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Review Article

Empirical Review of *Tuta absoluta* Meyrick Effect on the Tomato Production and Their Protection Attempts

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The tomato is one of the most nutritious, economically important, and delicate vegetables grown in the world. It is highly susceptible to insect pests and microbial pathogens. The tomato leafminer moth, *Tuta absoluta* Meyrick, is the current impediment to tomato production in the world. The insect showed invasive and notorious behavior and was affecting tomato production. To control this insect, the application of synthetic insecticides is seen as the primary solution. However, during the feeding stage, larvae hide within mined leaf mesophyll and bored fruits from chemical spray, besides fast developing resistance to several insecticides. Such characteristics of the insect reduced the effectiveness of the chemical control efforts. Currently, the natural, or ecofriendly pest control method is gaining the momentum to minimize the application of synthetic insecticide against this devastating insect. Studies showed that botanical extracts (phytochemicals) and natural enemies such as parasitoids, predators, entomopathogenic nematodes, entomopathogenic fungi, and entomopathogenic bacteria are effective for controlling *T. absoluta*. As a result, the basic attributes of the above-mentioned natural agents and their potential to control *T. absoluta* have been briefly discussed in this review. However, due to disease (pests), the expected outcome for the subsectors is still low. Therefore, the pinpointing of major diseases and pests and their control measures would help to significantly improve the crop production technology used by smallholder farmers and thereby sustainably improve tomato production in Ethiopia.

1. Introduction

The tomato (*Solanum lycopersicum* L.) is the second most important vegetable, next to potatoes, grown in the world [1]. It is an herbaceous plant in the genus *Solanum* and family *Solanaceae* with erect or prostrate growth habits [2]. It originated from the wild ancestor (wild cherry tomato, *S. lycopersicum* var. *cerasiforme*), which is native to western Latin America along the coast of Central Ecuador, Peru, Northern Chile, and Galapagos Island [3]. Its distribution is extended into Mexico, Colombia, Bolivia, and other Latin and North American, European, and African countries [4].

Tomato is rich in vitamins, minerals, and antioxidant components,and is highly commercialized in local and export markets. In 2019, it was estimated that tomato production covered around 5.03 million hectares of farmlands with 1.8 billion metric tons of annual production worldwide [5]. Asia shares 54.1% of tomato production, followed by America (17.7%), Europe (15.9%), and Africa, which contributes 11.9% of global tomato production [5]. Melomey et al. [6] indicated that China, India, Turkey, the USA, and Egypt are the leading countries in tomato production in the world.

In Africa, 51% of tomato was produced in mid-altitude countries [7], of which, Egypt, Nigeria, Algeria, Morocco, Tunisia, and Cameroon produced 6.8 (41.8%), 3.8 (23.4%), 1.5 (9.2%), 1.3 (8%), 1.3 (8%) and 1.2 (7.4%) million metric tons of tomato per year; however, Ethiopia produced only 34, 947 (2.2%) metric tons, which is far below the average of major tomato producing countries in Africa [5] even if the agroecology of the country is suitable for tomato production and productivity.

Although tomato production is increasing over time, several biotic and abiotic factors are becoming the major constraints. The most important biotic constraints are insect pests, microbial diseases, and nematode infections, which cause a direct and indirect impact on tomato production. Especially, the insect pest, *T. absoluta* has been highly affecting tomato production in the world and causes 80–100% of crop loses [8]. In Africa, the estimation taken from twelve sub-Saharan countries showed 1.05 million metric tons of tomatoes were damaged by *T. absoluta* from the total of 3.64 million metric tons of production annually [9]. This could have resulted in estimated economic loses of US$ 791.5 million. In Kenya, which is the most proximate country to Ethiopia, has lost 114,000 metric tons of tomato production by *T. absoluta* with US$ 59.3 million in annual economic damage [9]. These days, the devastation of *T. absoluta* in Ethiopia has been reaching throughout the country; however, there is a dearth of information on the status of economic damage.

