First Report of Economic Injury to Tomato Due to Zeugodacus tau (Diptera: Tephritidae): Relative Abundance and Effects of Cultivar and Season on Injury

Authors: Boopathi, T., Singh, S. B., Manju, T., Chowdhury, Samik, Singh, A. R., et al.

Source: Florida Entomologist, 100(1) : 63-69

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.100.0111

First report of economic injury to tomato due to *Zeugodacus tau* (Diptera: Tephritidae): relative abundance and effects of cultivar and season on injury

T. Boopathi[1,*], *S. B. Singh*[1], *T. Manju*[1], *Samik Chowdhury*[1], *A. R. Singh*[1], *S. K. Dutta*[1], *V. Dayal*[1], *G. T. Behere*[2], *S. V. Ngachan*[2], *S. Hazarika*[2], *and S.M.A. Rahman*[2]

Abstract

Insect infestation can adversely affect tomato (*Solanum lycopersicum* L.; Solanaceae) development and yield. Fruit flies (Diptera: Tephritidae) are a serious pest of tomato, and are spreading to areas where they were not previously found. This study was undertaken to determine if tephritid fruit flies were present, which species were most abundant, how tomato cultivars responded, and what amount of damage occurred in the Eastern Himalayas of India during May 2014 and 2015. Mature and ripe fruit (n = 20) per cultivar were picked at random from 12 cultivars at weekly intervals to assess percentage of infestation, fly species composition, larval infestation, pupal mortality, adult emergence, and sex ratio during 2 seasons. Seasonal fluctuation of male adults of *Zeugodacus tau* (Walker) (Diptera: Tephritidae) in tomato was studied by installing 3 modified clear traps, made from plastic bottles, that were baited with 0.5 mL Cue-lure and the insecticide dichlorovos 76% EC (Nuvan®). Survey and subsequent identification confirmed the presence of *Z. tau* in tomato in the Himalayas of India. This is the first report of the insect in the province, and of population outbreaks resulting in serious damage to tomato in India. Among fruit fly species present on tomato, *Z. tau* was more abundant (71.4–96.4%) in all geographical regions of Mizoram, India, than were *Bactrocera correcta* (Bezzi), *B. dorsalis* (Hendel), and *B. latifrons* (Hendel), which ranged from 3.6 to 28.6%. The highest percentage of infestation was in Champhai (72.7 ± 6.7%) and Kolasib (80.7 ± 3.5%) and the lowest in Mamit (14.7 ± 4.8%) and Serchhip (19.3 ± 4.7%). Cultivar influenced pupal mortality and adult emergence of *Z. tau*. Seasonal fluctuation of *Z. tau* males on tomato varied; the greatest numbers were trapped during May and Dec. Occurrence of *Z. tau* at high population densities was associated with high levels of damage and could lead to high economic losses in tomato fruit production.

Key Words: *Solanum lycopersicum*; tephritid infestation of tomato; species composition; Cue-lure trap; seasonal abundance; fruit fly

Resumen

La infestación de insectos puede afectar negativamente al desarrollo y rendimiento del tomate (*Solanum lycopersicum* L.; Solanaceae). Las moscas de la fruta (Diptera: Tephritidae) son una plaga seria del tomate, y se están extendiendo a las áreas donde no fueron encontradas anteriormente. Se realizó este estudio para determinar si las moscas de la fruta frutales estan presentes, cuáles son las especies más abundantes, cómo responden los cultivares de tomate y el nivel del daño que ocurrio en los Himalayas orientales de la India durante mayo del 2014 y 2015. Se seleccionaron frutos maduros y pasados (n = 20 por cultivar) al azar de 12 cultivares a intervalos semanales para evaluar el porcentaje de infestación, la composición de las especies de mosca, la infestación de larvas, la mortalidad de pupas, la emergencia de adultos y la proporción de sexos durante 2 estaciones. Se estudió la fluctuación estacional de machos adultos de *Zeugodacus tau* (Walker) (Diptera: Tephritidae) en tomate por medio de la instalación de 3 trampas claras modificadas, hechas de botellas de plástico, que fueron cebadas con 0,5 mL de Cue-lure y el insecticida Dichlorovos 76% CE (Nuvan®). El estudio y identificación subsiguiente confirmaron la presencia de *Z. tau* en tomate en los Himalayas de la India. Este es el primer informe de este insecto en la provincia, y de los brotes poblacionales que resultaron en daño serio al tomate en la India. Entre las especies de moscas de la fruta presentes en el tomate, *Z. tau* fue la más abundante (71,4 a 96,4%) en todas las regiones geográficas de Mizoram, India, que *Bactrocera correcta* (Bezzi), *B. dorsalis* (Hendel) o *B. latifrons* (Hendel), que fueron entre 3,6 y 28,6%. El mayor porcentaje de infestación fue en Champhai (72,7 ± 6,7%) y Kolasib (80,7 ± 3,5%) y el más bajo en Mamit (14,7 ± 4,8%) y Serchhip (19,3 ± 4,7%). El cultivar influyó en la mortalidad de pupas y en la emergencia de adultos de *Z. tau*. La fluctuación estacional de los machos *Z. tau* en el tomate varió; el mayor número de individuos fueron atrapados durante los meses de mayo y diciembre. La ocurrencia de poblaciones de *Z. tau* de alta densidad fue asocida con altos niveles de daño y estos podrían ocasionar grandes pérdidas económicas en la producción de tomate.

