
Review Article

A review on ecology, biology, and management of a detrimental pest, *Tuta absoluta* (Lepidoptera: Gelechiidae)

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Article history:

Submitted 20 January 2022

Accepted 13 April 2022

Published 29 July 2022

Keywords:

Bacillus thuringiensis (Bt)

Metamorphosis

Pest

Pesticides

Tuta Absoluta

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Abstract

Insect pests are the forcing barrier for crop production worldwide. Of those insects, lepidopteran forms a major group of pests damaging from larval, pupal to adult stages. The edible berry commonly known as tomatoes are vines, dicots, and are typically pubescent. Tomato is attacked by several pests, however a leaf mining insect i.e., *Tuta absoluta* of the lepidopteran group is a serious pest of tomato throughout the globe. The widespread outbreak resulting from this challenging pest posed a great threat in every habituated continent recently. The extensive infestations are fortified by feeding grubs on tomato and other Solanaceous crops have unprecedented economic losses of the yield. Due to the entophytic nature of the pest, it makes cultivators difficult to manage the tomato leaf miner pest. So, every approach is to be foreseen to manipulate the pest environment not favoring them for survival, multiplication, and growth. Thence, this article portrays a complete package of useful tactics including physical, biological, mechanical, biotechnical, botanical, and chemical measures which are fruitful to management the pests and their impacts. The best control strategies are accessed and complied herein considering the actual know-how on the nature of pests and effective mitigating measures to assure the crops in this paper.

Introduction

The agricultural sector is profoundly tested by plant vermin and diseases. A high yielding harvests, having a place with solanaceous families delivers high monetary returns and greatly increases the pay of smallholder ranchers' income when its wellbeing is kept (Soares et al., 2019; Mkonyi et al., 2020; Steyn et al., 2020). Tomato plants are inclined to attack by a wide scope of arthropods against whom defense mechanisms such as chemical defenses of

glandular trichomes and constitutive and wound-instigated safeguards are enacted. There are a few micro-organisms (bacteria, fungi, and viruses) associated with tomato crops; some are useful, while many are considered pathogens to the tomato plant. However, the interactions between micro-organisms, viruses, and plants are complex. The overall interactions of tomato, its pest, and microbes are strongly influenced by alteration in environmental parameters (Organization for economic

How to cite:

Yadav, S. P. S., Bhattarai, S., Ghimire, N. P., & Yadav, B. (2022). A review on ecology, biology, and management of a detrimental pest, *Tuta absoluta* (Lepidoptera: Gelechiidae). *Journal of Agriculture and Applied Biology*, 3(2): 77 - 96. doi: 10.11594/jaab.03.02.02

cooperation and development, 2017). A portion of the significant pests of tomatoes includes armyworms and fruitworms, cabbage loopers, leafminers, pinworms, aphids, thrips, stink bugs, and whiteflies (Trumble, 2020). However, at present, a neotropical and tenacious rural vermin is pulverizing these harvests by assaulting the plants and debilitating their development and yield limit, giving direct consequences for the market, processing units, and nurseries (Godfrey et al., 2018; Mansour et al., 2018; Mkonyi et al., 2020; Moeini-naghade et al., 2020; Zink et al., 2020; Abdel-baky et al., 2021). The *Tuta absoluta* is generally known as Tomato leaf miner (Lepidoptera: Gelechiidae) is an oligophagous, notorious, multivoltine, and an r-rated species that attacks countless Solanaceae plants and is viewed as a genuine danger to tomato cultivation around the world (Desneux et al., 2010; Abadi, 2014; Jac, 2017; Shiberu & Getu, 2017; Rostami et al., 2018; Coleman, 2020; Hoge, 2020; Khani et al., 2020; Abdel-baky et al., 2021). Tomato (*Solanum lycopersicum*) has been one of the most popular fruits of the world producing more than 60 million tons per year. Being the most valued crop, there are certain constraints in the production of tomatoes (Victor & Mwangi, 2019). *Tuta absoluta* swarms over the ground portions of the plant in each developmental stage. Tomato leaf miner, *T. absoluta* attacks the tomato plant in every possible stage and reduces the massive yields of the crops (Victor & Mwangi, 2019). Thus, it is perceived as a critical leaf mining, stalk borers, and fruit harming nuisance (Abdel-baky et al., 2021; Bastola et al., 2020; Jac, 2017). Throughout the country, it is a major factor behind the reduced production of tomatoes in both greenhouse and open field conditions (Gozel et al., 2020; Han et al., 2019; Munyua & Bream, 2017). It has turned into the most dangerous and a vital irritation for Solanaceae crop production in South America, Africa including Tanzania, and in few regions throughout the planet (Desneux et al., 2010; Jac, 2017; Mansour et al., 2018; Huda et al., 2020). *Tuta absoluta* is recognized by different names in same and various areas of the world like; tomato leaf miner (TLM), South American tomato moth, tomato borer or South American

tomato pinworm in South America, further *Phthorimaea absoluta* in Peru, and *Gnortymoschema absoluta*, *Scrobipalpula absoluta*, or *Scrobipalpuloides absoluta* throughout the world (Abdel-baky et al., 2021; Desneux et al., 2010; Hoge, 2020; Jac, 2017). Not only tomato but also it has been found to cause damage in other solanaceous plants like eggplants, potatoes, pepper, tobacco, and also solanaceous weeds (Chidege et al., 2017; Seplyarsky et al., 2010). In tomatoes, *Tuta absoluta* is found to damage every part from leaves, stems to fruits. The larva at first feed on the mesophyll cells of leaves then burrow into the stem and ultimately to fruits which causes significant loss to tomato production (Iamandei & Dinu, 2017). Actual damage is enhanced by direct feeding on leaves, stems, buds, calyx, young or ripe fruit by the pest and also by the invasion of other secondary pathogens from the wound made by feeding pest (Meshram, 2015). *T. absoluta* is a voracious feeder and has caused a catastrophic level of damage to crops worldwide.

These species spread rapidly, starting with one region then onto the next, by the wind which favors the spread of the pest in new regions. *Tuta absoluta* is a very invasive pest because it has great potential to adapt quickly in agro-ecological conditions and spread rapidly causing massive economic damages (Garzia et al., 2012). This sort of spread is a benefit for the nuisance, its energy being accessible for propagation. *T. absoluta* can fly a few kilometers and can be incidentally scattered by people in nearby or worldwide agricultural regions and because of its high demographical potential, which is chiefly because of a short generation period, a generally wide host range, a decent warm versatility, and its inclination to foster insect poison obstruction; they are fit to attack from one side of the planet to the other (Desneux et al., 2010; Hoge, 2020; Jac, 2017; Mansour et al., 2018; Wakil et al., 2018). They are profoundly dynamic around evening time and grown-ups typically stay stowed away during the day, having an extraordinary movement in the first part of the day (Hoge, 2020). Accordingly, the motivation behind this review is to make speculations regarding *T. absoluta* to

assess its frequency on the assortment of farming harvests.

