The new invasive pest *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in India and its natural enemies along with evaluation of Trichogrammatids for its biological control

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The South American tomato moth *Tuta absoluta* (Meyrick) is a devastating pest of tomato. In the present study *Tuta*-adapted strains of *Trichogramma* were evaluated. Amongst the three species, *Trichogramma achaeae* Nagaraja and Nagarkatti, *Trichogramma pretiosum* Riley and *Trichogrammatoidea bactrae* Nagaraja could parasitise *T. absoluta* eggs and the parasitism rates were 5.0%, 51.1% and 68.2% respectively. Adults emerged from the parasitized *T. absoluta* eggs (4.8%, 97.5% and 90.0% adult emergence respectively). The F1 generation adults of *T. pretiosum* could parasitise 29% of *Corcyra cephalonica* Stainton eggs, while the other two species were not successful in parasitizing. In addition, four 'hymenopteran' parasitoids, viz. *T. achaeae*, *Neochrysocharis formosa* (Westwood), *Habrobracon* sp. and *Goniozus* sp. were also observed to be associated with *T. absoluta* in the fields during the surveys undertaken in southern India.

Keywords: Invasive pest, India, natural enemies, *Tuta absoluta*.

TUTA ABSOLUTA (Meyrick) originated from South America; however, the type specimen for *T. absoluta* was collected from the Andean region of Perú. From 2006 to 2015, this pest crossed several borders, devastating tomato production in both protected and open fields in several countries, viz. Spain, France, Italy, Greece, Malta, Morocco, Algeria, Libya, Turkey, Syria, Lebanon, Jordan, Iraq, Iran, Saudi Arabia, Yemen, Oman, Egypt, Sudan, Ethiopia and Senegal. In November 2014, this pest was first detected infesting tomato fields in Pune, Maharashtra and subsequently in other districts, viz. Ahmednagar, Dhule, Jalgaon, Nashik and Satara[1,2]. *Tuta absoluta* has a high reproductive capability and is known to cause damage throughout the entire growth cycle of tomatoes. Our studies indicate that there are 10–12 generations in a year in favourable conditions. Even up to 100% damage has been recorded in different countries. In Karnataka, the pest was first observed in Bengaluru and Kolar areas[3]. If the pest is not curtailed, tomato farmers along with ketchup, sauce and puree industries in our country, will face serious threat.

Extensive surveys were conducted in Karnataka, Tamil Nadu and Gujarat by ICAR-National Bureau of Agricultural Insect Resources (ICAR-NBAIR), Bengaluru from January to March 2015. In Tamil Nadu, fruit damage by *T. absoluta* ranged between 0.5% and 13.5%; in Karnataka 2.0% and 100% and in Gujarat 5% and 12% (Table 1, Figure 1). In Kolar district, slight damage was also recorded on potato leaves. The occurrence of this pest in tomato fields at different growth stages, recorded at varying levels of infestation in four states, indicates that this pest is a great threat to our tomato farmers, right from the nursery stage of the plants till the harvesting stage. Egg, larval and adult stages of the pest could be recorded in the field (Figure 2). The larvae were observed to mine into the apical buds, tender new leaflets, flowers and they bore into the stems and green fruits. The characteristic large galleries caused by the larvae in the leaves, blisters caused by the galleries and the faecal matter within the blisters could be observed in the infested fields. The feeding leads to necrosis and drying of plant parts, and in cases of severe infestation, drying of entire fields. Fruits infested by *T. absoluta* could be identified by presence of characteristic pin holes. The damage generally attracts secondary pathogens leading to fruit rot.

The ICAR-NBAIR laboratory and net house studies indicate that under Bengaluru conditions, the pest can complete its life cycle in 21–23 days. Eggs are cylindrical and creamy white in colour and are laid singly or in small groups (Figure 2 *a*–*c*) on the surface of the leaves, buds, stems and calyx of young fruits. Neonate larva mines the leaf, stem or fruit (Figure 2 *e*). Incubation period is around seven days. Freshly hatched larvae are light yellow to green in colour. As the larvae mature, they turn dark green in colour. The characteristic dark band posterior to the head capsule of the larva help in identifying this pest (Figure 2 *f*). There are four larval instars, and the larval period is completed in eight days. Pupation occurs in a silken cocoon, either in the soil or on the leaf surface, within mines or among plant debris (Figure 2 *g*–*i*). Pupal period lasts for ten days. Adults are silvery brown with black spots on the fore wings (Figure 2 *j*). One female moth is known to lay up to 300 eggs.

