



***Tuta absoluta* management in China: progress and prospects**

Ming-hui Wang^{1,2}, Khasan Ismoilov^{1,2}, Wan-xue Liu³, Ming Bai^{4,5,6}, Xiao-shuan Bai⁷, Bin Chen⁸, Haoliang Chen⁹, Hong-song Chen¹⁰, Yong-cheng Dong¹¹, Kui Fang¹², Fu-rong Gui⁸, Guo-Hua Huang¹³, Chun-mei Jiang¹⁴, Hong-bo Jiang^{15,16}, Xiao-wei Li¹⁷, Chen Luo¹⁸, Chen Luo¹⁹, Zhao-zhi Lu²⁰, Yao-bin Lu^{17,21}, De-ying Ma²², De-qiang Pu²³, Yanyan Qu²⁴, Wen Sang²⁵, Li-mei Song²⁶, Xiao Sun²⁷, Yuan-xing Sun²⁸, Bin Wan²⁹, Xin-pu Wang³⁰, Wen-jia Yang³¹, Xue-qing Yang^{32,33}, Feng-Luan Yao³⁴, Zheng-pei Ye³⁵, Li-yun Zhang¹, Xiao-ming Zhang⁸, Ye Zhang³⁶, Chen-chen Zhao³⁷, Qiong Zhou³⁸, Wen-wu Zhou³⁹, Wen-ya Zhu³⁶, Cesar Rodriguez-Saona⁴⁰, Antonio Biondi⁴¹, Coline C. Jaworski⁴², Yibo Zhang^{3,*}, Nicolas Desneux⁴², Peng Han^{1,2,*}

- 1 School of Ecology and Environmental Sciences, Yunnan University, Kunming 650500, China
- 2 Southwest United Graduate School (SWUGS), Kunming 650092, China
- 3 Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing 100193, China
- 4 Key Laboratory of Animal Biodiversity Conservation and Integrated Pest Management, Institute of Zoology, Chinese Academy of Sciences, Beijing 100101, China
- 5 Key Laboratory of Zoological Systematics and Evolution, Institute of Zoology, Chinese Academy of Sciences, Box 92, Beichen West Road, Chaoyang District, Beijing 100101, China
- 6 Northeast Asia Biodiversity Research Center, Northeast Forestry University, Harbin 150040, China
- 7 College of Life Science and Technology, Inner Mongolia Normal University, Hohhot 010028, China
- 8 College of Plant Protection, Yunnan Agricultural University, Kunming 650201, China
- 9 Institute of Plant Protection and Agro-Products Safety, Anhui Academy of Agricultural Sciences, Hefei 230031, China
- 10 Plant Protection Research Institute, Guangxi Academy of Agricultural Science, Nanning 530007, China
- 11 Key Laboratory of Biology and Sustainable Management of Plant Diseases and Pests of Anhui Higher Education Institutes, College of Plant Protection, Anhui Agricultural University, Hefei 230036, China
- 12 Kunming Customs, Kunming 650051, China
- 13 Yuelushan Laboratory, Hunan Agricultural University, Changsha 410128, China
- 14 College of Life Science, Hubei university, Wuhan 430062, China
- 15 Key Laboratory of Entomology and Pest Control Engineering, College of Plant Protection, Southwest University, Chongqing 400716, China
- 16 Key Laboratory of Agricultural Biosafety and Green Production of Upper Yangtze River (Ministry of Education), Southwest University, Chongqing 400715, China
- 17 Institute of Plant Protection and Microbiology, Zhejiang Academy of Agricultural Sciences, Hangzhou 310021, China
- 18 College of Plant Protection, Yangzhou University, Yangzhou 225009, China
- 19 College of Plant Protection, Northwest A&F University, Yangling 712100, China
- 20 Shandong Engineering Research Center for Environment-Friendly Agricultural Pest Management, College of Plant Health and Medicine, Qingdao Agricultural University, Qingdao 266109, China
- 21 Xianghu Laboratory, Hangzhou 311258, China
- 22 College of Agronomy, Xinjiang Agricultural University, Urumqi 830052, China
- 23 Institute of Plant Protection, Sichuan Academy of Agricultural Sciences, Chengdu 610066, China
- 24 Institute of Plant Protection, Beijing Academy of Agriculture and Forestry Science, Beijing 100097, China
- 25 College of Plant Protection, South China Agricultural University, Guangzhou 510640, China
- 26 School of Life Science, Hebei University, Baoding 071002, China
- 27 State Key Laboratory of Crop Stress Adaptation and Improvement, School of Life Sciences, Henan University, Kaifeng 475004, China
- 28 College of Plant Protection, Gansu Agricultural University, Lanzhou 730070, China

- ²⁹ School of Life Sciences, Nanchang University, Nanchang 330031, China
- ³⁰ School of Agriculture, Ningxia University, Yinchuan 750021, China
- ³¹ Key Laboratory of Surveillance and Management of Invasive Alien Species in Guizhou Education Department, College of Biological and Environmental Engineering, Guiyang University, Guiyang 550005, China
- ³² College of Plant Protection, Shenyang Agricultural University, Shenyang 110866, China
- ³³ Key Laboratory of Major Agricultural Invasion Biological Monitoring and Control, Shenyang 110866, China
- ³⁴ Institute of Plant Protection, Fujian Academy of Agricultural Sciences, Fuzhou 350013, China
- ³⁵ Hainan Provincial Engineering Research Center for the Breeding and Industrialization of Natural Enemies, Environment and Plant Protection Institute, Chinese Academy of Tropical Agricultural Sciences, Haikou 571101, China
- ³⁶ College of Plant Protection, Shanxi Agricultural University, Taiyuan 030031, China
- ³⁷ College of Plant Protection, Henan Agricultural University, Zhengzhou 450046, China
- ³⁸ College of Life Sciences, Hunan Normal University, Changsha 410081, China
- ³⁹ Ministry of Agricultural and Rural Affairs Key Laboratory of Molecular Biology of Crop Pathogens, Institute of Insect Science, Zhejiang University, Hangzhou 310058, China
- ⁴⁰ Department of Entomology, Rutgers University, New Brunswick, New Jersey 08901, USA
- ⁴¹ Department of Agriculture, Food and Environment, University of Catania, Catania, Italy
- ⁴² Université Côte d'Azur, INRAE, UMR ISA, 06000 Nice, France
- * Corresponding authors: zhangyibo@caas.cn; penghan@ynu.edu.cn
- ORCID Peng Han: 0000-0002-5941-9362

With 2 figures and 1 table

Abstract: The South American tomato pinworm, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), has invaded most Afro-Eurasian countries. Since its first detection in China in late 2017, this pest has been now present in nearly 20 provinces/prefectures in China and is threatening tomato and other Solanaceous crops such as potato, eggplant, and tobacco. Here, we provide a timely review on the current distribution, damage, management, and research in China. A standard survey form was designed and 30 answered surveys from 25 provinces have been received. The data showed that the damage has been witnessed in most of the regions despite that the severities vary among the regions. The management is chemical-control biased, and more efforts are needed to increase the adoption of non-chemical alternatives in the Integrated Pest Management packages. An Integrated Pest Management (IPM) package called “CAMEFA” was developed and demonstrated in Yunnan and Xinjiang, the two earliest regions for the invasion. Yet, the adoption by local growers is still limited. Besides *T. absoluta*, we suggest a multi-pest approach by combining IPM tactics coping with other major insect pests sharing the crop. Lastly, international projects are deemed to serve as key lever for promoting IPM of *T. absoluta* and other invasive insect pests.

