



A Newly Emerged Pest of Tomato [Tomato Leaf Miner, *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae)]: In Bangladesh – A Review on Its Problems and Management Strategies

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MNH and TJ Planned the review article and prepared the structure. Authors MNH and TJ collected the relevant papers and wrote the first draft of the manuscript. Author HFET helped in preparation of the manuscript. Authors HFET and KAA read, edited the manuscript and suggested vital inputs to the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Worldwide, tomato leaf miner *Tuta absoluta* (Lepidoptera: Gelechiidae) is one of the most devastating invasive pests of tomato crops. It is one of the most important biotic constraints for tomato production which may lead to the production loss up to 100% if it cannot be controlled. *T. absoluta* comprises four developmental stages: egg, larvae, pupa, and adult with a rapid growth rate. Among these larvae is the most devastating stage which affects the fruit, leaves, and stem. Recently, *T. absoluta* is turned into a key pest of tomato in Bangladesh. This pest was first detected by IPM lab, Horticulture Research Centre, Bangladesh Agricultural Research Institute,

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Gazipur, Bangladesh from a commercial tomato grower in the village of Chaklarhat (26019'N, 88043'E) under the Tunirhat union of Panchagarh Sadar Upazila, Panchagarh district of Bangladesh in May 2016. Since its introduction in 2016, there was no sound action plan implemented. Therefore, this paper focused on relevant scientific knowledge regarding its biology, potential damage and different control measures which will open the windows for future researches for efficient and sustainable management strategies against *T. absoluta* in Bangladesh.

Keywords: Tomato; *Tuta absoluta*; invasive pest; control methods; breeding; insect resistance; management strategies.

1. INTRODUCTION

Globally, tomato (*Solanum lycopersicum* L.) is one of the most important economically growing vegetable crops in terms of human consumption due to its valuable nutritional components such as niacin, riboflavin, thiamine, beta-carotene, lycopene, iron, magnesium, phosphorus, potassium, and sodium [1,2]. Tomato belongs to the family Solanaceae which are diploid with 12 pairs of chromosomes ($2n = 24$) [3]. This crop originated from the South American Andes and the first used as a food in Mexico and extended worldwide. After potato, tomato is the second-largest vegetable crop grown all over the world. Worldwide 4,762,129 ha cultivable land was devoted to tomato cultivation in 2018 and the total production was about 182,258,016 metric tons [4]. In Bangladesh, Tomato has been growing as the second horticultural crop after potato which is cultivated in two seasons annually. For tomato cultivation in both winter and summer season, 68,366 acres cultivable land (8.59% of total cultivable land) was dedicated and the total production was about 3,88,725 metric tons in the year of 2016-2017 [5]. Recently, the production of tomato crops has been considerably affected by several insect pests and diseases [6,7]. Numerous insect pests feed on tomatoes [8] such as thrips, whitefly, Africa fruit bollworm, tomato fruit worm, leaf miner, leafhopper, aphid, mites, and mealy bug [9-11]. Among these, an invasive insect pest, tomato leaf miner, *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) has become the most destructive pest for tomato production in different parts of the world [12-14]. In Bangladesh, Tomato leaf miner, *Tuta absoluta* is newly emerged as an invasive pest of tomato and causing an explicative decrease in tomato production. *T. absoluta* can cause high production losses of tomato (i.e. up to 100%) in open field and greenhouse cultivation if left uncontrolled [14-17]. Thus, this review paper aims at establishing the problems package and management strategies towards an available,

eco-friendly, cost-effective, and sustainable management of the pest. Many insect pests can be controlled by the integration of different control measures that are not completely feasible when treated alone and *T. absoluta* is one of them. Therefore, it would be very important to integrate all applicable control methods such as biological and cultural methods, mass trapping, and appropriate use of registered insecticides to control those pests effectively [18,19].