Origin and distribution

Tomato leaf miner is thought to be native to central Chile, South America, and has been boundless in southern Europe, then, Asia in localized southern parts, the Middle East, and some African nations. At present, *T. absoluta* has been far-reaching practically all around the world on various solanaceous harvests (Desneux et al., 2011; Godfrey et al., 2018; Huda et al., 2020; Jac, 2017; Mansour et al., 2018, 2019; Mkonyi et al., 2020; Sanda et al., 2018) (Table 1). Nevertheless, introductions into new regions appear to be somehow linked to the importation of tomato fruits, with confirmed cases in Eurasia (UK, Netherlands, Romania, Russia, and Lithuania) (Desneux et al., 2010, 2011; Hoge, 2020). As of late, *T. absoluta* has been formally announced in South Asian nations like India (in Maharashtra) during October 2014, and in Nepal and Bangladesh during May 2016, separately. Further, it was found in West Asian nations including Iran in 2010 (Bastola et al., 2020; Huda et al., 2020; Khani et

al., 2020; Wakil et al., 2018). Subsequently, it then spread extremely quickly all through the Mediterranean shores, including regions for North Africa and the Middle East (Desneux et al., 2011; Hoge, 2020; Jac, 2017). Nowadays, *T. absoluta* is accounted for in 41 of the 54 African nations in Northern and Western parts especially Sudan, Kenya, and Ethiopia, causing decimating financial emergency (Bastola et al., 2020; Mansour et al., 2018) (Table 1). In a summarize, *T. absoluta* shows up as a significant danger to nations, whose tomato exports are significant for the economy, particularly exporters like Mexico, the USA, Canada, India, and China (Desneux et al., 2011). The fast dissemination of *T. absoluta* over wide geographic regions might be a consequence of different factors like its high biotic potential, endophytic feeding propensities, a wide scope of host plants, the intra-mainland dispersal assistance because of human transportation, and the artificial selection of insecticide-resistant populations (Huda et al., 2020; Jac, 2017). Thence, the dissemination ability of this pest is substantial, due to which the distribution of this nuisance is throughout the world.

Table 1 Geographical distribution of *Tuta absoluta*

S.N.	Region	Country	Year of establishment
1.	South America	Brazil (Peru)	Native
2.	South America	Argentina	Declared Pest on 1964
3.	Europe	Spain	2006
4.	North Africa	Algeria	2008
5.	North Africa	Tunisia	2008
6.	Western Europe	France	2008
7.	Southcentral Europe	Italy	2008
8.	Macaronesia	Canary Islands	2008
9.	Southern Europe	Albania	2009
10.	Southeastern Europe	Bulgaria	2009
11.	Northwestern Europe	Netherlands	2009
12.	Southwestern Europe	Portugal	2009
13.	Northwestern Europe	United Kingdom	2009
14.	North Africa	Morocco	2009
15.	Middle East	Israel	2010
16.	Central Europe	Hungary	2010
17.	Western Asia	Turkey	2010
18.	South East Europe	Serbia	2010
19.	North Africa	Egypt	2010
20.	West Africa	Sudan/Southern Sudan	2011
21.	East Africa	Ethiopia	2012

S.N.	Region	Country	Year of establishment
22.	East Africa	Kenya	2013
23.	South Asia	India	2013
24.	South Asia	Pakistan	2013
25.	South Asia	Afghanistan	2013
26.	East Africa	Tanzania	2014
27.	West Africa	Senegal	2014
28.	West Africa	Nigeria	2015
29.	West Africa	Niger Republic	2016
30.	South Asia	Nepal	2016

Cited from: (Garzia et al., 2012; Muniappan, 2015; Sanda et al., 2018; Shree et al., 2018)

Host range

Tomato leaf miner, *T. absoluta* is a harmful oligophagous insect assaulting several plant species with a high inclination towards the types of the Solanaceae family. It has a solid preference for tomato (*Solanum lycopersicum* L.) which is considered as the principal or primary host (Abdel-baky et al., 2021; Desneux et al., 2010; Huda et al., 2020). *T. absoluta* is a cosmopolitan species and regardless of having a clear bias on the tomato plant it additionally assaults another developed type of Solanaceae. It has a wide scope of hosts including significant host, minor host, wild host, and substitute host (Abdel-baky et al., 2021; Hoge, 2020; Jac, 2017). Further, various developed solanaceous species including potato (*S. tuberosum*), sweet pepper (*S. muricatum* L.), eggplant (*S. melongena*), tobacco (*Nicotiana tabacum* L.), cape gooseberry (*Physalis peruviana* L.), pepinodulce (*S. muricatum*), and peppers (*Capsicum annuum* L.) are its minor hosts (Bastola et al., 2020; Hoge, 2020; Huda et al., 2020; Jac, 2017; Moeini-naghade et al., 2020). In addition to cultivated hosts, *T. absoluta* uses other wild solanaceous plants including *S. nigrum* L., *S. elaeagnifolium* Cav., *S. lyratu*, *Physalis angulata*, *Lycopersicon hirsutum*, fiend's apple (*Datura stramonium* L.), *S. sisymbriifolium* L., *Datura quercifolia* Kunth, *S. puberulum*, *S. bonariense* L., *Datura stramonium*, *Datura ferox* L., *S. habrochaetes* S. Knapp, *S. americanum*, and tree tobacco (*Nicotiana glauca* Graham) as wild host, individually (Abdel-baky et al., 2021; Bastola et al., 2020; Desneux et al., 2010; Huda et al., 2020; Jac, 2017; Rostami et al., 2018; Wakil et al., 2018). Simultaneously, it can lay eggs and develop on other substitute hosts

including Amaranthaceae, Convolvulaceae, Fabaceae, and Malvaceae. Fabaceae belongings plants like *Phaseolus vulgaris*, *Vicia faba*, *Vigna unguiculata*, and *Medicago sativa* are profoundly susceptible. However, the number of eggs laid, the pace of larval development, and larval endurance might be lower on a portion of the alternate hosts or weed hosts contrasted with the essential host (Bastola et al., 2020; Godfrey et al., 2018; Hoge, 2020). Mostly the adult female moth prefers the apical part of the tomato leaf for its oviposition. It was found that the apical portion of the tomato leaf contains a low amount of calcium as compared to the middle and basal portions of the leaf. So, this might be the reason for the pest to precisely select the apical portion for oviposition. However, those plants which secrete chemicals like 2-tridecane or zingiberene aren't preferred by this pest for oviposition. Instead, those plants that have an absence of terpenes or less amount of terpenes are preferred for oviposition by this pest (Aynalem, 2018). *T. absoluta* shows a significant alignment with Solanaceae crops encompassing cultivated and wild species.

Seasonal occurrence

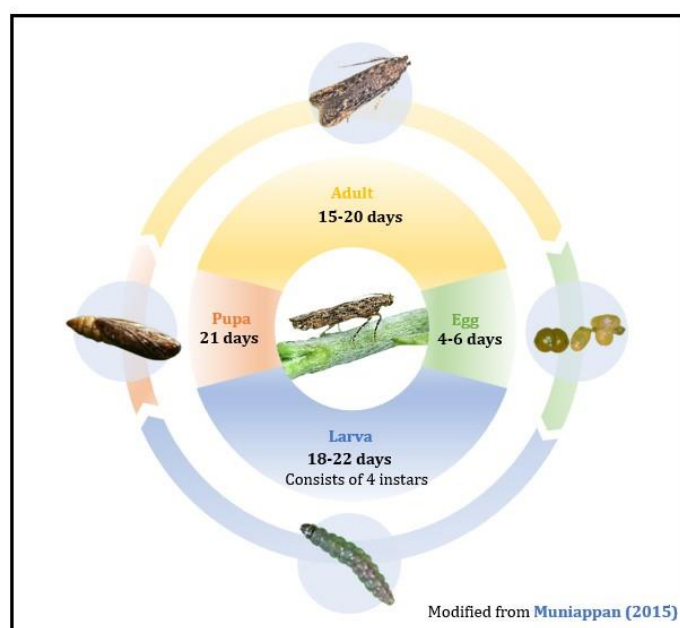
The climatic condition severely affects the growth and development as well as the invasion of this pest. As the cold season prevails, these pests maintain their viability and during the hot season, they spread to open fields (Victor & Mwangi, 2019). In favorable conditions, diapause does not appear and generation continues throughout the year. *Tuta absoluta* generally mated and lay eggs at night. It shows different pupation behavior according to the environment (Sanda et al., 2018). For the