Palabras Clave: *Solanum lycopersicum*; infestación de tefrítidos en el tomate; composición de especies; trampa Cue-lure; abundancia estacional; mosca de la fruta

[1]ICAR Research Complex for NEH Region, Mizoram Centre, Kolasib–796081, Mizoram, India; E-mail: boopathiars@gmail.com (T. B.), basantasinghsoibam@rediffmail.com (S. B. S.), manjuicar@gmail.com (T. M.), samikchowdhury33@gmail.com (S. C.), ratanplantpatho@gmail.com (A. R. S.), sudipiari@rediffmail.com (S. K. D.), vishambhar5009@gmail.com (V. D.)
[2]ICAR Research Complex for NEH Region, Umroi Road, Umiam-793103, Meghalaya, India; E-mail: ganeshbehere@gmail.com (G. T. B.), svngachan@rediffmail.com (S. V. N.), samarendra.ches@gmail.com (S. H.), r_aziz@rediffmail.com (S. M. A. R.)
*Corresponding author; E-mail: boopathiars@gmail.com (T. B.)

The Eastern Himalayas of India is unique in its agro-ecosystems, and consequently the insect pest problems are also distinct from the rest of the country. Pest problems in the region are innumerable and as many as 6,000 species of insects have assumed pest status on various crops over the decades (Boopathi et al. 2014). Tomato, *Solanum lycopersicum* L. (Solanaceae), is one of the most important vegetable crops in the Eastern Himalayas of India. In tomato, pests are the main limiting factor in production. Fruit flies (Diptera: Tephritidae) reduce tomato quality and cause abortion of infested fruit (Gupta et al. 1990; Boopathi et al. 2013a). Losses caused by fruit flies vary between 30 and 100% depending on the season (Hasyim et al. 2004; Dhillon et al. 2005; Boopathi 2013; Boopathi et al. 2013b). Fruit flies damage tomato fruit by laying eggs under the skin. The larvae that hatch from these eggs feed in the decaying flesh. Infested fruit become rotten and inedible, or abort, causing considerable loss in production (Boopathi 2013).

Fruit flies in the taxon *Zeugodacus* (= *Bactrocera*) *tau* (Walker) (formerly *Dacus tau*) are widespread in Asia and Australia (Drew & Hancock 2000; De Meyer et al. 2015). Several *Bactrocera* species are serious pests of vegetables (Allwood et al. 1999; Boopathi 2013; Boopathi et al. 2013a,b). Although these flies commonly attack fruit of species within the Cucurbitaceae, they also infest fruit of species from the following families: Leguminoseae (*Phaseolus vulgaris* L.), Moraceae (*Ficus racemosa* L.), Myrtaceae (*Psidium guajava* L.), Oleaceae [*Myxopyrum smilacifolium* (Wallich) Blume], and Sapotaceae [*Manilkara zapota* (L.) P. Royen] (Allwood et al. 1999; Boopathi et al. 2013a). Adult females prefer to lay eggs in soft fruit by piercing with their ovipositor.

Understanding fruit fly diversity, seasonal fluctuation of fruit fly populations, infestation level, species composition, and damage to fruit may contribute to improved management of the pest. This study was undertaken to assess seasonal fluctuation of *Z. tau* male adults in tomato, assess the level of infestation, and determine the species composition in 8 geographical regions of Mizoram (India) and in different tomato cultivars.

Materials and Methods

DIVERSITY OF TEPHRITID FRUIT FLIES IN TOMATO IN MIZORAM, INDIA

Tomato fruit samples were taken from 8 geographical regions in Mizoram, India (Table 1) during May of 2014 and 2015. Mizoram is located in the extreme southern part of the Eastern Himalayas of India, bordering Myanmar in the east and south, and Bangladesh in the west. Fifty mature and ripe fruits per region were picked at random to assess the level of infestation (%) by fruit flies and species composition in each region. Emerging flies were collected and sent to Dr. S. Ramani, University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, India, for identification.

Table 1. Location and altitude of tomato fruit sampled for fruit fly infestation and diversity in 8 geographical regions of Mizoram, India during 2014 and 2015.

Regions	Latitude	Longitude	Altitude (m asl)
Aizawl	23.82782°N	92.74030°E	1,228.5
Champhai	23.69280°N	93.37715°E	1,476.9
Kolasib	24.20016°N	92.66967°E	634.5
Lawngtlai	22.53930°N	92.85178°E	882.0
Lunglei	22.88252°N	92.73903°E	793.2
Mamit	23.95463°N	92.49025°E	948.0
Saiha	22.46190°N	93.05203°E	1,558.2
Serchhip	23.44592°N	92.85248°E	888.3

FIELD EXPERIMENT

A study was undertaken to determine percentage of infestation, larval infestation, biology, and species composition in tomato cultivars, in order to assess seasonal fluctuation of *Z. tau* male adults in tomato. The study was done at the research farm of ICAR Research Complex for NEH Region, Mizoram Centre, Kolasib, Mizoram, India, from May to Jun 2014 (season 1) and Nov 2014 to Jan 2015 (season 2). The research farm is located at 634.5 m above mean sea level at 24.12°N and 92.40°E, and has a mild-tropical climate. Cultivars of tomato were produced on raised beds, 1.5 × 1.0 m, in greenhouses. At 25 d after sowing, seedlings were transplanted at a spacing of 60 × 60 cm. Each cultivar was replicated 3 times in a randomized complete block design. Weeding, application of manure and fertilizers, irrigation, and other cultural practices were followed as per crop production guidelines (TNAU 2012). No plant protection measures were applied throughout cropping seasons.