The present study highlights potential natural enemies, identified and evaluated for field use to tackle this notorious pest through biological control. The infested plants in tomato fields in Karnataka were examined for presence of indigenous predators. A large population of the mirid bug *Nesidiocoris tenuis* (Reuter) (Figure 3 *a*) (10–30 per plant) was observed to be associated with *T. absoluta* in all the fields. This predator is utilized extensively as a major natural enemy of several insect pests (including *T. absoluta*) on tomato crops, especially in Mediterranean regions[4,5]. This species is zoo-phytophagous and there are stray reports that they can damage tomato plants

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Table 1. Survey on *Tuta* infestation in tomato fields conducted by ICAR–NBAIR (February–March 2015)

State/district	Place	Leaf mine (Blotch) (%)	Fruit damage (%)
Tamil Nadu			
Dharmapuri	Palakodu	3.5–5	Nil
Krishnagiri	Rayakottai, Kelamangalam, Ulimaranapalli, Binnamangalam, Hosur, Soolagiri, Bagalur	1–16.5	0.5–13.5
Coimbatore	Iruttupallam, Alandurai, Thondamuthur	Nil	Nil
Dindugal	Moolanur, Kaveriammapatti, Oddanchathiram	Nil	Nil
Karnataka			
Chintamani	Doddaulluru, Nandagudi Kadagaskanahalli, Kuruhatti	3–11	5–12.5
Kolar	Malur	90–100	90–100
Bengaluru Rural	Devanahalli, Doddaballapur, Hessarghatta, Rajanukunte, Hoskote	5.5–33.5	11–28.5
Bengaluru Urban	Anekal, Jigini, Halehalli	4.5–27.	2–17.0
Gujarat			
Surendranagar	Sayala, Limbudi	1–4.5	Nil
Rajkot	Dhoraji, Gondal, Jetpur	2–3	Nil
Junagadh	Vadal, Choki	5.5–17.0	5–12
Jamnagar	Jalansar	1–4	Nil
Anand	Anand	2	Nil

