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RESEARCH ARTICLE

Better concentration of cue-lure and sticky trap combination for monitoring and mass trapping of melon fly, *Zeugodacus cucurbitae* (Coquillett)

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Abstract

Fruit fly species (family: Tephritidae) are a major pest of cucurbits, leading to a significant reduction in the crop yields. Among all species infesting cucurbits, *Zeugodacus cucurbitae* is the major pest. Both monitoring and mass trapping of *Z. cucurbitae* heavily rely on 'male annihilation technique, using cue-lure (CL) male attractant-based traps embedded with killing agents/pesticides. To evaluate the effectiveness of CL concentrations in combination with different traps against *Z. cucurbitae*, the following field study was conducted in a sponge gourd field during the 2023 *zaid* season. Among all treatments, the highest mean weekly trap catches of *Z. cucurbitae* (fly captures per trap per week, FTW) were recorded with 25 % CL combined with blue sticky traps (10.16 ± 0.99). Seasonal incidence studies revealed that the population exhibited fluctuations, peaking at 9.80 ± 1.29 FTW during the 17th Standard Meteorological Week (SMW), followed by a decline with occasional secondary peaks during the 20th and 27th SMW. Correlation analysis between the population and weather parameters indicated significant negative correlations with minimum temperature (r = -0.666, p = 0.004) and wind speed (r = -0.604, p = 0.013) at 5 % level of significance. These factors accounted for 44.4 % and 36.5 % of the population fluctuation, respectively. Collectively, all weather parameters influenced the population to an extent of 60.3 %. The present study provides a pesticide-free approach for the management of the melon fruit fly, after considering all the weather factors influencing the results.

Keywords: male attractant; melon fruit fly; pest management; sticky traps; weather parameters

Introduction

Zeugodacus cucurbitae (Coquillett), commonly referred to as the 'melon fruit fly, is a significant economic pest that primarily infests cucurbitaceous crops (1). However, its host range extends beyond cucurbits, encompassing fruits from families Anacardiaceae, Annonaceae, Caricaceae, Fabaceae, Malvaceae, Myrtaceae, Oxalidaceae, Passifloraceae, Rutaceae and Solanaceae (2, 3). It exhibits a broad geographic distribution, covering a major portion of Africa, Southeast Asia, Oceania and the Hawaiian Islands of the United States. Notably, the species has become established throughout India, where it is a major limiting factor in cucurbit production (4). Yield losses due to the melon fruit fly in India ranged from 25 % to 55 % in different cucurbits (5, 6).

Male attractant-based parapheromone strategies have been long employed, utilizing traps embedded with male attractant lures combined with a killing agent. These traps attract and kill adult male populations by drawing them toward the lure, ultimately killing them, widely known as the Male Annihilation Technique (MAT) (7). In the context of parapheromones, Cue-Lure (CL) [4-(p-acetoxyphenyl)-2-butanone], raspberry ketone [4-(p-hydroxyphenyl)-2-butanone] and melolure [4-(3-oxobutyl) phenyl formate)] are extensively utilized as male attractants in the monitoring and mass trapping of melon fruit flies through MAT (8–11). Many studies have demonstrated the efficacy of male attractants based parapheromone traps, often outperforming food bait traps (12, 13). Consequently, parapheromone traps are widely preferred for estimating population dynamics, seasonal incidence and monitoring and mass trapping of the melon fruit flies (4, 14, 15). However, parapheromone traps often use high concentrations of undiluted insecticides, which, when improperly handled, significantly increase the risk of cross-contamination and pose hazards to farmers. Recent studies have employed an ethanol-lure-insecticide (Malathion 50 EC) mixing in the ratio of 6:4:2 (16-18). This means that in a total lure solution of 100 mL, 16.66 mL of insecticide is added. However, same amount and upon dilution, it is effective for spraying an area of approximately 180-200 m^2.

A previous study recommended 25 % CL solution as highly effective, resulting in significantly higher trap catches of the melon fruit fly (8). Similarly, another study reported significantly greater trap catches with a lure solution of CL and methyl eugenol (ME) mixed in a 10:90 ratio compared to a 100 % CL solution (19). In contrast to the above-mentioned studies, few researchers reported the highest trap catches of the melon fruit flies in traps baited with 100 % CL solution, while comparing the results with traps baited with zingerone and CL in varied proportions (20). Moreover, a study found that trap catches of the melon fruit fly were higher in 100 % CL but not statistically different from trap catches in 75 % and 50 % CL solutions (21). By analyzing literature, it's not clear what is the best concentration of CL for monitoring and mass trapping of melon fruit fly. Therefore, the present study aims at the development of optimized lure solutions along with combinations of different trapping methods that can enhance trap catches of melon fruit flies while minimizing the use of pesticides, thereby reducing environmental pollution.

