https://doi.org/10.33307/entomon.v51i1.1610
Entomon 51(1): 27-34
Article No. ent. 51104

Species diversity and population dynamics of fruit flies in cucurbit ecosystem

Atham Bhavana Sruthi*, Zadda Kavitha*, M. Shanthi, M. Sathiyaseelan and Anandabhairavi

Department of Entomology, Agricultural College and Research Institute, Madurai 680656, Tamil Nadu, India.
Email: sruthientomon@gmail.com; kavitha_j_v@yahoo.com

ABSTRACT: Investigation on the population dynamics of Tephritidae fruit flies (Diptera) was conducted by installing "Cuelure traps" in the cucurbit ecosystem, Madurai, Tamil Nadu, India. Two species of fruit flies, *Zeugodacus cucurbitae* and *Bactrocera dorsalis* were captured during the monitoring process. The population of *Z. cucurbitae* prevailed the whole season with its peak activity from 9th SMW and 40th SMW which coincided with the peak fruiting period of bitter gourd and snake gourd respectively. Relative abundance of *B. dorsalis* was more in the snake gourd (39%) than the bitter gourd (5%). The Simpson's index and the Shannon's index were higher in snake gourd than bitter gourd. The bitter gourd ecosystem has higher Margalef and Mehinick Index. The weather correlation showed that the population of both species and abiotic factors had no significant correlation in bitter gourd ecosystem. In snake gourd ecosystem, both the species exhibited strong inverse relationship with maximum and minimum wind speed.

KEY WORDS: Bitter gourd, snake gourd, *Zeugodacus cucurbitae, Bactrocera dorsalis,* relative abundance, diversity indices

INTRODUCTION

One of the largest families of Diptera, the fruit fly family, Tephritidae has over 4500 species, of which 250 are significant economically (David and Ramani, 2011). Ruiz *et al.* (2014) described fruit flies as a major pests of fruits in the world with India being considered as the home land for fruit flies (Dhillon *et al.*, 2005). India harbors a rich diversity of fruit flies and this presents a serious risk to the export industry (Vasudha *et al.*, 2019). Attack of fruit flies cause reduction in the harvest volume and fruit quality, and also exposes them to vulnerable secondary infections. Because of the polyphagous, florivorous and frugivorous nature of fruit flies, they are recognized as one of the top ten major threats of horticulture causing yield loss extending from 2 to 100 per cent based on the crop and season. Maggots infest and damage the pulp making the fruit unfit for consumption thus, reducing the marketability of fruits (Dhillon *et al.*, 2005).

Vegetable crops in India are occupying cultivation area of 1.03 crore hectares with a productivity of 18.94 metric tonnes (Anonymous, 2020-21). Among the vegetables grown in India, cucurbits are the

* Author for correspondence

significiant summer vegetable and are grown throughout the year except winter season. Atwal and Dhaliwal (2005) reported 50 per cent damage of cucurbits in India because of fruit flies. Fruit flies are reported to attack over 70 species of cucurbits of which, bitter gourd, snake gourd and musk melon are the most favored (Doharey, 1983).

Bitter gourd (*Momordica charantia*) is an important cucurbit vegetable. In India, during 2019–2020, bitter gourd was grown on approximately 1.01 lakh hectares, producing around 12.92 lakh metric tonnes of the crop (Anonymous, 2020–21). Tthe infestation of fruit flies in bitter gourd ranges between 41 to 89 per cent damaging fruits, tender stem and flowers (Ravindranath and Pillai, 1986). Melon fly, *Zeugodacus cucurbitae,* caused 28.56 per cent yield reduction in bitter gourd (Singh *et al.*, 2000). Snake gourd (*Trichosanthes anguina*) is an important single-season, cucurbit vegetable. In Tamil Nadu, snake gourd occupies an area of 1439 ha in cultivation, 35,411 tonnes production with 17.66 t ha^{-1} productivity (Sowmiya *et al.*, 2020). Monitoring fruit flies is important in understanding and determining its population dynamics, assessing infestation levels at different sites and measuring the effictiveness of a particular control strategy (Enkerlin *et al.*, 1996; Eliopoulos, 2007). Parapheromone trap *i.e.,* cue-lure trap was best suited to monitor and mass trap melon fruit flies (Pawar *et al.*, 1991; Permalloo *et al.*, 1998) hence it was used for the present study.

