Liu and Ji *CABI Agriculture and Bioscience* (2024) 5:90
https://doi.org/10.1186/s43170-024-00284-5

CABI Agriculture and Bioscience

REVIEW **Open Access**

Review of *Zeugodacus tau* (Walker) (Diptera: Tephritidae): biological characteristics and control strategy

Xuxiang Liu[1] and Qinge Ji[1*]

Abstract

Zeugodacus tau is an important worldwide quarantine pest. The female adults insert their oviposition tube into the fruit epidermis to lay eggs, and the larvae feed inside the fruit. Therefore, the hazard of *Z. tau* primarily rely on adult egg laying and larval feeding. *Zeugodacus tau* is widely distributed in China and has caused serious economic losses to the industry of fruit and vegetable. Due to the need for a systematic compilation of basic biological knowledge and the increasing economic importance of fruits and vegetables, this paper systematically summarized the distribution and damage, morphological characteristics, biological characteristics and control strategies of *Z. tau*. Basic biological knowledge, such as geographical distribution, host species, the characteristics of its damage, spread, and transmission, characteristics of each insect stage, occurrence generations, growth and development, population dynamics, and living habits, will deepen our understanding of *Z. tau*. Preventive measures, such as risk analysis, prediction of suitable areas and quarantine monitoring, can guide pest prevention for crop production in safe areas. Management measures, such as agricultural control represented by fruit bagging and clean fields, physical and chemical attractants designed and developed by the characteristics of colour, phototaxis and chemotaxis, chemical control based on new green pesticides, biological control supported by predatory and parasitic natural enemies, can fully guide the integrated prevention and control of *Z. tau*. Depending on the size of the planting management area, both broad-area joint prevention and control as well as localized comprehensive management can be flexibly selected. While ensuring economic benefits, it also takes into account the cost input, and is committed to achieving an economically efficient and long-term green control of *Z. tau*.

Keywords *Zeugodacus tau*, Biology, Morphological characteristic, Control, Management

Background

Zeugodacus tau (Walker 1849) (Diptera: Tephritidae) is a serious fruit-boring insect pest (Jaleel et al. 2018; Noman et al. 2021), and the potential economic loss to the Chinese pumpkin industry is as high as ¥23,157,830,800 (Fang et al. 2015). Walker (1849), first reported *Z. tau* in Fujian, China at which time it was classified as belonging to the genus *Dacus*. The genus was, however, later revised to *Bactrocera* and *Zeugodacus* (Walker 1849; Singh et al. 2010; Liu et al. 2023). *Zeugodacus tau* is a phytophagous insect, and its larva is latent feeding insect, which can damage various parts of the host (Guo et al. 2023). *Zeugodacus tau* has a wide range of hosts and strong fecundity and adaptability, and many countries and regions have listed *Z. tau* as a key quarantine species (Zhou et al. 1993; Hasyim et al. 2016).

---

*Correspondence:
Qinge Ji
jiqinge@yeah.net
[1] Biological Control Research Institute, Fujian Agriculture and Forestry University, The Joint FAO/IAEA Division Cooperation Center for Fruit Fly Control in China, Key Laboratory of Biopesticide and Chemical Biology, Ministry of Education, State Key Laboratory of Ecological Pest Control for Fujian and Taiwan Crops, Fuzhou 350002, People's Republic of China

As the most basic and important characteristic component of pests, biological characteristics are important reference for establishing integrated pest management (IPM) systems (Liang et al. 2020; Yao et al. 2021a; Duan et al. 2022). Therefore, it is necessary to fully understand the basic biological characteristics of *Z. tau*. However, early studies on the biological characteristics of *Z. tau* were relatively broad and did not detail the characteristics of each stage (Batra 1968; Gupta and Verma 1993). The increasingly serious damage caused by *Z. tau* urges us to further study the biological characteristics and control strategies of *Z. tau* (Boopathi et al. 2017; Sharma and Tiwari 2020). Therefore, this paper reviews the research progress on the distribution, damage, morphological characteristics, biological characteristics and control strategies of *Z. tau*, aiming to provide basic guidelines for IPM of *Z. tau*.

Geographical distribution

Zeugodacus tau has a wide distribution, primarily including China, India, Korea, Japan, Vietnam, Myanmar, Thailand, Laos, Bhutan, Brunei, the Philippines, Cambodia, Nepal, Singapore, Bangladesh, Malaysia, Sri Lanka and Indonesia (Allwood and Drew 1997; Akhtaruzzaman et al. 1999; Ohno et al. 2008; Kitthawee and Rungsri 2011; Prabhakar 2011; Jaleel et al. 2018). In China, *Z. tau* is primarily distributed in Fujian, Jiangxi, Guangdong, Taiwan, Hainan, Zhejiang, Anhui, Hunan, Hubei, Yunnan, Guizhou, Sichuan, Chongqing, Guangxi, Henan, Shanxi, Shaanxi and Gansu (Fig. 1), and especially in South China, where *Z. tau* occurs in large numbers, has many host species and causes serious damage (Wang et al. 2007; Sh et al. 2014; Li et al. 2020). In India, *Z. tau* is primarily distributed in Delhi, Sikkim, Jammu, Punjab, Uttar Pradesh, Kashmir, Uttar Pradesh, Bihar, Kerala, Uttarakhand, Mizoram, Tripura, Himachal Pradesh, West Bengal, Haryana, Karnataka, Meghalaya, Chhattisgarh, Tamil Nadu and Maharashtra (Agarwal and Sueyoshi 2005; Prabhakar 2011; Nair et al. 2017).

Host species

Zeugodacus tau has a wide host range (25 family, 62 species), and it is commonly found in species of the cucurbit family, such as pumpkin and luffa. Other species, such as, guava, jackfruit, passion fruit, heart fruit, mulberry, apple, eggplant, tomato, star fruit, capsicum, string bean, mango and peach, also serve as hosts (Table 1) (Khan et al. 2011; Li et al. 2014; Karnjanaungkool and Julsirikul 2021). For host selection, adult fruit flies primarily use vision and olfaction to search for and identify host plants. Therefore, exploring the selection of host plants by phytophagous insects and the relationships between them will elucidate the damage mechanism of fly pests, and provide scientific evidence for formulating control strategies (Niu et al. 2023).

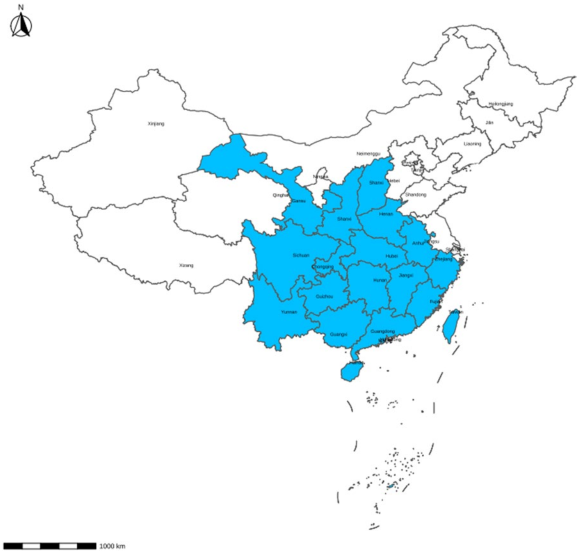

Fig. 1 Distribution map of *Zeugodacus tau* (blue-colored areas) in China

Damage symptoms

The oviposition tube of adult female *Z. tau* pierces into the pericarp and penetrates deep into the flesh to lay egg. This process creates egg piles in a similar manner as other fly pests. Hatched larvae feed on the flesh during development. The skin of the fruit rots and turns brown and black. Severely damaged fruits are often entirely consumed and most rot and fall. Less damage to fruit causes poor growth, which results in deformity thus affecting fruit quality and economic value. *Zeugodacus tau* is quite active and causes severe damage during its larval stage. Larvae move soon after hatching and continually eat the insides of fruits. Third-instar larvae eat the most and cause the most serious damage (Zhang et al. 1991; Deng 1992).

Dispersal and spread

Zeugodacus tau has strong flight and dispersal capabilities. The adult's flight (feeding, mating, and migration) and the spread aided by air currents are the main pathways for the natural dispersal of *Z. tau*. Unintentional human factors also play a crucial role. Trade transportation, especially fruit export from endemic areas, provides a way for the long-distance spread of fruit fly eggs and larvae hidden within the fruit. The pests are difficult to be found and have strong concealment (Huang et al. 2005; Gong et al. 2016; Ma et al. 2020).

Table 1 A comprehensive list of plant host species for *Zeugodacus tau*

Family	Host species	Common names	References
Anacardiaceae	*Mangifera foetida*	Horse mango	Tan and Lee (1982)
	Mangifera indica	Mango	Liu et al. (2005), Wee and Shelly (2013)
Arecaceae	*Borassus flabellifer*	Candied coconut	Allwood et al. (1999)
Caricaceae	*Carica papaya*	Pawpaw	Borah and Dutta (1996)
Celastraceae	*Siphonodon celastrineus*	–	Jamnongluk et al. (2003), Sumrandee et al. (2011)
Cruciferae	*Brassica oleracea*	Cabbage	Yuan (2022)
Cucurbitaceae	*Benincasa hispida*	Wax gourd	Julsirikul et al. (2019)
	Citrullus lanatus	Watermelon	Clausen et al. (1965), Allwood et al. (1999)
	Coccinia grandis	Ivy gourd	Allwood et al. (1999), Kitthawee and Dujardin (2010)
	Cucumis anguria	Anguria melon	Lin et al. (2005)
	Cucumis melo	Muskmelon	Allwood et al. (1999)
	Cucumis sativus	Cucumber	Lin et al. (2005), Kitthawee and Dujardin (2010), Prabhakar et al. (2012)
	Cucurbita maxima	True squash	Lin et al. (2005), Prabhakar et al. (2012)
	Cucurbita moschata	Pumpkin	Huque (2006), Kitthawee and Dujardin (2010)
	Cucurbita pepo	Zucchini	Allwood et al. (1999), Prabhakar et al. (2012)
	Diplocyclos palmatus	Small cucumbers	White and Elson-Harris (1992)
	Gomphogyne cissiformis	–	Allwood et al. (1999)
	Gymnopetalum integrifolium	–	Allwood et al. (1999)
	Gymnopetalum scabrum	–	Allwood et al. (1999)
	Lagenaria siceraria	Gourd	Clausen et al. (1965), Lin et al. (2005), Prabhakar et al. (2012), Nair et al. (2017)
	Luffa acutangula	Loofah	Allwood et al. (1999)
	Luffa aegyptiaca	Snake melon	Lin et al. (2005), Khan et al. (2011), Drew and Romig (2013), Julsirikul et al. (2019)
	Momordica charantia	Bitter melon	Prabhakar et al. (2012), Julsirikul et al. (2019)
	Momordica cochinchinensis	Quaker button	Kitthawee and Dujardin (2010), Dujardin and Kitthawee (2013)
	Momordica dioica	–	Nair et al. (2017)
	Sechium edule	Chayote	He et al. (2023)
	Siraitia grosvenorii	Monk fruit	Deng (1992), Pu et al. (1998)
	Trichosanthes cordata	–	Allwood et al. (1999)
	Trichosanthes rubriflos	–	Allwood et al. (1999)
	Trichosanthes cucumerina	–	Nair et al. (2017)
	Trichosanthes ovigera	–	Allwood et al. (1999)
	Trichosanthes tricuspidata	–	Clausen et al. (1965), Allwood et al. (1999), Kitthawee and Dujardin (2010)
	Trichosanthes wallichiana	–	Allwood et al. (1999)
	Zehneria wallichii	–	Allwood et al. (1999)
Fabaceae	*Phaseolus vulgaris*	Green bean	Allwood et al. (1999)
Flacourtiaceae	*Hydnocarpus anthelminthica*	–	Jamnongluk et al. (2003), Sumrandee et al. (2011)
Loganiaceae	*Fagraea ceilanica*	–	Allwood et al. (1999)
	Strychnos nux-vomica	Bitter fruit	Allwood et al. (1999)
Malvaceae	*Abelmoschus esculentus*	Okra	Yuan (2022)
Melastomataceae	*Melastoma malabathricum*	–	Drew and Romig (2013)
Moraceae	*Artocarpus heterophyllus*	Jackfruit	Clausen et al. (1965), Drew and Romig (2013)
	Ficus racemosa	–	Allwood et al. (1999)
	Ficus tinctoria	–	Drew and Romig (2013)
Muntingiaceae	*Muntingia calabura*	Jamaica cherry	Drew and Romig (2013)
Myrtaceae	*Psidium guajava*	Guava	Allwood et al. (1999)
	Syzygium malaccense	–	Drew and Romig (2013)
Oleaceae	*Myxopyrum smilacifolium*	–	Allwood et al. (1999)
Oxalidaceae	*Averrhoa carambola*	Carambola	Wee and Shelly (2013)
Passifloraceae	*Passiflora edulis*	Passion fruit	Octriana (2010), Drew and Romig (2013), Hasyim et al. (2016)