optimum growth, the required temperature for *T. absoluta* is 30 °C with an upper and lower development threshold of 34.6 and 14 °C, respectively (Aynalem, 2018). However, Lower threshold temperature does not show that the pest would experience high mortality under 14 °C as they can tolerate lower temperature (Han et al., 2018). The environmental condition severely affects the reproductive potential as well as the duration of the life cycle (Gebremariam, 2015). Between the months of November and May, *T. absoluta* develops its four generations. It develops 4-5 male flight peaks, with more voracious activity in summer (March and July) (Mansour et al., 2019). This pest is comparatively less dominant and active in the winter season but is adversely detrimental in the summer season.

Life cycle

Tuta absoluta is a miniature lepidopteron moth with fast propagation ability. Conceptive paces of *T. absoluta* shift contingent upon the temperature and ideal conditions with a possible limit of 10-12 ages per year (Huda et al., 2020; Mkonyi et al., 2020; Moeini-naghade et al., 2020; Wakil et al., 2018). It is a holometabolous insect that includes four development stages viz. egg, larvae, pupa, and adults (Bastola et al., 2020; Sanda et al., 2018). The female moths start laying eggs 2 to 3 days after emergence and can oviposit for over 20 days. They can lay eggs somewhere in the range of 250 and 300 in the course of their life. *Tuta* females store their eggs either separately or in little groups mostly on the underside or upper side of the leaves, and on stems and edges, blossoms, or buds. However, egg-laying on the fruit is extremely uncommon (Desneux et al., 2010; Zekeya et al., 2017; Godfrey et al., 2018; Sanda

et al., 2018; Shree et al., 2018; Wakil et al., 2018; Hoge, 2020; Moeini-naghade et al., 2020; Alimbekova & Duisembekov, 2021). The incubation period is between 4-6 days at a temperature range of 25-30°C (Huda et al., 2020). According to the research Arnó et al. (2019), it was found that 78-88% of eggs were hatched successfully that were laid on the host plant. However, the meantime for hatching the eggs was a little longer on the wild host species as compared to other major hosts. Further, eggs are brought forth into larvae, which form into four larval stages called instars. The term of the improvement of the average period of hatchlings stage is around 18 to 22 days (Alimbekova & Duisembekov, 2021; Jac, 2017; Moeini-naghade et al., 2020). Moreover, the pupal stage can finish its life expectancy within 21 days (Table 2). It is obscure whether this species goes through a diapause (Huda et al., 2020; Moeini-naghade et al., 2020; Retta & Berhe, 2015; Wakil et al., 2018). Adults rise out of the pupae in 5 to 8 days. The adult's life expectancy on average is around 15-20 days; 6-7 days for males, and 10-15 days for females (Godfrey et al., 2018; Huda et al., 2020; Wakil et al., 2018). The length of developmental periods (Egg to adult emergence) relies, especially upon the climatic conditions. The total life cycle requires around 76 and 24 days under cold and warm conditions, individually (Figure no. 1). However, the ideal temperature for the development of *T. absoluta* is viewed as 30°C, under research facility premises (Bastola et al., 2020; Godfrey et al., 2018; Hoge, 2020; Huda et al., 2020; Wakil et al., 2018). The female can lay outnumbered eggs i.e., they have high fecundity and a short duration life cycle. The necessary fundamentals with which a pest can be contagious to crop species.

Figure 1. Lifecycle of *Tuta absoluta*Table 2. Duration of development of *Tuta absoluta* (day) at 24°C in laboratory conditions

S.N.	Stages	Duration (Days)	References
1.	Eggs	3	(Alimbekova & Duisembekov, 2021; Shree et al., 2018)
2.	Larva	8-9	
i.	1 st Instar	2-3	
ii.	2 nd Instar	1-3	
iii.	3 rd Instar	1-3	
iv.	4 th Instar	1-3	
3.	Pupa	6-9	
4.	Adult	7-21	

Life stages depictions

Eggs

Eggs are curved tube-shaped, without blades, and are laid disengaged, comprising of 0.35-0.38 mm length, and 0.22-0.25 mm width (Alimbekova & Duisembekov, 2021; Dandria & Catania, 2009; El-Shafie, 2020; Jac, 2017). The recently laid eggs are smooth white to dazzling yellow in shading and become coppery-red to dark with two red eyespots prior to incubating (Bastola et al., 2020; El-Shafie, 2020; Godfrey et al., 2018; Hoge, 2020; Wakil et al., 2018). Thus, the eggs pigmentation changes with the following days after laying.

Larva

The caterpillar is round and hollow fit, with a distinct head, three sets of pectoral legs, and

five sets of ventral pseudopods on the stomach (Alimbekova & Duisembekov, 2021; Godfrey et al., 2018). They are dorsoventrally straightened, yellowish velvety in shading with dim head, and body length lies between 7 - 10 mm (Hoge, 2020; Jac, 2017; Wakil et al., 2018). As they develop, the hatchlings become yellowish-green during the second and third instars, and marginally pink with a purplish thorax in the last instar (Alimbekova & Duisembekov, 2021; Hoge, 2020; Wakil et al., 2018). In developed larvae, there is an observable red tone, as a spot or as lines arranged in width on the back, and further, there are snares of various sizes, orchestrated in a circle at the front legs (Alimbekova & Duisembekov, 2021). In the first larval period, they are 0.6 mm to 0.8 mm in length and become 7.3 mm to 8 mm in their

fourth stage (Sanda et al., 2018). During shedding, the larvae are briefly seen outside the feeding channel, neither they are for the most part present inside the plant structures (Moeini-naghade et al., 2020; Wakil et al., 2018). However long, food is accessible, the larval stages do not go into diapause, yet can overwinter as eggs, pupae, or adults relying upon ecological conditions (Jac, 2017; Moeini-naghade et al., 2020). The larval are the major threats to the cultivator's production that should be controlled wisely to maintain the pest populace at below ETL.

Pupa

The developed larvae generally fall and penetrate the soil, where pupation for the most part happens or either move to the calyx or leaves, where it turns a luxurious silk case to pupate called cocoon (Aynalem, 2018; Bastola et al., 2020; Desneux et al., 2010; Gebremariam, 2015; Godfrey et al., 2018). The pupa is elliptical and tapered fit running between 4-5 mm long, and 1.1-1.8 mm wide, and are dim green in shading and later turns intensive brown, near-adult bearing phase (Alimbekova & Duisembekov, 2021; Bastola et al., 2020; Huda et al., 2020). At this stage, they produce a slender, velvety case that transforms into prepupae and pupae (Hogea, 2020). It was found that those male pupae who fed on major hosts weighted more as compared to females feeding on the same host (Arnó et al., 2019). The pupal stage is the inactive phase but inside the case, the pests are actively being metamorphosed into systemic ordinate adults.