Materials and Methods

The experiment was carried on a farmer's field of 0.50 ha area cultivated with sponge gourd (*Luffa aegyptiaca*) (variety: Kashi Shreya) in Ramna village, Varanasi, Uttar Pradesh India (25.24139953806219°N, 83.00681292366033°E) during 14^{th} to 29^{th} SMW of the year 2023. 95 % CL (Sisco Research Laboratories Pvt. Ltd., Mumbai, India) was used as a male attractant-based parapheromone for preparation of traps. The lure solution was prepared by diluting CL with ≥ 99.9 % absolute ethanol (EMSURE® Merck, Bangalore, India) into different concentrations. The preparation of lure solutions is detailed in Table 1. Treatment 1 (T_1) to T_4 consisted of wooden blocks (5 × 5 × 2 cm^3) soaked in lure solutions for 24-48 hr, with each block attached at the centre of a yellow sticky trap (YST) (Chipku®, Turning Point Natural Care, Mumbai, India). T_5 utilized a low-cost bottle trap (BT) prepared according to previous study, featuring a wooden block of the same size soaked in lure solutions with 5 mL of Fipronil 5 % SC (Regent SC, Bayers, Thane, India), as an insecticide (22). T_6 consisted of gel lure (Akarsh CL) (5 g) applied as a paste at the centre of a YST. T_7 was a commercially available Tablet Lure (TL) (Mantra CL) placed in the McPhail trap (Harmony Ecotech Pvt. Ltd., Telangana, India). T_8 consisted of a yellow sticky trap without any lure as negative control. The traps (in triplicate) were installed randomly at a height of 1–1.5 m with an isolation distance of 20 m, just before the flowering of the crop. Data of the trap catches of the melon fruit flies was collected on weekly intervals. The traps were repositioned every fortnight and the wooden lures were recharged at intervals of 30-45 days. The collected fruit fly specimens were identified using the taxonomic literature at the Insect Molecular Biology Laboratory, Department of Entomology & Agricultural Zoology, Institute of Agricultural Sciences, Banaras Hindu University (BHU), Varanasi, Uttar Pradesh, India (23). Weather data was obtained from the Department of Agronomy, Institute of Agricultural Sciences, BHU, Varanasi, Uttar Pradesh, India. A one-way Analysis of Variance (ANOVA) was employed to compare the population of melon fruit fly trap week (FTW) across different treatments. Population dynamics was estimated based on the arithmetic mean of total melon fruit flies per week, which was then correlated with weekly weather parameters to calculate the Pearson correlation coefficient (r) (24). The impact of individual weather parameters on population dynamics was further analyzed using multiple linear regression. All statistical analysis were conducted using R statistical software (25).

Table 1. Details about experimental treatments and components volumes

Treatments	Chemical components (total volume 100 mL for solutions)
T_1: 75 % CL + YST	78.94 mL CL + 21.06 mL ethanol
T_2: 50 % CL + YST	52.63 mL CL + 47.37 mL ethanol
T_3: 25 % CL + YST	26.31 mL CL + 73.69 mL ethanol
T_4: 0 % CL + YST	100 mL ethanol
T_5: 25 % CL + BT	26.31 mL + 47.37 mL ethanol + 5 mL Fipronil 5 % SC
T_6: CL gel + YST	5 g + 5 mL Fipronil 5 % SC
T_7: TL + McPhail trap	Tablet lure
T_8: 25 % CL + BST	26.31 mL CL + 47.37 mL
T_9: YST	Yellow sticky trap alone

CL: Cue-Lure, YST: Yellow Sticky Trap, BST: Blue Sticky Trap, TL: Tablet Lure, BT: Bottle Traps.