Keywords: biological invasion; insect pests; IPM, multi-pest approach; international projects; South American tomato pinworm

1 Introduction

The South American tomato pinworm, *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae), originated from Peru (Guillemaud et al. 2015), is an invasive and destructive pest for tomato and other Solanaceous crops. So far, *T. absoluta* has invaded over 110 countries across South and Central Americas, Europe, Africa, and Asia since it was firstly observed in eastern Spain in 2006 (Desneux et al. 2010, 2011; Mansour et al. 2018; Biondi et al. 2018; Han et al. 2018, 2019a; Desneux et al. 2022). The pest mainly feeds on Solanaceous species including tomato, potato, eggplant, pepper, and tobacco (Biondi et al. 2018). Several plant species belonging to Amaranthaceae, Convolvulaceae, Fabaceae, and Malvaceae families can serve as its secondary host plants (Bawin et al. 2016). It can infest leaves, stems

and fruits and cause up to 80–100% yield losses in tomato crops if no timely control measures are taken (Desneux et al. 2010). Serious damage to crops is due to various biological and ecological characteristics in *T. absoluta*, such as the larval cryptic behavior, high reproduction potential with multiple overlapping generations per year, strong dispersal capacity and insecticide resistance (Biondi et al. 2018; Cherif et al. 2019; Guedes et al. 2019).

China is the world's largest producer of tomatoes. *Tuta absoluta* has spread to nearly 20 provinces/prefectures (hereafter as “provinces”) in China (Zhang YB unpublished data), since it was first detected in Xinjiang Uyghur Autonomous Region (thereafter as “Xinjiang”) in 2017 and then in Yunnan in 2018 (Han et al. 2018; Zhang et al. 2020, 2021; Wang et al. 2021). The current distribution of *T. absoluta* in China is likely to expand further because

of vast planting areas of suitable hosts (e.g. tomato, eggplant, potato etc.) and suitable climate. Indeed, China has the largest tomato planting area, reaching more than 1.1 million hectares, and representing 22% of the world tomato industry in 2021 (FAO 2023). Climatic suitability is another key factor affecting the distribution and spread of *T. absoluta*. Predictive models suggested that most parts of China are suitable for its distribution, except for the regions with extreme climates such as Xizang, Qinghai and Inner Mongolia (Xian et al. 2017; Zhao et al. 2023). The protected agricultural facilities are supposed to facilitate year-round persistence of *T. absoluta* where it should not (Liu et al. 2023). The rapid spread of the pest will cause serious economic losses, including reduced yield, extra management costs and decreased and/or restricted trade (Zhang et al. 2020; Xi et al. 2022). In 2023, the government has assigned it into “the list of major invasive alien species for management in China” and “the list of top-class crop diseases and pests in China” to inform better management nationwide in the future.

Applying synthetic pesticides is often the first option to cope with *T. absoluta* upon its arrival. However, alternative non-chemical control tactics such as biological control, mass trapping, and resistant plant varieties are expected to reduce the over-reliance on chemical pesticides, and combined use of these options is more effective than applied alone in early-invaded countries (Han et al. 2014, 2016; Dong et al. 2018; Desneux et al. 2022; Borges et al. 2023; Aygel & Aslan 2023). We also assume that open-field grown crops may rely more on chemical pesticides than those of protected crops despite such a statement needs evidence. In China, multiple national projects have been launched for the Integrated Pest Management (IPM) of *T. absoluta* since its invasion. So, what is the status of this pest in China now? What are the current management options adopted by growers? What are the research efforts for a better adoption of IPM packages? In the present review article, we summarized the current damage, management, and future efforts to improve IPM against this pest in China.

2 Distribution and damage

Tuta absoluta was first detected in northwestern China in Yili (Ili), Xinjiang between 2017 and 2018. It was then detected in Lincang, Yunnan province in southwest China (Zhang et al. 2020). A following nation-wide survey during 2018 and 2020 has shown that *T. absoluta* populations established in Xinjiang had a medium Population Colonization Coefficient (PCC) value (~ 0.03) in Northwest China, a high (~ 0.50 in Yunnan and Guizhou) and low (< 0.02 in Guangxi, Sichuan, Hunan, and Chongqing) PCC values in Southwest China, respectively (Zhang et al. 2021). Up to 2020, *T. absoluta* has spread and distributed in more than 35 cities of 8 provinces (Zhang et al. 2021) (Fig. 1A).

Rapidly, two years later in 2022, it had spread to more than 500 counties of 24 provinces (Personal communications by Zhang YB) (Fig. 1B). Owing to its rapid geographic expansion and the severe crop damage, *T. absoluta* poses a high threat to China’s tomato production industry. Wang et al. (2023) showed that most populations of *T. absoluta*, both in China and worldwide, exhibited high genetic homogeneity except for two distinct haplogroups. This finding may indicate two dispersal avenues of *T. absoluta* into China via northwest and southwest borders. *Tuta absoluta* was supposed to establish bridgehead populations in Xinjiang and Yunnan and then spread rapidly throughout the neighboring provinces nationwide. So far, *T. absoluta* has been found to damage tomato (fresh and processed), potato, eggplant, tobacco, Chinese lantern, black nightshade, and Dutch eggplant in China (see detailed information in Table 1). The highest damage severity was found on tomato, followed by eggplant, potato, and least on pepper, tobacco and other crop and/or non-crop plants.

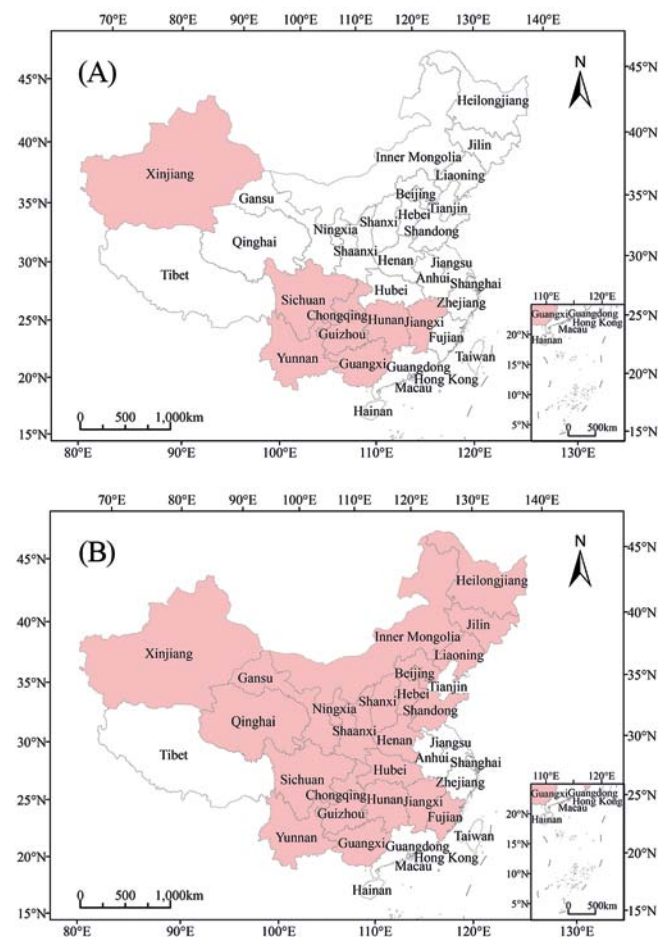


Fig. 1. Geographic distribution of *T. absoluta* in China up to 2020 (A) and up to 2023 (B) (Data are provided by researchers and/or extension advisors from different provinces in China). The red corresponds to the newly invaded provinces in China.