Table 1 (continued)

Family	Host species	Common names	References
Poaceae	*Bambusa pallida*	–	Drew and Romig (2013)
Rosaceae	*Prunus salicina*	Mountain plum	Lin et al. (2005)
Rubiaceae	*Morinda citrifolia*	–	Drew and Romig (2013)
Rutaceae	*Citrus maxima*	Shaddock	Drew and Romig (2013)
	Citrus reticulata	Citrus	Liu et al. (2005)
	Citrus sinensis	Orange	Jaleel et al. (2018)
Sapindaceae	*Dimocarpus longan*	Longan	Borah and Dutta (1996)
Sapotaceae	*Manilkara zapota*	Naseberry	Borah and Dutta (1996), Drew and Romig (2013)
Solanaceae	*Capsicum annuum*	Chili	Borah and Dutta (1996), Pal and Choudhuri (2007)
	Capsicum frutescens	–	Borah and Dutta (1996)
	Solanum lycopersicum	Tomato	Boopathi et al. (2017)
	Solanum muricatum	Ciku	Lin et al. (2005)
Vitaceae	*Vitis vinifera*	Grape	Jaleel et al. (2018)

CABI (2024)

Morphological characteristics

Eggs

The morphology of *Z. tau* egg have been described by several authors (Singh et al. 2010; Sharma and Tiwari 2020). According to these researchers, the eggs of *Z. tau* have similar size of approximately 1.30 ± 0.07 mm × 0.24 ± 0.04 mm and 1.31 ± 0.01 mm × 0.24 ± 0.00 mm (Singh et al. 2010; Sharma and Tiwari 2020). *Zeugodacus tau* eggs are white, glossy and prismatic in shape. The front end of the egg is pointed, the tail is slightly rounded, and the egg becomes darker as it nears hatching. The eggshells have polygonal dots. Fertilized eggs with thicker shells are translucent and sink in water, and unfertilized eggs with damaged shells are transparent and float (Fig. 2A) (Zhang et al. 1991; Singh et al. 2010; Sharma and Tiwari 2020).

Larvae

Zeugodacus tau larvae are divided into three instars (Zhang and Chen 2018). The body lengths of the first, second and third instars are 3.80 ± 0.07 mm × 0.55 ± 0.10 mm, 4.15 ± 0.73 mm × 1.25 ± 0.19 mm and 8.02 ± 1.02 m

Fig. 2 Morphological characteristics of the eggs (**A**), larvae (**B**), pupae (**C**) and adults (**D**) of *Zeugodacus tau*

m × 1.52 ± 0.17 mm, respectively. First-instar larvae with fewer markings are mostly translucent and less hardened. Second-instar larvae are milky white and slightly sclerotic. Third-instar larvae are yellowish white, with a thin head and a thick tail (Singh et al. 2010). The head is conical, and the mouth hook is black (Zhang et al. 1991). There are two spiracles: the anterior spiracle is annular with 14–18 digitations, and the posterior spiracle is crescentic with yellow holes. There are 3 pairs of long oval valve cracks, each of which is large and radially arranged, and the edges are obviously hardened (Zhang and Chen 2018). In the anal region, the lobes are large and protruded, surrounded by 2–6 discontinuous rows of small spikes. The spike closest to the anal lobe is thick, long and curved. After approximately two weeks, the larvae stop feeding and pupate in sand or soil (Fig. 2B) (White and Elson-Harris 1992; Singh et al. 2010).

Pupae

Zeugodacus tau pupae are oval in shape and approximately 4.90 ± 0.35 mm × 1.95 ± 0.29 mm in size (Singh et al. 2010). Pupae are light yellow at first then gradually darkens to reddish-brown (Deng 1992). The front and rear are round, the sides are slightly curved outwards, and traces of the front and rear spiracles are seen at both ends of the body (Fig. 2C) (Zhang et al. 1991; Singh et al. 2010).

Adults

Adults bodies are yellowish-brown to reddish-brown in colour, with an average length of 6–9 cm. The body length of female adults is generally greater than male adults. There is a red spot on the top of the head, and the head is yellow with 2 medium-sized black oval facial spots. The midsternal midplane is yellowish-brown with 3 yellow bands on the posterior side, and the scutellum is yellow with bristles (An et al. 2011). The wings are approximately 6–8 cm long, with a leading edge width of R_{2+3} veins that spread to a large brown spot (Singh et al. 2010). The brown transverse band and spotted short band are located at the leading edge of the second and third backplanes and the lateral edge of the fourth and fifth backplanes, respectively. The black longitudinal strip, which is sometimes cut off by the internode, is located in the middle of the backplane of the third to fifth backplanes and forming a "T" shape with the baseband on the basal segment. The feet are yellow, and the middle and hind tibia are reddish-brown or brown (Huang 2017). The end of ventral ovipositor of female adult is pointed, and the third backplane of male adult has a pectinate seta (Zhang and Chen 2018). The posterior lobe of the lateral caudal leaf is long, and the stereoscopic stripes are wide and dark. The time for adult flies to reach sexual maturity varies slightly due to factors such as food, weather and season. In most cases, it takes approximately two weeks to reach sexual maturity. For example, the duration of immature stage decreased with increasing temperature when muskmelon was breeding host. The time to sexual maturity of long-term domesticated strains in the laboratory is significantly shorter than wild strains (Fig. 2D) (Cayol 1999; Liu and Lin 2000; Agarwal and Sueyoshi 2005; Singh et al. 2010; An et al. 2011).

Biological characteristics

Generation

The number of generations of *Z. tau* varies by regions, ranging from one to several generations per year, with a severe overlap of insect generations. Overlapping may occur within eight generations in Xiamen, five generations in Huangyan, three to five generations in Guangxi, three to four generations in Hangzhou, and one generation in Longdong. *Zeugodacus tau* overwinter as adults or pupae, and adults overwinter in late November. Reproduction ceases at this time, but there is no diapause phenomenon, and normal adult activity may be observed when temperature conditions become suitable. Pupae that overwintered in soil begin to emerge in late May of the subsequent year (Zhang et al. 1991; Zhou et al. 1993; Zhang and Chen 2018).

Growth and development

Similar to other insects, the development rate of *Z. tau* is significantly affected by temperature, which is an important factor influencing its growth, development, and reproduction. The starting temperature for development of *Z. tau* is 13.83 °C, and the effective accumulated temperature is 407.22 °C (Lin and Zhang 1989). The starting development temperatures of *Z. tau* eggs, larvae, pupae, males and females are 9.34 °C, 15.68 °C, 9.09 °C, 18.27 °C and 23.20 °C, respectively. The accumulated development temperatures of *Z. tau* eggs, larvae, pupae, males and females are 15.84 °C, 79.79 °C, 161.30 °C, 217.61 °C and 222.07 °C, respectively (Zhang et al. 1991). Different temperatures significantly affect the survival rate, development duration, development rate, fecundity and lifespan of *Z. tau* (Yuan et al. 2015a). There is an S-shaped curve between growth rate and temperature, and the optimum development temperature is 25–26 °C (Zhou et al. 1994; Zhou 2005). The eggs of *Z. tau* exhibit weak high-temperature tolerance but strong low-temperature tolerance, and they can tolerate low-temperature stress (Liu et al. 2022).

The growth and development of *Z. tau* are not only affected by temperature but also influenced by humidity, light, host and space height. With food spoilage or inadequacy, the mortality rates of first- and second-instar larvae increase, but third instar larvae pupate prematurely, resulting in a smaller body size. Mature larvae generally exit the infested fruit, bounce to the ground, and burrow into soil, sand, rocks, and crevices to pupate. Most larvae pupate in soil with a relative water content of 20%-60%. Pupal development duration was shortest in soil with 40% and 60% relative water content, and the emergence rate was highest. When the relative water content of the soil reached 100%, all of the pupae died (Li et al. 2009). The depth of pupation is related to the degree of soil porosity. The general depth of entered soil is 2–3 cm, but the depth of pupation may reach 10 cm when the soil is loose. When a suitable pupation environment cannot be found, pupation may be directly exposed. If *Z. tau* does not escape from the victim fruit, it may pupate directly in the injured fruit. A medium-long photoperiod is conducive to the growth and development of *Z. tau*. Southwood classified *Z. tau* as an ecological responder of the "r" type (r-strategists characteristics: high reproductive rate, low investment, rapid growth, high mortality) (Zhou et al. 1995).

Population dynamics

Due to differences in location and climatic conditions, the population dynamics of *Z. tau* adults differ between regions. In China, the peak period of adult *Z. tau* occurrence is throughout the year. The peak period varies from 1–2 (see the numbers in Table 2) and lasts 1–6 months (Table 2).

Biological habits

Adult *Z. tau* emergence occurs throughout the day, but especially from 9:00 to 10:00. Adults become sexually mature 8–14 days after emergence, and then the males and females begin to mate. Mating generally occurs at dusk approximately one hour or more after sunset and lasts 408.03 ± 235.93 min or all night (Kabir et al. 1997). On the third day after mating, females begin to lay fertile eggs, which are mostly laid between 16:00 and 17:00. Females *Z. tau* lay eggs in newly formed wounds and cracks on fruits. When laying eggs on intact fruits, female *Z. tau* arches its body so that the retractable oviposition tube penetrates the fruit to lay eggs at a depth of approximately 5 mm below the epidermis. An average of 16.01 ± 12.01 eggs per day are deposited. A female *Z. tau* can lay multiple eggs in the same or multiple oviposition holes. Each hole contains several to dozens of eggs, and a total of 464.6 ± 67.97 eggs may be laid. The oviposition interval varies from 1 to 5 days, and the oviposition period is approximately 50 days (Zhang et al. 1991; Zhou et al. 1993).

The egg stage of *Z. tau* is 1.30 ± 0.41 days, the first, second and third instar larval stages are 1.20 ± 0.42 days, 1.70 ± 0.48 days and 4.00 ± 0.94 days, respectively, and

Table 2 The peak occurrence of *Zeugodacus tau* adults in several regions of China

Location/Time (months)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	References
Ruili			**1**										Xiao et al. (2001)
Dehong					*1*								Chen et al. (2019)
Hainan					**1**								Lin et al. (2014)
Youxian									*1*				Chen et al. (2022)
Dali					**1**		**2**						Liu and Sun (2017)
Yongshan								*1*	*1*				Tang et al. (2013)
Changsha										**1**	**1**		Liu et al. (2012)
Xiuwen										*1*	*1*		Yu et al. (2022)
Liuyang						**1**	**1**			**1**			Xiang et al. (2021)
Xishuangbanna					*1*	*1*	*1*						Deng et al. (2006)
New Territories						**1**	**1**	**1**					Liang (2018)
Chongqing							*1*	*1*	*1*				Wang et al. (2006)
Hangzhou							**1**	**1**	**1**				Zhou et al. (2010)
Xinyang							*1*	*1*	*1*				Mao et al. (2019)
Nanyang								**1**	**1**	**1**			Lu and Zhao (2020)
Nanchang								*1*	*1*	*1*			Li et al. (2020)
Tengchong								**1**	**1**	**1**			Chen et al. (2021)
Wuhan							*1*	*1*	*2*	*2*			Zhang et al. (2018)
Xiamen						**1**	**1**	**1**	**1**	**1**	**1**		Zhang et al. (1991)
Guangzhou	1	1	1	1	1					2	2	2	Chen et al. (1995)

Numbers represent the order in which different peak periods appear, and the same numbers indicate the same peak period the pre-pupal and pupal stages are 1.20 ± 0.42 days and 7.00 ± 0.47 days, respectively. The cycle from egg to adult is 14.20 ± 1.69 days. The lifespans of male and female adults are 111.90 ± 26.35 days and 92.56 ± 33.05 days, respectively (Singh et al. 2010). A biological study of *Z. tau* from India showed that females laid 4–10 eggs alone or in clusters, with the eggs buried vertically or slightly diagonally within the fruit. The pre-oviposition, oviposition, post-oviposition and hatching periods are 10–16 days, 11–28 days, 1–4 days and 1–3 days, respectively. The mean larval stages of the first, second and third instars are 1.4 days, 1.8 days and 2.8 days, respectively, and the total larval stage is 6.0 days. The prepupal stage lasts for 0.9 days and the pupal stage lasted for 8.2 days. The average lifespans of males and females are 28.4 days and 31.6 days, respectively (Ashraf et al. 2022). The time difference of more than a decade in collecting the *Z. tau*, the different methods used, the differences in food sources, and the differences in experimental methods led to significant differences in the lifespan results of the two studies. Another study on the biology of *Z. tau* from Nepal showed that the egg-to-pupa stage of *Z. tau* was 26–30 days (Sharma and Tiwari 2020). The main differences between studies are the time and place of the investigation and the hosts.