2. GENERAL BACKGROUND OF *T. absoluta*

2.1 Origin and Distribution of *T. absoluta*

Tomato leaf miner *T. absoluta*, commonly known as the South American tomato leaf miner and the pest was originated from central Chile [10,20,21]. *T. absoluta* was first identified in 1917 and as a pest of tomato in the 1960s in Peru [22]. However, *T. absoluta* was first recorded in Spain in 2006 [23,24]. Since the origin, *T. absoluta* has been widespread in South America, Europe then Asia and Africa [10,25,26]. Currently *T. absoluta* has been widespread almost all over the world on different solanaceous crops [27-31], but it has been introduced as an exotic invasive pest for tomato production in the world-leading tomato producer countries such as Egypt, India, Iran, Italy, Spain and Turkey [30,32]. In recent years, tomato leaf miner, *T. absoluta* has been officially reported in some South Asian countries like India in 2014 [33] and Nepal in 2016 [15]. In Bangladesh, tomato leaf miner, *T. absoluta* has first detected its infestation in a tomato field in the village of Chaklarhat (26019'N, 88043'E) under the Tunirhat union of Panchagarh Sadar Upazila, Panchagarh district of Bangladesh in May 2016 [34]. Since *T. absoluta* is one of the newly emerged insect pests of tomato in Bangladesh, the pest has caused significant economic losses in the tomato fields at Jessore, Comilla and Panchagarh Districts [34]. Extensive damage is imposed by this pest as a result of its

short life cycle, high reproduction capacity, a wide range of host plants and endophytic feeding habits [10,35,36].

2.2 Biology and Life Cycle

T. absoluta is a micro lepidopteron moth with rapid reproduction capability [28,37-40]. This pest may complete about 10–12 generations per year under suitable environmental conditions. The life cycle of *T. absoluta* consists of 4 developmental stages: egg, larva, pupa and adult which takes about 24-28 days to complete it, depending on temperatures [36,41]. The developmental periods (Egg to adult emergence) are 76.3, 39.8 and 23.8 days at 14°C, 19.7°C and 27.1°C, respectively [42]. Adults are nocturnal moth these active at night and hide between leaves in the day time. The adult (Fig. 1a) is consists of black spots [28] and grey to silvery scales [43] and black spots with silver or brown speckle on wings. They have also one pair of filiform (bead-like structure) antennae [44]. Adult lifespan ranges between 6–7 days for males and 10–15 days for females [45]. Females lay about 200 eggs during their lifespan [34]. Usually, the pest deposits eggs on the underside of leaves, the stems and occasionally on fruits

(Fig. 1b) [46]. Egg colour varies between creamy-white to bright yellow [10,47] with 0.2 mm diameter and 0.4 mm length [48]. Eggs hatch within 6-7 days into larvae between temperature range 25-30°C [29]. The most destructive stage of *T. absoluta* is the larval stage that can damage tomato plants during all the growing stages [10]. After hatching, young larvae penetrate tomato fruits (Fig. 1c) [46] and feeding damage is caused when the larvae enter into the leaf and feed on the mesophyll tissue of leaves, as a result, developed irregular mines on the leaf surface and reduce the photosynthetic capacity of the plant [14,49].

These mines are blotchy (Fig. 2a), which are differing from the wavy and narrow mines caused by *Liriomyza* spp. (Fig. 2b) [34]. Larvae pass through four instars and they will be completed within 20 days under favorable environmental conditions and they damage seriously on buds, fruits, leaves and stem [29,45,50]. Pupation can complete its lifespan within 21 days and mostly occur in the soil and it occasionally may take place in the calyx or on leaves [48]. The pupae are green in colour during emergence and changing it to brown near-adult bearing [29].

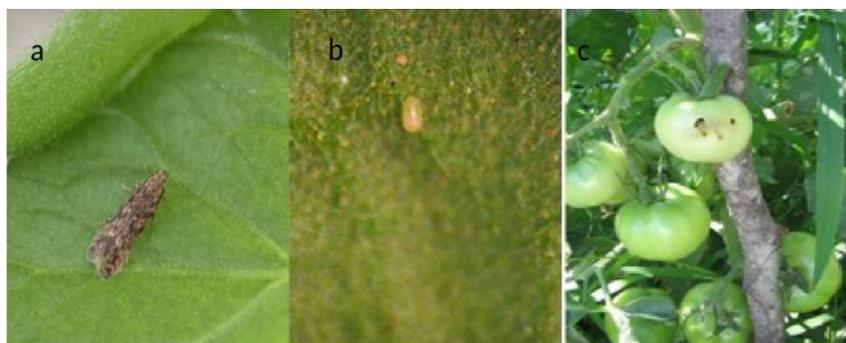


Fig. 1. *T. absoluta* (a) adult [14]; (b) Egg [46]; (c) Larva on tomato fruit [46]