PERCENTAGE OF INFESTATION, SPECIES COMPOSITION, AND BIOLOGY OF FRUIT FLIES IN TOMATO

Percentage infestation by fruit flies was assessed by randomly sampling mature and ripe fruit (n = 20) from each cultivar at weekly intervals to assess fly species composition, larval infestation, pupal mortality, adult emergence, and sex ratio during seasons 1 and 2. Fruit were placed in separate buckets (30 × 15 × 15 cm), each containing a slightly moist, finely sieved sand layer to facilitate pupation of emerging larvae (Vayssières et al. 2007). Fruit were observed weekly until they dried. Pupae were removed by sifting the sand through a 12 mesh sieve. Pupae were counted and placed in containers with fresh sand inside insect cages (15 × 15 × 15 cm) for adult emergence. Larval infestation, pupal mortality, adult emergence, fruit fly abundance, and male-to-female sex ratio were determined from recovered puparia. Emerging flies were collected and sent to Dr. S. Ramani, University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, India, for identification.

SEASONAL FLUCTUATION OF *Z. TAU* MALE ADULTS IN TOMATO

Three modified clear traps, made from plastic bottles (Steiner et al. 1965), were baited with 0.5 mL Cue-lure (Yasho Industries Pvt. Ltd., Mumbai, India) and the insecticide dichlorovos 76% EC (Nuvan®, Syngenta India Ltd., Mumbai, India). Cotton wicks were soaked in the mixture of lure and insecticide for 5 s and suspended in the trap from one end of a piece of string. The piece of string passed through the lid of the trap and was used to hang the trap on a bamboo stick. Care was taken to avoid contamination of the outer parts of the traps with the mixture. The traps were hung on the bamboo stick about 1.5 m above ground level and traps were spaced 25 m apart in tomato fields. Traps were collected weekly and the numbers of fruit flies in traps were counted; old traps and lures were replaced with new traps and lures.

STATISTICAL ANALYSES

Data were subjected to analysis of variance using SAS (SAS 2011). Effects of cultivar, season, and collection date on fruit fly abundance, and effects of season and collection date on the pattern of *Z. tau* male adults captured by Cue-lure-based traps were analyzed using 2-way ANOVA. If interactions were significant, they were used to explain the data; if interactions were not significant, means were separated using Tukey's HSD test.

Results

DIVERSITY OF TEPHRITID FRUIT FLIES ON TOMATO IN MIZORAM, INDIA

Percentage of infestation of tomatoes by fruit flies in the 8 geographical regions of Mizoram, India, varied during 2014 (14.7–72.7%) and 2015 (19.3–80.7%) (Table 2). The highest infestation (± SE) was in Champahi (72.7 ± 6.8%) and Kolasib (80.7 ± 3.5%) during 2014 and 2015, respectively; the lowest infestation was in Mamit (14.7 ± 4.8%) and Serchhip (19.3 ± 4.7%) during 2014 and 2015, respectively. Among fruit fly species reared from fruit, *Z. tau* was the most abundant species in the fruit fly complex in all geographical regions (71.4–96.4%) (Table 2). Other species reared from fruit [*B. correcta* (Bezzi), *B. dorsalis* (Hendel), and *B. latifrons* (Hendel)] were less frequently encountered (3.6–28.6%) in the regions surveyed.

CHARACTERS USED TO DISTINGUISH *ZEUGODACUS TAU*

The following characters were used to distinguish *Z. tau*: a medium-sized species; abdominal terga III–IV fulvous with a black "T" pattern and anterolateral corners of terga IV and V with broad black markings; face fulvous with a pair of medium-sized circular to oval black spots; wings with a narrow dark fuscous costal band overlapping wing veins R_{2+3} and expanding into a distinct apical spot and broad dark fuscous cubital streak; cells bc and c colorless; microtrichia in outer corner of cell c only; postpronotal lobes and notopleura yellow; scutum black with large areas of red-brown centrally and anterocentrally; lateral and medial postsutural vittae present; yellow spot anterior to mesonotal suture in front of lateral postsutural vittae; mesopleural stripe reaching midway between anterior margin of notopleuron and anterior notapleural seta; scutellum entirely yellow.

PERCENTAGE OF INFESTATION BY FRUIT FLIES IN TOMATO CULTIVARS

Percentage of infestation by fruit flies did not vary with season although the infestation varied among cultivars (Table 3). The cultivar by season interaction was not significant. None of the cultivars were free from fruit fly infestation. Percentage of infestation by fruit flies varied in season 1 (15.0–83.3%) and season 2 (18.3–86.7%) among the cultivars (Table 4). The highest level of infestation was in cultivar Badshah during season 1 (83.3 ± 7.3%) and season 2 (86.7 ± 4.4%) and the lowest level of infestation was in cultivar 9005-Siri during season 1 (15.0 ± 7.6%) and season 2 (18.3 ± 6.0%).