Management strategy

With the continuous development of modern agriculture and the deepening of economic and trade globalization, the difficulty and cost of controlling *Z. tau* have gradually increased. Natural conditions, such as temperature, light and humidity, and ambient conditions, such as the abundance of host species in most areas of China, have created the growth, development and colonization hazards of *Z. tau*. Therefore, the distribution of *Z. tau* is becoming quite widespread in China. Because of the current situation and economic importance of *Z. tau*, comprehensive, specific and targeted control strategies are necessary.

Risk analysis

Conducting a risk analysis of *Z. tau* and assessing the concentration points of potential risks (Papadopoulos et al. 2024). Implementing scientifically risk management measures based on the level of risk can help to plan and formulate pest control strategies in advance, thereby achieving the best epidemic prevention and control effectiveness (Zhou 2012; Qin et al. 2015; Lv et al. 2016). The risk assessment of *Z. tau* requires a comprehensive consideration of bioclimatological conditions and geographical environments, and the full utilization of software, such as CLIMEX, GARP, GIS, MAXENT, MED-FOES, IT2FLS and VARMAX for scientific prediction and analysis of the specific suitable living areas and grades of *Z. tau* in China. This provide basic guidelines for formulating specific quarantine management measures (Wang et al. 2018; Wang 2019).

A computer model of the viability of fruit flies (CMVFF) was used to predict the viability of *Z. tau* in China. The results showed that the safety, slight danger, danger and high danger zones accounted for 66.72%, 23.88%, 2.24% and 7.16%, respectively (Huang 2010). The Maxent niche model and ArcGIS were used to predict the suitable areas of *Z. tau* in China according to four types of suitable area indicators. The results showed that the potential distribution areas of *Z. tau* were primarily central, southern and southwestern China (Wu 2014).

Quarantine and monitoring

Zeugodacus tau has been listed as a key quarantine pest in many countries. In May 2007, *Z. tau* was included on the List of Imported Plant Quarantine Pests of the People's Republic of China, issued by the Ministry of Agriculture and Rural Affairs of the People's Republic of China. Based on current geographical distribution and risk analysis of *Z. tau*, it is necessary to strengthen the entry quarantine of related trade transport goods and closely investigate the pest situation in suitable domestic areas to guard against pest outbreaks (Reddy et al. 2010; Hasyim et al. 2016). Common quarantine techniques include irradiation, fumigation, soaking, refrigeration and heat treatment (Hossain et al. 2011; Faheem et al. 2012; Follett and Snook 2013). The irradiation dose approved by the International Plant Protection Convention (IPPC) is 150 Gy (Hallman 2012). According to the principle of minimum dose, study demonstrated that 72 Gy and 85 Gy were the lowest radiation doses for *Z. tau* quarantine, and the inhibition rate of adult emergence was near 100% (Zhan et al. 2015). However, Hossain et al. suggested that radiation doses of 300–350 Gy should be used to ensure adequate killing of the eggs and larvae of *Z. tau* (Hossain et al. 2006). The use of methyl bromide is common in pest fumigation (Bell 2000). For temperature treatment of *Z. tau*, Liu et al. showed that the greatest tolerance to heat and cold treatment at the third-instar larvae. The upper limits of chill injury zone of 1-day-old pupae and 3-day-old adults were 2.50 °C and 2.51 °C, respectively, and the lower limit of thermal injury zone were 38.29 °C and 39.39 °C, respectively. This series of temperature parameters related to the cold and heat tolerance of *Z. tau* provide basis for quarantine treatment (Liu et al. 2022).

The detection and identification of fruit flies is key for control and management of fly pests, and it is an important guarantee for maintenance of non-infected and low-occurrence areas of fruit flies (Zhu et al. 2022). The technical core of fly monitoring includes establishing monitoring locations (considering many factors, such as surrounding host, hanging height, daily maintenance and collection of monitoring data, and setting density according to monitoring purpose), selecting of lures (e.g., sex lures, food lures and synthetic baits) and matching traps (e.g., dry, wet and mixed dry and wet types) (Kong et al. 2021). Since 2000, the Guangxi Entry-Exit Inspection and Quarantine Bureau, which relies on the work of quarantine fly monitoring performed by the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ), has used chemical information, remote sensing and biotechnology for monitoring and investigation, and it has established a three-dimensional monitoring system for fruit and vegetable fly pests. Nearly 3000 fly monitoring points have been established at ports under Guangxi's jurisdiction (Lu et al. 2014). The technology for automatic monitoring of fruit fly pests based on electronic sensors is increasingly popular. Compared to traditional methods, automatic methods are time- and labour-saving, efficient and accurate and provide more options for the monitoring of fruit flies (Lello et al. 2023).

Agricultural practices

Fruit bagging

Bagging can protect fruit from pests, birds, sun exposure, pathogens, physiological diseases, pesticide residues and abrasions and further change the microenvironment of fruit development to provide multiple beneficial effects on external and internal quality (Buthelezi et al. 2021). Different types of protective bags are selected according to the economic value of growing fruits and vegetables, and the packaging materials such as paper, plastic and composite (Sharma et al. 2014). In general, the input cost of protective bags is proportional to economic value of growing fruits and vegetables (Sarker et al. 2009; Ali et al. 2021). For fruits with high economic value, paper bags may be used to protect the fruits at young stage and guard against damage of *Z. tau* (Mao et al. 2020).

Clean farmland

Green and yellow fruit with obvious egg laying traces and larval infestations should be removed quickly, as well as fallen insect-infected fruit. The damaged fruits are burned, buried deep or soaked in medicinal liquid to prevent the spread of *Z. tau* (Zhang and Chen 2018; Ma et al. 2020). For high-quality organic agriculture plantations, weed removal is also an important part of cleaning fields. It can not only reduce the impact of weeds on crop yield but also significantly clear excessive hosts of pests, which plays a crucial role in the development of clean organic agriculture (Abouziena and Haggag 2016).

Deep ploughing

Digging deep into orchard soil can destroy the overwintering sites of insect pupae and expose more pupae to the surface. The pupae either die because they cannot adapt to the low temperatures, or they are eaten by birds and other animals, thereby reducing the base number of overwintering population (Kumar et al. 2020). Before the emergence of residual overwintering *Z. tau* pupae, ground spraying of chemical agents to kill pests (vegetables using ground cover film) may compensate for the defects of deep ploughing (Verghese et al. 2004; Wang and Zhang 2009).

Scientific management

Management measures, such as free-range poultry, timely pruning, rational distribution, selection of early (late) ripening and insect-resistant varieties, crop rotation, optimal density planting, improvement of cultivation can reduce the incidence of farm pests (Liang 2013). Raising chickens, ducks and geese in a free-range manner not only helps to clear the fields of pests and weeds, but also the manure produced by poultry can increase soil fertility. However, when using organic fertilizer, attention should be paid to its full fermentation and maturation treatment to fully increase fertility and maximize fertilizer efficiency (Clark and Gage 1996; Zhou 2022). A scientific and reasonable planting plan should be formulated based on the specific situations for fruits and vegetables, and the optimal planting density should be selected to ensure sufficient growth space. Reasonable crop rotation improves the soil environment and its physical and chemical properties, and promotes crop growth. These measures fully utilize limited land resources and improve utilization efficiency (Bullock 1992; Wang et al. 2021b). Planting early (late) ripe varieties of vegetables and using mulch film for cultivation can stagger the fruit set period of vegetables with the egg-laying period of fruit flies, while effectively suppressing the emergence of adult flies. Regular pruning of fruit trees to remove bad leaves and branches enhances tree strength and its ability to resist pests and diseases. Scientific and effective management adds new vigour and vitality to agricultural control measures.

Physicochemical induction

Sticky traps

Sticky traps are effective pest control tools based on the differences in colour preferences of insects. The yellow board, as a representative classic sticky trap, attracts a variety of pests using the pest's taxis to yellow. The bait-killing agent yellow board and sex pheromone yellow board effectively and stably control fly pests (Wu et al. 2007; Yao et al. 2021b; Yan et al. 2023). The yellow board may be reasonably improved by changing its shape and adding windproof devices, such as fixed holes and metal strips, which improve the efficiency of attracting insects and reducing the trap rate of natural enemies (Huang 2021, 2022; Tu et al. 2022). However, newly emerged adult *Z. tau* prefer green and avoid red (Zhou et al. 2009). Yellow and yellowish-green are suitable for attracting *Z. tau* at ages of 5–7 days and 30–32 days, respectively (Li et al. 2017a, b).

Phototaxis

Based on the phototaxis of *Z. tau*, frequency trembler grid lamps may be used at night to trap adults and other phototactic pests. Frequency trembler grid lamp trapping is low cost and produces marked effects. The switching of frequency trembler grid lamp with light control is automatic, time-saving, labour-saving, convenient and fast, and it is an important pollution-free pest control method (Wang and Zhang 2009).

Chemotaxis

The active substances in male and bisexual lures play important roles in the field of fly pest control. Male lures have strong species-specific properties, and bisexual lures attract a wider range of pests (Cai et al. 2018b). Cue lure (CL), raspberry ketone (RK) and zingerone (ZG) attract male *Z. tau* adults. CL is a standardized lure for the monitoring and trapping of *Z. tau* (Tan and Nishida 2000, 2005; Ohno et al. 2008). As early as 1984, an outdoor CL activity test of home make was performed in nursery of the Fujian Institute of Subtropical Botany on the outskirts of Xiamen. The results showed that CL attracted the largest number of *Z. tau* (Zhang and Lin 1987). A study in Indonesia showed that camphor, which is the main component of the extract of *Elsholtzia pubescens*, had a similar attractant effect as CL, and it has been used in passion fruit orchards to trap *Z. tau* (Hasyim et al. 2007, 2016). From 2008 to 2015, Li et al. used McPhail traps in an 8-year investigation of the population dynamics of *Z. tau* in northern Jiangxi Province. The results showed that *Z. tau* accounted for 68.12% of the total population trapped by the lure, and *Z. tau* introduced from Fujian to Jiangxi Province was the dominant population in invasion region (Li et al. 2020). Boopathi et al. investigated the species of fruit fly in Indian Himalayas using three types of fly traps equipped with CL and reported the relative abundance and seasonal population dynamics of *Z. tau*-infested tomatoes in this region for the first time (Boopathi et al. 2017).