Table 1. Host plants that can be damaged by *T. absoluta* in China. Source references: (a) Sheng et al. (2023), (b) Wang et al. (2023), (c) Zhang et al. (2023), (d) Yin et al. (2021), (e) Jiang et al. (2022), (f) Li et al. (2021), (g) Zhang et al. (2020), (h) Fu et al. (2023), (i) Zhou et al. (2023b), (j) Wang et al. (2022), (k) Zhang et al. (2021), (l) Yang et al. (2023), (m) Du et al. (2022), (n) Luo et al. (2022). Crop type: G: greenhouse, F: open field.

Host plants (number)	Region	Crop type	Ref.
Fresh tomato (1)	Beijing	G	a
	Shandong	G	b
	Shanxi	G	c
	Yunnan	F	d, e
	Gansu	G	f
	Xinjiang	F	g, h, i
	Xinjiang; Yunnan	F	j
	Xinjiang; Yunnan	F	k
	Guangxi; Sichuan		
	Guizhou; Hunan		
	Chongqing		
Processed tomato (2)	Xinjiang	F	l
Potato (3)	Yunnan	F	k, e, m
	Xinjiang	F	g, k
Eggplant (4)	Yunnan	F	d
	Xinjiang; Yunnan	F	g, k
Dutch Eggplant (5)	Yunnan	F	k
Tobacco (6)	Yunnan	F	n
Chinese lantern (7)	Xinjiang	F	g, k
Black nightshade (8)	Xinjiang; Yunnan	F	g, k

3 Management efforts

3.1 Cross-border efforts

Xinjiang (Northwest China) and Yunnan (Southwest China) were inspected as the two earliest regions for *T. absoluta* invasion. We assume that the introduced populations in these two regions were the separate sources for recent wide spread of *T. absoluta* throughout China, but this needs to be confirmed by molecular tools (Guillemaud et al. 2015). To identify invasion routes and sources of invading populations unambiguously, insect samples are also needed from adjacent countries in Asia where *T. absoluta* had been present for years. The frontier ports between China and other countries are considered as hot zones for high invasion risk, despite rigorous quarantines.

Once clear evidence is obtained for a given invasion route, attention shall be paid to the re-invasion risk from other countries to China and/or reverse introduction from China to other countries. In this case, further joint-efforts

between countries for the surveillance and IPM programs are needed. For instance, two projects were built in parallel in northwest China and Tajikistan for a better cross-border management of *T. absoluta* from 2018 to 2021. In the projects, an IPM package called “CAMEFA” was developed and demonstrated in both regions. “C” refers to “chemical control” in which several selective insecticides are used for minimized risk of non-targets effects on beneficial organisms and lower risk of development of insecticide resistance (e.g. rotated spray of chlorantraniliprole, avemectin, and emamectin benzoate). “A” refers to “attract-and-kill” tools primarily based on synthetic sex pheromone and Delta traps (or DIY water traps). The recommended densities of the traps are 30–40 for one hectare in open fields and 2–3 for 500 m² greenhouse. “M” refers to use of mating disruption dispersers which proves to be highly efficient (but somehow costly) (Cocco et al. 2013). “E” refers to “natural enemies” including the release of the commercially-available biocontrol agent *Nesidiocoris tenuis*, *Chrysoperla carnea* (Ismoilov et al. 2020), and *Bacillus thuringiensis* (Berliner) (Bt)-based insecticide. “F” refers to “fertilization rate” suggesting that proper amount of nitrogen fertilization is useful for lowering the pest population which could otherwise be boosted by excessive nitrogen input (Han et al. 2014, 2016, 2019b). Lastly, “A” refers to “agronomic practices” including timely removal of infested plant parts, insect proof nets, closed greenhouses heating, and rotation growing with non-host crops. The “CAMEFA” package has been promoted in the two most susceptible regions by *T. absoluta* invasion in China: Xinjiang and Yunnan. Although the adoption of this package brings additional costs to growers, they often choose to adopt it since they may get infestation up to 80% and nearly zero harvest if no action is taken. The control appears successful, but the cost-effectiveness has not been assessed and recorded so far. The determination of Economic Injury Levels (EILs) shall be the first step for managing any insect pests, which could secure a high cost-effectiveness of the IPM packages. Indeed, the “CAMEFA” package does not allow us to meet the suitable EILs. In our case, the “CAFEMA” is not recommended as a specific package for a given area (or farm), but serves as a general recommendation. Local growers will decide which tactics and to which extent those selected tactics shall be used during the growing season.

3.2 Two typical cases in Northwest and Southwest China: greenhouse IPM vs. field IPM

In Northwest China, Xinjiang is the most susceptible region for *T. absoluta* damage. In this region, there are processing-tomato growing in large open fields and fresh tomato growing in greenhouses (approximately 42.3% versus 57.7% in terms of cultivation area). Processing-tomato is the key component of local agriculture and processing enterprises, which export tomato ketchup overseas (e.g. Europe). Based on our survey feedback, fortunately, processing-tomato in

open fields is currently facing minor damage by *T. absoluta*. We assume that this pest is unable to overwinter because of the extreme coldness in winter (the ambient temperatures usually go below minus 10–30 °C from December to March). Yet, this assumption still needs experimental evidence. Even though this pest has a low overwintering potential in open fields, it is possible that the dispersal from adjacent greenhouses (if available) to the fields during the early season serves as the basis for the population build-up later in the field. Greenhouse fresh tomatoes, unfortunately, have been an ideal host for *T. absoluta*. Area-wide severe damage has been witnessed (personal observation by Han P. during 2018–2020). What's even worse is that the invasion disrupted the existing IPM package on tomato owing to extensive spraying of insecticides since 2018. It has been proposed to elaborate a new package based on the existing management options in Xinjiang to cope with the challenge (Han et al. 2018). The “CAMEFA” package has been recommended for growers, but the adoption is not as much as we have expected. One of the key reasons is that the growers are not willing to afford the alternative biorational products by themselves, but no subsidies are available. It is a difficult task to provide clear “green” recommendations.

In Southwest China, tomato and potato are grown in the largest areas among the susceptible hosts. They are grown primarily by smallholder farmers because over 90% of this region is mountain areas and most fields are in small scales. In Yunnan, for example, approximately 60% of tomatoes are grown in open fields, and 40% are grown in greenhouses. The potatoes are grown in open fields. Since 2018, heavy damage on tomato and potato by *T. absoluta* has been observed in many areas in Yunnan (Personal observation by Han P. and Chen B.). Based on the survey feedback, the wide spread and damage of this pest has been attributed to climate suitability (it is a low-latitude region with abundant solar resource and average ambient temperatures range between 16–24 °C), high availability of host plants, lack of knowledge on the pest by growers, and no timely guidance on the control methods from extension advisors. For example, tomatoes are grown in open fields as out-of-season vegetables for considerable profits during the winter in Chuxiong where the average ambient temperature is above 10 °C during this period. Local growers are somehow aware of the pest; however, the management is not as efficient as expected. One reason is that the separate small-scale cultivation patterns make the “CAMEFA” package costly and more often inefficient owing to pest migration among the fields owned by different growers. Moreover, other economically-important insect pests (the whitefly *Bemisia tabaci*, the vegetable leafminer *Liriomyza sativae*, and thrips pests) make it hard to design an IPM package for multiple targets.