Thus, to overcome this problem, producers are highly reliant on the excessive use of synthetic pesticides to control *T. absoluta* [10]. To that end, farmers are continuously using large volumes of insecticides on their tomato farm [11], and chemical residues are contaminating the crop (tomato), affecting human health, the environment, and biodiversity [12, 13]. The overriding problems associated with excessive use of chemical pesticides necessitate prudent management options to reduce chemicals and supplement integrated pest management (IPM) with good horticultural practices [14]. Therefore, different attempts have been made to evaluate the effectiveness of natural enemies to manage *T. absoluta* [15–19]. This review is aimed at discussing the effectiveness of chemical insecticides, botanicals, and natural enemies such as parasitoids, predators, bacterial, fungal, and nematode entomopathogens against *T. absoluta*.

2. Insect Pests in Tomato Production

Insects are the most severe impediments to tomato production due to direct physical damage and act as indirect facilitators for the entry of other infectious pathogens like viruses, bacteria, fungi, and nematodes. Hofmaster [20] earlier identified nineteen arthropod pest species attacking tomatoes from different agro-ecologies in Eastern Virginia, of which lepidopteran insects, thrips, and stink bugs are the most serious groups that undermine tomato production.

Lepidopteran insects are the most diversified taxa, containing about 160,000 described species of butterflies and moths in 47 superfamilies [21]. Both larval and adult stages are associated with vascular plants, and most larvae feed on plant materials using biting and chewing mouthparts [22]. Lepidopteran insects therefore easily injure tomatoes, reduce fruit marketability, and cause low production [23].

Different species of lepidopteran insects challenge tomato production in Ethiopia. The most important ones are tomato leafminer (*Tuta absoluta*), potato tuber moth (*Phthorimaea operculella*), and African bollworm (*Helicoverpa armigera)* [24, 25]. Shiberu and Getu [25] reiterated that the newly introduced insect, *T. absoluta,* is becoming a serious threat for tomato production in Ethiopia and has alarmingly increased in covering the large tomato-producing areas of the country.

2.1. Occurrence and Distribution. The tomato leafminer, *T. absoluta* Meyrick 1917 (Lepidoptera: Gelechiidae), was discovered in Latin America, Peru, in 1917 [26] and recognized as a severe pest for 50 years on the continent [27]. At present, it is spreading throughout Latin America, the Mediterranean coastal area of Europe, Asia, India, China, Australia, New Zealand, the Russian Federation, the United States, and almost all countries in Africa [17].

Its distribution is extremely fast, and the insect spreads together with vegetable and fruit trade, farm equipment, and with the help of wind blow [28]. Ecological and environmental conditions like temperature and humidity do not limit the adaptation of *T. absoluta* in the new areas [29]. Therefore, the insect shows an invasive nature in its spread and occupies areas where wild and cultivated solanaceous plants are found worldwide.

The tomato leafminer, *T. absoluta* Meyrick, is a fast-reproducing lepidopteran moth that completes its life cycle within 30 to 35 days [30] (Figure 1). A female moth lays a maximum of 250 up to 300 eggs in dispersed forms at both the underside and upper side of the plant leaves preferably at apical shoots, stems, and sepals [31].

Egg hatching takes a short period, at least four to six days of incubation, and develops into four consecutive stages of larval instars [32]. The larvae feed on any stage of tomato plants, mainly apical buds, leaves, stems, and fruits, and cause maximum (100%) yield loses (Figure 2). They then develop into the dormant pupal stage, either in the soil, within mined leaves or within the galleries of the plant by forming small silky cocoons [33]. After pupation, the pupa develops into an adult, and the adults can survive for 10 to 15 days for females and 6 to 7 days for males. In general, *T. absoluta* can achieve, on average, twelve generations per year.

2.2. Host Range of the Tuta absoluta. Tomato (*S. lycopersicum* L.) is the primary host for *T. absoluta* while, the insect can feed on other wild and cultivated solanaceous plants, including eggplant (*Solanum melongena* L.), potato (*Solanum tuberosum* L.), pepper (*Capsicum annuum* L.), tobacco (*Nicotiana tabacum* L.), and black nightshade (*Solanum nigrum* L) plants [34].