The bisexual lure was developed based on the fact that fruit flies need to eat a certain amount of sugar and protein during the growth and development process to achieve synchronous control of male and female adults (Wang et al. 2021a). As an economical and safe lure for fly pests, protein baits have been studied for a hundred years. Fu demonstrated that protein baits effectively controlled *Z. tau* by hanging pot trapping and spot spraying (Fu 2011). Protein baits mixed with borax and trichlorfon and syrups mixed with arsenic and fenvalerate exhibited great control effects on *Z. tau* (Saikia and Dutta 1997; Chinajariyawong et al. 2003; Sunandita and Gupta 2001; Zhang 2014). With further research, solid lures with longer durations and different colours and shapes have been continuously produced and applied. A wax-based bait station with a mixture of sugar and toxic substances had excellent control effects on fly pests. However, more research is needed to develop new lures for *Z. tau* (Heath et al. 2009; Lin et al. 2022; Gan et al. 2023).

Host plant attractants

The use of plant resistance, plant extracts, plant secondary chemicals and their active components plays an important role in the control of fly pests. Li et al. confirmed that cucumbers, pumpkins and loofahs were the preferred oviposited fruits of *Z. tau* compared to citrus, winter and bitter melon (Li et al. 2007). Wang et al. studied the use of six kinds of fruits to induce female *Z. tau* adults to lay eggs and showed that ginger melon produced the most eggs from *Z. tau* (Wang et al. 2009). Yuan used a Y-type olfactometer to determine the effect of crude extracts from eight host plants on attracting *Z. tau* adults. The results showed that the crude extracts of eight host plants had obvious attraction effects (with relative attraction rates greater than 30.00%) on female *Z. tau* adults in their peak egg laying period. The hexane (40.83%) and ethanol (38.33%) extracts of papaya from Caricaceae, the ethyl acetate (32.50%) extract of pepino melon from Solanaceae and the ethyl acetate (31.12%) extract of pumpkin from Cucurbitaceae were obtained (Yuan 2022). *Melia azedarach* seeds, *Lantana camara* leaves, *Allium sativum* garlic heads, *Curcuma longa* bulbs and *Azadirachta indica* bulbs were fed different concentrations of ethanol extracts. With increasing feeding concentration, the phenomenon of delayed oviposition of *Z. tau* adults became more obvious (Thakur and Gupta 2012). Yuan et al. used the Y-type olfactometer and demonstrated that (E)-3-nonene-1-ol, n-hexadecane, octadecene and cili-3-hexene-1-ol had good attractant effects on *Z. tau* adults, and may be further developed as components of plant-derived lures for *Z. tau* adults (Yuan et al. 2023). Using Y-type olfactometry, Jia et al. used gas chromatography-mass spectrometry (GC–MS) to identify and analyse the volatile compounds of *Solanum muricatum* and demonstrated that nine compounds induced behavioural responses in adult female *Z. tau* (Jia et al. 2023).

Symbiotic bacteria

Symbiotic microorganisms in insects account for 1–10% of insect biomass, and symbiotic microorganisms play important roles in insect biological traits, diversity, ecological adaptability and stress resistance (Wang et al. 2021c). During long-term evolution, a unique reciprocal relationship formed between various microorganisms colonizing the gut of insects and their hosts, which provide unique survival advantages for the hosts (Feldhaar 2011; Jang and Kikuchi 2020). Bacteria are important symbionts of insect gut microbes, and their diversity is primarily influenced by host diet, developmental stage and environmental habitat (Yun et al. 2014; Luo et al. 2018). Forty-one species of Enterobacteriaceae bacteria were obtained from the intestinal bacteria of sexually mature *Z. tau* adults. *Enterobacter*, *Providencia* and *Serratia* were identified in the guts of male and female adults. All of the tested autoclave liquids had a significant attraction effect on *Z. tau*, and four strains of Enterobacterium had a good attraction effect on 8-day-old and sexually mature *Z. tau* (Luo 2016). Noman et al. identified intestinal bacteria in larvae, pupae, and male and female adults of *Z. tau*. Proteobacteria was the most representative phylum in each stage except larvae, and Firmicutes was the dominant phylum in larval stage. *Enterobacter*, *Providencia*, *Klebsiella* and *Pseudomonas* were identified in male and female adults, and *Enterobacter* was the main genus and had a positive impact on survival and reproduction of *Z. tau* (Noman et al. 2021). *Wolbachia*, which can kill males, feminize, induce parthenogenesis, and induce cytoplasmic incompatibility, can also infect *Z. tau*. Further exploration of the relationships between *Wolbachia* and *Z. tau* will reveal more symbiotic bacteria for the control of fruit fly (Liu et al. 2006; Kitthawee and Dujardin 2010; Mateos et al. 2020; Zheng et al. 2022).

Sterile insect technique

Since Knipling showed that the release of large numbers of sterile males effectively suppressed the natural *Cochliomyia hominivorax* population, the usefulness of the irradiation-based sterile insect technique (SIT) in the field of pest control has been gradually examined (Knipling 1955). Studies on the use of SIT for controlling *Bactrocera dorsalis*, *B. tryoni*, *Ceratitis capitata* and *Z. cucurbitae* were performed earlier and in larger numbers (Steiner et al. 1965, 1970; Andreawartha et al. 1967; Harris et al. 1986). The results of related studies on *Z. tau* showed that the proportion of infertile and malformed flies increased with increasing radiation dose. When virgin females mated with irradiated males at a certain proportion, the quality of offspring gradually deteriorated as the proportion of irradiated males increased (Islam et al. 2012). The radiation tolerance of *Z. tau* increased with increasing age and developmental stage (Zhan et al. 2015). Pan et al. showed that the irradiation effect of ^{60}Co at 100 Gy on the pupae of *Z. tau* 2 days before emergence was ideal for SIT (Pan 2013; Du et al. 2016). The fecundity and egg hatching rate of female *Z. tau* adults were significantly decreased by irradiation with ^{60}Co-γ above 150 Gy, and the ovaries and fallopian tubes of female adults became smaller. When the eggs, first- and third-instar larvae and pupae of *Z. tau* were treated with 250–350 Gy of ^{60}Co-γ, complete F1 sterility was achieved. Total F1 death was achieved in all ages of *Z. tau* treated with 400 Gy (Cai et al. 2018a; Yang et al. 2018).

Chemical control

Organophosphates, neonicotinoids and pyrethroids exhibited good controlling effects on *Z. tau* (Ao et al. 2019). Using dipping method, Mao et al. determined the virulence of 12 insecticides against *Z. tau* pupae and the effect of bivalent mixture. The test showed that dipterex and phoxim (1:9) and phoxim and chlorpyrifos (9:1) significantly controlled *Z. tau* (Mao et al. 2012). Cai et al. tested the activity of 10 pesticides single agents and 5 mixed preparations against *Z. tau* and determined that the activities of organophosphorus, microbial-derived insecticides, emamectin benzoate and phoxim mixtures were greater (Cai et al. 2014). According to the type, dosage form and concentration of insecticides, there are a variety of combinations to select in *Z. tau* control system (Table 3). To prevent the development of pest resistance to pesticides, different types of pesticides can be applied alternately. For centralized and continuous vegetable gardens, vegetable farmers can be organized to

Table 3 Guidelines for the use of alternative agents for the chemical control of *Zeugodacus tau*

Active ingredient	Concentration (%)	Dosage form	Dilution multiple
Abamectin	2.0	EC	4000
Deltamethrin	2.5	EC	2000
Cypermethrin	10.0	EC	2000
Cyfluthrin	30.0	EC	800
Phoxim	40.0	EC	800
Acetamiprid	40.0	SP	2000
Chlorpyrifos	48.0	EC	2000
Profenofos	50.0	EC	800
Karbofos	50.0	EC	600
Dichlorvos	80.0	EC	500
Dipterex	90.0	CT	1000

EC, SP and CT stand for emulsifiable concentrate, soluble power and crystal, respectively try large-scale joint prevention and treatment (Hasyim et al. 2007; Zhang and Chen 2018; Mao et al. 2020). It is worthwhile to mention other side effects of irrational use of those broad-spectrum pesticides such as organophosphates, e.g. pollution to environment, non-target effects to natural enemies, and thus stress potential pesticide risk to be reduced or avoided.

Biological control

Fungi

Entomogenous fungi first appeared in ancient Greek mythology, and China was one of the first countries to apply these resources (Wang et al. 2005). As an important pathogen of crop pests, entomopathogenic fungi have the advantages of a wide host range, numerous species, easy culture, safety and effectiveness, sustained damage control, no damage to natural enemies, and low resistance (Shah and Pell 2003; Li et al. 2017b; Liu 2017). The fungi *Beauveria*, *Metarhizium* and *Verticillium lecanii* play important roles in control of fly pests (Sookar 2013; Faye et al. 2021). Sun et al. tested the virulence of the MZ041024 strain of *V. lecanii* against three stages of *Z. tau* in laboratory and confirmed that the strain was most virulent to *Z. tau* adults, followed by pupae, and was the least virulent to larvae (Sun et al. 2013). Yuan et al. used the *Beauveria bassiana* strain XD0104015 to test the pathogenicity of *Z. tau* in laboratory and showed that the tested *B. bassiana* strain had strong pathogenicity against larvae, pupae and adults of *Z. tau* (Yuan et al. 2015b).

Predators

Compared to the presence of *Oecophylla longinoda*, fruit flies preferred to spend more time landing on trees without *O. longinoda*. Under greenhouse conditions, ant pheromones significantly affected the number of eggs laid and the number of pupations of flies on fruit (Adandonon et al. 2009). The activity of *O. longinoda* and *O. smaragdina* may reduce the damage of fruit flies (Ativor et al. 2012). Wong et al. found that each larva of *C. capitata* could be attacked by seven *Iridomyrmex humilis* species in laboratory, with a fatality rate of 50% (Wong et al. 1984). Campolo et al. showed that *Tapinoma nigerrimum* was influenced by larval movement and olfaction cues when it preyed on the larvae of *C. capitata* (Campolo et al. 2015). Therefore, as social predators, ants have a certain biological control potential for fruit fly pests, and further research on predatory ants and *Z. tau* is needed (Peng and Christian 2006; Mele et al. 2007; Sinzogan et al. 2008).

In rainy, low-temperature and high-humidity years, from July to September, when the temperature is approximately 23 °C, the humidity is greater than 75%, and the monthly sunshine is less than 131 day degrees, the number of spiders in the field is large, the activity is frequent, and the desire to hunt is strong. Manager may create a habitat for spider activity by planting straw and hanging grass and promote the construction of a web for spider mites to prey on target fly pests and reduce the possible damage due to *Z. tau* adults and larvae (Fan 2011). Other predatory enemies, such as bugs, mites, ladybugs, earwigs, lacewings, and vertebrates, including birds and frogs, should also be explored for the prevention and control of *Z. tau* (Chen et al. 2023).

Parasitoids

Diachasmimorpha anshunensis is a larval dominant parasitoid that is suitable for rearing on honey at 22–25 °C. *Diachasmimorpha anshunensis* prefers to parasitize *Z. tau* larvae at three instars, with a recommended duration of eight hours. The peak egg-laying period for *D. anshunensis* females was 2–7 days after emergence, and the average daily egg-laying capacity of *D. anshunensis* females was the highest (18.71 eggs per female) three days after emergence. This newly discovered native larval parasitoid is highly important for the control of *Z. tau* in China (Shi 2022).

Spalangia endius is a multi-host parasitoid that has a good parasitic effect on fruit fly pupae. The adults lay eggs on *Z. tau* pupae of different ages and develop into adults, but the parasitism rate of *S. endius* decreased with increasing of *Z. tau* ages. Three- and four-day old pupae of *Z. tau* were used as hosts to develop into adults, which had a shorter developmental duration and a longer lifespan of female offspring (Liu et al. 2016b).

The ability to select and adapt to multiple hosts is a necessary prerequisite for survival and reproduction of polyparasitic parasitoids, and host selection behaviour is result of long-term adaptation to each host (Liu et al. 2016a). After switching hosts, *S. endius* feeding on *Z. cucurbitae* preferred to parasitise *Z. tau*, and *S. endius* feeding on *Z. tau* and *Z. cucurbitae* were more easily adapted to *Z. cucurbitae* and *Z. tau*, which suggests that *S. endius* prefers hosts with overlapping ecological niches when switching hosts (Li et al. 2022). For both hosts with overlapping ecological niches, more studies of *S. endius* have been performed on the control and prevention of *Z. cucurbitae*, and more in-depth assessments of relevant aspects of *Z. tau* are urgently needed (Beddington et al. 1978; Li 2016; Li et al. 2021).