3.3 A nationwide survey

A survey form was designed and disseminated to the researchers from 25 provinces in China where *T. absoluta* is

supposed to pose high threat. There were both choice questions and open questions for the interviewed researchers who have expertise either on IPM of *T. absoluta* or on other agricultural insect pests. The researchers were suggested to discuss and interview with the extension advisors from local Plant Protection Units and growers for explicit answers. With those answers, we managed to get clear information on the following aspects for each province: (a) the overall status of *T. absoluta* and its estimated damage, (b) the relative use of various IPM components (chemical control, biological control, behavior-based control, agronomic and cultural control, and early diagnosis & monitoring), (c) the specific tool/product/option being used for each type of component, (d) the challenges for local farmers in the management, as well as (e) the open remarks on what local farmers expected from the researchers, extension advisors and the government. The scores obtained were calculated for each province, and they were averaged if more than two survey feedbacks were received. The information gathered were used for further analyses. We assume that the information collected from different provinces could robustly represent the status in each province, and all the gathered information have been further analysed. The goal was to draw a general picture of how the IPM is implemented across China.

Out of 25 provinces concerned, 7, 3, 6, and 9 were identified as being heavily damaged (40–60%), moderately damaged (20–40%), slightly damaged (< 20%), and not yet damaged. There is no clear geographical pattern for the damage severities, which indicates a complex picture of the colonization and dispersal pathway nationwide. Notably, the presence of *T. absoluta* in several provinces that have been predicted as optimal suitable areas (Xian et al. 2017) has not been confirmed so far (e.g. Guangdong, Hainan and Zhejiang). Pheromone traps are suggested to be used to monitor the pest at more regular intervals in those regions.

The IPM pyramid was built based on the 20 answered surveys from 16 provinces where *T. absoluta* is present (Fig. 2A). Based on the scores for each component from each interviewee, the proportions were calculated among control components employed within the integrated pest management package. The survey feedback shows that chemical control is the most used, followed by agronomic and behavior-based control, with biological control being the least adopted. Early detection and monitoring procedures are moderately adopted, but not sufficiently wide to cover all the susceptible areas. For chemical control, the most used insecticides are chlorantraniliprole, avermectin, and emamectin benzoate. In most provinces, these chemicals are suggested to be used in rotation to minimize the risk of insecticide resistance emergence in *T. absoluta* (Guedes et al. 2019). Field release and conservation of arthropod natural enemies for the biological control have been rarely done, despite there were field demonstrations by researchers in several regions (e.g. *Nesidiocoris tenuis* in Xinjiang, *Trichogramma pretiosum* in Gansu, *Trichogramma chilonis* in Jiangsu and *Chrysoperla*

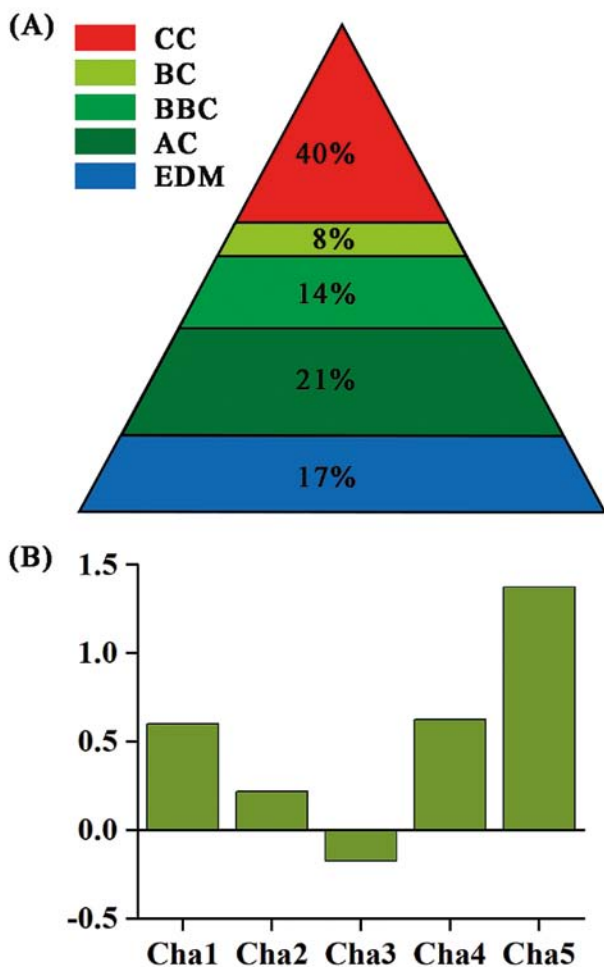


Fig. 2. Current IPM adoption against *T. absoluta* in China based on 20 answered surveys from 16 provinces. **(A)** Diagram on the proportions among control strategies currently adopted by local growers within the IPM pyramid; CC: chemical control; BC: biological control; BBC: behavior-based control; AC: agronomic control; EDM: early diagnosis and monitoring. **(B)** The average weight of each challenge for local farmers during the management. Challenge 1 (Cha 1): No or little knowledge on the presence/biology of the pest; Challenge 2: High cost associated with multiple spraying of insecticides; Challenge 3: Control failure by insecticides (owing to insecticide resistance); Challenge 4: Alternative non-chemical “green” products are NOT available; Challenge 5: “Green” products are available (promoted by companies), but too expensive. Five challenges were asked for the interviewees from 16 provinces for their single choice for either “strongly disagree”, “somewhat disagree”, “not sure”, “somewhat agree”, or “strongly agree” which are scored as -2, -1, 0, 1 and 2. The values are then averaged for the weight. The values below 0 indicate “disagree”. The values above 0 indicate “agree” (the higher the values, the more they agree).

carnea in Yunnan). Pheromone-based mass trapping and mating disruption are applied in fields, but the options are not performed properly, and as a result, it is quite costly. Agronomic practices are adopted including crop rotation by non-host crops, greenhouse closing-heating, and sanitation

practices including removal-and-kill of the infested leaves and fruits. Although the detection of early-season populations based on pheromone traps is important, there is limited use of this procedure from local plant protection units especially when growers are not willing to buy those products by themselves. Overall, we have seen a slight change in the proportion of each control tactic employed in the package in China in 2023, compared with the overall status of the newly-invaded ranges (mostly Asia) in 2021 that estimated in an earlier study (Desneux et al. 2022).