Therefore, *T. absoluta* is an important threat for tomato production with high yield loses (100%) if it is not controlled [35]. It causes high quality and yield loses in the crop worldwide due to direct feeding, and the wounds made by this insect facilitate the entry of secondary plant pathogens [36]. Mainly the tomato cultivars that produce a volatile compound called "terpenoid" attract mated females of *T. absoluta* for oviposition [37]. However, *T. absoluta* cannot prefer the tomato cultivars rich in 2-tridecane or zingiberene because the chemicals confer resistance against beet armyworm. Plants with the absence or less content of herbivore repellent compound are preferred by *T. absoluta* to lay their eggs [38].

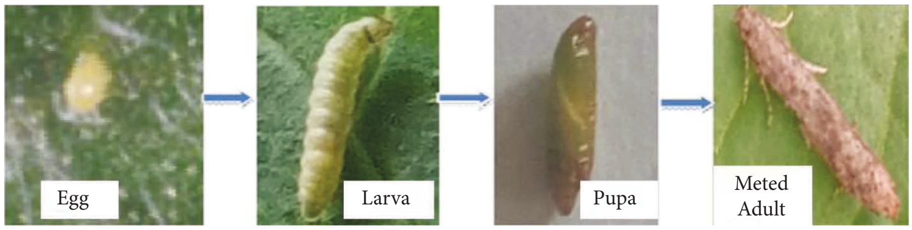

Figure 1: Reproduction process and developmental stage of the *Tuta absoluta*.

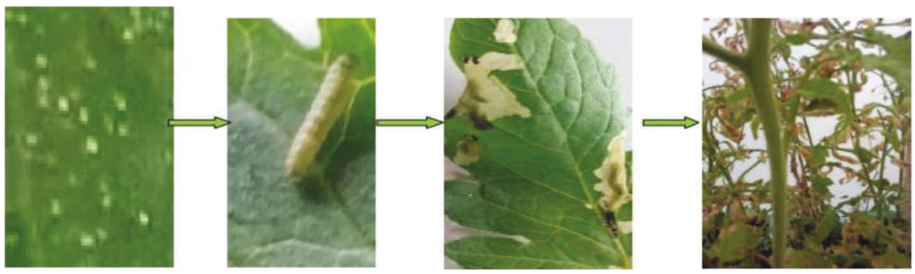

Figure 2: Feeding style and damage status of the tomato leafminer, *Tuta absoluta*.

3. Disease (Pest) Control

3.1. Use of Synthetic Insecticides. Insecticides are the most important inputs used to control pests and boost crop production both in large- and small-scale agricultural systems. However, the misuse and abuse of these pesticides impose health hazards on humans and pollute the environment. Improper and illegal use of insecticides on edible crops exposes humans to consumption of residually accumulated chemicals together with fruits, vegetables, and leafy green crops and aggravates the bioaccumulation effect that results in noncommunicable and systemic diseases [39].

The continuous application of insecticides on farmland brings about complicated problems for the biodiversity of the terrestrial and aquatic environment. Organisms found in the soil and aquatic environment are beneficially valued components to balance and maintain the natural ecosystem [40]. However, extensive use of insecticide has an influence on the abundance and species richness of domestic and wild organisms found in the soil and water bodies [41]. Excessive use of insecticides rendered consistent negative effects on biodiversity and reduces the biological control potential of the natural enemies by influencing their survival [42].

Insecticides are the common tools to control *T. absoluta* and other pests in modern and conventional agricultural sectors around the world. Some of them, such as cartap, methamidophos, permethrin, fi;ubendiamide, diamides, abamectin, deltamethrin, organophosphates, and pyrethroid, are frequently used to control *T. absoluta* [43]. The effectiveness of these insecticides varies in terms of larval mortality, ranging between 13.7 and 66% in laboratory and 18 to 25.7% in greenhouse conditions [44].