Summary and prospects

From *Dacus* to *Bactrocera*, and then to *Zeugodacus*, the taxonomic status of *Z. tau* has been continuously adjusted at the genus level, while *Zeugodacus* was a subgenus before it became a genus. In terms of both geographical distribution and morphological characteristics, the three genera exhibit a high degree of similarity. However, due to regional differences, the abundance of different genera varies, and the host plant preferences of fruit flies from different genera are also distinct. Most of the current research focused on the genera *Bactrocera*, such as *B. dorsalis* and *B. tryoni*. There are relatively few studies on the other two genera. Systematically organizing their biological knowledge and fully understanding and mastering their distribution, damage, and morphological characteristics will help formulate more comprehensive and targeted pest management strategies (Suckling et al. 2014; Khan et al. 2016).

Economic and practical trapping and killing strategies play important roles in the monitoring and control of *Z. tau*. With the continuous development of trapping technology, compared to the original single-liquid trapping agent using simple transparent plastic bottles, the current types of traps and lures are increasingly diversified. The possibility of joint use of various control technologies has made the construction of IPM systems a development trend (Abd-Elgawad 2021). In future agriculture, unmanned, intelligent, digital, intensive, large-scale and mechanised pest control programs with unified leadership and overall planning will aid in the integrated management of fly pests (King 2017).

As an uninjurious long-term pest control strategy, biological control is highly important for the establishment of an IPM system (Waage and Greathead 1988; Bailey et al. 2010; Barratt et al. 2018). There are only a few reports on the application of fungi and parasitic and predatory natural enemies for biological control of *Z. tau*, and more in-depth studies are needed to investigate the possible application of entomopathogens (bacteria, viruses and nematodes) and natural enemies (bugs, mites, lacewing, ladybugs, and earwigs) for the green control of *Z. tau* (Lacey et al. 2015).

Notably, *Z. tau*, which is famous for damaging melon crops, has been the subject of fewer research reports than *Z. cucurbitae*, which also prefers melons. To a certain extent, successful cases of *Z. cucurbitae* control can guide the management of *Z. tau* (Dhillon et al. 2005; De Meyer et al. 2015; Diksha et al. 2022). Therefore, the author suggests that more in-depth research and comprehensive management of *Z. tau* be performed from the following aspects. First, based on the prediction of suitable areas, risk analysis and real-time monitoring, the distribution and spread of *Z. tau* should be updated in a timely and effective manner, and a regional real-time monitoring and reporting system for *Z. tau* should be established. Second, we summarised and integrated important information on the biology and ecology of different geographic populations of *Z. tau* to pave the way for formulating of more targeted management measures. Third, based on existing control methods and control experience of other Tephritidae pests, novel ideas are constantly integrated into control strategies for *Z. tau* to achieve long-term goal of establishing and improving an integrated control system. Last but not least, there is a sincere hope that the integrated management of *Z. tau* can take advantage of the rapid development of big data and artificial intelligence to provide an example for building a new era of intelligent pest management and service platforms.

Abbreviations

IPM	Integrated pest management
CMVFF	Computer model on viability of fruit fly
AQSIQ	General administration of quality supervision, inspection and quarantine of the People's Republic of China
IPPC	International Plant Protection Convention
CL	Cue lure
RK	Raspberry ketone
ZG	Zingerone
SIT	Sterile insect technique
EC	Emulsifiable concentrate
SP	Soluble power
CT	Crystal

Acknowledgements
Not applicable.

Author contributions
All authors have read and agreed to the published version of the manuscript.

Funding
This work was funded by the National Key Research and Development Program of China (2023YFD1400700) and the International Atomic Energy Agency Coordinated Research Project (IAEA CRP D41027).

Availability of data and materials
The data used to support the findings of this study are included in the article.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
All authors approve the manuscript for publication.

Competing interests
All authors declare that they have no competing interests.

Received: 22 April 2024 Accepted: 16 August 2024

References

Abd-Elgawad MM. The Mediterranean fruit fly (Diptera: Tephritidae), a key pest of citrus in Egypt. J Integr Pest Manag. 2021;12(1):28.

Abouziena HF, Haggag WM. Weed control in clean agriculture: a review. Planta Daninha. 2016;34(2):377–92.

Adandonon A, Vayssières JF, Sinzogan A, Van Mele P. Density of pheromone sources of the weaver ant *Oecophylla longinoda* affects oviposition behaviour and damage by mango fruit flies (Diptera: Tephritidae). Int J Pest Manag. 2009;55(4):285–92.

Agarwal ML, Sueyoshi M. Catalogue of Indian fruit flies (Diptera: Tephritidae). Orient Insects. 2005;39(1):371–433.

Akhtaruzzaman M, Alam MZ, Sardar MA. Identification and distribution of fruit flies infesting cucurbits in Bangladesh. Bangladesh J Entomol. 1999;9(1/2):93–101.

Ali MM, Anwar R, Yousef AF, Li BQ, Luvisi A, Bellis LD, Aprile A, Chen FX. Influence of bagging on the development and quality of fruits. Plants. 2021;10(2):358.

Allwood AJ, Drew RAI. National and regional needs for future activities on fruit flies (Diptera: Tephritidae) in the Pacific region. In: Allwood AJ, Drew RAI, editors. Management of fruit flies in the Pacific. A regional symposium. Nadi: Fiji; 1997. p. 262–4.

Allwood AJ, Chinajariyawong A, Kritsaneepaiboon S, Drew RAI, Hamacek EL, Hancock DL, Hengsawad C, Jipanin JC, Jirasurat M, Krong CK, Leong CTS, Vijaysegaran S. Host plant records for fruit flies (Diptera: Tephritidae) in Southeast Asia. Raffles Bull Zool. 1999;47(7):1–92.

An KP, Wu BF, Shen K, Zhang RJ. Research progress on characteristics and control techniques of *Zeugodacus tau*. J Changjiang Veget. 2011;20:7–13.

Andreawartha HG, Monro J, Richardson NL. The use of sterile males to control populations of Queensland fruit fly, *Dacus tryoni* (Frogg.) (Diptera: Tephritidae).II. Filed experiments in New South Wales. Aust J Zool. 1967;15(3):461–73.

Ao GF, Lin J, Liu XX, Ji QE. Advances in research on insecticide resistance in the Tephritidae. Chin J Appl Entomol. 2019;56(3):401–15.

Ashraf S, Ganaie NA, Mir SH, Rashid S. Biology of *Zeugodacus tau* (Walker) on bottle gourd. Indian J Entomol. 2022;170: e21178.

Ativor IN, Afreh-Nuamah K, Billah MK, Obeng-Ofori D. Weaver ant, *Oecophylla longinoda* (Latreille) (Hymenoptera: Formicidae) activity reduces fruit fly damage in citrus orchards. J Agric Sci Technol A. 2012;2(4A):449–58.

Bailey KL, Boyetchko SM, Längle T. Social and economic drivers shaping the future of biological control: a Canadian perspective on the factors affecting the development and use of microbial biopesticides. Biol Control. 2010;52(3):221–9.

Barratt BIP, Moran VC, Bigler F, Van Lenteren JC. The status of biological control and recommendations for improving uptake for the future. BioControl. 2018;63(1):155–67.

Batra HN. Biology and bionomics of *Dacus (Zeugodacus) hageni* De Meijere. Indian J Agric Sci. 1968;138(6):1015–20.

Beddington JR, Free CA, Lawton JH. Characteristics of successful natural enemies in models of biological control of insect pests. Nature. 1978;273(5663):513–9.

Bell CH. Fumigation in the 21st century. Crop Prot. 2000;19(8–10):563–9.

Boopathi T, Singh SB, Manju T, Chowdhury S, Singh AR, Dutta SK, Dayal V, Behere GT, Ngachan SV, Hazarika S, Rahman SMA. First report of economic injury to tomato due to *Zeugodacus tau* (Diptera: Tephritidae): relative abundance and effects of cultivar and season on injury. Fla Entomol. 2017;100(1):63–9.

Borah SR, Dutta SK. Comparative biology of *Dacus tau* (Walker) on cucurbitaceous vegetables. J Agric Sci Soc North East India. 1996;9(2):159–65.

Bullock DG. Crop rotation. Crit Rev Plant Sci. 1992;11(4):309–26.

Buthelezi NMD, Mafeo TP, Mathaba N. Preharvest bagging as an alternative technique for enhancing fruit quality: a review. HortTechnology. 2021;31(1):4–13.

CABI. Center for Agriculture and Bioscience International; 2024. https://www.cabi.org/.

Cai J, Yang HX, Wu QS, Dong XL. Screen and efficacy of insecticides against pumpkin fruit fly, *Bactrocera (Zeugodacus) tau* (Walker) under laboratory and field conditions. Hubei Agric Sci. 2014;53(8):1819–22.

Cai J, Yang HX, Shi S, Zhong GH, Yi X. Behavioral, morphological, and gene expression changes induced by ^{60}Co-γ ray irradiation in *Bactrocera tau* (Walker). Front Physiol. 2018a;9:118.

Cai XM, Li ZQ, Pan HS, Lu YH. Research and application of food-based attractants of herbivorous insect pests. Chin J Biol Control. 2018b;34(1):8–35.

Campolo O, Palmeri V, Malacrinò A, Laudani F, Castracani C, Mori A, Grasso DA. Interaction between ants and the Mediterranean fruit fly: new insights for biological control. Biol Control. 2015;90:120–7.

Cayol JP. Changes in sexual behavior and life history traits of tephritid species caused by mass-rearing processes. In: Aluja M, Norrbom A, editors. Fruit flies (Tephritidae): phylogeny and evolution of behavior. CRC Press: Boca Raton; 1999. p. 843–60.

Chen HD, Zhou CQ, Yang PJ, Liang GQ. Population dynamics of *Zeugodacus cucurbitae*, *Bactrocera dorsalis* and *Z. tau* in Guangzhou. J Plant Prot. 1995;22(4):348–54.

Chen M, Ning DL, Lang GF, Yu HX. Observation experiment on population dynamics of fruit fly in Dehong Prefecture. Yunnan Agric. 2019;8:67–8.

Chen JY, Liu HJ, Zhu H, Hou ZS, Wu XD. Population dynamics of fruit fly (Tephritidae) in Tengchong, Yunnan Province. Plant Quar. 2021;35(6):79–81.

Chen YK, Mei YY, Yang ZX, Li XW, Chen YH, Lin YF, Li YM, Li ZW. Occurrence and key meteorological influencing factors of fruit flies in melon vegetables in Hunan. J Hunan Agric Univ (Nat Sci). 2022;48(4):443–8.

Chen XX, Du YJ, Huang JH, Li S, Jiang DH, Mo MH, Pang H, Sun XL, Wang Q, Wang S, Xia YX, Xu XN, Zang LS, Zhang J, Zhang LS, Zhang WQ, Yin H. Recent progresses in biological control of crop pathogens and insect pests in China. Plant Prot. 2023;49(5):340–70.

Chinajariyawong A, Kritsaneepaiboon S, Drew RAI. Efficacy of protein bait sprays in controlling fruit flies (Diptera: Tephritidae) infesting angled luffa and bitter gourd in Thailand. Raffles Bull Zool. 2003;51(1):7–15.

Clark MS, Gage SH. Effects of free-range chickens and geese on insect pests and weeds in an agroecosystem. Am J Altern Agric. 1996;11(1):39–47.

Clausen CP, Clancy DW, Chock QC. Biological control of the oriental fruit fly (*Dacus dorsalis* Hendel) and other fruit flies in Hawaii. Biology, Environmental Science; 1965. p. 1322.

De Meyer M, Delatte H, Mwatawala M, Quilici S, Vayssières JF, Virgilio M. A review of the current knowledge on *Zeugodacus cucurbitae* (Coquillett) (Diptera, Tephritidae) in Africa, with a list of species included in *Zeugodacus*. ZooKeys. 2015;540:539–57.