MATERIALS AND METHODS

Field experiments on monitoring of fruit flies infestation was performed in bitter gourd and snake gourd fields during February, 2021 to April, 2021 and July, 2021 to October, 2021 respectively in Ayyur village, Alanganallur block of Madurai district, Tamil Nadu (Table 1).

Fruit flies caught in the cue-lure traps during the monitoring studies were preserved and divided into two groups according to the visible morphological distinguishing triats such as presence or absence of prominent black spot on the apical region of the wing and dark or pale colour of the body. Identification of the two fruit fly species was carried out by Dr. K. J. David, Principal Scientist, National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru.

Table 1. Details of the locations of experimental plots

Location	Latitude	Longitude
Meenakshipuram	10°4’14.1708" N	78°4’46.4556" E
Errampatti	10°4’30.8892" N	78°5’3.4008" E
Alagapuri	10°3’47.124" N	78°4’41.5848" E
Urseri	10°4’5.0304" N	78°4’10.8132" E
Azhagapuri	10°4’37.3656" N	78°4’52.6224" E
Azhagapuri	10°4’37.3584" N	78°4’52.5648" E
Meenakshipuram	10°4’3.792" N	78°4’9.006" E
Kovilpatti	10°4’35.8428" N	78°4’55.794"E

Monitoring of melon flies in cucurbit ecosystem was done by installing the para-pheromone traps, cue-lure (4-(p-acetoxyphenyl)-2- butanone) procured from Barrix Agro Sciences Pvt. Ltd. Traps were placed @ 5 nos./acre in bitter gourd and snake gourd fields at the time of flowering. They were hung at 1 to 1.5m height in iron wired pandal. Weekly fruit fly catches in the cuelure traps were recorded from flowering till last harvest. Weather data *viz.,* maximum and minimum temperature, max and min wind speed, precipitation (rainfall) and relative humidity, were acquired from NASA ARC POWER website during the monitoring period (Sowmiya *et al.*, 2020). Meteorological data were aggregated into weekly averages and correlated with the corresponding trap catches of fruit flies to analyze the influence of meteorological factors on population fluctuations of fruit flies.

Diversity indices *i.e.,* Simpson’s index (Simpson, 1949) and Shannon-Wiener index (Shannon and Weaver, 1949) were calculated to determine the species diversity of melon flies in bitter gourd and snake gourd ecosystems.

Simpson’s index (D) is the proportion of particular species in relation to total number of species. Values of this index generally range from 0.0 to 1.0 and the ecosystem with higher value was considered as diversified ecosystem.

$$D = \sum \left(\frac{n_i(n_i - 1)}{N(N-1)} \right)$$

Shannon's index (H) was calculated by summing the proportions of different species in respect to the total number of species (pi). Normally values of this index range from 0.0 to 5.0. Diversified ecosystems have higher index values.

$$H' = -\sum p_i \ln p_i$$

Menhinick's index (N) was calculated by dividing the number of species by the square root of the total number of individuals caught in the traps (Whittaker and Rh, 1977).

$$D_{Mn} = \frac{S}{\sqrt{N}}$$

Margalef index (D) is a species richness indicator calculated by the formula given below where, S represents the number of species and N denotes the number of individuals in the sample (Clifford, 1975).

$$D_{Mg} = \frac{(S-1)}{\ln N}$$

Relative abundance = (No. of fruit flies of one species / No. of fruit flies of all species) X 100.

RESULTS AND DISCUSSION

The species in the parapheromone traps in bitter gourd and snake gourd fields were identified as *Zeugodacus cucurbitae* (Coquilett) and *Bactrocera dorsalis* (Hendel).