4 Research efforts

Various aspects of eco-biology of this pest have been explored since its invasion into Europe (Desneux et al. 2010; Biondi et al. 2018). However, upon its invasion into China, the researchers prioritize the needs of optimizing the existing IPM tactics widely adopted in earlier-invaded areas (Desneux et al. 2022). Herein, we do not intend to list all the endeavours, and instead, we focus on the most promising efforts. Monitoring and mass trapping based on the synthesized sex pheromone is now widely used in China for the management. Yet, the polygyny exhibited by this pest may compromise the effectiveness of sex pheromone-based control techniques and growers should be cautious about the over-reliance on this technique (Wang et al. 2021). Placing sex pheromone-based sticky traps at a height of 0.5 meters using the ladder suspension method has been shown to achieve better effectiveness than the vertical suspension in greenhouse settings (He et al. 2022). This practice might be applicable for large greenhouse growers worldwide. In biological control programs, the performance of the predator *Chrysoperla carnea* against *T. absoluta* was firstly evaluated under field conditions and proved to be quite promising (Ismoilov et al. 2020), while the parasitoid *Necremnus tutae* could also be an effective biocontrol agent which exhibited both reproductive and nonreproductive effects in host mortality (Zhang et al. 2022a, b). A combined use of these two biocontrol agents might achieve satisfactory control as the former targets more *T. absoluta* eggs and the latter targets the larvae. Other on-going biorational studies, such as crop induced resistance, push-pull, survey and evaluation of other biocontrol agents, are expected to enrich the current IPM packages. Yet, the future management of *T. absoluta* might be challenged by the growing adoption of protected agriculture (i.e. greenhouse facilities) in China. This is because the greenhouse facilities have been shown to facilitate the year-round persistence of *T. absoluta* in the region(s) where it should not thrive in terms of climate suitability (Li et al. 2021; Liu et al. 2023). Based on the “prevention first” principle, IPM practices in greenhouses shall be given high priority to achieve successful area-wide control. This is especially true for the case of Shandong as mentioned in the section below.

Meanwhile, we have seen numerous in-depth basic studies from China with an attempt to develop novel IPM tactics against this pest. Among them, RNAi (RNA interference) is one of the hottest and most powerful approaches. For instance, co-silencing two vitellogenin genes can inhibit ovarian development and reduce female fecundity of *T. absoluta* (Yang et al. 2023). Yet, RNAi is often not as efficient as expected. Nanocarrier-delivered dsRNA has been shown to be a useful approach (Wang et al. 2023). Moreover, the first attempt to establish a CRISPR/Cas9 zygote micro-injection protocol for generating heritable mutations in *T. absoluta* using the ommochrome synthesis gene *cinnabar* as the target gene has been made (Ji et al. 2022). This well-known, powerful genome-editing tool is supposed to facilitate the discovery of suitable RNAi targets and development of novel control tactics. As Sterile Insect Technique (SIT) is useful for area-wide IPM programs, the optimal dose of gamma radiation for *T. absoluta* sterility has been screened and the findings pave the way for establishing itself as a key component of IPM packages (Zhou et al. 2023a). Technology Readiness Level (TRL) is the key for practical IPM programs. So far, all these basic research efforts, however, could merely allow for control tactics with low TRL in a laboratory environment. Further optimization efforts are needed to increase their TRLs. The rhythms of males' responses to the sex pheromone and of the adults' flight toward the UV lights were recorded (Zhang et al. 2023), and this knowledge is also vital for designing IPM packages.

5 Future solutions for a better IPM of *T. absoluta*

5.1 Keep the general rule "Prevention is better than cure"

Commercial seedling nursery centres are a key part of modern vegetable production, but they also serve as reservoir of insect pests. Rigorous prevention procedures are thus required before distributing any seedlings nationwide. The seedlings shall be carefully inspected for *T. absoluta* eggs and larvae before the journey. Taking Shandong as an example, this region is famous for producing and distributing tomato seedlings nationwide by over 10,000 commercial nurseries. Unfortunately, *T. absoluta* has been recently detected in high densities in greenhouse tomatoes in this region. This may create a new hotspot of "artificial colonies" of the pest, posing high dispersal risks to vast areas in China. Therefore, rigorous quarantine and management options against the pest on tomato seedlings in Shandong are crucial for the successful IPM nationwide.

5.2 Optimize existing IPM tactics for field demonstrations

There are diverse IPM tactics available in China, even though some of them are not exclusive but workable for

T. absoluta. But, they are seldom adopted by growers. In this regard, researchers and extension advisors are encouraged to focus more on the applied aspects of those tactics, instead of "being addicted to" running cutting-edge studies for "printing publications". For instance, more efforts are needed for testing and optimizing biocontrol agents, pheromone-based options, plant resistance inducers, push-pull approach, and other agronomic practices in fields.

5.3 Provide subsidies for boosting the outcomes of field demonstrations

Sustainable non-chemical control options are preferred over chemical control if they provide efficient control of pests. Since they are often more costly, subsidies shall be an important lever for boosting the adoption of those non-chemical tactics by growers. This is particularly important when the TRL of a given technique does not allow for high cost-effectiveness. Fostering the habit of using a given tactic in end-users might, in turn, be helpful for increasing the TRL by researchers and extension advisors, so that a positive feedback loop among researchers, extension advisors and end-users is formed.

5.4 Combine IPM tactics for the multi-pest approach

It is important to avoid over-reliance on a single IPM tactic for a given pest and focus-on-a-single-pest within the crop. These two scenarios refer to "low integration" in IPM strategies. Low integration levels of various IPM tactics might lead to unsustainable and ineffective management on multiple pests within a given crop, as well as undesired high cost to growers (Barzman et al. 2015). To increase the "integration" level of a range of tactics for multiple pests, studies based on "Multidimensional Management of Multiple Pests" (3MP) theoretical frameworks might be helpful (Han et al. 2024). In the "soil-crop-pest-natural enemies" multitrophic network, the space dimension involves identifying the bottom-up, top-down, and interactive effects of diverse management tactics on pest prevalence (Han et al. 2022). An IPM package is also encouraged to consider multiple pests since control of one pest may affect others. Thus, the time dimension requires understanding how multiple insects interact with each other over the crop growing season (Poelman & Dicke 2014; Dong et al. 2020; Emery & Mills 2020; Han et al. 2020). Still, we shall keep in mind that the 3MP framework (within the IPM paradigm) is not a principle that can be directly and uniformly applied to every situation, but a philosophy that can guide end-users to use it as appropriate for their own situation. The knowledge can be used by outreach advisors to aid the design of IPM packages, increasing the adoption of IPM in cropping systems and even over an extended spatial and temporal scale. Considering the realistic status in China, the multi-pest approach based on the 3MP framework is expected to target *T. absoluta*, *B. tabaci*, and *L. sativae* holistically in tomato.

5.5 Engage in international projects for lowering the risk of reinvasion and reverse invasion

International policies usually appreciate international projects in which joint efforts are made to fight shared invasive pests. As most of the Afro-Eurasia countries are now challenged by *T. absoluta*, international joint effort is supposed to trigger a chain-reaction and it will eventually pay off for all parties. International projects are easy to attract the eyes of policy-makers, and they may decide to invest more budgets on the relevant projects. Next, more research and/or extension budgets create a higher chance of obtaining better management of *T. absoluta*. The overall incidence of the pest could be considerably reduced. As a result, the risk of reinvasion from one country to the other and reversion invasion from the other to this country shall be much lower. Therefore, international joint effort is the key for recruiting resources for managing *T. absoluta* and other similar invasive species that are of worldwide interest.