Fig. 2. Infestation of tomato leaf caused by (a) *Tuta absoluta*; (b) *Liriomyza* spp. [34,47]

2.3 Hosts

Tomato leaf miner *T. absoluta* is a harmful oligophagous insect attacking several plant species with a high preference towards the species of the Solanaceae family. It has a strong preference for tomato (*Solanum lycopersicum* L.) which is considered as the main host [51-53]. Despite the clear favouritism of this insect on tomato plants it also attacks some other cultivated species of Solanaceae including; potato (*Solanum tuberosum*), eggplant (*Solanum melongena*), tobacco (*Nicotiana tabacum* L.), pepinodulce (*Solanum muricatum*), and peppers (*Capsicum annuum* L.) [10,45]. Besides, this pest also attacks some wild species of Solanaceae such as *Solanum bonariense* L., *Solanum sisymbriifolium* L., *Lycopersicon hirsutum*, *S. elaeagnifolium*, *S. hirtum*, *S. lyratum*, *S. nigrum*, *S. puberulum*, *Physalis angulata*, and *Nicotiana glauca*, etc [28,45]. Occasionally, it is also capable to infest on different plant species, like bean (*Phaseolus vulgaris* L.), Jerusalem cherry (*Solanum pseudocapsicum* L.), Peruvian groundberry (*Physalis peruviana*), green beans (*P. vulgaris*), Dutch eggplant (*Solanum aculeatissimum* Jacq.), *Malva* sp., and coralillo (*Lycium chilense*) [40,45]. Recently, *T. absoluta* is capable of attacking some weeds species as an alternative host like; *Datura ferox*, *Datura stramonium*, *Lycium chilense*, *Nicotiana glauca*, and *Solanum nigrum* [38,39,50,54].

2.4 Management Strategies of *Tuta absoluta*

Considering feeding habits, rapid reproduction capacity, and resistance to the pesticide of *T. absoluta* in the affected territories, it is challenging to control. In Bangladesh, there has not been any reliable, cost effective and sustainable control measures that can be used in the management of the pest by the resource poor farmers. However, there exist several efficient and sustainable control methods that can help to reduce the infestation of *T. absoluta* [47,55]. Therefore, several researchers across the world have been reported using different management strategies for effective control of *T. absoluta*. Methods such as Physical methods, Cultural methods, Biological methods, Chemical methods, the use of pheromone traps and mass trapping, cultivation of *T. absoluta* resistant tomato varieties [47], and Integrated pest management (IPM) have been recommended

[28,36,53]. However, a combination of two or more of the above control measures could be much more effective than any single practice for controlling *T. absoluta* [10].

2.4.1 Physical control methods

The aim of the Physical control methods is to prevent or decrease pest attack in a crop. several physical methods act either mechanically or by attacking pests' sustainability or behavior [56]. Tomato leaf miner and other flying insects such as whitefly, thrips, and bollworm can be physically eliminated from the tomato field as well as greenhouse by practicing diverse techniques [28,40,20]. There are several Physical control methods such as insect suction traps (i.e. yellow sticky traps, Black Sticky Traps, water trap, Tuta Trap Tray, Tray Trap Technology (TTT), and so on), Trap cropping, Field burning, and Elimination of breeding grounds. These methods used to reduce the populations of *T. absoluta*. Insect exclusion screens can also suppress insect density without the mortality of insects. Moreover, insect behavior also can be changed by using colour and chemicals [56,47].

2.4.1.1 Screening the greenhouse

This is one of the most effective physical control measures against *T. absoluta* inside the greenhouse tomato cultivation [10]. The main source of pest invasion is the infested seedling. So, the use of insect-free seedlings is very essential for obtaining a leaf miner free plant. According to PPD [41], to reduce the infestation of tomato seedling, protection of nursery bed by 1.6 mm mesh size net house is very effective. The greenhouse must be sealed properly and screened at vents in the roof and sides. To restrict the entrance of the insects, nets with a minimum density of 9 x 6 threads/cm² should be used [40]. The well-regulated use of double-entry doors can minimize the entry of insects inside the greenhouse [28]. Special consideration should be made for ventilation when the net house or greenhouse will be used. Moreover, the collection and destruction of infested plant parts should be performed regularly [36]. Human movements should be avoided from infested to non-infested greenhouses and cultivators should make secure that live adult moths are not present on their persons before entering greenhouses may also be effective. Soil infested with pupa may also be carried from one place to another.