It was established that the use of certain insecticides could control *T. absoluta*. However, repeated applications of the insecticides over 30 times per cultivation period with four and six weekly sprays [45] increased residual chemicals and caused food contamination, environmental pollution, and human health problems, as well as reducing the number of natural enemies involved to control *T. absoluta* [46]. This could be due to the fact at their most damaging stage, the larvae of the insect hide itself inside the mesophyll tissues of the plant, which cannot be easily exposed to chemical spray [47].

Apart from that, continuous use of insecticides reduces their effectiveness due to the resistance of the insect [48]. To this end, insecticide-resistant populations of *T. absoluta* were reported in Brazil [49], in Chile [50], in *Argentina* [51], and in Italy [52]. The resistance level to insecticides defers from population to population [53], weather conditions, and the exposure rate of generations to the insecticides in question [54].

The resistance folds of *T. absoluta* against several insecticides are indicated in parenthesis: abamectin (5.2–9.4 folds), cartap (5.1–21.9), methamidophos (1.04–4.2), permethrin (1.5–6.6) in Brazil [43], chlorantraniliprole (0.2–2.4), fi;ubendiamide (1.2–1.7) in Italy [52], deltamethrin (1.2–2.34), Indoxacarb (13.6–27.3), spinosad (1.14–8.9), bifenthrin (1.7–11.4), difi;ubenzuron (0.92–2.3), trifi;umuron (1.22–3.19), and tefi;ubenzuron (1.3–1.88) in Brazil [49].

3.2. Use of Botanicals. Botanicals are bioactive compounds extracted from several potent plants and herbals used to control pests in organic farming with less expense to human health and the environment. Compounds extracted from plants are more readily biodegradable and less likely toxic to be nontarget organisms [55]. The herbicidal, insecticidal, fungicidal, bactericidal, nematicidal, molluscidal, and rodenticidal properties of botanicals are well described with various modes of action [55].

Rajashekar et al. [56] reviewed a number of the most important plant species and their parts used to extract active compounds for different pest control methods. Bioactive compounds such as essential oils, flavonoids, alkaloids, glycosides, esters, phenols, and fatty acids have repellent, antifeedant, toxicant, growth retardant, chemosterilant, oviposition inhibitant, ovicidal, and larvicidal properties against several agricultural pests [57].

Therefore, bioactive compounds in botanicals are serving to control *T. absoluta* in different developmental stages. Ethanol-extracted Neem (*Azadirachta indica*) and petroleum ether-extracted Jatropha (*Jatropha curcus*) seeds caused 24.5 and 18–25% egg and 86.7–100% and 87–100% larval mortality, respectively [58]. Crud extracts of jojoba (*Simmondsia chinsis*) seed, Garden thyme (*Thymus vulgaris*), and *Castor* bean (*Ricinus communis*) oil caused 75, 95, and 58% of larval mortality, respectively [59]. Moreover, aqueous extracts of Chinaberry (*Melia azedarach*), *Geranium* (*Pelargonium zonale*), Garlic (*Allium sativum*), Onion (*Allium cepa*), and Basil (*Ocimum basilicum*), effected 91, 87, 85, 80, and 74% of mortality against 2nd instar larvae of *T. absoluta*, respectively [60]. Aqueous extracts of *A. indica* seed, *Cymbopogon citrates*, and *A. sativum* evaluated in Ethiopia scored 98, 97, and 95% of larval mortality against *T. absoluta* [61]. However, the types of solvents used, concentrations of extracts, application timing, and exposure time can determine the effectiveness of the phytochemicals.

3.3. Natural Enemies. Natural enemies are living organisms that include parasitoids, predators, beneficial nematodes, and entomopathogenic microbes used to reduce or suppress the pest population below the economic threshold level [62]. Natural enemies are parts of biological control and have no identified side effects on nontarget plants, animals, humans, and the environment [63]. They can be generalists (that infect or attack hosts or prey from different genera or species of pests indiscriminately) and specialists (that attack host or prey from specific genera or species of pests selectively) [64]. Their safeness to environment, biodiversity, ecosystem, and cost-effectiveness asserts to promote natural enemies in advances [65].