EFFECTS OF CULTIVAR AND SEASON ON BIOLOGY OF FRUIT FLIES IN TOMATO

Cultivar affected the numbers of puparia recovered, numbers of adults emerged, and numbers of males and females. The season by cultivar interaction affected the number of non-emerged puparia and percentage of adult emergence. The cultivar Badshah had the most fruit fly puparia per 20 fruit during season 1 (29.0 ± 7.6) and season 2 (30.0 ± 1.2) (Table 4). The fewest fruit fly puparia per 20 fruit were in cultivars Bhulaxmi (5.3 ± 2.9) and 9005-Siri (5.3 ± 1. 5) during season 1. In season 2, cultivar Nun-7610 had the fewest fruit fly puparia per 20 fruit (4.0 ± 0.6). The fewest non-emerged puparia were found in cultivar Emerald during season 1 (0.7 ± 0.3). In season 2, the fewest non-emerged puparia (0.3 ± 0.3) were found in cultivars Nun-7610 and JK Akshay. The most non-emerged fruit fly puparia were found in cultivars Nun-7610 (14.7 ± 3.7) and Badshah (9.0 ± 1.2) during seasons 1 and 2, respectively (Table 4).

Adult emergence varied considerably among cultivars and seasons, with cultivars Emerald (93.1 ± 3.7%) and JK Akshay (97.4 ± 2.6%) exhibiting the highest percentage of adult emergence during seasons 1 and 2, respectively (Table 4). The lowest percentage of adult emergence was in cultivars Nun-7610 (24.2 ± 2.5%) and Arka Alok (42.4 ± 14.2%) during seasons 1 and 2, respectively. The greatest number of adults emerged in cultivar Badshah during seasons 1 (18.3 ± 2.9) and 2 (21.0 ± 2.3) (Table 4). The smallest number of adults emerged in cultivars 9005-Siri (2.0 ± 0.6) and Nun-7610 (3.7 ± 0.3) during seasons 1 and 2, respectively. The greatest numbers of males and females were found in cultivar Badshah during season 1 (9.0 ± 2.3 and 9.3 ± 1.7, respectively) and season 2 (9.0 ± 2.3 and 9.3 ± 1.7, respectively) (Table 4). The smallest numbers of males (1.3 ± 0.3) and females (0.7 ± 0.3) were found in cultivar 9005-Siri during season 1; in season 2, the smallest numbers of males (2.0 ± 0.0) and females (1.0 ± 0.6) were found in

Table 2. Percentage of fruit fly infestation and diversity of fruit flies in tomato fruit in 8 geographical regions of Mizoram, India, during 2014 and 2015.

			Species composition (%)	
Year	Location	Fruit infested (%) (mean ± SE)[a]	*Zeugodacus tau*	Other species[b]
2014	Aizawl	47.3 ± 8.7 b	89.2	10.8
	Champhai	72.7 ± 6.8 a	80.7	19.3
	Kolasib	62.0 ± 4.2 ab	96.4	3.6
	Lawngtlai	23.3 ± 7.0 cd	71.4	28.7
	Lunglei	48.7 ± 4.1 b	85.6	14.4
	Mamit	14.7 ± 4.8 d	93.3	6.7
	Saiha	31.3 ± 4.7 c	94.4	5.6
	Serchhip	54.7 ± 6.6 b	86.1	13.9
2015	Aizawl	38.7 ± 6.4 c	85.9	14.1
	Champhai	58.0 ± 5.8 b	74.5	25.5
	Kolasib	80.7 ± 3.5 a	86.6	13.4
	Lawngtlai	39.3 ± 4.7 c	92.6	7.4
	Lunglei	49.3 ± 4.7 bc	93.9	6.1
	Mamit	32.7 ± 5.8 c	91.9	8.1
	Saiha	33.3 ± 8.1 cd	87.1	12.9
	Serchhip	19.3 ± 4.7 d	82.2	17.8

[a]Data in interaction analyzed with Least Squares Means and means separated with the Tukey test at $P < 0.01$.
[b]*Bactrocera correcta*, *B. dorsalis*, and *B. latifrons*.

Table 3. Analysis of variance values associated with analysis of cultivar and season influences on biology of fruit flies.

		Biology of fruit flies															
										% adult emergence							
		% fruits infested		No. of puparia		No. of non-emerged puparia		No. of adults emerged		Male		Female		No. of adults		Sex ratio (M:F)	
Source	df	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Season (S)	1	0.303	0.585ns	0.003	0.959ns	0.160	0.691ns	0.244	0.624ns	0.725	0.399ns	0.011	0.916ns	0.050	0.824ns	0.133	0.718ns
Cultivar (C)	11	12.881	<0.001	4.172	<0.001	1.879	0.068ns	5.920	<0.001	1.678	0.109ns	4.380	<0.001	7.068	<0.001	1.673	0.110ns
S × C	11	0.178	0.998ns	1.806	0.080ns	2.877	0.006**	1.140	0.354ns	3.038	0.004**	1.393	0.209ns	0.674	0.755ns	0.868	0.577ns

Asterisks indicate level of significance: **, $P < 0.01$; ns, not significant.

cultivars Nun-7610 and Pusa Rohini, respectively. The male-to-female sex ratio of *Z. tau* was lowest in cultivar Jessica (1:1.33) and highest in cultivar Bhulaxmi (1:0.33) in season 1 (Table 4). In season 2, the male-to-female sex ratio of *Z. tau* was lowest in cultivar Swaraksha (1:1.34) and highest in cultivar Pusa Rohini (1:0.39).

SPECIES COMPOSITION OF FRUIT FLIES IN TOMATO CULTIVARS

Among fruit fly species, *Z. tau* was the most common species in all cultivars (66.67–100.00%) (Table 5). The other species detected (*B. correcta*, *B. dorsalis*, or *B. latifrons*) occurred less frequently (0.0–33.3%). Cultivars Pusa Rohini, Emerald, Arka Alok, Nun-7610, Bhulaxmi, 9005-Siri, Badshah, Alankar, and Swaraksha were infested only by *Z. tau*. The cultivars Jessica, JK Akshay, and Chiranjeevi were infested by all 4 fruit fly species. *Zeugodacus tau* was found infesting 85.7% of fruit in cultivars Jessica and JK Akshay and 66.7% in cultivar Chiranjeevi. Percentage of infestation by other species was higher in cultivar Chiranjeevi (33.3%) and lower in cultivars Jessica and JK Akshay (14.3%).