2.4.2 Cultural control methods

Cultural control methods are the oldest practices used to control pests' infestations. These techniques are normally used to create unfavorable environments for the pests to avoid high-risk of infestations or alleviate the pest density. Cultural control methods are aimed to prevent infestations from developing of pest population because only cultural practices cannot suppress the outbreak of the pests. Moreover, in IPM programs, cultural practices play an important role to control an insect [57]. There are several cultural control methods that aid to reduce the density of the pests. There are some cultural practices such as Good agricultural practices, Management of plant material, and Destruction of crop residues showed the effective result to reduce the population of *T. absoluta* [10].

2.4.2.1 Good agricultural practices

Tuta absoluta can be controlled by good agricultural practices including ploughing, cultural practices, crop rotation with non-Solanaceous crops (preferably Cruciferous crops), sufficient irrigation, and optimum use of fertilizers, destruction of pests infected plant parts, leaves, and fruits [28,58]. Intercropping tomato with a gallant soldier (*Galinsoga parviflora* L., Asteraceae) and coriander (*Coriandrum sativum* L., Parsley) shows a positive effect on decreasing pest density and enhancing natural enemies [45,59]. Keeping a proper planting distance between rows is also helpful, not having crowding of plants, as is the removal of weeds and keeping the area clean from fascicle residues. It is also encouraged to destruct the wild solanaceous host plants surrounding the growing area because the pest can re-infest the growing crop which is hosted by these wild solanaceous species at all developmental stages of *T. absoluta*. This pest can also be eradicated in greenhouses with the help of some important cultural control practices like selective removal and destruction of infested plant materials and crop rotation. Moreover, the wild host plants should also be removed to keep the crop growing area free from further growth of a strong population of *T. absoluta* that might cause significant damage [10].

2.4.2.2 Management of plant material

The use of pest-free transplants is an effective control measure against *T. absoluta* [28]. At the

beginning stage of pest infestation, it is important to eradicate any of the symptomatic leaves and stems infested by larvae or pupae and place them in plastic bags to destroy. Weeds (i.e. *Lycium chilense*, *Nicotiana glauca*, and *Solanum nigrum*) should be removed from the crop growing area that may be host to the pest. Infested plant material (from weeding or pruning) should not leave on the ground so that later it will not allow growing a potential population, as the larvae will quickly leave them and colonize on a new plant [10,28].

2.4.2.3 Destruction of crop residues

After harvesting, the crop residues should be destroyed as soon as possible. Crop residues covered with plastic for a minimum three weeks reportedly decrease the number of *T. absoluta* adults up to 94% during the fall. Crop residues can also be destroyed by burning or grinding combined with insecticide sprays [60]. Soil solarisation is also effective to reduce the number of pupae that remain in the soil in warm climates [10,60].

2.4.3 Biological control methods

2.4.3.1 Predators

Several researchers have found greater effectiveness of predators as natural enemies to reduce the population of *T. absoluta* in both open-field tomato farms and greenhouses. It also plays an important role in the IPM program for its plenty and outstanding benefits as it is self-prolific, safe, effective therewith environment-friendly, economical, and sustainable [10,18,36]. [12] and [61] defined the mirid *Nesidiocoris tenuis* as a universal and effective predator against *T. absoluta*. This species can prey up to 100 eggs of *T. absoluta* per day [53,62]. It was found in Tunisian [63], Cyprus, Egypt, France, Jordan, Iran [64], Israel, Italy, Morocco, Spain, and Turkey [12]. According to [65], *Macrolophus pygmaeus*, *Nesidiocoris tenuis* (Reuter), and *Orius* spp. are efficient predators, among which, *M. pygmaeus* and *N. tenuis* can control 75 to 97% leaves and 56 to 100% fruits infestations caused by *T. absoluta*, respectively [53,66]; by killing the eggs and larvae [53,67]. In 2012-13 and 2013-14, an experiment was conducted in Turkey to ascertain the efficiency of individual and collective use of predacious insects, *N. tenuis* and the egg parasitoid, *Trichogramma evanescens* as biological control agents against *T. absoluta*. This experiment revealed that the capability to control *T. absoluta* by collective use

of *N. tenuis* and *T. evanescens* was about 95% which showed a higher damage reduction percentage than the single use of *N. tenuis*. However, using the *N. tenuis* only was effective to control the *T. absoluta* about 90% in tomato fruit [68]. 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* [69,70].