3.3.1. Use of Parasitoids. Parasitoids are parasitic insects during their early developmental stage and later kill and destroy their host to live as free adults [66]. Parasitoids encompass insect species in five main orders such as hymenopetera, diptera, coleoptera, lepidopetra, and neuropetra [67]. Although parasitoids are abundant in every ecosystem in terms of species and number of individuals, 78% of species are found under the order hymenopetera [68]. Parasitoids are either endoparasitoid (species that feed and develop within the host) or ectoparasitoid (species that feed and develop on external parts of their host) and parasitize eggs, larvae, pupa, adults, and combinations of their host developmental stages. Depending on the species, an adult female parasitoid would search their host, lay eggs inside or onside of the host, and hatched eggs develop into larvae [69]. Then, larvae start to feed on their host and kill the host through parasitism, form cocoons to become shelled pupae, and develop into adults. Adult parasitoids find their host through smell, either the direct odor of the host or associated odors of their host's activities [70]. Therefore, parasitoids are the most important natural enemies utilized to manage agricultural pests from several genera and species worldwide [71].

Reports showed more than 50 species of parasitoids effective against *T. absoluta* that infect eggs, larvae, and pupae [72]. Out of these, *Trichogrammatoidea bactrae*, *Trichogramma pretiosum,* and *Encarsia porteri* infect eggs [73], and *Pseudapanteles dingus*, *Dineulophus phtorimaeae*, *Necremnus* sp. nr *artynes,* and *Bracon* sp. infect the larvae of *T. absoluta* [74]. Mainly, *P. dingus* reduced the population of *T. absoluta* by 64%, whereas *T. pretiosum* and *E. porteri* were reduced by 50% during tomato production [75].

3.3.2. Use of Predators. Predators are organisms that kill and consume several preys during their lives, and can be predacious when immature [66]. Predators have a relatively large body size (larger than their prey), enhanced sensory perception (vision, hearing, olfactory, touch, etc.), enhanced weaponry or predatory behavior (have enlarged jaws, beaks, and teeth to kill their prey immediately), active prey searching ability (active foraging), and need a stable ecological system to maintain their abundance lower than their prey [76]. Ants, certain bugs, beetles, spiders, mice, armadillos, birds, and several large animals are common groups of predators in the ecosystem [77]. Mostly, predatory insects, birds, and relatives are used for pest management in agriculture through pest consumption to reduce pests below the economic threshold level in organic farming systems [78]. There are some predators that prey on *T. absoluta* in different developmental stages. *Nesidiocoris tenuis* and *Mesoglossus pygmaeus* efficiently prey eggs of the insect and reduce fruit infestation by 56–100% and leaflet infestations to 75–97%, respectively [79].

3.3.3. Use of Entomopathogenic Nematodes. Entomopathogenic nematodes (EPN) are cosmopolitan, nonsegmented, cylindrical, and elongated organisms that have a great role in biological control [80]. Nematode species under 23 families are described as parasitic association-forming organisms with insects; out of these, seven families: *Mermithidae* and *Tetradonematidae* (Order: Stichosomida); *Allantonematidae*, *Phaenopsitylenchidae*, and *Sphaerulariidae* (Order: Tylenchida); and *Heterorhabditidae* and *Steinernematidae* (Order: Rhabditida) encompass the most potential species for insect pest control [81].

Thus, EPNs are important to control *T. absoluta* mostly at the larval stage (79 to 100% mortality) and are less effective in the pupal stage (10% mortality) [82]. Leaflet bioassay showed 77–92% larval infection of nematodes inside the galleries, as well as pot experiment showed 87–95% reduction of tomato infestation [82]. Two effective species of nematodes, *Heterorhabditis bacteriophora* and *Steinemematidae carpocasae,* caused 92–96% and 89–91% of larval mortality in the laboratory, and both species showed 48–51% of *T.* control of *absoluta* in greenhouse conditions [83]. *H. bacteriophora, S. carpocapsae,* and *S. feltiae* performed better in terms of mortality (77–97.4%) against *T. absoluta* at the 4th instar larvae than at the 1st instar larvae (36.8–60%) mortality [84].