SEASONAL FLUCTUATION OF *Z. TAU* MALE ADULTS DETECTED BY CUE-LURE-BASED TRAPS

Season ($F = 108.4$; df = 1; $P < 0.001$) and collection date ($F = 31.3$; df = 10; $P < 0.001$) affected the pattern of *Z. tau* males captured by Cue-lure-based traps (Table 6). The interaction of season and collection date also was statistically significant ($F = 126.4$; df = 10; $P < 0.001$). The seasonal fluctuation of *Z. tau* males captured in traps is shown in Fig. 1. The numbers of *Z. tau* males caught in Cue-lure-based traps ranged from 29.3 to 168.6 fruit flies per trap in season 1, and from 17.0 to 95.3 per trap in season 2. In season 1, numbers of *Z. tau* male (Fig. 1a) reached peak abundance on 8 May 2014 (168.7 ± 7.0), followed by a decline. The smallest number of *Z. tau* males caught was on 26 Jun 2014 (29.3 ± 5.6). In season 2, numbers of *Z. tau* males trapped (Fig. 1b) increased from mid-Nov, reaching a peak on 21 Dec 2014 (95.3 ± 4.9), and followed by a decline toward the end of Dec 2014. The smallest number of *Z. tau* males captured was on 16 Nov 2014 (17.0 ± 2.6).

Discussion

Zeugodacus tau was found to infest all tomato cultivars evaluated. This is the first report of the insect in Mizoram, India. More importantly, this is a drastic shift in feeding behavior by *Z. tau,* changing from feeding on cucurbits to Solanaceae such as tomatoes. *Zeugodacus tau* always has been regarded primarily as a cucurbit feeder. Some tephritid species have genuinely wide host ranges, both because some apparent polyphagous "species" have proven to be an unrecognized species complex, and because host shifts undeniably occur. If host shifts occur far more frequently than host speciation, then the process is similar to the theory of island biogeography, where species richness of island communities is a balance between the rate at which new species colonize the island and existing species go extinct. Fruit fly host records signifying comparative host use might be useful for recognizing lineages, races, and species (cryptic or otherwise). This assumption is consistent with the generalization that different biological species have different host requirements and are correspondingly attracted to different host species.

Fruit flies can cause significant to total crop failure on tomato (José et al. 2013). Among fruit fly species present on tomato, *Z. tau* was more abundant in all geographical regions of Mizoram, India, than were other fruit fly species, i.e., *B. correcta*, *B. dorsalis*, or *B. latifrons*. This study clearly revealed the presence of *Z. tau* in

Table 4. The biology of tephritid fruit flies infesting tomato fruit, as affected by season and cultivar.