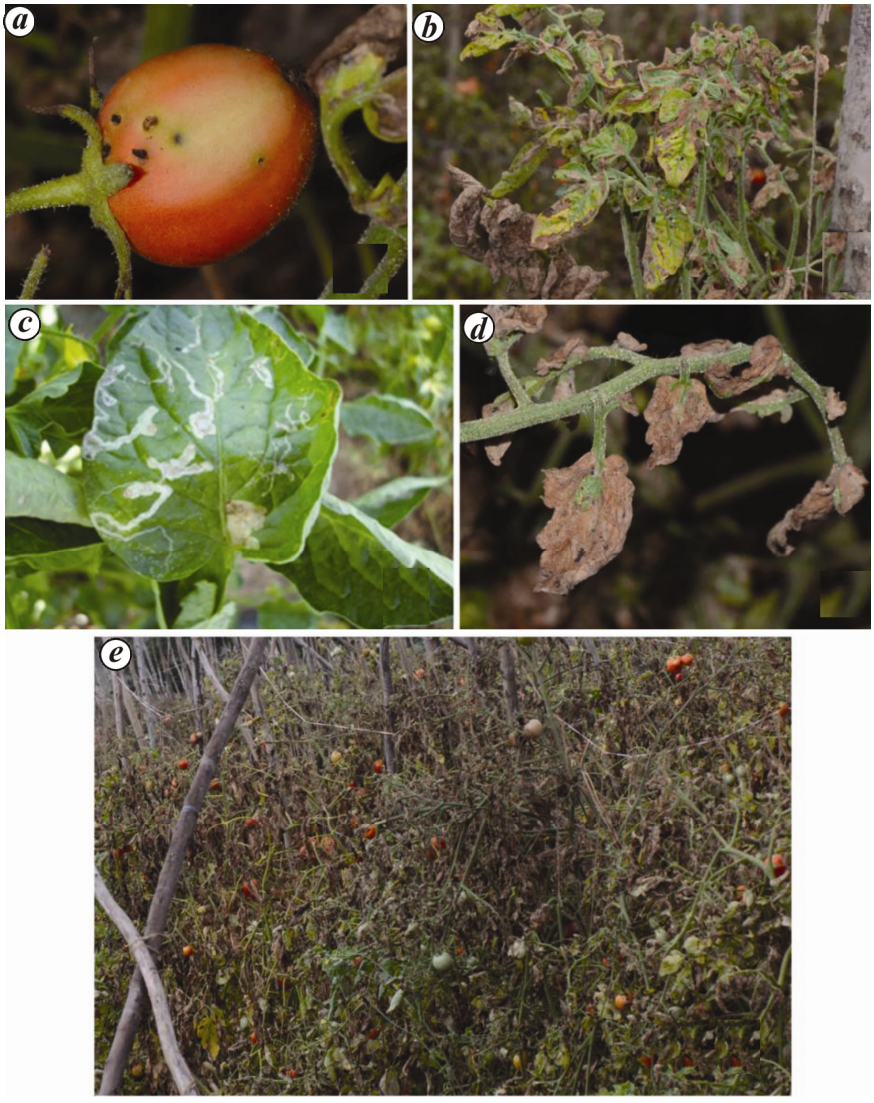

Figure 1 *a*–*e*. Damage symptoms of *Tuta absoluta* (Meyrick): ***a***, Pinhead sized entry and exit holes on the fruit; ***b***, Plant with leaf blotch symptoms; ***c***, Irregular galleries/mines on leaf; ***d***, Severe leaf damage; ***e***, Field symptoms of damage.