Bitter gourd ecosystem

Melon fruit fly, *Z. cucurbitae*:

During the 6th standard meteorological week (SMW), when the crop is in full flowering stage, mean fruit fly catch was 11/trap/week (T/W) (Table 2). Afterwards, trap catch was increased gradually and peak population was noted during fruiting stage *i.e.,* 9th SMW with 26 fruit flies/trap (Ff/T). Then the fruit fly count was gradually reduced during 10th and 11th standard meteorological weeks with 23 and 21 Ff/T respectively. During the 12th SMW, trap catches reduced abruptly (12 Ff/T). In the subsequent week (13th SMW) again mean trap catch reached to 21.0. During the last harvest, in 14th SMW, trap catch of 15/week was recorded.

A correlation was drawn between the weekly fruit fly catches and weather parameters (Temperature and wind speed ranges, precipitation and moisture). Using this correlation matrix, the influence of different weather parameters on fruit fly presence was investigated. The population of *Z. cucurbitae* was found to be positively related to maximum temperature, minimum temperature and maximum wind speed. Negative correlation was detected between the trap catches of *Z. cucurbitae* and relative humidity, rainfall & minimum wind speed. In bitter gourd, population of *Z. cucurbitae* exhibited insignificant correlation with all the weather parameters. However, studies of Dhillon *et al.* (2005) reported a positive relationship between rainfall and fruit fly population. The population of *B. dorsalis* exhibited a significant positive correlation with temperature (both maximum and minimum levels) while showing a significantly negative correlation with relative humidity (Table 3).

Oriental fruit fly, *B. dorsalis*:

The flies were not captured in the traps from 6th SMW to 12th SMW. Their population appeared in the traps during 13th SMW with a mean number of 2/trap. In 14th SMW, during the final harvest of the crop, 7.0 *B. dorsalis* flies were noted per trap (Table 2). *B. dorsalis* population displayed positive correlation with maximum temperature, minimum temperature, rainfall and maximum wind speed. Weather parameters *i.e.,* minimum wind speed and relative humidity were showing negative correlation with the abundance of this fruit fly population (Table 3, Fig. 1).

Snake gourd ecosystem

Melon fruit fly, *Z. cucurbitae*:

Observations were recorded from the 29th SMW during full flowering stage and mean fruit fly catch of 11/trap was noted (Table 4). Subsequently during 31st SMW, catches were increased to 17/trap. Later, number of fruit flies trapped decreased to 11.0 in 32nd SMW. Following this, during the fruiting stage, *i.e.,* from 33rd to 37th SMW, catches ranged between 15 to 20/T/W. During the end of the fruiting stage, peak number of fruit flies (27/T/W) were captured

Table 2. Seasonal incidence of cucurbit fruit flies in bitter gourd ecosystem (February to April, 2021)

SMW	Crop stage	Mean catch (No. /trap/week)	
		Z. cucurbitae	*B. dorsalis*
6	Flowering	11.0	0.0
7	Flowering	14.0	0.0
8	Initial fruiting	21.0	0.0
9	Flowering & fruiting	26.0	0.0
10	Flowering & fruiting	23.0	0.0
11	Flowering & fruiting	21.0	0.0
12	Flowering & fruiting	12.0	0.0
13	Fruiting	21.0	2.0
14	Last harvest	15.0	7.0

* SMW – Standard meteorological week

Table 3. Correlation between fruit fly trap catches and abiotic factors in bitter gourd

Parameters		Correlation coefficient	
		Z. cucurbitae	*B. dorsalis*
Temperature (°C)	Maximum	+ 0.330	+ 0.577
	Minimum	+ 0.150	+ 0.540
Relative humidity (%)		-0.283	- 0.595
Rainfall (mm)		-0.269	+ 0.409
Wind speed	Maximum	+ 0.021	+ 0.309
	Minimum	+ 0.309	-0.434

in 40th SMW. Population *of Z. cucurbitae* evinced positive relation with the minimum temperature, RH and rainfall (Table 5). The studies of Boopathi *et al*. (2013) observed that the minimum temperature is an important predictor of fruit fly catches in Chilli in Mizoram. When the interaction of *Z. cucurbitae* trap catches and wind speed was probed through, a significantly negative association was noted with both maximum (0.741) and minimum levels (0.760). Peak population of *Z. cucurbitae* and *B. dorsalis* trapped were 26.0 (9th SMW) and 7.0/trap/week (14th SMW) respectively. Sowmiya *et al.* (2020) also documented maximum number of fruitfly catches in 9th and 10th standard weeks (11.30 to 12.00 fruit flies/trap) in snake gourd in Tiruchirappalli district of Tamil Nadu, India.