Adult

Adults are yellowish, mottled dim, and pole molded with a body length of 5-6 mm, and a couple of long filiform antennae with alternating light and dark bands (Coleman, 2020; Dandria & Catania, 2009; Godfrey et al., 2018; Huda et al., 2020; Jac, 2017). The size of an adult moth is small and is about 7 mm in length along with a wingspan of about 1 cm (Abadi, 2014; Bastola et al., 2020; Gebremariam, 2015). The forewings of *T. absoluta* are flimsy, spear formed, and the edges, particularly the underside, are layered. The upper part of the

forewings has clear apparent dark lines arranged in columns with dim to shiny scales (Alimbekova & Duisembekov, 2021; Huda et al., 2020). Though, the hindwings are trapezoidal, bent, with a periphery on the external side, and contain apparent dark spots (Hogea, 2020; Jac, 2017). The grown-up's head is yellowish to dark in shading with a simple eye, and white to dark mustache rings (Alimbekova & Duisembekov, 2021). This species shows some degree of sexual dimorphism. The design of the wings shifts between the genders. Further, the male comprises one huge bristle and the female of three thin blisters. Besides, the underside of the male's midsection is filthy whitish, the edges of which go to dim, and the females are white, with 4 dark lines bent along the edge (Alimbekova & Duisembekov, 2021; Genç, 2016). Between the genders, the females are more extensive and more voluminous than the males (Desneux et al., 2010; Hogea, 2020). The main difference between male and female moths is that the genital opening in females is found between tubercles and is distinguished by a longitudinal suture at the middle of the eighth abdominal segment (Aynalem, 2018; Muniappan, 2015). The moths are not viewed as solid fliers, even though they might fly for brief distances to discover appropriate hosts (Godfrey et al., 2018). The adults seems dim and pale in locally areas which makes them to camouflage and escape the predators.

Damage

Tuta absoluta is perhaps the most harmful insect nuisance of solanaceous harvests. Whenever it has become set up, without satisfactory control measures, pervasions of *T. absoluta* can bring about 90–100% loss of field-created crops (Alimbekova & Duisembekov, 2021; Dlamini, 2020; Hogea, 2020; Jac, 2017; Wakil et al., 2018). This vermin is probably going to cause a monetary loss of more than 50 million USD. *T. absoluta* had effectively plagued 1.0 M ha of the tomato-developed region (22% of the completely developed surface) out of 4.4 M ha in 2011. In the direst outcome imaginable, future attacks by *T. absoluta* on the planet would bring about an expansion of around \$500 M each year for pest management in tomato

crops, which straightforwardly lead to a decrease in tomato yield and its overall fare (Abdel-baky et al., 2021; Bastola et al., 2020; Cherif & Verheggen, 2019; Desneux et al., 2011). The subsequent stage (larvae) is the riskiest one because the larvae assault all parts of the harvests including foliage, stem, apical buds, blossoms, and fruits except for roots during all development stages (Godfrey et al., 2018; Hoge, 2020; Khani et al., 2020; Mkonyi et al., 2020; Wakil et al., 2018). The larvae feed upon crops, creating huge displays in leaves, tunneling in stalks, and burning-through apical buds, and green and ripe fruits and forms dark frass because of which pervasions are genuinely simple to notice (Hoge, 2020; Jac, 2017; Rostami et al., 2018; Wakil et al., 2018). The mines on the leaf might turn out to be enormous to the point that the leaves seem skeletonized, decreasing the plant's capacity to photosynthesize and produce fruits (Godfrey et al., 2018; Wakil et al., 2018). On the leaves, larvae feed just on mesophyll, leaving just the epidermis flawless with its defecation, which along these lines extends, and afterward the harmed tissue dries (Bastola et al., 2020; Hoge, 2020).

The mines in the leaves further appear whitish with unpredictable spots which are found covered with droppings (Bastola et al., 2020). Further, the openings made from the mining on the fruit are generally situated around the bowl are faintly noticeable right away, as they are regularly covered with petioles. A couple of days after the entrance of the pest, holes start to be noticeable, as the harmed parts become dark because of the amassing of waste and result in fruit decay in light of colonization of microorganisms (Alimbekova & Duisembekov, 2021; Godfrey et al., 2018; Wakil et al., 2018). Under extraordinary assault, the harmed leaves become yellow, shrink, and senescence; the fruits are obliterated, and the plant ultimately dies. The yield and fruit quality are both significantly affected by direct feeding as well as auxiliary microorganisms entering into the host plants through injuries made by the vermin (Bastola et al., 2020). Consequently, if the larva is left uncontrolled at the beginning phases of its development, it might burn through all plants including buds and blossoms

that can bring about their abscission, decrease of plant development, poor plant architecture, and a loss of fruit set in the farm (Godfrey et al., 2018; Mkonyi et al., 2020; Oztemiz, 2014). This pest has enormously contributed to the damage of the different parts of the crop especially the leaves portion and the most damage-causing stage is the larval stage which has the voraciously feeding habit.

Control and management

Because of the absence of the management of agro-economic exercises, the cultivation of crops prompts enormous measures of harm and loss (Yadav & Paudel, 2022). *Tuta absoluta* has the capacity of destroying the cultivated as well as non-cultivated crops of the solanaceous family leading to massive economical loss of up to 80%. Due to this reason, efforts had been put on by various researchers, and growers for the suitable and most effective sustainable management strategy of *T. absoluta* (Mansour et al., 2019). Management of this pest can be carried into the pre-invasion and post-invasion methods. Pre-invasion methods include those methods that prevent the pest to enter and spread into any new area. This method includes plant quarantine measures along with proper inspection and treatment. Similarly, the post-invasion method includes the methods to eradicate or destroy the pest at the early stage of incursion or any suitable and sustainable management technique (El-Shafie, 2020). The aforesaid biological parameters mentioned in the biology section favor the actuation of the pest population so appropriate control and broad management practices or strategies ought to be embraced before the damage threshold (DT) to secure the raised production in the field.

Cultural method

Intercropping

Intercropping certain minor crops with the main crop can forbid this pest infestation. In the case of tomato, intercropping with a gallant soldier and coriander shows a constructive outcome on diminishing vermin thickness and improving regular adversaries (Cherif & Verheggen, 2019; El-Shafie, 2020; Huda et al., 2020; Mansour et al., 2019). The intercropping

of main crops with minor crops diverts the pest from the main crops, draws in towards themselves, and eventually limits the odds of pervasion.

Adjusting the planting dates

Whenever the situation allows, producers ought to avoid early and late-season tomato crops if *T. absoluta* is known to be present (Mansour et al., 2019; Wakil et al., 2018). The suitable adjustment in the planting date can protect the significant production stages of crops by avoiding pest occurrence.

Obliteration of wild and alternate hosts

It is additionally urged to destruct the wild solanaceous host plants and weeds encompassing the crop field inside 50m of pervaded fields because the nuisance can re-swarm the crop which is facilitated by these species at all developmental phases of *T. absoluta*. They go about as a repository for the remaining populaces of the vermin (Dlamini, 2020; Huda et al., 2020; Jac, 2017; Mansour et al., 2018; Wakil et al., 2018). The wild and alternate hosts must be removed from the field since they give chances of regermination to the pest. The pest utilizes to oviposit their eggs on those which can be deterring for the significant harvests.