2.4.3.2 Parasitoids

Parasitoids are one of the most potent biological control agents that can be used to control the population growth of *T. absoluta*. The most significant *T. absoluta* egg parasitoids have been originated from the family Trichogrammatidae, Encyrtidae, and Eupelmidae [20,22,36]. The egg parasitoid *T. achaeae* was found most effective against *T. absoluta* [71] while compared the efficacy of *Trichogramma toideabactrae*, *Trichogramma pretiosum* [72], and *Trichogramma urquijoi*. The parasitism rates of *T. absoluta* eggs are 57.05% and 63.92% for *Trichogramma cacoeciae* and *Trichogramma bourarachae* which reduce the yield losses up to 78.89% and 87.62%, respectively in greenhouse tomato production [73]. In different geographical locations, various parasitoids showed their efficacy such as *Trichogramma pretiosum* was an effective parasitoid in Sub-Saharan Africa [22] and *Stenomesus* sp. was a potential parasitoid in the arid region of Algeria [65]. A research was

carried out in Tunisia on recently adapted parasitoid for organic tomato production and found two ectoparasitoids that are *Bracon* sp. and *Necremnusartynes* (Hymenoptera: Eulophidae), attacking and developing on *T. absoluta*, where the eulophid wasp was the most abundant with average parasitism rates of 25.5% [74].

2.4.3.3 Entomo-pathogenic microbes

The uses of microorganisms, like fungi, bacteria, and nematodes as biopesticides for the control of *T. absoluta* are effective [75]. Microbes invade the pest by their pathogenic effect which leads to the death of the pests [14]. In Europe and America, *Bacillus subtilis* (bacteria) and *Metarhizium anisopliae* (fungus) observed as the successful formulation to reduce the population of *T. absoluta* on tomato where *M. anisopliae* and *Beauveria bassiana* have also been observed as an effective formulation [22]. The fungi *Aspergillus flavus* and *Fusarium* sp. caused 100% larval mortality of *T. absoluta* within 6 days of treatment in a laboratory study of Algeria [76]. A study performed under open field conditions showed that *B. bassiana* and *M. anisopliae* at 2.5×10^9 conidial/ml gave similar mortality of *T. absoluta* as that of Chlorantraniliprole (Fig. 3). Similarly, maximum mortality ensued at 2.5×10^9 conidial/ml of *B. bassiana* (84.04%) followed by *M. anisopliae* (76.31%) after 10 days of the treatment under glasshouse condition [75].

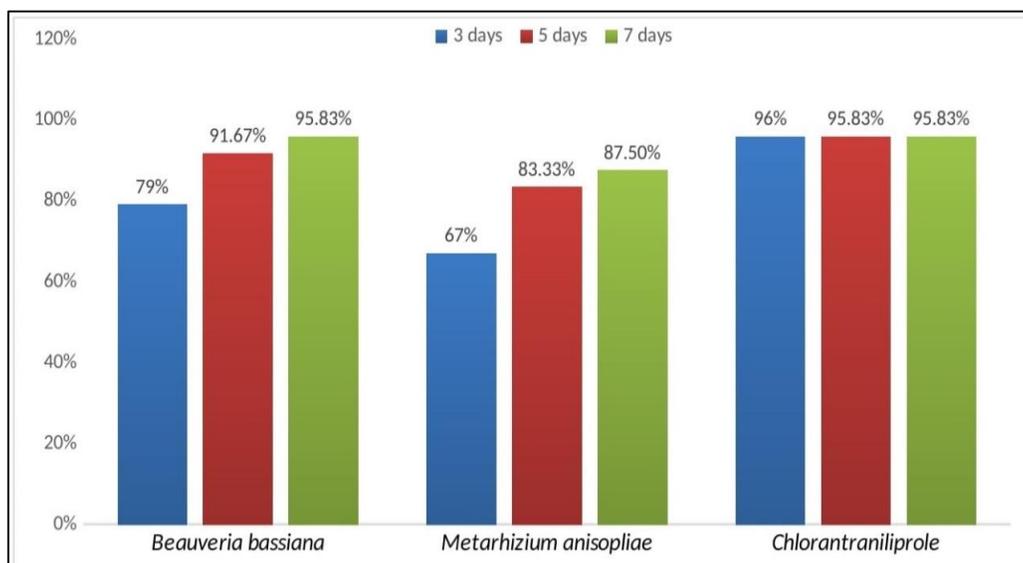


Fig. 3. Mortality of *T. absoluta* adult using Entomo-pathogenic microbes [75]