3.3.4. Use of Entomopathogenic Fungi. Entomopathogenic fungi (EPF) are phylogenetically diversified, heterotrophic, and eukaryotic filamentous microorganisms that reproduce by sexual or asexual spores or both [85]. The majority of EPF, such as *Beauveria bassiana, Metarhizium anisopliae, Metarhizium acridum, Metarhizium brunneum, Isaria fumosorosea, Hirsutella thompsonii, and Lecanicillium lecanii*, are grouped under the phylum Ascomyceta [14]. They are pathogenic to different genera of insects and cause muscardine disease with broad host ranges with minimal environmental effect, human health problem, and insect resistance [86]. Although their effectiveness depends on ecological conditions, *B. bassiana* and *M. anisopliae* are the most widely studied and commercialized fungal species. These EPF showed high larval mortality against several agriculturally important insect pests.

EPF infection begins with spore attachment, followed by spore germination, and then blastospore cuticle penetration. The mechanical pressure and enzymatic degradation allow the assistance for cuticle penetration of mycelia and entry into the insect body. After successful penetration of the cuticle, the fungus produces hyphal bodies that slowly spread into the hemocel and result in the death of the host insect through toxification and food competition [85]. *B. bassiana* and *M. anisopliae* have highly effective modes of action to kill their insect hosts. Their success will be due to large amounts of exoskeleton-degrading enzyme production and degradation of different structural components of the insect exoskeleton [87].

Lipase first breaks the fatty acid components of the insect cuticle, followed by a protease that degrades the protein components and plays an important role in providing nutrients for fungus before and after the cuticle is penetrated [88]. Chitinase usually acts after the proteases have significantly digested the cuticle protein and chitin component is exposed [89]. This shows that the virulence of EPF species depends upon the types of enzymes produced.

It is interesting to note that EPF grows over the cadaver of the host insect after death if the condition is relatively humid and they produce new, external, and infective conidia to cause infection on another healthy host. Thus, quick sporulation of EPF over insect cadavers can mediate infection of other individuals from the same species or relatives and favor horizontal dissemination under favorable conditions [90]. However, under very dry conditions, the fungus may persist in the hyphal stage inside the cadaver and not achieve successful horizontal dissemination.

Studies showed that *B. bassiana* can result in more than 95% of larval mortality against *T. absoluta* compared to 88% of death with chemical insecticide [86], and *M. anisopliae* significantly reduced the mean number of infestations to 9.8 as compared to 21.7 of untreated control [91]. It is also established that the effectiveness of the strains against different insect pests differs from locality to locality [92]. For instance, Youssef and Hassan [93] reported fungi species obtained from the local environment, and their formulated products were more effective than commercial ones against *T. absoluta*. Both *B. bassiana* and *M. anisopliae* showed 95–100% mortality for larvae of *T. absoluta* [94–96]. Besides their effective biocontrol potential, entomopathogenic fungi are cosmopolitan in different habitats and geographic conditions that make it easy to screen potent strains for mycoinsecticide production.

3.3.5. Use of Entomopathogenic Bacteria. Entomopathogenic bacteria are prokaryotic microorganism that has pathogenic properties against insects. They are spore-forming bacteria that include the genera *Bacillus*, Paenibacillus, and *Clostridium*, and nonspore-forming ones that belong to the genera of *Pseudomonas*, *Serratia*, *Yersinia*, Photorhabdus, and Xenorhabdus [97].

Bacillus thuringiensis (*Bt*) is a Gram-positive and spore-forming bacterium that produces parasporal crystal proteins called δ-endotoxin, hemotoxin, and vegetative proteins and has been used as a biological insecticide starting from 1950s to control certain insect pests among the order lepidoptera, coleoptera and diptera [98]. The plasmid genes of *Bt* that encode parasporal crystal proteins are a key source for transgenic expression to provide pest resistance in plants [99]. This feature makes *Bt* the most important biopesticide in the world market besides direct control of the pest.