Results and Discussion

The population dynamics of the melon fruit fly was derived from the data of total fruit flies collected from all the eight treatments from 14^{th} to 29^{th} SMW and averaged per week. The population begins with 5.40 ± 0.66 FTW on the first week, gradually increased and reached its peak on the 17^{th} SMW (9.80 ± 1.29 FTW). Following this peak, the population declined till 19^{th} SMW, after which a second peak of 6.44 ± 0.53 FTW was observed on the 20^{th} SMW. Later the population declined after the 24^{th} SMW (Fig. 1). Our research findings

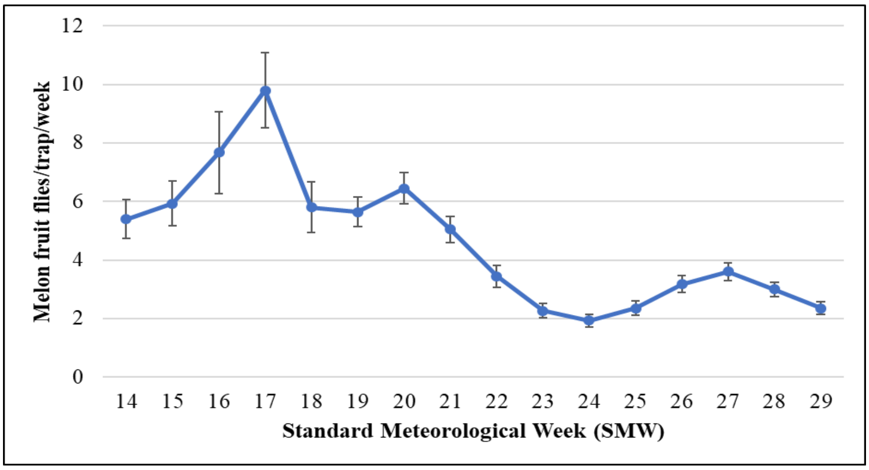

Fig. 1. Population dynamics of the melon fruit fly, *Z. cucurbitae* in the sponge gourd.

aligned with the previous research, who also reported a peak in the trap catches of the melon fruit fly during the 17th SMW, followed by a decline after the 20th SMW (26). The observed population trend during the study period was consistent with the findings of earlier studies, particularly during the latter half of the season (27, 28). The three peaks in the population were observed to coincide with the active flowering, bud initiation and fruit maturity stages. This pattern could be attributed to the oviposition deterrent activity of the fruit flies (29). Upon oviposition in a fresh fruit, the adult female pierces the fruit with its ovipositor, triggering a sense of herbivory in the plants. This herbivory induces the synthesis of secondary plant metabolites, such as phloroglucinol and chrysin, both of which play crucial roles as oviposition deterrents (30-33). This further prevents the oviposition of fruits by melon fruit fly, eventually leading to decrease in population.

The relationship between weather parameters and total weekly trap catches of the melon fruit flies showed a significant negative correlation with T_{min} (r = -0.666, p = 0.004) and WS (r = -0.604, p = 0.013) (Fig. 1). Further, the population showed a negative correlation with T_{max}, Rf, RH_m, RH_e and SSH (Table 2). The results obtained aligned with those of earlier studies, which also reported a significant negative correlation between T_{min} and the trap catches of the melon fruit fly (14, 34). The microclimate in and around the sponge gourd crop may have provided a more favourable environment for the melon fruit fly, particularly during cooler nights. Additionally, findings by other research groups demonstrated that wind speed significantly influences the permeating of CL, influencing population of fruit flies (14, 35). The positive correlation with the SSH contribute to higher temperatures, which can accelerate the developmental rates of melon fruit flies (14). Additionally, the previous research showed negative correlation of the trap catches of the fruit flies and T_{max}, Rf, RH_m and RH_e, during the later period of the year (36). Similarly, other researchers recorded a negative correlation between RH_e and Rf with the melon fruit fly population, further supporting the reliability of our research findings (37). The multiple regression analysis revealed that the population was primarily influenced by T_{min}(44.4 %), followed by WS (36.5 %) and RH_e (16.7 %). Weather parameters with the least impact were Rf (8.6 %,) followed by T_{max} (3.8 %), RH_m (2.1 %) and SSH (1.1 %). The multiple regression model infers 60.3 % of the variation in melon fruit fly population due to weather parameters (Table 3). In contrast, few researchers reported a 75.4 % influence of weather conditions on the population dynamics of the melon fruit fly (38). Another study found an even higher impact, with 97.3 % of population variation explained by weather parameters (39). The discrepancy in the results may be attributed to differences in trapping methods.