In snake gourd, unlike in bitter gourd, both species of fruit flies *i.e., B. dorsalis* and *Z. cucurbitae* were noticed from the initiation of the observation period itself (13 weeks from 29th to 41st SMW). However, in the trapped fruit fly population, proportion of *Z. cucurbitae* was more than *B. dorsalis*. Number of *Z. cucurbitae* fruit flies captured was high from 37th to 41st SMWs and top population of 27.0/trap was recorded in 40th SMW. *B. dorsalis* population ranged between 8.0 (31st SMW) and 17.0 (39th SMW)/trap (Fig. 2). The current results align with the reports of Sowmiya *et al.* (2020) and Dale and Patel (2010) who has observed peak population of melon flies in *kharif* season in 35th standard week in snake gourd in Trichy region of Tamil Nadu, India and guava ecosystem in Sardarkrushinagar, Gujarat, India respectively. In the current investigation, a high level of fruit fly infestation was documented in snake gourd fields than in bitter gourd. Am *et al.* (2017) disclosed that the occurence of fruit flies was high in snake gourd than in bitter gourd in Coimbatore district and this is in support of outcome of the present study.

Oriental fruit fly, *B. dorsalis:*

B. dorsalis population was noted in cuelure traps from the initiation of the observation period itself unlike bitter gourd. During initial week of observation *i.e.,* 29th SMW, 9.0 *B. dorsalis* males

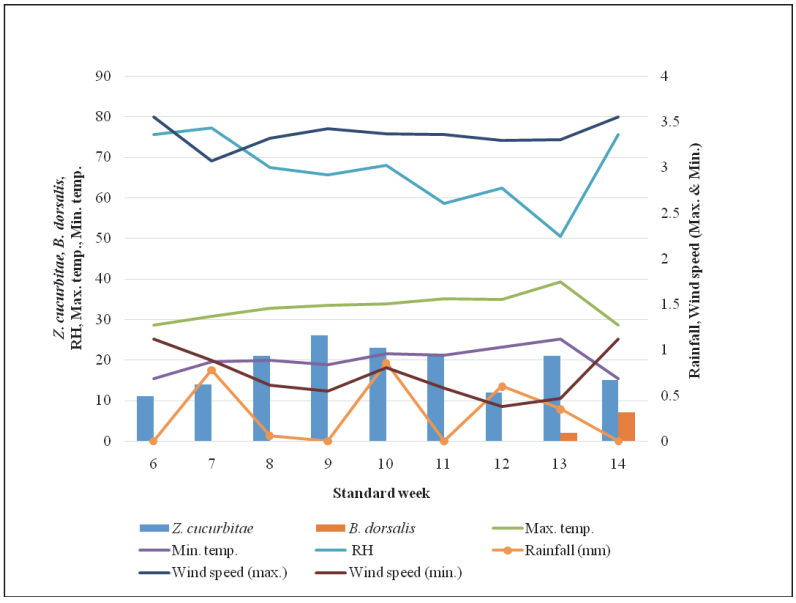

Fig. 1 Abundance of fruit flies and their correlation with weather parameter s in bitter gourd ecosystem