Field sanitation

Plants ought to be regularly inspected for any proof of pervasion and all invaded materials ought to be arranged cautiously. Any suggestive leaves, stems, and fruits influenced by the presence of larvae or pupae ought not to leave on the ground since pests can colonize on another plant in a moment. Rather, those materials ought to be put in plastic packs to obliterate (Huda et al., 2020; Jac, 2017; Wakil et al., 2018). Furthermore, all gear utilized in fields with realized invasions should be entirely cleaned by high-pressure washing or steam and legitimate planting distance between lines is additionally useful to forestall pest travel (Huda et al., 2020; Mansour et al., 2019; Wakil et al., 2018). A minute reproductive unit of pest can harm entire bunches of the crops so the field sanitation after each progressive season ought to be set up.

Annihilation of harvest buildups

Subsequent to reaping, the harvest deposits should be annihilated at the earliest opportunity. They can be obliterated by one or the other copying, covered, or covered with straightforward plastic film to age them followed by an insecticidal spray. Soil solarization is likewise successful to decrease the number of pupae that stay in the soil in warm environments. Moreover, the consolidation of crop residues in the soil after harvest viably interferes with the existing pattern of *T. absoluta* by killing the juvenile stages (Huda et al., 2020; Jac, 2017; Wakil et al., 2018). After each cultivation season, the fields produce leftover, which should be obliterated since they may be contaminated. So appropriate removal of those leftover masses ought to be done to end the auxiliary stages of the pest.

Management of plant material

The utilization of pest-free transplants is an effective control measure against *T. absoluta* (El-Shafie, 2020; Huda et al., 2020). For the availability of safe and secure plant material, the legislative and private seed enterprises are responsible. So, to have the pest-free seeds those endeavors ought to be compressed by the concerned specialists. Further, the phytosanitary majors can be consistently followed by them.

Other social techniques

Tuta absoluta can be constrained by acceptable agricultural practices including furrowing, crop rotation with non-Solanaceous harvests (ideally Cruciferous crops), adequate water system, and ideal utilization of fertilizers (Huda et al., 2020; Jac, 2017; Wakil et al., 2018). Similarly, moth-proof sealing can be used in greenhouses to prevent the crop from being attacked. Adequate use of biofertilizers to enhance the resistance over the pest from the bottom level has been practiced in some tomato cultivation areas (Coleman, 2020; El-Shafie, 2020). Covering of soil with plastic screens or mulching of soil helps to prevent the emergence of new adults from buried pupae (Abbes et al., 2012; Han et al., 2019). The most effective control methods are the cultural method at the

community level, which decreases the surpassed dissemination of pest biological units through the particulate region.

Physical method

One of the most popular physical control methods that have been applied to control *T. absoluta* is the use of the pheromones trap. Pheromones are chemical substances that act as a messenger which affects the behavior of other animals and insects. They are mostly wind-borne but can be placed on soil and vegetation. Sex pheromones of insects are the chemicals secreted by the female insect to attract and deceive their male counterpart (Sanda et al., 2018). The majority of female sex hormones that were discovered in pest of Lepidoptera was the composition of two or more compounds that not only summon long-range male attraction but also induce courtship behavior (Retta & Berhe, 2015). The female sex pheromones of *T. absoluta* are composed of two components, major component represents about 90% of the volatile material (3E, 8Z, 11Z)-3,8,11-tetradecatrien-1-yl acetate or TDTA which is found in the sex gland of females. The insect populations can be monitored by using two techniques; mass annihilation and mating disruption techniques (Sanda et al., 2018). Male annihilation methods are usually efficient against newly introduced pests when population density is low. Mating disruption by sex pheromone alters the ability of males to locate and find females which can be effective only in a confined environment such as in greenhouses (El-Shafie, 2020). But a recent study has shown that *T. absoluta* has polygenic nature and capacity for asexual reproduction which might be a major threat against the sex pheromones trap. Despite these facts, the sex pheromones trap has been able to capture more than 100 males per trap per day. It was found that those traps which were placed 15-20 cm above the ground captured 5 times as many adult pests than those traps placed at 1 m above the ground (Aynalem, 2018). One of the most successful, simple, effective, efficient, and sustainable traps introduced is Tray Trap Technology (TTT) which can attract, trap and kill more than five thousand adults per tray (Sanda et al.,

2018). Thus, trapped insects can be killed mechanically or chemically (Aynalem, 2018). Similarly, the light trap for massive trapping was significant to trap the pest density of 1/500m² or 1/350m² during the summer-winter season. But this management system did not work properly in the winter-summer season to control the pest population (Han et al., 2018). Similarly, proper screening of roofs and sides of greenhouses, the use of double-entry doors can help to reduce the movement of pests into the greenhouse. Removal of green leaves that are mined by the pest can help to reduce the migration of pests into the massive crop (Retta & Berhe, 2015). Pheromones mass trapping, with high densities of sex pheromone water traps, has been used in an open field to trap the pest. However, pheromone water traps need a lot of maintenance and labor as compared with insecticide-based control. Pheromone's water trap may kill the pest from 26 % to 45% (Abbes et al., 2012). The implication of pheromone traps attracts the males and sequentially kills them which directly decreases the prevailing male pest population in the ecosystem. This causes mating disruption and further control the pest population significantly.

Mechanical method

Trapping

There are several insects' suction traps that can be utilized to trap *T. absoluta* and control their population. The snares include light traps and traps baited with sex pheromone lures (Huda et al., 2020).

Light traps

Light traps attract both males and females. Seasonal catches showed that in crops, males appear about a week earlier than females. These traps are more effective for catching males (Hogea, 2020).

Traps baited with sex pheromone lures

Traps baited with sex pheromone lures can be utilized for populace checking, mass obliteration, mating disturbance, and early discovery of *T. absoluta* in recently attacked regions (Bastola et al., 2020; Hogea, 2020; Mansour et al., 2018). Sex pheromones are synthetics

delivered by an organic entity as a liquid that attracts opposite sexes that cause sexual fervor. These tricking synthetics are utilized in the snares as a lure to trap the grown-ups (Godfrey et al., 2018; Huda et al., 2020; Wakil et al., 2018).

Delta traps

The most ordinarily utilized kind of pheromone trap is the Delta trap which comprises the three-sided molded body open at closes. Inside is a removable plate with cement and in it is situated the snare with pheromones. Delta traps are of two kinds i.e., Cardboard delta triangle with tacky surface and Cardboard delta triangle with a removable liner. Either one may be reasonable for catching *T. absoluta* (Hogea, 2020; Jac, 2017).

Water traps

The water trap comprises a plastic compartment holding water and a pheromone bait. The bait is gotten over the water with a wire appended at the two finishes of the compartment. These snares are simpler to keep up with less delicate dust than Delta or light snares and have a bigger catching limit than Delta traps (Bastola et al., 2020; Jac, 2017).

Tacky rolls

These are rolls with *T. absoluta* pheromone joined into the sticky glue, with the pheromone gradually released from the adhesive layer (Jac, 2017).

Insect proof netting

The utilization of bug confirmation screens or nets shows an extraordinary degree of anticipation of *T. absoluta* invasions on host plants. It is a prophylactic measure that can stifle insect density without the mortality of insects by making a mechanical avoidance among host and vermin (Hogea, 2020; Huda et al., 2020).

Covering materials

Different covering materials like polycarbonate or polyethylene movies can be utilized to cover the field surface, which straightforwardly changes the pupae improvement and further forestalls the adults arriving at the host (Hogea, 2020).