Likewise, a study was conducted to determine the effectiveness of three different entomopathogenic nematodes (EPN) against *T. absoluta*, namely *Heterorhabditis bacteriophora*, *Steinernema carpocapsae*, and *Steinernema feltiae*, where *S. feltiae* was the most effective nematode species under laboratory conditions in Turkey during 2013-2014. The results exposed that these EPN had a good potentiality to control the *T. absoluta* larvae [36,77]. Similarly, the effectiveness of entomopathogenic nematodes *Steinernema carpocapsae*, *Steinernema feltiae*, and *Heterorhabditis bacteriophora* also observed against *T. absoluta* at its late larval instars [10,54,78]. Another entomopathogenic bacterium *Bacillus thuringiensis*, that has also been used as very effective bio-insecticide for control of tomato pests [10,54,78,79]. In IPM based programs, biological control has been used extensively to control the pest in tomato crops. Bio-insecticides like *B. thuringiensis* do not create any environmental hazard as they are environmentally safe and eco-friendly.

2.4.3.4 Bio-pesticides (Plant extracts)

Plant-based pesticides are better management strategies than synthetic pesticides because plant-based pesticides are eco-friendly, biodegradable, easily obtainable, economical, and sustainable [36]. Active metabolites exist in plants act as a toxicant for the control of pests which may be contact or systemic [36]. Currently, several plant species have been used to control different agricultural pests by using crude extracts of seeds, leaves, bark, bulbs, and fruits globally [80]. Ethanol and hexane extracts of *Acmella oleracea* showed the highest mortality of 88 to 100% after six hours of application [81]. Neem extracts at various concentrations caused 24.5% egg and 86.7 to 100% larval death [82]. Petroleum ether extract of *Jatropha* caused 18 to 25% egg and 87 to 100% larval mortality within 4 days of treatment and 33 to 46.7% egg and 23.5 to 48.5% larval death within 24 hours of application at several concentrations [36,83,84]. An experiment was carried out in Egypt where Neem oil (Azadirachtin) showed the highest mortality (92%) on *T. absoluta* larva where the combined use of garlic + neem + green miracle and garlic + basil showed 43% and 40% larval mortality, respectively inside the mines [85]. In Tunisia, an experiment was conducted on botanical extracts of Neem oil + Azadirachtin named "Bioticide" and biological insecticide "Thuricide" based on *B. thuringiensis* var. *kurstaki* (Btk) along with mass trapping significantly reduced the damage of *T. absoluta*

[86]. Similarly, in Ethiopia it was reported that *Azadirachta indica*, *Nicotiana spp.*, *A. sativum*, and *Cymbopogon citratus* have shown significant effects on the larvae of *T. absoluta* at 10% concentration after a week of application [75]. Crude extracts of *A. sativum*, *Cymbopogon citratus*, and *A. indica* seed showed 95%, 97%, and 98% larval death, successively after 7 days of application [87]. Abdel-Baky and Al-Soqeer [88] observed that jojoba seed extracts achieved 75% larval death at second instar while applied at 100% concentration. [89] reported that Castor bean extracts and thyme extracts achieved 58% and 95% larval death, respectively. Moreover, extracts from some other plants such as basil, chinaberry, eucalyptus, garlic, geranium, and onion have also been showed insecticidal action into different efficacies to achieve larval death of *T. absoluta* [53,85,90].

2.4.4 Chemical control methods

T. absoluta can be effectively controlled by the chemical control methods as the main control measure of this pest. However, these control measures using chemical insecticides have significant side effects on beneficial arthropods [27,91,92], negative impacts on both human health and on the environment [93], and quit development of insecticide resistance [28,94]. Moreover, the effectiveness of chemical insecticides to control tomato leaf miner has been poor due to mine-feeding behaviour of its larvae or improper spraying method [51]. To avoid these, synthetic pesticides should not use at the beginning of the cropping season and obviously should avoid when symptoms of *T. absoluta* are not present. By using chemical insecticides with a minimal dose, low infestations by *T. absoluta* should be controlled. Insecticides should be selected carefully in the early stage of the crop growth. Several active ingredients should use alternately and not combined all at once so that this will not allow the pest to develop resistance in a shorter lifetime.