Table 2. Correlation coefficient of fruit fly population with weather parameters

	Weather parameters						
	T_{max}	T_{min}	Rf	RH_m	RH_e	SSH	WS
r	-0.196	-0.666*	-0.294	-0.145	-0.409	0.109	-0.604*
***p* value**	0.466	0.004	0.269	0.592	0.115	0.686	0.013

*Significant at p < 0.05, T_{max}: maximum temperature, T_{min}: minimum temperature, Rf: rainfall, RH_m: relative humidity (Morning), RH_e: relative humidity (Evening), SSH: sunshine hours and WS: wind speed

Table 3. Multiple regression equation for the population dynamics of the melon fruit fly and weather parameters during the study period on sponge gourd

Weather parameters	Regression models	R^2
Overall parameters	$Y = 2117.878 - 39.916X_1 + 17.446X_2 - 0.294X_3 - 4.197X_4 - 5.014X_5 - 8.613X_6 - 6.619X_7$	0.603*

Y: melon fruit flies/trap/week, R^2: coefficient of determination, maximum temperature (X1), minimum temperature (X2), rainfall (X3), morning relative humidity (X4), evening relative humidity (X5), sunshine hours (X6), wind speed (X7), *significant at p < 0.05

The one-way ANOVA analysis of the FTW revealed significant differences among the treatments ($F_{(8,36)}$ = 28.479, p < 0.0001). The treatment T_8 (25 % CL + BST) was the most effective treatment, yielding significantly higher trap catches (10.16 ± 0.99 FTW) compared to all other treatments. T_1 (75 % CL + YST) and T_2 (50 % CL + YST) also demonstrated significantly higher trap catches (6.28 ± 0.60 FTW and 4.88 ± 0.17 FTW, respectively) than most other treatments, though their mean trap catches were at par with each other. T_4 (0 % CL + YST), on the other hand, proved to be the least effective treatment (2.72 ± 0.27 FTW). The complete ranking of treatments based on trap catches is presented in Table 4. This suggests that a combination of 25 % CL and BST can be arbitrarily considered as a most effective treatment. Our findings partially align with another study, who reported 25 % CL as the most effective treatment for capturing melon fruit flies (8). However, our results suggest that combining 25 % CL with BST yielded more fruit fly per trap compared to embedding 25 % CL within bottle trap. This needs further validation as of till now it is the first report of the melon fruit fly preferring blue sticky traps over the yellow ones. All the previous studies were inclined towards the melon fruit fly being more responsive to yellow sticky traps than any other coloured traps (40, 41). The research findings are further supported by results from previous studies, reporting reduced concentration of CL showing higher trap catches of the melon fruit flies (19, 42). Lures can stimulate olfactory response only to an extent and are mostly dependent on the age of fruit flies and time of the day (43, 44). Also, repeated exposure to high concentrations might lead to habituation, where the flies become less responsive to the lure over time (45). Fruit flies often use pheromones to attract mates. A lower concentration of CL might mimic a natural pheromone

Table 4. Melon fruit flies/trap/week in different concentration of cue-lure and trap combination

S. No.	Treatments	(FTW)
T_4	0 % CL + YST	$2.72±0.27^{a}$
T_6	Fruit fly food bait + YST	$3.10±0.09^{ab}$
T_9	YST	$3.38±0.15^{ab}$
T_5	25 % CL + bottle trap	$3.41±0.15^{ab}$
T_7	Fruit fly tablet lure	$3.72±0.43^{ab}$
T_3	25 % CL + YST	$3.87±0.12^{ab}$
T_2	50 % CL + YST	$4.88±0.17^{bc}$
T_1	75 % CL + YST	$6.28±0.60^{c}$
T_8	25 % CL + BST	$10.16±0.99^{d}$

FTW: Melon fruit flies/trap/week, CL: Cue-lure, YST: Yellow sticky trap, BST: Blue sticky trap. Treatment traps arranged in ascending order of their relative efficacy in terms of FTW ± standard error. Means followed by the same small letter in the column indicate they are not significantly different from each other at a 5 % level of significance (p < 0.05) level, triggering mating behaviour and leading to increased trap catches. This study offers a trap-pesticide-free alternative to conventional methods, with significant implications for monitoring and mass trapping programs targeting the melon fruit fly.

Conclusion

The result of the following experiment identified 25 % CL embedded with blue sticky trap to be the most superior treatment with significantly higher trap catches of the melon fruit fly. The population fluctuation was in synchrony with the major crop developmental stages of sponge gourd, with minimum temperature and wind speed significantly influencing the population dynamics of the melon fruit fly throughout the cropping season. The current discovery provides a new insight in understanding the population ecology of the melon fruit fly, which is essential for developing a trap-insecticide-free management strategy, addressing a critical challenge in melon crop production.

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Authors' contributions

SN designed and monitored experiments and arranged the resources and edited the manuscript. PC, VA and PKM conducted the experiments, analyzed the data and wrote the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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