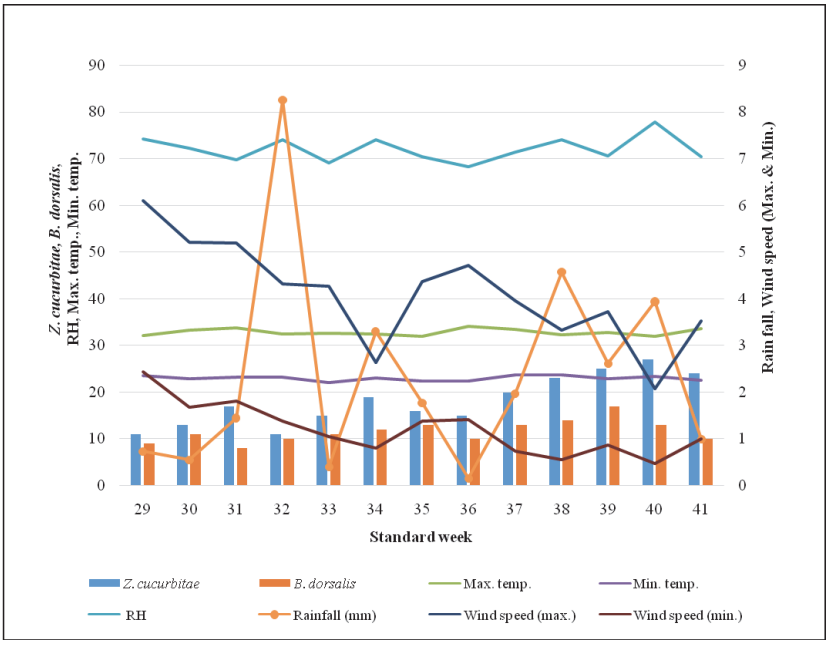

Fig. 2 Seasonal incidence of fruit flies in snake gourd ecosystem

were found/trap. Henceforth, number of trapped flies ranged between 8.0 (31st SMW) to 14.0 (38th SMW). During the study period, the highest number of *B. dorsalis* fruit flies captured using cuelure traps was 17 per week, recorded during 39th SMW. Population of *B. dorsalis* and minimum temperature, relative humidity and rainfall were positively correlated however, their interaction was inconsequential. With the maximum temperature, *B. dorsalis* population revealed an insignificant and negative correlation. Interrelationship of maximum (0.558) and minimum wind speeds (0.674) with the abundance of *B. dorsalis* fruit flies was a significantly negative relationship.

Relative abundance:

In bitter gourd, *Z. cucurbitae* was found to be more abundant than *B. dorsalis*. The same trend was noticed in snake gourd also. However, relative abundance of *B. dorsalis* was more in snake gourd (39%) than bitter gourd (5%). Population of *Z. cucurbitae* was high (95%) in bitter gourd than snake gourd (61%).

Studies of Akhtaruzzaman *et al.* (1999) and Ganie *et al*. (2013) confirmed that *Z. cucurbitae* was more abundant than other species of fruit flies in gourds. However, according to Prabhakar *et al.* (2009) *Z. tau* was found to be the dominant species compared to *Z. cucurbitae* and *B. scutellaris* in the northern Himalayan forest regions. This may be due to the variation in the geographical locations and climatic factors.

Table 4. Seasonal incidence of cucurbit fruit flies in bitter gourd ecosystem (February to April, 2021)

SMW	Crop stage	Mean catch (No. /trap/week)	
		Z. cucurbitae	*B. dorsalis*
29	Initial flowering	11.0	9.0
30	Flowering	13.0	11.0
31	Flowering & fruiting	17.0	8.0
32	Flowering & fruiting	11.0	10.0
33	Flowering & fruiting	15.0	11.0
34	Flowering & fruiting	19.0	12.0
35	Flowering & fruiting	16.0	13.0
36	Flowering & fruiting	15.0	10.0
37	Flowering & fruiting	20.0	13.0
38	Flowering & fruiting	23.0	14.0
39	Flowering & fruiting	25.0	17.0
40	Fruiting	27.0	13.0
41	Last harvest	24.0	10.0

* SMW – Standard meteorological week

Table 5. Correlation of seasonal incidence of fruit fly and weather factors

Parameters		Correlation coefficient	
		Z. cucurbitae	*B. dorsalis*
Temperature (°C)	Maximum	- 0.177	-0.344
	Minimum	0.380	0.103
Relative humidity (%)		0.362	0.165
Rainfall (mm)		0.001	0.215
Wind speed	Maximum	-0.741*	-0.558*
	Minimum	-0.760*	-0.674

Species diversity indices:

Simpson's diversity index was comparatively high (0.47) in snake gourd ecosystem than in bitter gourd (0.09) (Table 6). This had clearly revealed higher fruit fly diversity in snake gourd fields. Shannon's diversity index values in bitter gourd and snake gourd were 0.20 and 0.66 respectively. Hence, it is evident that diversity of melon flies was more in snake gourd than bitter gourd. Studies of Kishor *et al.* (2018) in Coimbatore district, Tamil Nadu also confirmed highest fruit fly diversity in snake gourd