Botanical method

Numerous plants and plant parts extract like dynamic metabolites can be utilized to control *T. absoluta* (Table 3). The most elevated paces of mortality of *T. absoluta* larvae can be accomplished by the utilization of concentrate of *T. vulgaris* leaves, the seeds of *R. communis*, essentials oil of *Syzygium aromaticum* (L.), and *Azadirachta indica*. Since they show high insecticidal toxicity towards *T. absoluta* larvae. Thus, these plants' concentrate could be consolidated in IPM programs against this pest (Bastola et al., 2020; Huda et al., 2020; Mansour et al., 2018). The botanical pesticides take time to control the pest but have negligible pesticide residual effect on the environment. So, these pesticides should be advanced and applied in regular fields.

Table 3 List of botanical pesticides with their application rate

S.N.	Botanical Compounds	Application rate	References
1.	Oleorgan (Neem oil 40%)	3 ml L ⁻¹	(Hogea, 2020)
2.	<i>Acmella oleracea</i> extract	10 µg mg ⁻¹	(Aynalem, 2018)
3.	Azadirachtin 300 ppm	5 ml L ⁻¹	(Bastola et al., 2020)
4.	<i>Piper amalago</i> extract	2,000 mg L ⁻¹	(Aynalem, 2018)
5.	<i>Quassia amara</i> extract 75%	-	(Hogea, 2020)
6.	<i>Eucalyptus globulus</i> extract	-	(Sanda et al., 2018)

Biological method

Biological control is a significant part of the incorporated administration of *T. absoluta*. A few specialists detailed a reduction in

populaces of *T. absoluta* identified with an expansion in predator populaces when moderate natural controls are applied (Wakil et al., 2018). The regular adversaries are for the most

part generalist feeders and are being sharp in utilizing *Tuta* as a food source (Godfrey et al., 2018).

Organic control can be accomplished with the accompanying items: Laser 240 SC, Bactospeine DF, Oleorgan, Quamar, and delivering parasitoids and hunters (Hogea, 2020). The introduction of predators, parasitoids, or entomopathogenic organisms gives a great extent to control the pest in a short duration but the rearing of those agents in the laboratory requires sharp skills and high capital which have reduced the chances of applicability in the regular fields.

Predators

A few analysts have discovered more noteworthy adequacy of predators as natural foes to decrease the number of inhabitants in *T. absoluta* in both open-field homesteads, and nurseries (Huda et al., 2020). The few ruthless species, particularly from the order Hemiptera, having a place with the families Miridae,

Anthocoridae and Nabidae, for instance, *Dicyphus errans*, *D. bolivari*, *Macrolophus pygmaeus*, *Nesidiocoris tenuis*, and *Nabis pseudoferus* has been assessed as normal foes of the *T. absoluta* (Hogea, 2020; Lahiri & Orr, 2018; Wakil et al., 2018) (Table 4). Notwithstanding, *N. tenuis* has been displayed as a widespread and successful predator against this vermin as it can devour more eggs at higher nuisance densities (Hogea, 2020; Huda et al., 2020). Adult predators feed on the egg lying on the leaves. They were able to reduce 75%-90% loss created by the Tomato leaf miner (Sanda et al., 2018). Other recognized predators of *T. absoluta* are *D. maroccanus*, *Amblyseius swirskii*, and *Amblyseius cucumeris* who show profoundly encouraging outcomes and viability of predator use when joined with different techniques in controlling *T. absoluta*; by killing their eggs and hatchlings (Huda et al., 2020; Jac, 2017). Accordingly, the action of those insectivorous insects can manage the pest populaces uniformly through impeding their eggs and larval stages.

Table 4 List of predators with their application rate

S.N.	Predators	Application rate	References
1.	<i>Campyloneuropsis infumatus</i>	-	(Muniappan, 2015)
2.	<i>Nesidiocoris tenuis</i>	1.5–2 adults m ⁻²	(Mansour et al., 2018; Sanda et al., 2018)
3.	<i>Macrolophus pygmaeus</i>	2 adults m ⁻²	(Backer et al., 2014; Sanda et al., 2018)
4.	<i>Macrolophus caliginosus</i>	0.25 adults m ⁻²	(Backer et al., 2014; Mansour et al., 2018)
5.	<i>Mesoglossus pygmaeus</i>	-	(Aynalem, 2018)
6.	<i>Oxyopes lineatus</i>	-	(Rostami et al., 2018)
7.	<i>Protonectarina sylveirae</i>	-	(Wakil et al., 2018)
8.	<i>Dicyphus errans</i>	-	(Lahiri & Orr, 2018)
9.	<i>Dicyphus maroccanus</i>	-	(Jac, 2017)
10.	<i>Vespidae</i> spp.	-	(Muniappan, 2015)
11.	<i>Amblyseius swirskii</i>	-	(Sanda et al., 2018)

Parasitoids

Parasitoids are perhaps the strongest natural control specialists that can be utilized to control the populace development of *T. absoluta* (Huda et al., 2020). Various numbers of species have been found to parasitoid on *T. absoluta*. They have a place with the families Eulophidae, Braconidae, Ichneumonidae, Trichogrammatidae, Encyrtidae, Eupelmidae, Pteromalidae, and Chalcididae (Hogea, 2020; Huda et al., 2020; Wakil et al., 2018). The eggs are parasitized essentially by Trichogramma

spp. wasps including *T. achaeae*, *T. toideabactrae*, *T. nerudai*, *T. pretiosum*, *T. bactrae*, and *T. urquijoi* (Desneux et al., 2010; Hogea, 2020; Huda et al., 2020; Jac, 2017; Lahiri & Orr, 2018; Mansour et al., 2018) (Table 5). Among the larval parasitoids, eulophid parasitoids, particularly to the class Necremnus; *N. tenuis* show high mortality of *T. absoluta* followed by *Bracon nigricans* (Desneux et al., 2010; Hogea, 2020). *T. absoluta* is additionally known to be assaulted by an idiobiont ectoparasitoid species, *Necremnus artynes*, *Necremnus tutae*, and

Bracon sp. with average parasitism rates (Desneux et al., 2010; Huda et al., 2020; Lahiri & Orr, 2018). The optimum release of those

parasitoids can optimally control the larval stages of the pest and thus acts as the base of the organic control criterion.

Table 5. List of parasitoids with their application rate

S.N.	Parasitoids	Application rate	References
1.	<i>Tupiocoris cucurbitaceus</i>	-	(Aynalem, 2018)
2.	<i>Copidosoma desantisi</i>	-	(Muniappan, 2015)
3.	<i>Dineulophus phtorimaeae</i>	-	(Aynalem, 2018)
4.	<i>Goniozuz nigrifemur</i>	-	(Muniappan, 2015)
5.	<i>Pseudapanteles dingus</i>	-	(Aynalem, 2018)
6.	<i>Trichogramma achaeae</i>	75 adults m ⁻²	(Sanda et al., 2018)
7.	<i>Trichogramma evanescens</i>	70–75 adults m ⁻²	(Alsaedi et al., 2017)
8.	<i>Trichogramma cacoeciae</i>	25 adults m ⁻²	(Aynalem, 2018; Mansour et al., 2018)
9.	<i>Trichogramma embryophagum</i>	-	(Alsaedi et al., 2017)
10.	<i>Trichogramma bourarachae</i>	50 adults m ⁻²	(Mansour et al., 2018)

Entomopathogens

The utilization of microbial specialists would be an ideal choice to keep away from issues like ecological dangers and pesticide obstruction. The larvae and adults are more vulnerable to assault by entomopathogenic as contrasted with the eggs and pupae (Abdel-baky et al., 2021).