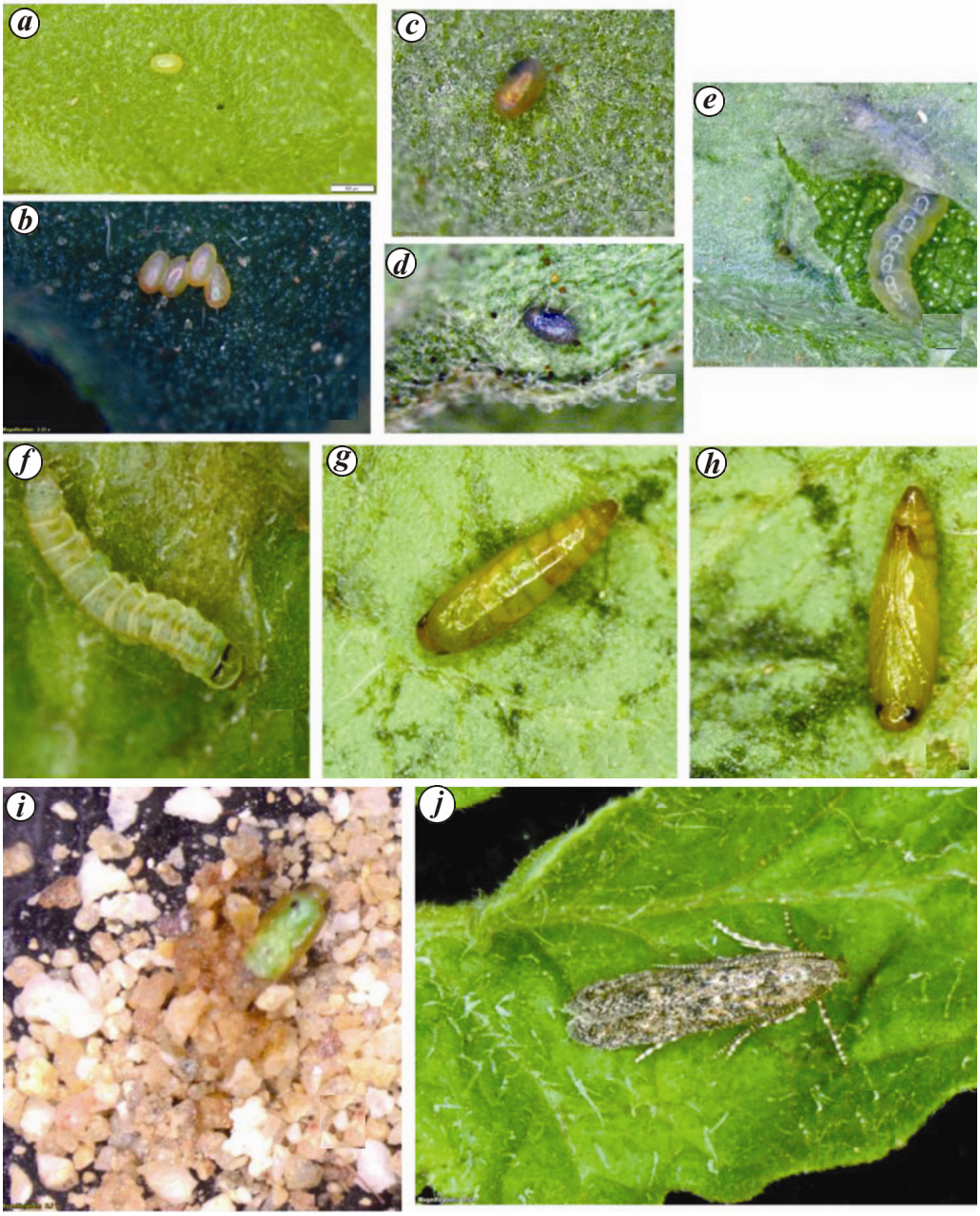

Figure 2 ***a–j.*** Life stages of *Tuta absoluta* (Meyrick): ***a***, Egg; ***b***, Egg cluster; ***c***, Mature egg; ***d***, Parasitized egg; ***e***, Larva inside the gallery; ***f***, Larva feeding on leaf; ***g***, Dorsal view of pupa; ***h***, Ventral view of pupa; ***i***, Pupation in soil; ***j***, Adult moth.

(when the pest population is low) by causing necrotic rings on the stems and flower abortion. However, Perdikis *et al.*[6] reported that *N. tenuis* has a low potential to cause damage on tomato stems and flowers, even when it occurs at high densities. Hence, it would be useful to conserve this predator in *Tuta*-infested tomato fields. Field-collected eggs and larvae of *T. absoluta* were brought to the laboratory, reared and observed for the presence of parasitoids. Four hymenopteran parasitoids, viz. *Trichogramma achaeae* Nagaraja and Nagarkatti (Figure 2 *d*: parasitized *T. absoluta* egg), *Neochrysocharis formosa* (Westwood), *Habrobracon* sp. and *Goniozus* sp. were observed to be associated with *T. absoluta* (Figure 3 *b–d*).

Amongst the four hymenopterans, *N. formosa* appeared to be pre-dominant. Luna *et al.*[7] reported the first record of *N. formosa* (generally recorded as a parasitoid of serpentine leaf miner *Liriomyza trifolii* (Burgess)) parasitizing larvae of *T. absoluta* in tomato crops in Northern Buenos Aires Province, Argentina. This parasitoid was present only in organic outdoor and protected crops, predominantly during the late season and parasitism rates varied from 1.5% to 5%. Further, Luna *et al.*[8] and Biondi

et al.[9] recorded *N. formosa* as a parasitoid of *T. absoluta* in France and Italy respectively. Zappalà *et al.*[10] compiled the list of natural enemies attacking *T. absoluta* in Europe, North Africa and Middle East. *Trichogramma nerudai* Pintureau and Gerding, *Trichogramma pretiosum* Riley and *Trichogramma rojasi* Nagaraja and Nagarkatti, were detected as egg parasitoids of *T. absoluta* in Argentina[8]; *T. achaeae* in France, and *Trichogramma bourarachae* Pintureau and Babault, in Tunisia[10]. Several braconids have been recorded as larval parasitoids of *T. absoluta* – *Bracon* (*Habrobracon*) *concolorans* (Marshall) was recorded from Jordan, Cyprus, Egypt, France, Italy and Spain[10–12]; *Bracon lucileae* Marsh, *Bracon lulensis* Berta and Colomo, *Bracon tutus* Berta and Colomo and *Bracon* sp. from the Mediterranean Basin and South America (Desneux *et al.*[13]) and *Agathis fuscipennis* (Zetterstedt) from Italy (Loni *et al.*[12]). According to USDA-New pest response guidelines and CABI-Invasive Species Compendium, *Parasierola nigrifemur* (Ashmead), a bethylid is recorded as larval parasitoid[14,15].

Eggs of *T. absoluta* were collected from infested fields in Karnataka, and steps initiated to rear them in the laboratory. Larval stages were reared on tomato leaves and unripe fruits. A layer of sand was provided on the floor of rearing containers, where pupation occurred. Adults which emerged were released into oviposition cages with tomato leaf bouquets, tissue paper strips and muslin cloth strips. Adult females preferred to lay eggs on tomato leaves, however in a no-choice situation, eggs were laid on tissue paper and muslin cloth strips.