6 Conclusion and future outlooks

T. absoluta has been listed as one of the key invasive insect pests in China. Our survey feedback showed that this species is still expanding its geographical distribution, despite important variations in damage severity across regions. First, current management is obviously chemical control-biased, and efforts are needed to increase the adoption of non-chemical alternatives in the IPM packages. While basic research is important for developing novel control techniques, applied research is more urgently needed from researchers to optimize the existing IPM tactics and make them applicable for growers as soon as possible (Desneux et al. 2022). Second, it is necessary to combine IPM tactics through the multi-pest approach in which other major insect pests on the same crop shall also be considered besides *T. absoluta*. Third, “lack of knowledge on the pest” is the biggest challenge that growers face. Extension advisory is urgently needed to increase the growers’ awareness and knowledge of the pest as they are the key players of the combat (Chen et al. 2024). Lastly, international projects are expected to serve as a key lever for achieving better IPM of *T. absoluta* and other invasive insect pests. As biological invasion management is interwoven with today’s other hot topics including biodiversity loss, climate change, and food security, a systemic approach will be helpful for addressing those topics. For instance, more efforts are needed for the radical redesigns of the cropping system involving biological control (Ismoilov et al. 2020; Yao et al. 2022), induced resistance via sprays of synthetic elicitors (Salazar-Mendoza et al. 2023), companion plants conserving the arthropod natural enemies (Arnó et al. 2018), and manipulation of fertilization regimes to enhance crop resistance to insect pests while minimizing environmental impacts (Han et al. 2019b).

Acknowledgments: We thank the Yunnan Province Science and Technology Department “Yunnan International Joint Laboratory of Fruit-Vegetable-Flower Invasive Insect Pest Management (Yunnan FVF-IPM Joint Lab)” (No. 202303AP140018), the “Yunnan Xingdian Talent Support Program” (No. K264202230209), the Key R&D Program of Ningxia (No. 2023BCF01045), the ADOPT-IPM project funded by the European Union’s Horizon Europe framework programme under grant agreement number 101060430, and the “National Key R&D Program of China” (2023YFC2604500) for funding.

References

- Arnó, J., Oveja, M. F., & Gabarra, R. (2018). Selection of flowering plants to enhance the biological control of *Tuta absoluta* using parasitoids. *Biological Control*, 122, 41–50. <https://doi.org/10.1016/j.biocontrol.2018.03.016>
- Aygel, G., & Aslan, M. M. (2023). Population density and infestation rate of *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae) on different tomato varieties in mersin field conditions. *Ksu Tarim ve Doga Dergisi-ksu Journal of Agriculture and Nature*, 26(1), 27–37. <https://doi.org/10.18016/ksutarim-doga.vi.1058984>
- Barzman, M., Bårberi, P., Birch, A. N. E., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., ... Sattin, M. (2015). Eight principles of integrated pest management. *Agronomy for Sustainable Development*, 35(4), 1199–1215. <https://doi.org/10.1007/s13593-015-0327-9>
- Bawin, T., Dujeu, D., De Backer, L., Francis, F., & Verheggen, F. J. (2016). Ability of *Tuta absoluta* (Lepidoptera: Gelechiidae) to develop on alternative host plant species. *Canadian Entomologist*, 148(4), 434–442. <https://doi.org/10.4039/tce.2015.59>
- Biondi, A., Guedes, R. N. C., Wan, F., & Desneux, N. (2018). Ecology, worldwide spread, and management of the Invasive South American tomato pinworm, *Tuta absoluta*: Past, present, and future. *Annual Review of Entomology*, 63(1), 239–258. <https://doi.org/10.1146/annurev-ento-031616-034933>
- Borges, I., Oliveira, L., Durao, A., Arruda, P., & Soares, A. O. (2023). Feeding preference and intraguild interactions between the parasitoid *Trichogramma achaeae* and the predator *Macrolophus pygmaeus*, two biological agents of *Tuta absoluta*. *Pest Management Science*, 79(11), 4376–4382. <https://doi.org/10.1002/ps.7635>
- Chen, D. M., Zhang, L. Y., Peng, Y., & Si, X. Z. (2024). Exploring the association between social media and farmers’ knowledge of a worldwide invasive agricultural pest, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Pest Management Science*. <https://doi.org/10.1002/ps.7796>
- Cherif, A., Attia-Barhoumi, S., Mansour, R., Zappalà, L., & Grissa-Lebdi, K. (2019). Elucidating key biological parameters of *Tuta absoluta* on different host plants and under various temperature and relative humidity regimes. *Entomologia Generalis*, 39(1), 1–7. <https://doi.org/10.1127/entomologia/2019/0685>
- Cocco, A., Deliperi, S., & Delrio, G. (2013). Control of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in greenhouse tomato crops using the mating disruption technique. *Journal of Applied Entomology*, 137(1-2), 16–28. <https://doi.org/10.1111/j.1439-0418.2012.01735.x>
- Desneux, N., Han, P., Mansour, R., Arnó, J., Brévault, T., Campos, M. R., ... Biondi, A. (2022). Integrated pest management of