Entomopathogenic bacteria

Tuta absoluta except for *Bacillus thuringiensis* var. *kurstaki* has been demonstrated both as in fact practical and financially effective pest control methodology in the primary field. Bt and *Bacillus subtilis* are suggested as extremely compelling bio-insecticidal sprays in solanaceous harvests since they are profoundly deleterious to the larva of *T. absoluta* (Bastola et al., 2020; Desneux et al., 2010; Huda et al., 2020; Jac, 2017; Lahiri & Orr, 2018) (Table 6). The entomopathogenic bacteria can be the suitable choice for controlling the pest throughout the world because of its wide spectrum of utility.

Entomopathogenic fungi

Among biological control methods, entomopathogenic parasites have been found con-

ceivably extremely impressive for their successful use against *T. absoluta* (Abdel-baky et al., 2021). As of now, *Metarhizium anisopliae*, *Beauveria bassiana*, *Aspergillus flavus*, and *Fusarium* sp. are viewed as the most outstanding entomopathogenic growths utilized broadly against pest contagions and are the most mainstream and regularly discovered species created as bio-pesticides against *T. absoluta* eggs and larvae (Abdel-baky et al., 2021; Huda et al., 2020; Lahiri & Orr, 2018; Vega, 2018) (Table 6). The entomopathogenic fungi are significantly appropriate for the wise management of the initial metamorphological stages i.e., egg and larvae stage.

Entomopathogenic nematodes

The successful entomopathogenic nematodes applied against *T. absoluta* are *Steinernema carpocapsae*, *Steinernema feltiae*, and *Heterorhabditis bacteriophora* that are fit for tainting late larval instars of *T. absoluta*. Among them, *S. feltiae* shows the best outcomes against this vermin. These entomopathogens assault *T. absoluta* larvae, pupae, and adults that stay stowed away within displays in leaves (Huda et al., 2020; Jac, 2017; Lahiri & Orr, 2018).

Table 6 List of entomopathogenic organisms with their application rate

S.N.	Entomopathogenic organisms	Application rate	References
1.	<i>Beauveria bassiana</i>	8×10^5 conidia ml ⁻¹	(Abdel-baky et al., 2021)
2.	<i>Heterorhabditis bacteriophora</i>	-	(Jac, 2017)
3.	<i>Phthorimaea operculella</i> granulovirus (PhopGV)	1.4×10^5 occlusion body ml ⁻¹	(Mansour et al., 2018)
4.	<i>Bacillus thuringiensis</i> var. <i>kurstaki</i>	2 g L ⁻¹	(Mansour et al., 2018; Sanda et al., 2018)
5.	<i>Metarhizium anisopliae</i>	1.0×10^5 conidia ml ⁻¹	(Abdel-baky et al., 2021)
6.	<i>Steinernema carpocapsae</i>	-	(Jac, 2017)
7.	<i>Steinernema feltiae</i>	-	(Jac, 2017)

Biotechnical method

Genetic control using RNA interference (RNAi)

RNA interference (RNAi) leads to posttranscriptional gene silencing directed by the presence of double-stranded RNA (dsRNA) molecules (El-Shafie, 2020). RNA technology has been an effective method to control the pest population. But efficiency can greatly vary from insect order. This new technology promise to control pest by interfering with RNA transcripts using RNAi which may lead to the total death of the pests (Han et al., 2019; Sanda et al., 2018). It has been shown that the larvae of the *T. absoluta* species that fed on leaves containing dsRNA of the targeted gene had a significantly lower accumulation, 60% of the target gene transcript, and increased mortality of larva result in less damage of crop. The generation of the transgenic substance produces a hairpin sequence for both transcripts, which helps to reduce the foliar damage caused by *T. absoluta* (Aynalem, 2018; Sanda et al., 2018). The incorporation of those lethal genes in the genome of the pest causes deaths of the pest and further those genes are mandatorily transferred to the successive generation causing a progressive control over the pest species.

Inherited sterility techniques

Inherited sterility techniques are commonly practiced techniques to control the pest population. It does not show any effect on the environment and is a very successful technique to control invasive pests (Aynalem, 2018). In this technique, radiation sterilized male pests are released into the wild population to control the reproduction while mating with female pests. Initially, for the sterilization of male

pests, γ -radiation with highly radioactive material was used but nowadays X-irradiators are used for sterilization of insect pests (Aynalem, 2018; Huda et al., 2020; Mansour et al., 2018). Normally, the irradiated male insect is mixed into the natural population and mate with an untreated female to produce abnormal offspring (Aynalem, 2018; Han et al., 2019). Similarly, when wild fertile females are mated with partially sterile males, abnormalities induced by radiation are inherited to another generation leading to several generations. Egg hatching is reduced to an extreme extent and thus produced offspring are sterile. An increase in doses of radiation leads to produce malformed offspring (Aynalem, 2018; Mansour et al., 2018). Thus, this method of sterility can be successfully adapted as it does not harm any pest management system.

Development of host resistance variety

Selecting varieties that are impervious to insect pests is quite possibly the main administration rehearses that assist to shield the plants from pervasion. As of late, reproducing programs for the advancement of insect-resistant varieties are acquiring consideration in many parts of the world for effective pest control strategies. Generally, wild relatives of genus *S.* i.e., *S. Arcanum*, *S. chilense*, *S. corneliomulleri*, *S. lycopersicum*, and *S. pennellii* contain registrant qualities for *T. absoluta*. The alleles of those wild varieties can be fused into famous developed species to create crop assortments with alleles connected with obstruction (Huda et al., 2020; Mansour et al., 2018). Allele-chemicals such as (acyl-sugars, zingiberene, and 2-tridecanone) have been included during

the development of the resistance to *T. absoluta*. The rate of oviposition of *T. absoluta* was found to be low as compared to the non-resistance variety. The presence of high concentrations of 2-TD, ZGB, and AA in the resistant tomato cultivars helps to reduce the oviposition rate (Aynalem, 2018; Han et al., 2019). Further, through the application of nano-genomics-based technology, the zinc nanoparticles or Titanium dioxide nanoparticles can be incorporated in the genome of indigenous variety to develop the foremost hybrid species with the higher production and pest resistance ability (Katel et al., 2021). At present, there have been goliath and various quantities of nanomaterials created for repayment of a combination of degradations, including aromatic compounds, natural pesticides, organochlorines, organophosphates, and natural mixtures. Because of its excellent properties, its application has no disadvantage and is also used in the design and farming fields (Yadav et al., 2022). The utilization of modern innovative techniques can generate effective control over the insect pest species. The produced enhanced varieties of crops can tolerate surplus resist the pest attacks.

