. absoluta* females were used to trap and capture males, and only about 100 males were captured per trap per day [55]. However, characterization of the female pheromone has opened up an effective tactic to trap males. This is because males emerge earlier than females and females mate several times. Components of *T. absoluta* female pheromones are (3E, 8Z, 11Z) -3, 8, 11-tetradecatrien-1-yl acetate or TDTA (1) and (3E, 8Z) -3, 8-tetradecadien-1-yl acetate or TDDA (2) [51]. The pheromone based control of tomato leaf miner, *Tuta absoluta* is more recommended to be used in combination with other techniques, as it is environmentally safe management method. It is the technique that can be used for pest detection, population monitoring, mass annihilation and mating disruption [37]. Traps containing water and detergent instead of sticky surfaces are also used. *T. absoluta* males are attracted to the lure and then fall into the water and drown. Water traps capture high number of adult males without becoming saturated with insects. Pheromone based traps are only limited to the male *T. absoluta*, which according to the research done does not target mated *T. absoluta* females, which should be the major concern since they are the ones that locate oviposition sites.

The traps need to be replaced after every 4 – 6 weeks and are placed not more than 60 cm from the ground, since *T. absoluta* is a low flying insect [56-57]. Four factors that need to be considered when using the traps include colour of the trap (dark coloured traps catch more insects than lighter colors) [57] height of the trap; position of the trap with respect to vegetation;

and the density of the traps in a given unit area [58] In addition, completely open traps can increase the number of insects caught per trap.

3. 5. Integrated Pest Management (IPM)

Several studies recommend use of Integrated Pest Management (IPM) strategy for effective management of *T. absoluta* [13]. A combination of physical and biological agents such as parasitoids, predators [59] [60] and traps [61] can create an effective IPM [60].

T. absoluta is one of those insects that require more than one practice to be controlled successfully. It is critical to combine all available controlling measures including cultural methods, biological control agents and the correct use of registered pesticides to control the pest effectively [53] IPM programs for *T. absoluta* may be achieved through the use of sex pheromone.

Using *T. absoluta* virgin females, Quiroz (1978) captured more than 100 males/trap/day, and Uchoa-Fernandes and Vilela (1994), using the same technique, compared different trap designs, heights, and displacement in tomato fields for capturing *T. absoluta* males. They reported high specificity and sensitivity of traps baited with natural pheromone, besides being more economical and convenient than the light traps. The integration of chemical and biological control is often critical to the success of an integrated pest management (IPM) program for arthropod pests. An integrated pest management strategy can be used for the control of *Tuta absoluta*:

1) Clearing the soil and area of crop residues, fruits and wild host plants.
2) Mass trapping begin prior to planting or upon planting,
3) The use of sulphur, neem oil, *Bacillus thuringensis* in conjunction with the application of either δ-methrine, spinosad, Indoxacarb or other recommendable bio-pesticide if occasional individuals of *Tuta absoluta* are observed.
4) Elimination and burning of infected plants during the growing season and of the remnants of the crop immediately after the last fruits have been harvested [62].

3. 6. Botanicals

Botanicals are very important natural resources used to control different agricultural pests for long period of time [63-65] and Crude extracts from seeds, leaves, bark, bulbs, and fruits of the different plant species have been extensively tested on agricultural pests for bioactivity worldwide [63]. For instance, extracts from neem plants were reported to be efficient against *T. absoluta* under laboratory condition [66]. Neem plant contains a number of active metabolites such as alkaloids which can control insect pests. These compounds have been reported to have control efficacy against tomato borer. Other plants which are promising in management of *T. absoluta* include Piper [67] whereas compounds from *Acmella oleracea* were revealed to be active against *Tuta absoluta* [68].

The phytochemicals 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 caused 70% larval and pupal mortality in two day exposure through exhibiting acute toxicity at the concentration of 2,000 mg L^{-1} [67]. The allelochemicals found in Piperaceae are diverse with insecticidal/insectistatic properties. Piperamides exhibits dual biological activity on insects, neurotoxic and affect lipid metabolism and helps to manage chemical resistant insect populations. The ethanolic extract from the Neem (*Azadirachta* *indica*) and petroleum ether extract from Jatropha (*Jatropha curcus*) seeds are tested on *T. absoluta* egg and larval stage as bio-insecticides. Thus, 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 [68].

The extracts obtained from jojoba *(Simmondsia chinsis)* seed at 100% concentration resulted in 75% mortality on 2nd larval instars of *T. absoluta*. The botanical extracts from "Tossegn" Garden thyme (*Thymus vulgaris*) and Castor bean (*Ricinus communis*) also caused 95 and 58% larval mortality of *T. absoluta*, respectively. The aqueous extracts obtained from five different plant species showed moderate to high mortality on *T. absoluta* developmental stages. These extracts are from chinaberry (*Melia azedarach*) leaves and fruit caused (91%), geranium (*Pelargonium zonale*) (87%), garlic (*Allium sativum*) (85%), onion (*Allium cepa*) (80%), Basil (*Ocimum basilicum*) flower (74%) and leaves (54%) mortalities on 2^{nd} instars larvae at 6% concentration after 5 days exposure. Garlic also acts as a repellant for larvae in 37.5% and caused weight loss on first larval instars of *T. absoluta*. Clover (*Trifolium repens*) and Eucalyptus (*Eucalyptus camaldulensis*) oil extract also caused moderate (67 and 63%) mortality of 1st instars larvae at the highest (2000 ppm) concentration after 6 days exposure.
In the contrast, *in vitro* evaluation of the efficacy of camel urine against *T. absoluta* cleared that the mortality percentages of 4th and 2nd larval instars caused by urine concentrations 25% and 50% were equal to that recommended dose of the insecticide Malathion after 48 hrs of application. The highest mortality percentages of these larvae stages were obtained 24 hrs after application, which can be agreed with the observations of [69] who observed that the antimicrobial activity of camelurine was very slightly and determinedly evident after 48 hours of application.

4. CONCLUSIONS

The agricultural pests are main threats for the vegetables, fruits, cereals and flower production in several countries. *T. absoluta* is one of the invasive tomato pests and it is devastating worldwide. It will result in 80 to 100% crop damage if it is not controlled. Intensive chemical treatment leads to the development of resistance, hampering the ecological and biological world. Therefore alternative methods should be considered. A shift from current pest management strategies is thus necessary. It is critical to combine all the control measures viz. cultural, biological, use of botanicals, chemical and finally IPM approach to control the pest effectively. Various active substances are effective and can be used in combination with biological control agents.

An IPM strategy that adopts a holistic approach at the agro ecosystem level, rather than concurrent piecemeal pesticide applications, is likely to enhance the control of *T. absoluta* and other pests, such as the several Noctuidae species, which also cause considerable yield loss within these agro ecosystems. More educated farmers are better off positioned to acquire new skills and knowledge from others sources to complement the existing practices and apply them to the farming situation.

There is therefore an urgent need to train farmers and extension workers using appropriate measures on management of *Tuta absoluta* using farmer's field schools (FFS). Effective management option in conjunction with integrated pest management (IPM) is vital to global crop protection, sustainable agriculture and improved public health.

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