Table 6. Diversity and richness indices of fruit flies in bitter gourd and snake gourd

Particulars	Bitter gourd		Snake gourd	
	Z. ucurbitae	*B. dorsalis*	*Z. cucurbitae*	*B. dorsalis*
Relative abundance (%)	95.0	5.0	61.0	39.0
Species diversity indices				
Simpson's index	0.09		0.47	
Shannon's index	0.20		0.66	
Species richness indices				
Menhinick index	0.15		0.10	
Margalef index	0.19		0.16	

ecosystem. Values of Margalef and Menhinick indices are more in bitter gourd indicating more species richness in bitter gourd than the snake gourd.

Species richness indices: With Menhinick values of 0.15 in bitter gourd and 0.10 in snake gourd, it is apparent that species richness of fruit flies was more in snake gourd. Margalef richness index was comparatively high (0.19) in bitter gourd fields than snake gourd (0.16).

Two species of fruit flies, *Z. cucurbitae* and *B. dorsalis*, were trapped in cuelure traps during monitoring studies of fruit flies carried out in the cucurbit ecosystem (bitter gourd and snake gourd) at Madurai district, Tamil Nadu. The population of *Z. cucurbitae* was dominant over the other fruit fly species. Simpson's index and Shannon's index, were higher in snake gourd than in bitter gourd, indicating that the fruit fly population in snake gourd was more diverse. The bitter gourd showed higher values of the Margalef and Menhinick indices, indicating that it has more species richness than the snake gourd. In the snake gourd habitat, the population of *Z. cucurbitae* and *B. dorsalis* showed a significantly negative correlation with abiotic weather factors such as max and min wind speeds. The weather correlation shown that both *Z. cucurbitae* and *B. dorsalis* had no significiant correlation with weather factors in bitter gourd to strenthen the point that the fruit fly has a strong population built up over the weather fluctuations.

ACKNOWLEDGMENTS

This research was supported by Department of Agricultural Entomology, Madurai. The authors would like to thank to Dr. K.J. David, fruit fly specialist, NBAIR for identifying the specimens.

REFERENCES

Akhtaruzzaman M., Alam M. and Sardar M. (1999) Identification and distribution of fruit flies infesting cucurbits in Bangladesh. Bangladesh Journal of Entomology 9 (1/2): 93–101.

Am M., Sridharan C. and Awasthi N. (2017) Varying infestation of fruit fly, *Bactrocera cucurbitae* (Coquillett) in different cucurbit crops. Journal of Entomology and Zoology Studies 5(53): 1419–1421.

Anonymous (2020-21) Horticulture. edited by Department of Agriculture and Farmers Welfare:Government of India. https://agricoop.nic.in/en/statistics/horticulture.

Atwal A. and Dhaliwal G. (2005) Agricultural pests of South Asia and their management. Kalyani Publication. New Delhi 110002. pp 277–278.

Boopathi T., Singh S.B., Ngachan S.V., Manju T. and Ramakrishna Y. (2013) 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(2): 194–198.

Clifford H.T.A.S.W. (1975) An introduction to numerical classification. Academic Press, London. 229pp.

Dale N.S. and Patel R.K. (2010) Population dynamics of

fruit flies (*Bactrocera* spp.) on guava and its correlation with weather parameters. Current Biotica 4(2): 245–248.

David K. and Ramani S. (2011) An illustrated key to fruit flies (Diptera: Tephritidae) from Peninsular India and the Andaman and Nicobar Islands. Zootaxa 3021 (1): 1–31.

Dhillon M., Singh R., Naresh J. and Sharma H. (2005) The melon fruit fly, *Bactrocera cucurbitae*: A review of its biology and management. Journal of Insect Sciences. 5 (1): 40.

Doharey K. (1983) Bionomics of fruit flies (*Dacus* spp.) on some fruits. Indian Journal of Entomology 45(4): 406–413.