Chemical method

Focusing on the results of pesticides on natural foes, particularly ruthless predators, since they are natural adversaries of *T. absoluta* (Jac, 2017; Munyua & Bream, 2017). The fundamental technique for controlling this nuisance is the utilization of synthetics. Notwithstanding, the significant piece of the nuisance's life cycle passes inside the host plant's tissues, which makes its synthetic control troublesome, and because of the rehashed exposure of chemical insecticides, the pest has created protection from many pesticides (Abdel-baky et al., 2021; Hoge, 2020; Moeini-naghade et al., 2020). Infection generally occurs at the early stage of plant growth attacking different plant parts (leaf, stem, bud, flower, fruit) which make it difficult in identifying the pest. Similarly, tomato

plants have different morphology and architecture which protect feeding larvae from insecticides and pesticides (Dlamini, 2020; El-Shafie, 2020). Insecticides of various classes and compositions are used to control the pest (Table 7). Initially, pesticides that contain Organophosphates had been used but now they have been replaced by pyrethroids. During the early 1980s, Cartap which was alternated with pyrethroids and thiocyclam was rapidly used to control the pest and was highly effective too. Later on, insecticides such as spinosad, abamectin, tebufenozide, and chlorfenapyr were used in controlling the pest during the 1990s. Excessive and uncontrolled use of these pesticides aggravates resistance problems over abamectin, cartap, methamidophos, and permethrin (Victor & Mwangi, 2019). Current investigations show that *T. absoluta* is impervious to the wide scope of pesticides including chlorantraniliprole, abamectin, deltamethrin, methamidophos, permethrin, cartap in Argentina, Brazil, South Africa, and Chile (Alsaedi et al., 2017; Hoge, 2020; Jac, 2017) (Table 7). However, some pesticides are as yet viable against *T. absoluta* including Chlorantraniliprole, Emamectin benzoate, Imidachloprid, spinosad, indoxacarb, spinetoram, Novaluron, flubendiamide, dichlorovus (Bastola et al., 2020; Huda et al., 2020; Khani et al., 2020; Wakil et al., 2018). Among which Spinosad and Chlorantraniliprole are best on second instar hatchlings and eggs of *T. absoluta* followed by indoxacarb (Khani et al., 2020; Moeini-naghade et al., 2020). Further, the eight dynamic substance formulations chlorantraniliprole, chlorfenapyr, blended in with indoxacarb, spinosad, blended in with abamectin, emamectin benzoate, and imidacloprid give the most encouraging control results above 90% mortality against *T. absoluta* larvae happening in crops (Gozel et al., 2020; Jac, 2017; Mansour et al., 2018). Thusly, the chemicals applied to the crops might be substantially harmful but it gives effective and efficient control over the pests in a brief time.

Table 7 List of chemical pesticides with their application rate

S.N.	Chemical Compounds	Application rate	References
1.	Spinosad 45% SC	0.3 ml L ⁻¹	(Bastola et al., 2020; Hoge, 2020)
2.	Triflumuron	50 cc hl ⁻¹	(Mansour et al., 2018)
3.	Emamectin benzoate 5% SC	2 gm L ⁻¹	(Oztemiz, 2014)
4.	Indoxacarb 15 SC	10.8 mg ai L ⁻¹	(Moeini-naghade et al., 2020)
5.	Imidachloprid 17.8 % SL	0.3ml L ⁻¹	(Bastola et al., 2020)
6.	Chlorantraniliprole 18.5% SC	0.3 ml L ⁻¹	(Oztemiz, 2014)
7.	Zeta-cypermethrin	232 mg ai L ⁻¹	(Khani et al., 2020)
8.	Diafenthiuron	125 cc hl ⁻¹	(Mansour et al., 2018)
9.	Lufenuron 50 g L ⁻¹ EC	0.5ml L ⁻¹	(Oztemiz, 2014)
10.	Abamectin 0.15% EC	0.3ml L ⁻¹	(Khani et al., 2020)
11.	Flubendiamid	30 g hl ⁻¹	(Mansour et al., 2018)
12.	Cyromazin	30 g hl ⁻¹	(Mansour et al., 2018)

Integrated pest management (IPM) strategies

The IPM is an effective and eco-accommodating sensitive methodology for the control of pests that relies upon mixes of all accessible vermin control strategies. The integration of physical, cultural, mechanical, biological, botanical, and development of *T. absoluta* obstruction assortments can create a successful IPM. The mix of these vermin control techniques with one another with fitting utilization of enlisted insect sprays that are less dangerous to the environment could be viable for controlling *T. absoluta* without hampering the agro-environments (El-Shafie, 2020; Huda et al., 2020; Jac, 2017; Sanda et al., 2018). Additionally, various IPM modules should be enlisted and followed for the systematic control of this pest by the concerned authorities.

Future research prospective on *T. absoluta*

The Solanaceae crops are the major green harvests produced throughout the world. The intrusion of this pest prompted the decline of crops production. The above-mentioned control and management practices don't ensure to diminish the pest, and might be costly and probably won't be in promptly accessible structure. Along these lines, there is a need for methodical, reasonable, and better IPM methodologies that can control this adverse pest. In a nutshell, chemical pesticides are expensive and cause superficial degradation in the environment. However, the farmers adhere to applying

them in their fields since they are effectively accessible in the Agri shops. Yet, plant-based pesticides ought to be pushed to utilize since they are biodegradable & naturally available in the environment, and are inexpensive. Moreover, the pheromone traps might be an effective pest-killing mechanical practice, but they cannot be taken as the management practices, though they are significantly pertinent for early detection of the pest. Likewise, there are comparatively fewer studies that can support the efficacy of pheromone traps for *T. absoluta*. Further, the application of entomopathogenic organisms can be an effective way to control this pest. But these management practices are not implemented in traditional low scale farmers' fields as of recently. Through entomopathogenic fungi and bacteria such as *Metarhizium anisopliae* and *Bacillus subtilis* are being applied every so often periodically. They are tedious strategies and do not completely control the pest. Thus, they are being failed to be utilized. Essentially, the parasitoids have not been used in the farmer's fields until now. Though there is advancement in the biotechnical cosmos, the development of resistant and tolerant varieties has not been developed. Thusly, there is an earnest need to recognize and create legitimate parasitoids and hybrid varieties. There is an immense need for the introduction of IPM strategies modules after deliberate research and studies for the development of feasible and reasonable administration practices to control *T. ab-*

soluta based on plant-based pesticides, profoundly found native entomopathogenic microbes, predators, parasitoids, and mechanical tools to provide an effective, efficient, and affordable solution to low scale farmers for boosting their crop production and economy.

Conclusion

Being an invasive pest, *T. absoluta* has produced a significant threat to Tomato crops. They are highly devastating and cause a massive reduction in yield. Since it lives and feeds inside the mines of leaves, stems, and tomato fruit creating a tunnel, it is very difficult to manage at an early stage. The chemical controls method may not be successful even at the early stage due to the residual pest inside the mines. *T. absoluta* has also developed resistance to some of the chemical pesticides which lead to very difficult handling of the pest population. Similarly, various biological agents, predators, and parasitoids can be used to control the pest population at the early stage of pest attack. This will help to reduce the damage of crops up to a huge extent. Being highly potential for reproduction, this pest can extend its population at a rapid rate under favorable environmental conditions. One of the best management strategies adapted is the use of biopesticides and biological agents to control the pest population. This will not breach any principle of Integrated pest management and is safe for humans as well as the environment. Many studies have shown that adopting this method of pest control leads to an 80% of reduction of pests. The proper advancement and adaptation of modern technologies could be helpful in the management of *T. absoluta*. For the effective management of *T. absoluta*, monitoring, cultural and physical, biological, botanical, chemical pesticides should be integrated to form a efficient and effective IPM modules that can check it. Significantly, the main basis for drafting this article is to illustrate the lifecycle, hosts, damages and possible management tactics.

Author's declaration

The authors declare no irreconcilable circumstances. All authors contributed equally in all phases of the preparation of this manuscript.

Likewise, the final version of the manuscript was approved by all authors.

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