Deng YP. Biological characteristics and control of *Bactrocera tau* in orchards of *Momordica grosvenori* Swingle. Plant Prot. 1992;18(2):24–5.

Deng YL, Li ZY, Zhang HR. Population dynamics of *Bactrocera dorsalis*, *B. cucurbitae* and *B. tau* (Diptera: Tephritidae) in Xishuangbanna. Southwest China J Agric Sci. 2006;4:643–8.

Dhillon MK, Singh R, Naresh JS, Sharma HC. The melon fruit fly, *Bactrocera cucurbitae*: a review of its biology and management. J Insect Sci. 2005;5(1):40.

Diksha, Mahajan E, Singh S, Sohal SK. Potential biological control agents of *Zeugodacus cucurbitae* (Coquillett): a review. J Appl Entomol. 2022;146(8):917–29.

Drew RAI, Romig MC. Tropical fruit flies (Tephritidae: Dacinae) of south-east Asia: Indomalaya to North-West Australasia. Wallingford: CABI Press; 2013.

Du YG, Ji QE, Pan J, Lai ZX. Suitability of the pumpkin fruit fly, *Bactrocera tau* (Walker) (Diptera: Tephritidae) for a sterile insect technique program. Egypt J Biol Pest Control. 2016;26(4):665–9.

Duan Y, Chen Q, Guo P, Miao J, Xia PL, Gong ZJ, Jiang LY, Li T, Wu YQ. Research progress on the occurrence, damage and control of *Mythimna loreyi* (Lepidoptera: Noctuidae). Acta Entomol Sin. 2022;65(4):522–32.

Dujardin JP, Kitthawee S. Phenetic structure of two *Bactrocera tau* cryptic species (Diptera: Tephritidae) infesting *Momordica cochinchinensis* (Cucurbitaceae) in Thailand and Laos. Zoology. 2013;116(2):129–38.

Faheem M, Saeed S, Sajjad A, Rehman A, Farooq M. In search of the best hot water treatments for Sindhri and Chaunsa variety of mango. Pak J Zool. 2012;44(1):101–8.

Fan WX. Occurrence and control technology of pumpkin fly in Xichuan County. Anhui Agri Sci Bull. 2011;17(12):137–8.

Fang Y, Li ZH, Qin M, Wu ZG, Zhao SQ, Wu LF, Zhao ZH, Chen K, Qin YJ, Wang C, Zhao T. The potential economic impact of the pumpkin industry caused by *Bactrocera tau* (Walker). Plant Quar. 2015;29(3):28–33.

Faye PD, Bal AB, Ndiaye NM, Diop F, Sangaré YK, Haddad C, Coly EV, Dieng EO, Niassy S. Field efficacy of *Metarhizium acridum* (Hypocreales: Clavicipitaceae) in the control of *Bactrocera dorsalis* (Diptera: Tephritidae) in citrus orchards in Senegal. Int J Trop Insect Sci. 2021;41:1185–95.

Feldhaar H. Bacterial symbionts as mediators of ecologically important traits of insect hosts. Ecol Entomol. 2011;36(5):533–43.

Follett PA, Snook K. Cold storage enhances the efficacy and margin of security in postharvest irradiation treatments against fruit flies (Diptera: Tephritidae). J Econ Entomol. 2013;106(5):2035–42.

Fu D. Test report on control of *Zeugodacus tau* in vegetable by Guoruite 3 and protein bait. South China Agric. 2011;5(3):6–7.

Gan XH, Wu YG, Tao XB, Xue JB, Peng AM, Zhou DC, Hu CH, Wang QT, Yin ZP. Innovation and application of monitoring and trapping technology for fruit fly adults in Central China. Contemp Hortic. 2023;46(10):49–50+53.

Gong XZ, Zhong Y, Huang JQ, Qiu S, Du ZX, Pang RW. Progress in domestic research of *Bactrocera latifrons* Hendel. North Hortic. 2016;11:195–8.

Guo TD, Qin YJ, Li ZH. Advances in host selection and response of Tephritidae insects. Plant Prot. 2023;49(5):196–206.

Gupta D, Verma AK. Effect of nutritionally different diets on preoviposition period of the fruit fly *Dacus tau* (Walker) (Diptera: Tephritidae). Ann Agric Res. 1993;8(2):258–60.

Hallman GJ. Generic phytosanitary irradiation treatments. Radiat Phys Chem. 2012;81(7):861–6.

Harris EJ, Cunningham RT, Tanaka N, Ohinata K, Schroeder WJ. Development of the sterile-insect technique on the Island of Lanai, Hawaii, for suppression of the Mediterranean fruit fly. Proc Hawaii Entomol Soc. 1986;26:77–88.

Hasyim A, Istianto M, de Kogel WJ. Male fruit fly, *Bactrocera tau* (Diptera; Tephritidae) attractants from *Elsholtzia pubescens* Bth. Asian J Plant Sci. 2007;6(1):181–3.

Hasyim A, Muryati M, De Kogel W. Population fluctuation of adult males of the fruit fly, *Bactrocera tau* Walker (Diptera: Tephritidae) in passion fruit orchards in relation to abiotic factors and sanitation. Indonesian J Agri Sci. 2016;9(1):29–33.

He YX, Xu YJ, Chen X. Biology, ecology and management of tephritid fruit flies in China: a review. Insects. 2023;14(2):196.

Heath RR, Lavallee SG, Schnell E, Midgarden DG, Epsky ND. Laboratory and field cage studies on female-targeted attract-and-kill bait stations for *Anastrepha suspensa* (Diptera: Tephritidae). Pest Manag Sci. 2009;65(6):672–7.

Hossain MA, Wadud MA, Khan SA, Islam MS. Dose mortality response on different developmental stages of fruit fly, *Bactrocera tau* (Walker) to gamma radiation. Nucl Sci Appl. 2006;15(2):120–4.

Hossain MA, Hallman JG, Khan SA, Islam MS. Phytosanitary irradiation in South Asia. J Entomol Nematol. 2011;3(3):44–53.

Huang Z. The morphological characteristics, harm, host and imported risk of *Bactrocera (Zeugodacus) tau* (Walker). Wuyi Sci J. 2017;33:42–6.

Huang JQ. Preparation and trapping experiment of yellow sticky insect parasol of *Bactrocera dorsalis*. South China Fruits. 2021;50(2):19–22.

Huang JQ. Evaluation of field trapping effect of a *Bactrocera dorsalis* adhesive plate. South China Fruits. 2022;51(3):21–4.

Huang KH, Guo QX, Yu Y, Huang Z. Risk analysis of *Bactrocera* (*Zeugodacus*) tau (Walker). Wuyi Sci J. 2005;21:77–80.

Huang Z. Morphological identification, artificial diet, suitability analysis and prediction, qualitative and quantitative risk analysis of important *Bactrocera* species. MSc thesis, Hainan University, Haikou; 2010.

Huque R. Comparative studies on the susceptibility of various vegetables to *Bactrocera tau* (Diptera: Tephritidae). Pakistan J Biol Sci. 2006;9(1):93–5.

Islam MZ, Hossain MA, Alim MA, Khan M, Khan SA. Determination of male sterility dose and optimization of male ratios of pumpkin fly, *Bactrocera tau* (Walker) (Diptera: Tephritidae) in support of sterile insect technique application. Bangladesh J Entomol. 2012;22(2):93–101.

Jaleel W, Lu L, He Y. Biology, taxonomy, and IPM strategies of *Bactrocera tau* Walker and complex species (Diptera; Tephritidae) in Asia: a comprehensive review. Environ Sci Pollut Res. 2018;25(20):19346–61.

Jamnongluk W, Baimai V, Kittayapong P. Molecular phylogeny of tephritid fruit flies in the *Bactrocera tau* complex using the mitochondrial COI sequences. Genome. 2003;46(1):112–8.

Jang S, Kikuchi Y. Impact of the insect gut microbiota on ecology, evolution, and industry. Curr Opin Insect Sci. 2020;41:33–9.

Jia PF, Zhang XY, Wang B, Ji QE. Evaluation of the attractant effect of *Solanum muricatum* (Solanales: Solanaceae) on gravid female adults of *Zeugodacus tau* (Diptera: Tephritidae) and screening of attractant volatiles. Insects. 2023;14(7):591.

Julsirikul D, Sutawa W, Kitthawee S. Genetic and geometric analyses of *Zeugodacus tau* (Walker) (Diptera: Tephritidae) in different host types. Genom Genet. 2019;12(2&3):41–6.

Kabir SMH, Rahman R, Molla MAS. Biology of *Dacus (Zeugodacus) tau* Walker (Tephritidae: Diptera). Bangladesh J Zool. 1997;25(2):115–20.

Karnjanaungkool S, Julsirikul D. Host preference of the pumpkin fruit fly, *Zeugodacus tau* (Walker) under laboratory conditions. Life Sci Environ J. 2021;22(2):252–61.

Khan M, Rashid T, Howlader A. Comparative host susceptibility, oviposition, and colour preference of two polyphagous tephritids: *Bactrocera cucurbitae* (Coq.) and *Bactrocera tau* (Walker). Res J Agric Biol Sci. 2011;7:343–9.

Khan Z, Midega CA, Hooper A, Pickett J. Push-pull: chemical ecology-based integrated pest management technology. J Chem Ecol. 2016;42(7):689–97.

King A. Technology: the future of agriculture. Nature. 2017;544(7651):S21–3.

Kitthawee S, Dujardin JP. The geometric approach to explore the *Bactrocera tau* complex (Diptera: Tephritidae) in Thailand. Zoology. 2010;113(4):243–9.

Kitthawee S, Rungsri N. Differentiation in wing shape in the *Bactrocera tau* (Walker) complex on a single fruit species of Thailand. ScienceAsia. 2011;37(4):308–13.

Knipling EF. Possibilities of insect control or eradication through the use of sexually sterile males. J Econ Entomol. 1955;48(4):459–62.

Kong DY, Teng SN, Sun T, Ye J. Development of the technique for fruit fly survey. Plant Quar. 2021;35(5):16–20.

Kumar V, Kumar V, Yadav P. Importance of summer ploughing for sustainable agriculture. IJTRD. 2020;7(3):336–7.

Lacey LA, Grzywacz D, Shapiro-Ilan DI, Frutos R, Brownbridge M, Goettel MS. Insect pathogens as biological control agents: back to the future. J Invertebr Pathol. 2015;132:1–41.

Lello F, Dida M, Mkiramweni M, Matiko J, Akol R, Nsabagwa M, Katumba A. Fruit fly automatic detection and monitoring techniques: a review. Smart Agric Technol. 2023;5: 100294.

Li XZ, Liu YH, He ZY. Taxis response and selective propensity of *Bactrocera tau* to six host fruits. Chin Bull Entomol. 2007;44(1):82–5.

Li XZ, Liu YH, Wang JJ, Li SB. Growth, development and water-loss dynamics in *Bactrocera tau* (Walker) (Diptera: Tephritidae) pupae exposed to determined humidity. The Pan-Pac Entomol. 2009;85(3):150–8.

Li L, Liu T, Li BS, Zhang FH, Dong SJ, Wang YJ. Toxicity of phosphine fumigation against *Bactrocera tau* at low temperature. J Econ Entomol. 2014;107(2):601–5.

Li L, Ma HB, Niu LM, Han DY, Zhang FP, Chen JY, Fu YG. Evaluation of chromatic cues for trapping *Bactrocera tau*. Pest Manag Sci. 2017a;73(1):217–22.

Li Y, Jiang CJ, Zhao YY, Feng M, Jin Y. Application of entomogenous fungi in biological control of forest pests. Agric Jilin. 2017b;15:64–5.

Li XZ, Yang HY, Hu KP, Wang JG. Temporal dynamics of *Bactrocera (Zeugodacus) tau* (Diptera: Tephritidae) adults in north Jiangxi, a subtropical area of China revealed by eight years of trapping with cuelure. J Asia Pac Entomol. 2020;23(1):1–6.

Li L, Chen JY, Niu LM, Han DY, Zhang FP, Fu YG. Field evaluation of *Spalangia endius* Walker in controlling *Zeugodacus cucurbitae* (Coquillett). Int J Pest Manag. 2021;67(3):216–21.