Several chemicals have been used in different parts of the world to minimize the infestation of *T. absoluta*. Synthetic pesticides like Organophosphates and Pyrethroids have been used in the 1970s and abamectin, Chlorfenpyr, Tebufonzide, and Spinosad have been introduced in the 1990s to control *T. absoluta* in Egypt [95]. In Africa, chemicals like Abamectin, Emamectin benzoate, Organophosphates, Pyrethroids, and Spinosad have been used against *T. absoluta* [22]. In Nepal, Plant

Protection Directorate has recommended to spray, Chlorantraniliprole (Trade name: Coragen, Alcora), Novaluron (Trade Name: Remon, Pedestal, Remo 10) and Spinosad (Trade name: Tracer) at 1 ml per liter of water, 3 ml per 10 liter of water and 1 ml per 3 liter of water, respectively against *T. absoluta* [41]. In Central-East Tunisian a research was conducted where insecticide indoxacarb (50 cc/hl) controlled *T. absoluta* larvae (with more than 95% efficacy nine days after insecticides application) successfully compared to diafenthiuron (125 cc/hl) and triflumuron (50 cc/hl) in greenhouse conditions [46]. On the other hand, in Northeastern Tunisian tomato greenhouses, insecticides flubendiamid (30 g/hl) and cyromazin (30 g/hl) attained 77% and 96% larval mortality of *T. absoluta* after three weeks of treatment, while the efficacy of azadirachtin is not more than 40% [96]. Besides, a good performance was observed by applying active ingredients indoxacarb, pyrethroids and spinosad, against *T. absoluta* larvae under laboratory and field conditions in Tunisia [46].

2.4.5 Sex pheromone-based control strategies

The sex pheromone trap is an authentic technique to investigate the existence of *T. absoluta* [10,20,28,40,63] and also helps to determine the critical time for pesticide applications leading to optimum use of registered insecticides [43]. Sex pheromones are chemicals released by an organism in the form of fluid which attracts an individual of the same species of the opposite sex that cause sexual excitement. They act as natural sexual attractants [10,40]. *T. absoluta* sexpheromone bait has been recognized as (3E, 8Z, 11Z), 3,8,11-tetradecatrienyl acetate as a major and (3E,8Z) tetradecadien-1-yl acetate as a minor element using for mating disruption [10,40]. Most of the female sex pheromones have been detected in Lepidopterans which consist of a mixture of two or more components that attract male from long-distances and also express courtship behaviour [40]. Sex pheromone-based control of *T. absoluta* is an eco-friendly management technique, therefore this technique is more recommended to be used along with other control methods. Sex pheromone trap can be used for pest detection, population monitoring, mass annihilation, and mating disruption [40,63,97]. In South America, Europe, Asia, and North Africa, the sex pheromone trap has been successfully applied in controlling tomato leaf miner on both greenhouses and open

fields. In Egypt, sex-pheromone trap showed a significant result when integrated with other pesticides for controlling the infestation of tomato by *T. absoluta* [98].

2.4.6 Development of *Tuta absoluta* Resistance tomato varieties

Selecting tomato varieties that resistant to insect pests are one of the most important management practices that help to protect the tomato plants from infestation by these pests. Recently, breeding programs for the development of insect resistance tomato varieties are gaining more attention in many parts of the world for cost-effective pest control methods [57,99,100]. Generally, wild relatives of genus *Solanum* contain insect registrant genes. The presence of glandular trichome and allelochemicals are linked with insect-resistant [101]. Trichomes secrete insecticidal compounds that are effective against larvae of *T. absoluta* [102]. Recently, several countries are focusing their research on the development of insect resistance tomato varieties by incorporating alleles responsible for resistance to insect existing in wild species into popular cultivated varieties to produce the alleles linked with resistance [103-106].