- Tuta absoluta*: Practical implementations across different world regions. *Journal of Pest Science*, 95(1), 17–39. <https://doi.org/10.1007/s10340-021-01442-8>
- Desneux, N., Luna, M. G., Guillemaud, T., & Urbaneja, A. (2011). The invasive South American tomato pinworm, *Tuta absoluta*, continues to spread in Afro-Eurasia and beyond: The new threat to tomato world production. *Journal of Pest Science*, 84(4), 403–408. <https://doi.org/10.1007/s10340-011-0398-6>
- Desneux, N., Wajnberg, E., Wyckhuys, K. A. G., Burgio, G., Arpaia, S., Narváez-Vasquez, C. A., ... Urbaneja, A. (2010). Biological invasion of European tomato crops by *Tuta absoluta*: Ecology, geographic expansion and prospects for biological control. *Journal of Pest Science*, 83(3), 197–215. <https://doi.org/10.1007/s10340-010-0321-6>
- Dong, Y. C., Wang, Z. J., Bu, R. Y., Dai, H. J., Zhou, L. J., Han, P., ... Desneux, N. (2020). Water and salt stresses do not trigger bottom-up effects on plant-mediated interspecific interactions between a leaf chewer and a sap-feeder. *Journal of Pest Science*, 93(4), 1267–1280. <https://doi.org/10.1007/s10340-020-01258-y>
- Dong, Y. C., Han, P., Niu, C. Y., Zappalà, L., Amiens-Desneux, E., Bearez, P., ... Desneux, N. (2018). Nitrogen and water inputs to tomato plant do not trigger bottom-up effects on a leafminer parasitoid through host and non-host exposures. *Pest Management Science*, 74(3), 516–522. <https://doi.org/10.1002/ps.4750>
- Du, X., Yan, J. J., Zhang, M. D., Ali, A., Gao, Y. L., & Hu, X. Q. (2022). Population dynamics of eight pests on different potato cultivars in Southwest China. *International Journal of Pest Management*, 1–10. <https://doi.org/10.1080/09670874.2022.2077467>
- Emery, S. E., & Mills, N. J. (2020). Effects of predation pressure and prey density on short-term indirect interactions between two prey species that share a common predator. *Ecological Entomology*, 45(4), 821–830. <https://doi.org/10.1111/een.12855>
- FAO (2023). FAOSTAT statistics database. <https://www.fao.org/faostat/zh/#data/QCL>. Updated on March 24, 2023.
- Fu, K. Y., Li, A. M., Ding, X. H., Jia, Z. Z., Ahmat, T. E. X., Rouzi, A. Z. G., ... Guo, W. C. (2023). The effect of different ecological factors on *Trichogramma pintoi* (Voegelé) parasitizing eggs of tomato leafminer, *Tuta absoluta* (Meyrick). *Zhongguo Shengwu Fangzhi Xuebao*, 39(3), 507–513. <https://doi.org/10.16409/j.cnki.2095-039x.2023.01.011>
- Guedes, R. N. C., Roditakis, E., Campos, M. R., Haddi, K., Bielza, P., Siqueira, H. A. A., ... Nauen, R. (2019). Insecticide resistance in the tomato pinworm *Tuta absoluta*: Patterns, spread, mechanisms, management and outlook. *Journal of Pest Science*, 92(4), 1329–1342. <https://doi.org/10.1007/s10340-019-01086-9>
- Guillemaud, T., Blin, A., Le Goff, I., Desneux, N., Reyes, M., Tabone, E., ... Lombaert, E. (2015). The tomato borer, *Tuta absoluta*, invading the Mediterranean Basin, originates from a single introduction from Central Chile. *Scientific Reports*, 5(1), 8371. <https://doi.org/10.1038/srep08371>
- Han, P., Lavoit, A. V., Le Bot, J., Amiens-Desneux, E., & Desneux, N. (2014). Nitrogen and water availability to tomato plants triggers bottom-up effects on the leafminer *Tuta absoluta*. *Scientific Reports*, 4(1), 4455. <https://doi.org/10.1038/srep04455>
- Han, P., Desneux, N., Michel, T., Le Bot, J., Seassau, A., Wajnberg, E., ... Lavoit, A. V. (2016). Does plant cultivar difference modify the bottom-up effects of resource plant limitation on plant-insect herbivore interactions? *Journal of Chemical Ecology*, 42(12), 1293–1303. <https://doi.org/10.1007/s10886-016-0795-7>
- Han, P., Zhang, Y. N., Lu, Z. Z., Wang, S., Ma, D. Y., Biondi, A., & Desneux, N. (2018). Are we ready for the invasion of *Tuta absoluta*? Unanswered key questions for elaborating an Integrated Pest Management package in Xinjiang, China. *Entomologia Generalis*, 38(2), 113–125. <https://doi.org/10.1127/entomologia/2018/0739>
- Han, P., Bayram, Y., Shaltiel-Harpaz, L., Sohrabi, F., Saji, A., Esenali, U. T., ... Desneux, N. (2019a). *Tuta absoluta* continues to disperse in Asia: Damage, ongoing management and future challenges. *Journal of Pest Science*, 92(4), 1317–1327. <https://doi.org/10.1007/s10340-018-1062-1>
- Han, P., Desneux, N., Becker, C., Larbat, R., Le Bot, J., Adamowicz, S., ... Lavoit, A. (2019b). Bottom-up effects of irrigation, fertilization and plant resistance on *Tuta absoluta*: Implications for Integrated Pest Management. *Journal of Pest Science*, 92(4), 1359–1370. <https://doi.org/10.1007/s10340-018-1066-x>
- Han, P., Becker, C., Le Bot, J., Larbat, R., Lavoit, A. V., & Desneux, N. (2020). Plant nutrient supply alters the magnitude of indirect interactions between insect herbivores: From foliar chemistry to community dynamics. *Journal of Ecology*, 108(4), 1497–1510. <https://doi.org/10.1111/1365-2745.13342>
- Han, P., Lavoit, A. V., Rodriguez-Saona, C., & Desneux, N. (2022). Bottom-up forces in agroecosystems and their potential impact on arthropod pest management. *Annual Review of Entomology*, 67(1), 239–259. <https://doi.org/10.1146/annurev-ento-060121-060505>
- Han, P., Rodriguez-Saona, C., Zalucki, M. P., Liu, S. S., Desneux, N. (2024). A theoretical framework to improve the adoption of green Integrated Pest Management tactics. *Communications Biology* 7, 337. <https://doi.org/10.1038/s42003-024-06027-6>
- He, Y. C., Ma, L. H., Pu, Q., Mao, Z. Y., Wang, S. M., Wang, T. Z., ... Zhu, Z. R. (2022). Greenhouse trapping assessment and population dynamics of leaf miner *Tuta absoluta* (Meyrick) in E-Shan, Southwest China. *International Journal of Pest Management*, 1–8. <https://doi.org/10.1080/09670874.2022.2084177>
- Ismoilov, K., Wang, M. H., Jalilov, A., Zhang, X., Lu, Z. Z., Saidov, A., ... Han, P. (2020). First report using a native lacewing species to control *Tuta absoluta*: From laboratory trials to field assessment. *Insects*, 11(5), 286. <https://doi.org/10.3390/insects11050286>
- Ji, S. X., Bi, S. Y., Wang, X. D., Wu, Q., Tang, Y. H., Zhang, G. F., ... Liu, W. X. (2022). First report on CRISPR/Cas9-Based genome editing in the destructive invasive pest *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). *Frontiers in Genetics*, 13, 865622. <https://doi.org/10.3389/fgene.2022.865622>
- Jiang, Z. X., Wu, D. H., Yang, S. W., Li, Y. R., Yang, Z. X., Yang, M. X., ... Zhang, X. M. (2022). Effects of deltamethrin on the predatory ability of *Orius similis* against *Tuta absoluta*. *Plant Protection*, 48(06), 127–132. <https://doi.org/10.16688/j.zwbh.2022395>
- Li, X. W., Li, D., Zhang, Z. J., Huang, J., Zhang, J. M., Hafeez, M., ... Lu, Y. B. (2021). Supercooling capacity and cold tolerance of the South American tomato pinworm, *Tuta absoluta*, a newly invaded pest in China. *Journal of Pest Science*, 94(3), 845–858. <https://doi.org/10.1007/s10340-020-01301-y>
- Liu, X. X., Yang, M. L., Arnó, J., Kriticós, D. J., Desneux, N., Zalucki, M. P., & Lu, Z. Z. (2023). Protected agriculture matters: Year-round persistence of *Tuta absoluta* in China where it should not. *Entomologia Generalis*, 44, 279–287. <https://doi.org/10.1127/entomologia/2023/1784>