Season	Cultivar	Fruit fly infestation (mean % ± SE)[a]	Biology of fruit flies (mean ± SE)[a]						
			No. of Puparia	No. of non-emerged puparia	No. of adults emerged	Adult emergence (%)	No. of adults		Sex ratio (M:F)
							Male	Female	
1	Pusa Rohini	30.00 ± 5.77 efg	9.00 ± 1.53 bc	2.33 ± 0.67 d	6.67 ± 1.45 bcd	73.21 ± 8.81 ab	4.67 ± 0.88 bc	2.00 ± 1.00 bc	1:0.43 ± 0.19 a
	Emerald	41.67 ± 9.28 c-g	8.33 ± 2.03 bc	0.67 ± 0.33 d	7.67 ± 1.76 bcd	93.06 ± 3.67 a	5.00 ± 1.00 bc	2.67 ± 0.88 bc	1:0.52 ± 0.15 a
	Jessica	56.67 ± 10.14 a-e	9.00 ± 3.00 bc	3.33 ± 1.20 cd	5.67 ± 2.33 bcd	61.11 ± 14.70 ab	2.33 ± 0.88 bc	3.33 ± 1.45 bc	1:1.33 ± 0.17 a
	Arka Alok	71.67 ± 10.14 a	17.67 ± 1.76 b	9.33 ± 2.03 abc	8.33 ± 2.33 bcd	46.89 ± 11.71 bc	4.33 ± 1.45 bc	4.00 ± 1.00 bc	1:0.99 ± 0.15 a
	Nun-7610	63.33 ± 13.64 a-d	19.33 ± 4.84 a	14.67 ± 3.71 a	4.67 ± 1.20 cd	24.24 ± 2.47 c	2.67 ± 0.67 bc	2.00 ± 0.58 bc	1:0.75 ± 0.14 a
	Chiranjeevi	53.33 ± 15.90 b-e	11.67 ± 4.41 bc	6.00 ± 2.52 bcd	5.67 ± 2.03 bcd	48.33 ± 6.01 bc	2.67 ± 1.20 bc	3.00 ± 1.00 bc	1:1.27 ± 0.37 a
	Bhulaxmi	23.33 ± 6.01 fg	5.33 ± 2.85 c	1.00 ± 0.00 d	4.33 ± 2.85 cd	69.19 ± 11.88 ab	2.67 ± 1.20 bc	1.67 ± 1.67 bc	1:0.33 ± 0.33 a
	JK Akshay	38.33 ± 10.93 d-g	12.67 ± 2.96 bc	4.67 ± 1.76 bcd	8.00 ± 1.53 bcd	65.27 ± 6.16 ab	4.33 ± 1.20 bc	3.67 ± 0.67 bc	1:1.00 ± 0.29 a
	9005-Siri	15.00 ± 7.64 g	5.33 ± 1.45 c	3.33 ± 2.03 cd	2.00 ± 0.58 d	50.83 ± 25.83 bc	1.33 ± 0.33 c	0.67 ± 0.33 c	1:0.50 ± 0.29 a
	Badshah	83.33 ± 7.26 a	29.00 ± 7.57 a	10.67 ± 4.91 ab	18.33 ± 2.85 a	67.77 ± 10.28 ab	9.00 ± 2.31 a	9.33 ± 1.67 a	1:1.24 ± 0.48 a
	Alankar	48.33 ± 8.82 b-f	15.67 ± 4.98 bc	4.33 ± 1.86 bcd	11.33 ± 3.48 b	72.07 ± 7.00 ab	6.00 ± 1.00 ab	5.33 ± 2.60 b	1:0.80 ± 0.34 a
	Swaraksha	66.67 ± 4.41 abc	14.67 ± 2.03 bc	6.00 ± 1.73 bcd	8.67 ± 2.03 bc	58.48 ± 10.84 b	4.67 ± 1.45 bc	4.00 ± 0.58 bc	1:1.00 ± 0.25 a
2	Pusa Rohini	23.33 ± 6.01 f	8.33 ± 3.18 bc	4.00 ± 3.00 a	4.33 ± 1.45 bc	60.91 ± 17.25 bc	3.33 ± 1.33 c	1.00 ± 0.58 b	1:0.39 ± 0.31 a
	Emerald	48.33 ± 4.41 cde	14.67 ± 4.33 bc	7.67 ± 3.38 a	7.00 ± 1.53 bc	54.83 ± 15.83 c	3.67 ± 0.88 c	3.33 ± 0.88 b	1:1.00 ± 0.29 a
	Jessica	53.33 ± 7.26 bcd	19.33 ± 1.67 ab	7.67 ± 2.03 a	11.67 ± 2.73 b	59.52 ± 10.74 c	7.67 ± 1.45 ab	4.00 ± 1.53 b	1:0.52 ± 0.14 a
	Arka Alok	66.67 ± 9.28 bc	13.00 ± 3.06 bc	6.67 ± 0.67 a	6.33 ± 2.67 bc	42.41 ± 14.21 c	3.33 ± 1.76 c	3.00 ± 1.15 b	1:0.92 ± 0.22 a
	Nun-7610	68.33 ± 7.26 ab	4.00 ± 0.58 c	0.33 ± 0.33 a	3.67 ± 0.33 c	93.33 ± 6.67 ab	2.00 ± 0.00 c	1.67 ± 0.33 b	1:0.83 ± 0.17 a
	Chiranjeevi	58.33 ± 6.01 bc	11.00 ± 3.46 bc	3.33 ± 1.45 a	7.67 ± 2.85 bc	65.20 ± 14.70 abc	4.33 ± 1.76 bc	3.33 ± 1.20 b	1:0.86 ± 0.14 a
	Bhulaxmi	31.67 ± 4.41 ef	11.33 ± 6.44 bc	6.67 ± 4.67 a	4.67 ± 2.03 bc	46.03 ± 12.70 c	3.00 ± 1.53 c	1.67 ± 0.88 b	1:0.61 ± 0.45 a
	JK Akshay	36.67 ± 6.01 def	8.67 ± 2.60 bc	0.33 ± 0.33 a	8.33 ± 2.33 bc	97.44 ± 2.56 a	3.33 ± 0.67 c	4.00 ± 1.00 b	1:1.17 ± 0.08 a
	9005-Siri	18.33 ± 1.67 f	14.33 ± 7.97 bc	5.33 ± 2.96 a	9.00 ± 5.03 bc	64.63 ± 5.65 bc	3.00 ± 0.58 c	3.33 ± 1.86 b	1:0.97 ± 0.39 a
	Badshah	86.67 ± 4.41 a	30.00 ± 1.15 a	9.00 ± 1.15 a	21.00 ± 2.31 a	69.61 ± 5.03 abc	10.00 ± 2.08 a	11.00 ± 1.73 a	1:1.22 ± 0.39 a
	Alankar	51.67 ± 8.33 bcd	7.67 ± 0.88 bc	2.00 ± 0.58 a	5.67 ± 0.67 bc	74.54 ± 6.23 abc	3.33 ± 0.67 c	2.33 ± 0.67 b	1:0.83 ± 0.36 a
	Swaraksha	70.00 ± 5.77 ab	16.33 ± 4.84 b	8.67 ± 3.18 a	7.67 ± 1.76 bc	48.70 ± 4.90 c	3.33 ± 0.88 c	4.33 ± 0.88 b	1:1.34 ± 0.09 a

[a]Data in interactions analyzed with least squares means and means separated with the Tukey test at $P \leq 0.01$. Means (± SE) per season in a column followed by the same lowercase letter did not differ significantly ($P > 0.01$)

Table 5. Species composition of fruit flies in tomato cultivars.