Three types of allelochemicals (acyl-sugars, zingiberene and 2-tridecanone) which was linked with resistant to *T. absoluta* [107,108]. These allelochemicals function as a toxicant, antinutritional, herbal and medicinal for pest and disease resistant factors [109]. Glandular trichome density and allelochemicals have been linked with conferring resistance to *T. absoluta* and other insect pests [104,108]. Generally greater resistant showed by those genotypes which have a higher density of glandular trichome [106]. Several researchers have identified these allelochemicals in some wild species of *Solanum*. Acyl sugars (AA) has detected in *S. pennellii* [107,109,110] and *S. galapagense* [112], Zingiberene (ZGB) has detected in *S. habrochaites* var. *hirsutum* [113], and 2-tridecanone (2-TD) has detected in *S. habrochaites* var. *glabratum* [107,114,115]. The presence of these allelochemicals, the oviposition rate, plant damage severity, injuries to the leaves, and the percentage of affected leaves were reduced significantly [105]. High concentrations of 2-tridecanone, Zingiberene, and Acyl sugars directly associated with the reduction of *T. absoluta* oviposition rate in tomato varieties [103-105].

Globally total 17 species have been recognized as wild relatives of the genus *Solanum*; *S. cheesmaniae*, *S. galapagense*, *S. chilense*, *S. chmielewskii*, *S. lycopersicum*, *S. habrochaites*, *S. neorickii*, *S. pennellii*, *S. arcanum*, *S. corneliomulleri*, *S. huaylasense*, *S. peruvianum*, *S. pimpinellifolium*, *S. juglandifolium*, *S. lycopersicoides*, *S. ochranthum*, and *S. sitiens* [116,117]. Among these, six wild species of *Solanum*, *S. Arcanum*, *S. chilense*, *S. corneliomulleri*, *S. lycopersicum*, and *S. pennellii* which are resistance to *T. absoluta* [118]. These genotypes showed significant larval death and continuing larval and pupal lifespan which led to reduce adult emergence of *T. absoluta*. On the other hand, *S. pennellii* and *S. habrochaites* showed outstanding resistant against *T. absoluta* [119]. Vitta et al. [120] also detected a wild species *S. habrochaites* as highly resistant to *T. absoluta*. Moreover, it will be very helpful to conduct further breeding programs for the development of *T. absoluta* resistant tomato varieties by utilizing glandular trichome and allelochemicals existing in different wild species of genus *Solanum*.

2.4.7 Integrated pest management (IPM)

The IPM is an efficient and eco-friendly sensitive approach for the control of pests that depends on combinations of all available pest control methods [28,53,121]. To control *T. absoluta* successfully the use of Integrated Pest Management (IPM) strategy might be very effective [37]. The integration of physical, cultural (crop rotation, changing planting/harvest dates to avoid pest's infestation, elimination and burning of infected plant parts) [53], biological agents such as predators, parasitoids, entomopathogenic microbes [48,122], biopesticides [10,18], and cultivation of *T. absoluta* resistance tomato varieties [47] can be develop an effective IPM [61]. The combination of these pest control methods with each other with appropriate use of registered insecticides [54,121] that are less hazardous to the environment could be effective for controlling *T. absoluta* without hampered the agro-ecosystems.

3. CONCLUSION AND RECOMMENDATIONS

Tomato is one of the most important and popular vegetable crops in Bangladesh which is grown on both open fields and greenhouses. However, recently, the average yield of tomato has been decreasing due to several factors including

diseases and pests. *T. absoluta* has recently been introduced as a devastating insect pest in Bangladesh which has become a major economic pest causing yield losses of up to 100% in tomato production. Therefore, the havoc caused by this pest demands urgent action while the pest's status has been increasing all over the world as it spreads into new belts over the last decade. Currently, Tuta Trap Tray and Tray Trap Technology (TTT) control measures have been shown more effective against *T. absoluta* as a single control method compare to other control methods. Moreover, the continuous application of chemical pesticides to control *T. absoluta* has led to the development of resistance against pesticides, disturbing the ecological and biological world. Therefore, to control this pest effectively, it is important to integrate all available control methods include physical, cultural, biological methods, and optimum use of registered pesticides. Besides these, there is need for multidisciplinary endeavour involving research scientists to detect genetic mechanisms and strategies that will be helpful to pause further colonization of *T. absoluta* in Bangladesh. Moreover, policymakers should establish appropriate policies; agricultural extension workers should communicate with farmers to provide successful agricultural solutions; to train up extension workers and farmers using accurate measures to control *T. absoluta*; and farmers to apply innovations for sustainable tomato production in this country. Moreover, the proper utilization of conventional breeding and molecular approaches to develop *T. absoluta* resistant tomato varieties could be the best sustainable control strategy. Finally, there is need for more collaborative efforts among the research scientists from public and private sectors as well as tomato growers to control *T. absoluta* in Bangladesh.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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