- Luo, M. L., Tian, X. C., Liu, W. X., Zhang, G. F., He, Y. S., Chen, X. L., ... Yu, L. (2022). Assessment of the fitnesses traits of a major invasive pest, *Tuta absoluta* (Meyrick) on four tobacco varieties. *Plant Protection*, 48(06), 162–168. <https://doi.org/10.16688/j.zwbh.2022340>
- Mansour, R., Brévault, T., Chailleux, A., Cherif, A., Grissa-Lebdi, K., Haddi, K., ... Biondi, A. (2018). Occurrence, biology, natural enemies and management of *Tuta absoluta* in Africa. *Entomologia Generalis*, 38(2), 83–111. <https://doi.org/10.1127/entomologia/2018/0749>
- Poelman, E. H., & Dicke, M. (2014). Plant-mediated interactions among insects within a community ecological perspective. In C. Voelckel & G. Jander (Eds.), *Annual Plant Reviews: Insect-Plant Interactions* (pp. 309–337). Wiley. <https://doi.org/10.1002/9781118829783.ch9>
- Salazar-Mendoza, P., Bento, J. M. S., Silva, D. B., Pascholati, S. F., Han, P., & Rodriguez-Saona, C. (2023). Bottom-up effects of fertilization and jasmonate-induced resistance independently affect the interactions between tomato plants and an insect herbivore. *Journal of Plant Interactions*, 18(1), 2154864. <https://doi.org/10.1080/17429145.2022.2154864>
- Sheng, S. M., Sun, Z. W., Ye, X. B., Ma, J. C., Zhang, Z., Xuan, W. J., ... Zhang, G. F. (2023). Preliminary report of trapping efficacy on *Tuta absoluta* using water pan sex pheromone traps in greenhouse. *Shandong Nongye Kexue*, 55(11), 26–29. <https://doi.org/10.14083/j.issn.1001-4942.2023.11.004>
- Wang, H., Xian, X. Q., Gu, Y. J., Castañé, C., Arnó, J., Wu, S., ... Zhang, Y. B. (2022). Similar bacterial communities among different populations of a newly emerging invasive species, *Tuta absoluta* (Meyrick). *Insects*, 13(3), 252. <https://doi.org/10.3390/insects13030252>
- Wang, R. J., Dai, X. Y., Liu, Y., Chen, H., Su, L., Zhang, F., ... Zhai, Y. F. (2023). Predatory capability of *Orius sauteri* adults on eggs of tomato leaf miner (*Tuta absoluta*). *Shandong Nongye Kexue*, 55(11), 35–39. <https://doi.org/10.14083/j.issn.1001-4942.2023.11.006>
- Wang, X. D., Ji, S. X., Bi, S. Y., Tang, Y. H., Zhang, G. F., Yan, S., ... Liu, W. X. (2023). A promising approach to an environmentally friendly pest management solution: Nanocarrier-delivered dsRNA towards controlling the destructive invasive pest *Tuta absoluta*. *Environmental Science. Nano*, 10(4), 1003–1015. <https://doi.org/10.1039/D2EN01076C>
- Wang, Y. S., Tian, X. C., Wang, H., Castañé, C., Arnó, J., Wu, S. R., ... Wan, F. H. (2023). Genetic diversity and genetic differentiation pattern of *Tuta absoluta* across China. *Entomologia Generalis*, 43(6), 1171–1181. <https://doi.org/10.1127/entomologia/2023/2026>
- Wang, M. H., Ismoilov, K., Li, H., Zhang, X., Lu, Z. Z., Feng, L. K., ... Han, P. (2021). Polygyny of *Tuta absoluta* may affect sex pheromone-based control techniques. *Entomologia Generalis*, 41(4), 357–367. <https://doi.org/10.1127/entomologia/2021/1174>
- Xi, M. S., Wang, Z. L., Liu, X. X., Li, Z. H., Zhang, X., Lu, Z. Z., & Han, P. (2022). Assessment of the economic loss to the tomato industry caused by *Tuta absoluta* in China based on @risk. *Journal of Biosafety*, 31(4), 300–308. <https://doi.org/10.3969/j.issn.2095-1787.2022.04.002>
- Xian, X. Q., Han, P., Wang, S., Zhang, G. F., Liu, W. X., Desneux, N., & Wan, F. H. (2017). The potential invasion risk and preventive measures against the tomato leafminer *Tuta absoluta* in China. *Entomologia Generalis*, 36(4), 319–333. <https://doi.org/10.1127/entomologia/2017/0504>
- Yang, W. J., Yan, X., Han, P., Wang, M. H., Zhang, C., Song, J. H., ... Wan, F. H. (2023). Ovarian development and role of vitellogenin gene in reproduction of the tomato leaf miner *Tuta absoluta*. *Entomologia Generalis*, 44, 423–432. <https://doi.org/10.1127/entomologia/2023/2024>
- Yao, F. L., Monticelli, L. S., Boll, R., Konan, K. A. J., Thomine, E., Scala, M., ... Desneux, N. (2022). Combining mirid predators to reduce crop damage and sustain biocontrol in multi-prey systems. *Journal of Pest Science*, 95, 1645–1657. <https://doi.org/10.1007/s10340-022-01560-x>
- Yin, Y. Q., Zheng, L. P., Li, F. Q., Ma, T. C., Song, W. H., Chen, F., ... Chen, A. D. (2021). Occurrence and control of *Tuta absoluta* (Meyrick) in Midu County, Yunnan Province. *Huanjiang Kunchong Xuebao*, 43(03), 559–566. <https://doi.org/10.3969/j.issn.1674-0858.2021.03.4>
- Zhang, G. F., Ma, D. Y., Wang, Y. S., Gao, Y. H., Liu, W. X., Zhang, R., ... Wan, F. H. (2020). First report of the south American tomato leafminer, *Tuta absoluta* (Meyrick), in China. *Journal of Integrative Agriculture*, 19(7), 1912–1917. [https://doi.org/10.1016/S2095-3119\(20\)63165-3](https://doi.org/10.1016/S2095-3119(20)63165-3)
- Zhang, G. F., Xian, X. Q., Zhang, Y. B., Liu, W. X., Liu, H., Feng, X. D., ... Dai, A. (2021). Outbreak of the south American tomato leafminer, *Tuta absoluta*, in the Chinese mainland: Geographic and potential host range expansion. *Pest Management Science*, 77(12), 5475–5488. <https://doi.org/10.1002/ps.6588>
- Zhang, G. F., Zhang, Y. B., Zhao, L., Wang, Y. S., Huang, C., Lü, Z. C., ... Wang, F. L. (2023). Determination of hourly distribution of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) using sex pheromone and ultraviolet light traps in protected tomato crops. *Horticulturae*, 9(3), 402. <https://doi.org/10.3390/horticulturae9030402>
- Zhang, Y. B., Tian, X. C., Wang, H., Castañé, C., Arnó, J., Collatz, J., ... Zhang, G. F. (2022a). Host selection behavior of a host-feeding parasitoid *Necremnus tutae* on *Tuta absoluta*. *Entomologia Generalis*, 42(3), 445–456. <https://doi.org/10.1127/entomologia/2021/1246>
- Zhang, Y. B., Tian, X. C., Wang, H., Castañé, C., Arnó, J., Wu, S. R., ... Zhang, G. F. (2022b). Nonreproductive effects are more important than reproductive effects in a host feeding parasitoid. *Scientific Reports*, 12(1), 11475. <https://doi.org/10.1038/s41598-022-15296-2>
- Zhao, J. Y., Ma, L., Song, C. F., Xue, Z. S., Zheng, R. R., Yan, X. Z., & Hao, C. (2023). Modelling potential distribution of *Tuta absoluta* in China under climate change using CLIMEX and MaxEnt. *Journal of Applied Entomology*, 147(10), 895–907. <https://doi.org/10.1111/jen.13181>
- Zhou, S. X., Li, X. W., Zhang, J. M., Liu, C. G., Huang, J., Zhang, Z. J., ... Lu, Y. B. (2023a). Screening the optimal dose of gamma radiation for *Tuta absoluta* sterility: Paving the way for sterile insect technique programs. *Entomologia Generalis*, 44, 415–422. <https://doi.org/10.1127/entomologia/2023/1898>
- Zhou, J. H., Luo, W. F., He, W., Sun, X. J., Zhong, W. J., & Xu, J. J. (2023b). Evaluation of feeding capacity and growth and development of *Tuta absoluta* (Lepidoptera: Gelechiidae) based on functional responses and two-sex life table. *Acta Entomologica Sinica*, 66(4), 531–537. <https://doi.org/10.16380/j.kcxb.2023.04.010>

Manuscript received: November 23, 2023

Revisions requested: January 31, 2024

Revised version received: February 26, 2024

Manuscript accepted: March 4, 2024