	Species composition (%)	
Cultivar	*Zeugodacus tau*	Other species[a]
Pusa Rohini	100.0	0.0
Emerald	100.0	0.0
Arka Alok	100.0	0.0
Nun-7610	100.0	0.0
Bhulaxmi	100.0	0.0
9005-Siri	100.0	0.0
Badshah	100.0	0.0
Alankar	100.0	0.0
Swaraksha	100.0	0.0
Jessica	85.7	14.3
JK Akshay	85.7	14.3
Chiranjeevi	66.7	33.3

[a]*Bactrocera correcta*, *B. dorsalis*, and *B. latifrons*.

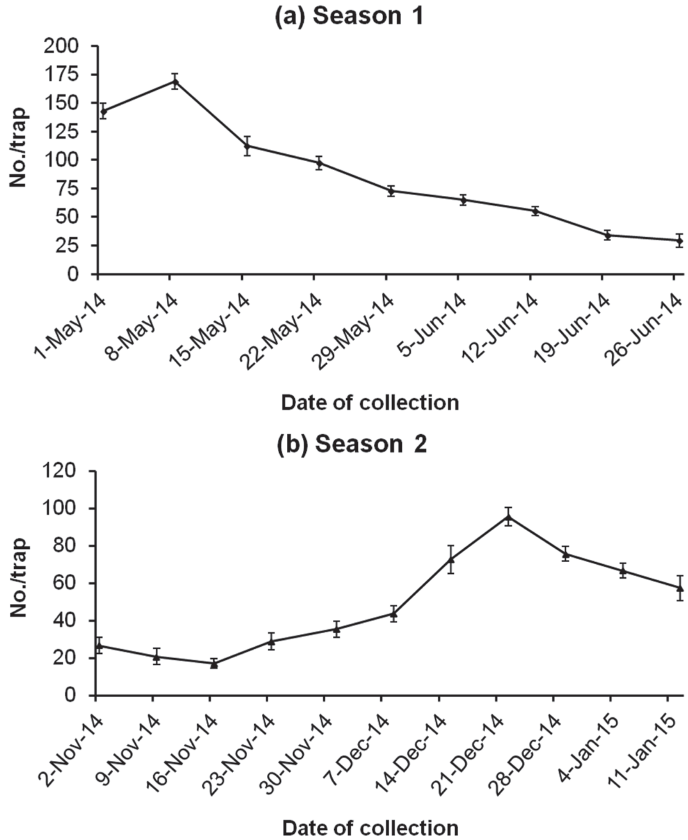

Fig. 1. Seasonal pattern of *Zeugodacus tau* male adults (mean ± SE) captured by Cue-lure-based traps in tomato in (a) season 1, and (b) season 2.

Mizoram (India) and its environs, and shows that the pest is well distributed in all locations studied. The highest levels of infestation were in Champhai and Kolasib (Mizoram, India) during 2014 and 2015, respectively. The relative pest abundance of the flies at the different locations appeared to be influenced by the characteristics of the area where they are situated. Champhai is situated in denser forest than the other locations, and had the highest observed pest density. This finding was expected because of the high diversity of plants; hence, there are many hosts. This is consistent with the reports of Harris & Lee (1989) and Vargas et al. (1990), who suggested the distribution and abundance of various tropical tephritids was affected by availability of host fruits. Previously, Mwatawala et al. (2010) and De Meyer et al. (2015) reported that the cucurbit feeders *Zeugodacus cucurbitae* (Coquillett) and *Dacus punctatifrons* Karsch were serious pests of tomatoes in Cameroon.

The infestation level was highest as fruit matured, and little or no infestation occurred in the earlier fruit stages. Most fruits became increasingly susceptible to fruit fly damage close to harvest. Mwatawala et al. (2006) also reported that fruit flies cause more severe damage to mature tomato fruit than to young fruit. Preventing fruit fly oviposition during fruit maturation is difficult because excessive insecticide residues on the fruit make them illegal to sell. Unfortunately, none of the cultivars were free from fruit fly infestation. *Zeugodacus tau* was the most common species in the complex in all cultivars, and is now considered a major insect pest of tomato in India because of its prevalence, rapid spread, and destructive nature (Boopathi et al. 2013a).

The pattern of *Z. tau* males captured by Cue-lure-based traps varied with season and collection date. The pattern is consistent with reports of Selvaraj et al. (2006) and Sithanatham et al. (2006), where fruit flies were caught during Apr and May, also a period of fruit formation. Similarly, Boopathi et al. (2013a) and Boopathi et al. (2013b) reported that most fruit flies were caught during Apr and May in chilli and guava crops. The effectiveness and efficiency of the traps shows their importance in surveillance and detection programs involving *Z. tau*.

Table 6. Analysis of variance of effects of seasonal pattern of *Zeugodacus tau* male adults on tomato captured by Cue-lure-based traps.

	Seasonal pattern of *Zeugodacus tau* male adults		
Source	df	*F* value	*P* value
Season (S)	1	108.455	<0.001
Collection date (C)	10	31.302	<0.001
S × C	10	126.406	<0.001

Presence of fruit flies was confirmed on tomato, and the extent of loss varied depending on geographical region, cultivar and season. *Zeugodacus tau* was the most common species in the complex in all geographical regions and tomato cultivars. Occurrence of *Z. tau* at high population densities is associated with the highest level of damage, and could lead to high economic losses in tomato fruit production. The apparent drastic shift of feeding by Z. *tau* from cucurbits to tomato means that tomato growers will need to plan to monitor and manage this new pest.