The insecticidal activity of the *Bt* toxin is host specific for each type of *cry* gene encodes structurally specific crystal δ-endotoxins that affix with specific binding sites of the particular membrane receptors [100]. This characteristic is important to minimize the side effects of *Bt* toxins for many nontarget beneficial insects, plants, and animals, including humans [101]. Crickmor et al. [102] estimated the presence of more than 700 crystal protein-coding genes located on large molecular weight plasmids that were sequenced, identified, and classified into 74 groups according to amino acid sequence similarity. These genes were cloned, sequenced, and named as *cry* and *cyt* genes, and more than 100 *cry* gene sequences were organized into 32 groups and different sub-groups based on their nucleotide similarities and range of specificity [103].

The *cry* genes that encode protein toxins for lepidopteran insects are *cry1*, *cry*2, and *cry*9 groups and cause up to 98% of larval mortality against *T. absoluta* [104,105] whereas *cry*3, *cry*7, *cry*8, and *cry1*Ia1 are responsible for the production of protein toxins used against Coleopteran insects [106]. Furthermore, *cry*5, *cry*12, *cry*13, and *cry*14 are genes that encode nematocidal proteins [103], and *cry*4, *cry*10, *cry*11, *cry*16, *cry*17, *cry*19, and *cyt* proteins are toxic to dipteran insects [107]. A given *Bt* strain can carry one or more crystal toxin genes, and therefore, these strains may synthesize one or more crystal proteins. This could be result from a mechanism of horizontal plasmid gene transfer among *Bt* strains to diversify toxin genes [108].

Bt can cause the infection when susceptible insect hosts ingest parasporal crystal proteins that are alkaline-soluble and can produce active insecticidal components in the insect gut of pH 8 to 12 [109]. An activated toxin is then attached to specific receptors found in the midgut epithelial cell membrane and creates ion channels or pores through membrane lyses. These membrane pores or clefts disrupt the osmotic and metabolic processes and the larvae stop feeding and go to death due to starvation.

Therefore, chewing insects in different orders are susceptible to *Bt* insecticidal parasporal crystal toxins [110]. Although δ-endotoxins are playing a vital role in the pathogenicity of the insect pest, certain strains of *Bt* produce extracellular compounds such as phospholipases, *ß*-exotoxins, proteases, and chitinases to kill the host [111]. There are also several strains that produce vegetative insecticidal proteins encoded by *Vip* genes and contribute for virulence increment.

4. Conclusion and Recommendation

This review deduced that the application of synthetic insecticides is less effective in the management of *T. absoluta* due to high pest resistance, health risk, and environmental pollution. However, natural enemies and botanicals are relatively effective alternatives with less expense to human and environmental health. Plant phytochemicals, parasitoids, predators, entomopathogenic nematodes, entomopathogenic fungi, and entomopathogenic bacteria showed high effectiveness in *T. absoluta* management. It is important to note that ecofriendly pest control methods are applicable to manage devastating pest, *T. absoluta,* for healthy tomato production within a safe environment. Adaptation and popularization of the use of bioagents in pest (*T. absoluta*) control have paramount importance in safe food production, environmental protection, and chemical resistant pest reduction. Therefore, inspiring policies in ecofriendly pest management, large-scale production of bioagents and distribution, extensive awareness creation to users, actual practices, and upgrading of the use of natural enemies in the management of *T. absoluta* has been highly suggested.

Abbreviations

EPN: Entomopathogenic nematodes
EPF: Entomopathogenic fungi
Bt: *Bacillus thuringiensis*
cry: Crystal protein toxin coding gene
cyt: *Hemolytic* toxin coding gene
vip: *Vegetative* insecticidal protein-coding gene
IPM: *Integrated* pest management.

Data Availability

All data are included within the manuscript.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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