Eliopoulos P.A. (2007) Evaluation of commercial traps of various designs for capturing the olive fruit fly, *Bactrocera oleae* (Diptera: Tephritidae). International Journal of Pest Management 53(3):245–252. doi:10.1080/09670870701 419000.

Enkerlin W., Lopez L. and Celedonio H. (1996) Increased accuracy in discrimination between captured wild unmarked and released dye-marked adults in fruit fly (Diptera: Tephritidae) sterile released programs. Journal of Economic Entomology 89 (4): 946–949. doi:10.1093/jee/89.4.946.

Ganie S., Khan Z., Ahangar R., Bhat H. and Hussain B. (2013) Population dynamics, distribution and species diversity of fruit flies on cucurbits in Kashmir Valley, India. Journal of Insect Sciences. 13(1): 65. doi:10.1673/031.013.6501.

Hollingsworth R., Vagalo M. and Tsatsia F. (1997) Biology of melon fly, with special reference to Solomon Islands. ACIAR Proceedings. pp 140–144

Kishor P., Kempraj T., Elaiyabharathi T. and Kavitha C. (2018) Species diversity and relative abundance of fruit flies (Tephritidae: Diptera) in cucurbitaceous vegetables. Madras Agricultural Journal 105 (4/6): 196–200.

Pawar D., Mote U. and Lawande K. (1991) Monitoring of fruit fly population in bitter gourd crop with help of lure trap. Journal of Maharashtra Agricultural University 16: 281– 281.

Permalloo S., Seewooruthun S., Joomaye A., Soonnoo A., Gungah B., Unmole L. and Boodram R. (1998) An area wide control of fruit flies in Mauritius. Proceedings of the 2nd Annual Meeting of Agricultural Scientists, Food and Agricultural Research Council. pp 203–210.

Prabhakar C.S, Sood P., Kapoor V., Kanwar S.S., Mehta P.K. and Sharma P.N. (2009) Molecular and biochemical characterization of three bacterial symbionts of fruit fly, *Bactrocera tau* (Tephritidae: Diptera). Journal of General and Applied Microbiology 55(6): 479–487. doi:10.2323/jgam.55.479.

Ravindranath K. and Pillai K. (1986) Control of fruit-fly of bitter gourd using synthetic pyrethroids. ENTOMON 11 (4): 269–272.

Ruiz M.J,. Juarez M.L., Alzogaray R.A., Arrighi F., Arroyo L., Gastaminza G., Willink E., Bardoìn A d V. and Vera T. (2014) Toxic effect of citrus peel constituents on *Anastrepha fraterculus* Wiedemann and *Ceratitis capitata* Wiedemann immature stages. Journal of Agricultural and Food Chemistry 62(41): 10084–10091. doi:10.1021/jf503063b.

Shannon C.E. and Weaver W. (1949) The mathematical theory of communication. Urbana: University of Illinois Press 27 (3): 379–423. doi: 10.1002/j.1538-7305.1948.tb01338.x.

Simpson E.H. 1949. Measurement of diversity. *Nature* 163 (4148): 688–688.

Singh S., Alok M., Bisen R. and Malik Y. (2000) Host preference of red pumpkin beetle, *Aulacophora foveicollis* and melon fruit fly, *Dacus cucurbitae*. Indian Journal of Entomology 62(3): 242–246.

Sowmiya L., Chandrasekaran M., Soundararajan R. and Ramesh D. (2020) Influence of weather factors on the occurrence, population fluctuation and species diversity of fruit flies in snake gourd ecosystem. International Journal of Current Microbiology and Applied Sciences 9(9): 165–173. doi:10.20546/ijcmas.2020.909.020.

Vasudha A., Ahmad A. and Agarwal M. (2019) An Overview of Indian Dacine fruit flies (Diptera: Tephritidae: Dacinae: Dacini). International Journal of bio-resource, Environment and Agriculture Sciences. 10(5): 491–506. doi: 10.23910/IJBSM/2019.10.5.2016.

Whittaker R.H. (1977) Evolution of species diversity in land communities. Pascal and Francis Bibliographic Databases 10: 1–67

(Received October 07, 2025; revised ms accepted January07, 2026; published March 31, 2026)