Acknowledgments

The inventory was funded by the National Innovation on Climate Resilient Agriculture (NICRA), Indian Council of Agricultural Research, Pusa, New Delhi, India. We thank the Principal Investigator (NICRA), ICAR Research Complex for NEH Region, Umroi Road, Umiam, Meghalaya, for providing the facilities and support. We thank S. Ramani, University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, India, for his help in the identification of fruit fly species.

References Cited

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

Boopathi T. 2013. Population dynamics of fruit flies, *Bactrocera* spp. in tomato, *Lycopersicon esculentum* Mill. Journal of Eco-friendly Agriculture 8: 81–83.

Boopathi T, Singh SB, Sithanantham S. 2013a. Exploratory bio-ecology studies on fruit flies, *Bactrocera* spp. in Mizoram. Hexapoda 20: 83–87.

Boopathi T, Singh SB, Ngachan SV, Manju T, Ramakrishna Y, Lalhruaipuii CS. 2013b. Influence of weather factors on the incidence of fruit flies in chilli (*Capsicum annuum* L.) and their prediction model. Pest Management in Horticultural Ecosystems 19: 194–198.

Boopathi T, Mohankumar S, Karuppuchamy P, Kalyanasundaram M, Ravi M, Preetha B, Aravintharaj R. 2014. Genetic evidence for diversity of spiralling whitefly, *Aleurodicus dispersus* (Hemiptera: Aleyrodidae) populations in India. Florida Entomologist 97: 1115–1122.

De Meyer M, Delatte H, Mwatawala M, Quilici S, Vayssières J-F, Virgilio M. 2015. A review of the current knowledge on *Zeugodacus cucurbitae* (Coquillett) (Diptera, Tephritidae) in Africa, with a list of species included in *Zeugodacus*, pp 539–557 *In* De Meyer M, Clarke AR, Vera MT, Hendrichs J [eds.], Resolution of Cryptic Species Complexes of Tephritid Pests to Enhance SIT Application and Facilitate International Trade. ZooKeys Special Issue 540. Pensoft Publishers, Sofia, Bulgaria.

Dhillon MK, Singh R, Naresh JS, Sharma HC. 2005. The melon fruit fly, *Bactrocera cucurbitae*: a review of its biology and management. Journal of Insect Science 5: 1–16.

Drew RAI, Hancock DL. 2000. Phylogeny of the tribe Dacini (Dacinae) based on morphological, distributional, and biological data, pp 491–504 *In* Aluja M, Norrbom AL [eds.], Fruit Flies (Tephritidae): Phylogeny and Evolution of Behavior. CRC Press, New York, New York.

Gupta D, Verma AK, Bhalla OP. 1990. Population of fruit-flies (*Dacus zonatus* and *D. dorsalis*) infesting fruit crops in north-western Himalayan region. Indian Journal of Agricultural Sciences 60: 471–474.

Harris EJ, Lee CYL. 1989. Influence of bittermelon, *Momordica charantia* L. (Cucurbitaceae), on distribution of melon fly, *Dacus cucurbitae* Coquillet (Diptera: Tephritidae) on the island of Molokai, Hawaii. Proceedings of the Hawaiian Entomological Society 29: 49–56.

Hasyim A, Muryati K, Mukminin, Rizka. 2004. Fruit fly control in Indonesia. Annual Report. Indonesian Fruits Research Institute, Solok, West Sumatra.

José L, Cugala D, Santos L. 2013. Assessment of invasive fruit fly fruit infestation and damage in Cabo Delgado Province, Northern Mozambique. African Crop Science Journal 21: 21–28.

Mwatawala MW, De Meyer M, Makundi RH, Maerere AP. 2006. Biodiversity of fruit flies (Diptera: Tephritidae) in orchards in different agro-ecological zones of the Morogoro region, Tanzania. Fruits 61: 321–332.

Mwatawala M, Maerere AP, Makundi R, De Meyer M. 2010. Incidence and host range of the melon fruit fly *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae) in central Tanzania. International Journal of Pest Management 56: 265–273.

Selvaraj P, Sithanantham S, Boopathi T, Vasumathi S. 2006. Native fruit fly species composition monitoring with methyl eugenol traps: initial results in Tamil Nadu, India, pp. 135 *In* Proceedings of International Conference on Biodiversity of Insects: Challenging Issues in Management and Conservation. Bharathiar University. Coimbatore, Tamil Nadu, India, 30 Jan to 3 Feb 2006.

Sithanatham S, Selvaraj P, Boopathi T. 2006. The fruit fly *Bactrocera invadens* (Tephritidae: Diptera) new to India. Pestology 30: 36–37.

SAS. 2011. SAS® 9.3 System Options: Reference, 2nd Edition. SAS Institute Inc., Cary, North Carolina.

Steiner LF, Harris EJ, Mitchell WC, Fujimoto MS, Christenson LD. 1965. Melon fly eradication by over flooding with sterile flies. Journal of Economic Entomology 58: 519–522.

TNAU (Tamil Nadu Agricultural University). 2012. Crop Production Guide 2012. Department of Agriculture, Government of Tamil Nadu, Chennai and Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

Vargas RI, Stark JD, Nishida T. 1990. Population dynamics, habitat preference, and seasonal distribution patterns of oriental fruit fly and melon fly (Diptera: Tephritidae) in an agricultural area. Environmental Entomology 19: 1820–1828.

Vayssières J-F, Sanogo F, Noussourou M. 2007. Inventory of the fruit fly species (Diptera: Tephritidae) linked to the mango tree in Mali, and tests of integrated control. Fruits 62: 329–341.