Li L, Han DY, Zhang FP, Chen JY, Wang JY, Ye ZP, Fu YG. Preference and adaptability of the generalist parasitoid *Spalangia endius* (Hymenoptera: Pteromalidae) to novel hosts. Acta Entomol Sin. 2022;65(9):1177–84.

Li YR. Evaluation of *Spalangia endius* (Walker) for Control of *Bactrocera cucurbitae* (Coquillett). MSc thesis, South China Agricultural University, Guangzhou; 2016.

Liang P, Gu SH, Zhang L, Gao XW. Research status and prospects of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in China. Acta Entomol Sin. 2020;63(5):624–38.

Liang ZL. The preliminary evaluation of the insect-resistant cabbage and the breeding of male sterile line. MSc thesis, Huazhong Agricultural University, Wuhan; 2013.

Liang WZ. Study on Population Dynamics of *Bactrocera* spp. in New Territories, Hong Kong. MSc thesis, South China Agricultural University, Guangzhou; 2018.

Lin ZJ, Zhang QY. Study on the starting temperature and effective accumulated temperature of the development of *Bactrocera tau* (Walker). Biol Dis Sci. 1989;2:17–8.

Lin MG, Cai B, Zhou H, Wang XJ, Li F, Shi J. Study on population dynamics and comprehensive control of cantaloupe fly pests in off-season greenhouse in Hainan Province. North Hortic. 2014;24:115–8.

Lin J, Hao XX, Yue GQ, Yang DQ, Lu NF, Cai PM, Ao GF, Ji QE. Efficacy of wax-based bait stations for controlling *Bactrocera dorsalis* (Diptera: Tephritidae). Pest Manag Sci. 2022;78(8):3576–86.

Lin MY, Chen SK, Liu YC. The host plants of *Bactrocera tau* in Taiwan. In: Tainan District Agricultural Improvement Farm Research Report. 2005, vol. 45. p. 39–52.

Liu CL. Application of entomopathogenic fungi in biological control of agricultural and forestry pests. Heilongjiang Agric Sci. 2017;3:68–73.

Liu Y, Lin M. Morphology, development, longevity and mating behavior of *Bactrocera tau* (Diptera: Tephritidae). Chin J Entomol. 2000;20(4):311–25.

Liu Q, Sun J. Analysis on population dynamics and impact factors of fruit fly from Binchuan, Dali. J Anhui Agri Sci. 2017;45(20):131–3+197.

Liu LH, Liu YH, Zhou B, Zhang YQ. Studies on damage and quantity dynamics of *Bactrocera tau* (Walker) in different host fields. J Southwest Agric Univ (Nat Sci). 2005;27(2):176–9.

Liu R, Li ZH, Sun X, Shen ZR. First discovery of *Wolbachia* infection of *Bactrocera (Zeugodacus) tau* from China. Chin Bull Entomol. 2006;3:368–70.

Liu KF, Zhou Q, Tan M, Liu JY. Population dynamics of tephritid fruit flies in Yuelu Moutain Area. Changsha J Environ Entomol. 2012;34(4):420–4.

Liu H, Li L, Niu LM, Zhang FP, Han DY, Fu YG. Impact of host species on the development and parasitic efficiency of *Spalangia endius*. J Biosafe. 2016a;25(3):194–8.

Liu H, Li L, Zhang FP, Han DY, Gong Z, Niu LM, Fu YG. Selection, development, and longevity of *Spalangia endius* (Hymenoptera: Pteromalidae) in pupae of different ages of *Bactrocera tau* (Walker) (Diptera: Tephritidae). J Environ Entomol. 2016b;38(2):431–6.

Liu H, Wang XY, Chen ZH, Lu YY. Characterization of cold and heat tolerance of *Bactrocera tau* (Walker). Insects. 2022;13(4):329.

Liu XX, Zhang QY, Xu WJ, Yang YB, Fan QW, Ji QE. The effect of cuelure on attracting and feeding behavior in *Zeugodacus tau* (Walker) (Diptera: Tephritidae). Insects. 2023;14(11):836.

Lu CX, Zhao Y. Population dynamics of important economic crops fruit flies in Neixiang Henan Province. China Fruits. 2020;6:41–5+54.

Lu HL, Li WF, Liu LQ. The construction and practice platform for cross-border of animal and plant epidemic surveillance, risk assessment and early warning in China-ASEAN. Plant Quar. 2014;28(5):35–9.

Luo MJ, Zhang HH, Du YG, Idrees A, He LY, Chen JH, Ji QE. Molecular identification of cultivable bacteria in the gut of adult *Bactrocera tau* (Walker) and their trapping effect. Pest Manag Sci. 2018;74(12):2842–50.

Luo MJ. Molecular diversity analysis of the intestinal bacterial communities from adult *Bactrocera tau* (Walker) and their trapping effect. MSc thesis, Fujian Agriculture and Forestry University, Fuzhou; 2016.

Lv F, Du YZ, Zhou YJ, Yang WY. Research summary of pest risk analysis. Plant Quar. 2016;30(2):7–12.

Ma C, Zhao SQ, Zhao QY, Sun T, Song ZJ, Liu H. Beware of the spread and harm of *Zeugodacus depressus* (Shiraki). China Plant Prot. 2020;40(6):79–81.

Mao HY. The toxicity of several insecticides to the pupas of *Bactrocera tau*. Plant Quar. 2012;26(3):24–5.

Mao HY, Zhao Y, Ding HF, Jiao YJ, Sun GQ, Lu CX, Han SP. Monitoring on the population dynamics of major fruit flies in Henan province. China Plant Prot. 2019;39(11):77–83.

Mao HY, Ding HF, Jiao YJ, Huang H, Han SP. The monitoring of population dynamics of *Zeugodacus tau* in Henan from 2013 to 2017. Plant Quar. 2020;34(1):82–4.

Mateos M, Montoya MH, Lanzavecchia SB, Conte C, Guillén K, Morán-Aceves BM, Toledo J, Liedo P, Asimakis ED, Doudoumis V, Kyritsis GA, Papadopoulos NT, Augustinos AA, Segura DF, Tsiamis G. *Wolbachia pipientis* associated with tephritid fruit fly pests: from basic research to applications. Front Microbiol. 2020;11:1080.

Mele PV, Vayssières JF, Tellingen EV, Vrolijks J. Effects of an African weaver ant, *Oecophylla longinoda*, in controlling mango fruit flies (Diptera: Tephritidae) in Benin. J Econ Entomol. 2007;100(3):695–701.

Nair N, Thangjam BC, Bhattacharjee T, Debnath MR. Species composition of Dacine fruit flies (Diptera: Tephritidae: Dacinae: Dacini) associated with Cucurbits in Tripura, a North Eastern state of India. J Entomol Zool Stud. 2017;5(3):330–5.

Niu YB, Li RJ, Li WZ, Zhao M, Xing CY, Guo XR. Host selection and its application in the management of Tephritidae flies. China Plant Prot. 2023;43(10):19–25.

Noman MS, Shi G, Liu LJ, Li ZH. Diversity of bacteria in different life stages and their impact on the development and reproduction of *Zeugodacus tau* (Diptera: Tephritidae). Insect Sci. 2021;28(2):363–76.

Octriana L. Identification of parasitoid and analysis of its parasitic level on fruit fly *Bactrocera tau* in passion fruit. J Hort. 2010;20(2):179–85.

Ohno S, Tamura Y, Haraguchi D, Kohama T. First detection of the pest fruit fly, *Bactrocera tau* (Diptera: Tephritidae), in the field in Japan: evidence of multiple invasions of Ishigaki Island and failure of colonization. Appl Entomol Zool. 2008;43(4):541–5.

Pal S, Choudhuri P. Insect pests of paprika (*Capsicum annuum* L. var longum) in terai region of West Bengal. Agric Sci Dig. 2007;27(2):138–9.

Pan J. Artificial rearing and irradiation sterility of *Bactrocera tau* (Walker). MSc thesis, Fujian Agriculture and Forestry University, Fuzhou; 2013.

Papadopoulos NT, Meyer MD, Terblanche JS, Kriticos DJ. Fruit flies: challenges and opportunities to stem the tide of global invasions. Annu Rev Entomol. 2024;69:355–73.

Peng RK, Christian K. Effective control of Jarvis's fruit fly, *Bactrocera jarvisi* (Diptera: Tephritidae), by the weaver ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae), in mango orchards in the Northern Territory of Australia. Int J Pest Manag. 2006;52(4):275–82.

Prabhakar CS, Sood P, Mehta PK. Fruit fly (Diptera: Tephritidae) diversity in cucurbit fields and surrounding forest areas of Himachal Pradesh, a North-Western Himalayan state of India. Arch Phytopathol Plant Prot. 2012;45(10):1210–7.

Prabhakar CS. Biodiversity of fruit flies (Tephritidae: Diptera) and utilization of gut bacteria in their management. India: Chaudhary Sarwan Kumar Himachal Pradesh Vishvavidyalaya: Plampur; 2011. p. 175.

Pu RL, Xie BL, Liu CX, Huang LS. Study on the sex pheromone of *Zeugodacus cucurbitae* to trap *Zeugodacus tau* in *Siraitia grosvenorii*. J South Agric. 1998;2:26–7.

Qin YJ, Paini DR, Wang C, Fang Y, Li ZH. Global establishment risk of economically important fruit fly species (Tephritidae). PLoS ONE. 2015;10(1): e0116424.

Reddy PV, Verghese A, Sreedevi K, Manivannan S. Irradiation as a quarantine treatment against tephritid fruit flies—a review. Curr Biot. 2010;3(4):581–92.

Saikia DK, Dutta SK. Efficacy of some insecticides and plant products against fruit fly, *Dacus tau* (Walker) on ridge gourd *Luffaa cutangula* L. J Agric Sci. 1997;10(1):132–5.

Sarker D, Rahman MM, Barman JC. Efficacy of different bagging materials for the control of mango fruit fly. Bangladesh J Agric Res. 2009;34(1):165–8.

Sh W, Kerdelhue C, Ye H. Genetic structure and colonization history of the fruit fly *Bactrocera tau* (Diptera: Tephritidae) in China and Southeast Asia. J Econ Entomol. 2014;107(3):1256–65.

Shah PA, Pell JK. Entomopathogenic fungi as biological control agents. Appl Microbiol Biotechnol. 2003;61(5–6):413–23.

Sharma S, Tiwari S. Biology of pumpkin fruit fly, *Zeugodacus tau* Walker (Diptera: Tephritidae) in cucumber in Kathmandu Nepal. J Plant Prot Soc. 2020;6:100–7.

Sharma RR, Reddy SVR, Jhalegar MJ. Pre-harvest fruit bagging: a useful approach for plant protection and improved post-harvest fruit quality—a review. J Hortic Sci Biotechnol. 2014;89(2):101–13.

Shi S. The biological characteristics and artificial rearing of *Diachasmimorpha anshunensis*. MSc thesis, Fujian Agriculture and Forestry University, Fuzhou, Fujian; 2022.

Singh SK, Kumar D, Ramamurthy VV. Biology of *Bactrocera (Zeugodacus) tau* (Walker) (Diptera: Tephritidae). Entomol Res. 2010;40(5):259–63.

Sinzogan AAC, Mele PV, Vayssières JF. Implications of on-farm research for local knowledge related to fruit flies and the weaver ant *Oecophylla longinoda* in mango production. Int J Pest Manag. 2008;54(3):241–6.

Sookar P. Study of two potential entomopathogenic fungi, *Metarhizium anisopliae* and *Beauveria bassiana* for the biocontrol of fruit flies (Diptera: Tephritidae) of economic importance in Mauritius. PhD thesis. Mauritius University, Mauritius; 2013.

Steiner LF, Harris EJ, Mitchell WC, Fujimoto MS, Christenson LD. Melon fly eradication by overflooding with sterile flies. J Econ Entomol. 1965;58(3):519–22.

Steiner LF, Hart WG, Harris EJ, Cunningham RT, Ohinata K, Kamakahi DC. Eradication of the oriental fruit fly from the Mariana Islands by the methods of male annihilation and sterile insect release. J Econ Entomol. 1970;63(1):131–5.