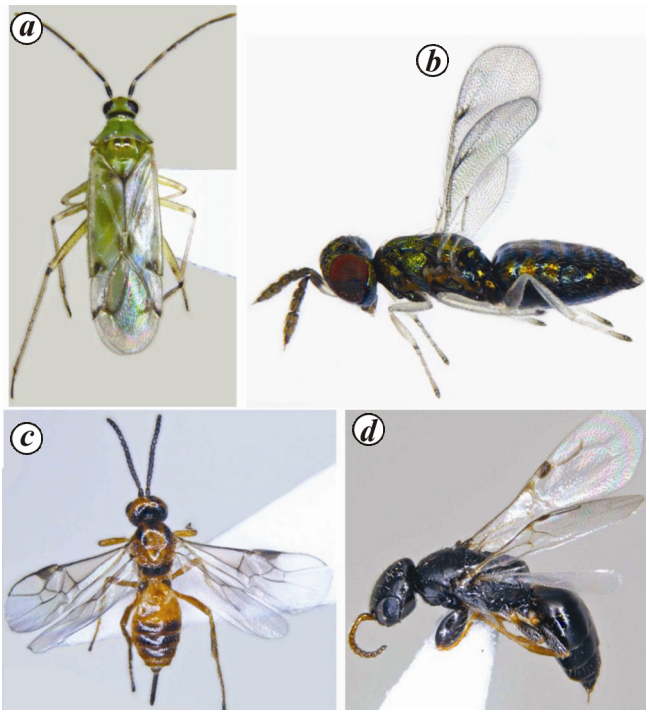

Figure 3 ***a–d.*** Natural enemies of *Tuta absoluta* (Meyrick): ***a***, Adult of *Nesidiocoris tenuis* Reuter; ***b***, Female of *Neochrysocharis formosa* (Westwood); ***c***, Female of *Habrobacon* sp.; ***d***, Female of *Goniozus* sp.

Some selected trichogrammatids from the live insect repository of NBAIR were evaluated for their parasitizing efficiency on *T. absoluta* eggs. Amongst the five trichogrammatid species tested, *T. achaeae*, *T. pretiosum* and *Trichogrammatoidea bactrae* Nagaraja could parasitise *T. absoluta* eggs, and the parasitism rates were 5.0%, 51.1% and 68.2% respectively. Adults emerged from parasitized *T. absoluta* eggs (4.8%, 97.5% and 90.0% adult emergence respectively), however, they appeared to be weak, smaller and with reduced longevity. Chailleux *et al.*[16] also observed that adult trichogrammatids emerging from *Tuta* eggs possessed inferior biological traits like wing deformations, lower parasitism rates and reduced longevity. Some reports indicate that field releases of trichogrammatids were not consistently effective, which could have been because of the weak adults emerging from the parasitized *T. absoluta* eggs. Majority of the earlier reports recorded the parasitism potential of trichogrammatids based on blackening of *Tuta* eggs. However, information is scarce on the per cent *Trichogramma* adult emergence from parasitized *Tuta* eggs, and the parasitizing efficiency of the emerged adults. Laboratory, cage and greenhouse studies indicate that strainal variations exist in trichogrammatids with respect to their parasitizing efficiency on *T. absoluta* eggs[16–19]. In order to develop a *Tuta* adapted strain of *Trichogramma*, trichogrammatids which emerged from *Tuta* eggs were further allowed to parasitise rice moth (*Corcyra cephalonica* Stainton) eggs. Amongst three species, the F_1 generation adults of *T. pretiosum* could parasitise 29% of *C. cephalonica* eggs, while the other two species were not successful in parasitizing.

Greenhouse studies indicated that *T. achaeae* was most efficient in management of *Tuta absoluta*[16,18,19]. *Trichogramma pretiosum* was introduced from Colombia into Brazil[20] and was reported to be unsuccessful in managing *T. absoluta* population[21]. Though most studies indicate *T. achaeae* as the most potential egg parasitoid, our studies indicate that *T. pretiosum* was superior considering the parasitizing efficiency of adults emerging from parasitized eggs. Further evaluation studies should focus on both *T. achaeae* and *T. pretiosum*, with special emphasis on *Tuta* adapted strains.

The present study is thus the first record of 'hymenopteran' natural enemies of *T. absoluta* in India. Apart from these, spiders (*Argiop*e sp.) and mirid bugs (*N. tenuis*) have already been reported[22,23].

The major tomato-growing districts in the states of Maharashtra, Karnataka, Andhra Pradesh, Bihar, West Bengal, Tamil Nadu and Gujarat have to be under constant surveillance and monitoring for the occurrence of *T. absoluta.* Though the preferred host plant of *T. absoluta* is tomato, in other countries, infestation by this pest has also been reported on potato, egg plant, hot pepper,

tobacco and many other cultivated and weed hosts belonging to the family Solanaceae. Hence, it is important to regularly survey solanaceous plants for the occurrence of *T. absoluta* and also document natural enemies attacking different stages of the pest in different states. It is crucial to educate farmers on pest stages and symptoms of damage caused by *T. absoluta* so that they can initiate action on time and prevent spread of the pest. It would also be useful to help the farmers in identifying potential bio-agents of the pest.

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