Suckling DM, Stringer LD, Stephens AE, Woods B, Williams DG, Baker G, El-Sayed AM. From integrated pest management to integrated pest eradication: technologies and future needs. Pest Manag Sci. 2014;70(2):179–89.

Sumrandee C, Milne JR, Baimai V. Ovipositor morphology and host relations of the *Bactrocera tau* complex (Diptera: Tephritidae) in Thailand. Songklanakarin J Sci Technol. 2011;33(3):247–54.

Sun Y, Yuan SY, Li LH, Deng Q, Yang JP, Xiao DJ. Determination of virulence of *Verticillium lecanii* against *Bactrocera tau*. J South Agric. 2013;44(10):1662–6.

Sunandita, Gupta D. Testing of boric acid and protein hydrolysate bait mixture against fruit fly, *Bactrocera tau* Walker. Indian J Entomol. 2001;63(2):125–9.

Tan KH, Lee SL. Species diversity and abundance of *Dacus* (Diptera: Tephritidae) in five ecosystems of Penang. West Malaysia Bull Entomol Res. 1982;72(4):709–16.

Tan KH, Nishida R. Mutual reproductive benefits between a wild orchid, *Bulbophyllum patens*, and *Bactrocera* fruit flies via a floral synomone. J Chem Ecol. 2000;26(2):533–46.

Tan KH, Nishida R. Synomone or kairomone?-*Bulbophyllum apertum* flower releases raspberry ketone to attract *Bactrocera* fruit flies. J Chem Ecol. 2005;31(3):497–507.

Tang MF, Lu RF, Wan Y. Study on population dynamics of *Bactrocera tau* in citrus orchard based on monitoring through attractants. Acta Agric Jiangxi. 2013;25(12):62–5.

Thakur M, Gupta D. Effect of different plant extracts on reproduction of fruit fly *Bactrocera tau* (Walker). Biopestic Int. 2012;8(1):32–7.

Tu HL, Gao XY, Tian ZY, Bai Q, Zeng XR. Trap effectiveness of different trapping methods for three fruit flies in monocropping bitter gourd fields. China Cucurb Veget. 2022;35(4):92–6.

Verghese A, Tandon PL, Stonehouse JM. Economic evaluation of the integrated management of the oriental fruit fly *Bactrocera dorsalis* (Diptera: Tephritidae) in mango in India. Crop Prot. 2004;23(1):61–3.

Waage JK, Greathead DJ. Biological control: challenges and opportunities. Philos Trans R Soc Lond B Biol Sci. 1988;318(1189):111–28.

Walker F. List of the specimens of dipterous insects in the collection of the British Museum. London: British Museum; 1849. p. 689–1172.

Wang XL, Zhang RJ. Review on biology, ecology and control of *Bactrocera (Tetradacus) minax* Enderlein. J Environ Entomol. 2009;31(1):73–9.

Wang HQ, Wan PP, Huang YJ, Liu YS, Ding AY. Research on the application of entomogenous fungi in biological control of insect pests. Shandong Sci. 2005;4:37–41.

Wang ZL, Liu YH, Jiang XP, Liu H, Pei MY, Liu MS. The distribution and occurrence of *Bactrocera tau* (Walker) (Dptera: Tephritdae) inspected with lure in Chongqing. J Southwest Agric Univ (Nat Sci). 2006;2:309–13+325.

Wang ZL, Liu YH, Liu H, Zhang CL, Wang ZY. Partial sequences on mtDNA 16S rRNA and phylogeny in 26 populations of *Bactrocera tau* in Chongqing. Chin Bull Entomol. 2007;44(4):556–61.

Wang P, Yuan SY, Li JP, Li WW, Pu JX, Luo DQ. Study on ovipositon preference of *Dactrocera tau* (Walker). J Honghe Univ. 2009;7(2):3–39.

Wang C, Cai PM, Yi CD, Chen JH. Bibliometric based analysis of the risk assessment of alien invasive pest from 2007 to 2017 and introduction of several risk assessment models. J China Agric Univ. 2018;23(8):225–38.

Wang B, Huang ZF, Yang DQ, Ji QE, Cai PM. Improvement of protein bait produced from beer yeast waste for controlling *Bactrocera dorsalis* (Diptera: Tephritidae) in China. J Asia Pac Entomol. 2021a;24(3):573–9.

Wang TL, Wang XJ, Liu EK. Advantages and disadvantages of crop rotation and research prospects. Anhui Agri Sci Bull. 2021b;27(24):104–5+120.

Wang WX, Zhu TH, Lai FX. Research advances in symbiotic microorganisms in insects and their functions. Acta Entomol Sin. 2021c;64(1):121–40.

Wang C. Prediction of the potential suitable growth areas of *Drosophila suzukii* (Matsumura) and Assessment of Economic Losses in China. MSc Thesis, Fujian Agriculture and Forestry University, Fuzhou; 2019.

Wee SL, Shelly T. Capture of *Bactrocera* fruit flies in traps baited with liquid versus solid formulations of male lures in Malaysia. J Asia Pac Entomol. 2013;16(1):37–42.

White IM, Elson-Harris MM. Fruit Flies of Economic Significance: Their Identification and Bionomics. Wallingford: CABI Press; 1992. p. 601.

Wong TT, McInnis DO, Nishimoto JI, Ota AK, Chang VC. Predation of the Mediterranean fruit fly (Diptera: Tephritidae) by the Argentine ant (Hymenoptera: Formicidae) in Hawaii. J Econ Entomol. 1984;77(6):1454–8.

Wu WY, Chen YP, Yang EC. Chromatic cues to trap the oriental fruit fly. Bactrocera Dorsalis J Insect Physiol. 2007;53(5):509–16.

Wu QM. Prediction of suitable distribution area and risk analysis of six important fruit flies. MSc thesis, Fujian Agriculture and Forestry University, Fuzhou; 2014.

Xiang D, Luo MY, Zhao LJ, Luo XH, Luo X, Feng CS. Study on dynamic monitoring and control technology of fruit fly species in Liuyang. Hunan Agric Sci. 2021;5:43–7.

Xiao S, Jiang XL, Zhang CL, Yin XS, Yang YX. Brief report on inspection investigation of the quarantine fruit fly in Ruili. Yunnan Province Plant Quar. 2001;2:83–4.

Yan XB, Liu J, Lu YN, Yao YH, Wang SX, Wu DF. Effects of different trapping methods on the control of adult loofah flies. J China Capsic. 2023;21(2):44–7+52.

Yang HX, Wu QS, Shi S. Effect of ^{60}Co-γ irradiation treatment on the sterility of pumpkin fruit fly, *Bactrocera (Zeugodacus) tau* (Walker) and quality of pumpkin. J Environ Entomol. 2018;40(4):815–9.

Yao Q, Quan LF, Xu S, Dong YZ, Li WJ, Chen BX. Biology and management of the litchi stink bug, *Tessaratoma papillosa* (Hemiptera: Tessaratomidae): Progress and prospects. Acta Entomol Sin. 2021a;64(5):645–54.

Yao W, Lin WZ, Wu JC, You GC, Liang CF. Trapping effect of yellow and blue sticky traps against pests in the orchard interplanted with *Indigofera endecaphylla* Jacq under different temporal and spatial conditions. Chin J Tropic Agric. 2021b;41(1):92–6.

Yu JY, Ren KL, Xue WP, Li TQ, Wang XJ, Geng K. Species and population dynamics of fruit fly in the garden of kiwi fruit in Xiuwen County. South China Fruits. 2022;51(2):117–21.

Yuan SY, Kong Q, Shen DR, Zhang HR, Xue CL, He C. Threshold temperature and effective accumulated temperature for *Bactrocera tau* (Walker). Plant Prot. 2015a;41(5):148–50.

Yuan SY, Kong Q, Sun Y, Xue CL, Shen DR, Chen B, He C. Determination of the pathogenicity of *Beauveria bassiana* to *Zeugodacus tau*. Jiangsu Agric Sci. 2015b;43(9):158–60.

Yuan SY, Kong Q, Wang CM, Xie K, He C, Shen DR, Zhang R, Tang FF. Olfactory behavioral responses of *Bactrocera tau* (Walker) addicting to 4 kinds of host volatiles. J Northeast Agric Sci. 2023;48(2):104–9.

Yuan WW. Attractant effect of extracts from the host plants on female *Zeugodacus tau* (Walker) Adults. MSc thesis, Fujian Agriculture and Forestry University, Fuzhou; 2022.

Yun JH, Roh SW, Whon TW, Jung MJ, Kim MS, Park DS, Yoon C, Nam YD, Kim YJ, Choi JH, Kim JY, Shin NR, Kim SH, Lee WJ, Bae JW. Insect gut bacterial diversity determined by environmental habitat, diet, developmental stage, and phylogeny of host. Appl Environ Microbiol. 2014;80(17):5254–64.

Zhan GP, Ren LL, Shao Y, Wang QL, Yu DJ, Wang YJ, Li TX. Gamma irradiation as a phytosanitary treatment of *Bactrocera tau* (Diptera: Tephritidae) in pumpkin fruits. J Econ Entomol. 2015;108(1):88–94.

Zhang Y, Chen JY. Recent advances in research of *Bactrocera (Zeugodacus) tau* (Walker) in China. Chin J Tropic Agric. 2018;38(11):70–7.

Zhang QY, Lin XY. Activity test of sex attractant of *Bactrocera cucurbitae*. Subt Plant Res Commun. 1987;2:21–4.

Zhang QY, Lin ZJ, Liu JY, Lin XY. *Bactrocera (Zeugodacus) tau* (Walker) biological characteristics. Plant Quar. 1991;5(3):164–7.

Zhang ZY, Li L, Deng Y, Jiao L, Ling XX, Zhang HY. Population dynamics of fruit fly pests in Wuhan. Hubei Province J Huazhong Agric Univ. 2018;37(5):52–8.

Zhang Y. Research on the population dynamics and trapping control technique of fruit fly pests in three tropical orchards of Hainan. MSc thesis, Hainan University, Haikou; 2014.

Zheng LY, Lun CZ, Liu LJ, Li ZH. Influences of insect symbionts on host growth, development and reproduction: a review. J Plant Prot. 2022;49(1):207–19.

Zhou SK, Li GX, Qiu ZH, Li Z, Li XR. Study on biological characteristics and control of *Bactrocera (Zeugodacus) tau* (Walker). Plant Prot. 1993;19(5):11–2.

Zhou CQ, Wu KK, Chen HD, Yang PJ, Dowell RV. Effect of temperature on the population growth of *Bactrocera tau* (Walker) (Dipt., Tephritidae). J Appl Entomol. 1994;117(1–5):332–7.

Zhou CQ, Chen HD, Lin PQ. A comparative study on the effects of light temperature and humidity three factors on the fecundity of populations of fruity flies. Acta Sci Nat Univ Sunyatseni. 1995;34(1):68–75.

Zhou JH, Shang HW, Li HL. Color taxis and the influence of different hosts on growth and development of *Zeugodacus tau*. J Zhejiang Agric Sci. 2009;3:555–8.

Zhou W, Jiang XS, Qiu ZG, Chen ZL, Shi ZH. Dynamics of population growth and decline of *Zeugodacus tau* in Hangzhou. J Zhejiang Agric Sci. 2010;2:355–6.

Zhou B. Bionomics of *Bactrocera tau* (Walker) (Diptera: Tephritidae) and the effect of foods on population dynamics. MSc thesis, Southwest Agricultural University, Chongqing; 2005.
Zhou Z. Study on the spread risk assessment, loss evaluation and management of alien invasive animals in China. MSc thesis, Nanjing Agricultural University, Nanjing; 2012.
Zhou T. Application of different microbial agents and material ratios in aerobic fermentation of chicken manure and the fertilizer efficiency of fermented products. MSc thesis, Shandong Agricultural University, Tai'an; 2022.
Zhu CW, Gong Y, Li YY, Wang SC, Dong SX, Huang LL, Ni Y. Establishment of fruit fly intelligent image identification based on deep learning. Plant Quar. 2022;36(1):13–8.

Publisher's Note