PLANT SCIENCE TODAY
Vol 13(1): 1-13
https://doi.org/10.14719/pst.11747

eISSN 2348-1900

RESEARCH ARTICLE

Effects of selective insecticides on *Zeugodacus cucurbitae* (Diptera: Tephritidae) reared on bitter gourd under laboratory conditions

Suman Samilita Dash[1,2*], Arundhati Sasmal[1], Arvind Nath Singh[2*], Sujan Majumder[1], Hiranmoy Das[2], Tribikram Samal[1], Deepa Khulbe[1], Nahida Afreen[2] & Rajesh Kumar[2]

[1]Department of Entomology, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar 751 003, Odisha, India
[2]Indian Council of Agricultural Research- Indian Institute of Vegetable Research, Varanasi 221 305, Uttar Pradesh, India

*Correspondence email - arvindnathsingh@gmail.com, sumandash.rs22@ouat.ac.in

Received: 11 September 2025; Accepted: 03 December 2025; Available online: Version 1.0: 14 January 2026; Version 2.0: 26 January 2026

Cite this article: Suman SD, Arundhati S, Arvind NS, Sujan M, Hiranmoy D, Tribikram S, deepa K, Nahida A, Rajesh K. Effects of selective insecticides on *Zeugodacus cucurbitae* (Diptera: Tephritidae) reared on bitter gourd under laboratory conditions. Plant Science Today. 2026; 13(1): 1-13. https://doi.org/10.14719/pst.11747

Abstract

Chemical control has traditionally served as the principal method for managing pests in cucurbit crops; however, the urgent need to mitigate environmental risks and ensure food safety has driven the exploration of sustainable alternatives. The present study was carried out during *Kharif* 2024 at the Entomology Laboratory, ICAR–Indian Institute of Vegetable Research, Varanasi, to evaluate the influence of insecticides from diverse chemical groups on the biology and morphometrics of the melon fruit fly, *Zeugodacus cucurbitae*. The test insecticides included chlorantraniliprole, cyantraniliprole, thiamethoxam, imidacloprid, indoxacarb and azadirachtin. Their effects were examined on developmental duration, adult longevity, oviposition period, fecundity and body dimensions. The results revealed that anthranilic diamides exerted the most pronounced impact. Chlorantraniliprole and cyantraniliprole markedly prolonged developmental time (female longevity of 37.23 and 33.76 days, respectively, versus 30.82 days in control) and azadirachtin, as well as cyantraniliprole, significantly suppressed fecundity (52.40 and 54.26 eggs compared with 81.40 in control). Among concentrations, imidacloprid at 16 ppm (45.33 eggs) and azadirachtin at 16 ppm (50.48 eggs) per female adult caused the greatest reduction in fecundity, whereas indoxacarb at 4 ppm showed minimal effect (79.78 eggs). Morphometric traits were similarly affected, with chlorantraniliprole reducing larval length (1st instar 1.49 mm and 3rd instar 9.15 mm against 1.85 mm and 10.05 mm in control) and adult female width (13.55-14.41 mm vs 15.79 mm in control). Indoxacarb responses closely resembled control, while azadirachtin produced intermediate suppression. Overall, the findings indicate that anthranilic diamides, particularly chlorantraniliprole and cyantraniliprole, along with the botanically derived azadirachtin, are promising candidates for disrupting the growth and reproduction of *Z. cucurbitae*. When used in rotation or integrated with botanicals and ecological strategies, these insecticides can form a sustainable foundation for melon fruit fly management.

Keywords: azadirachtin; bitter gourd; chlorantraniliprole; cyantraniliprole; melon fruit fly; *Zeugodacus cucurbitae*

Introduction

The melon fruit fly *Zeugodacus cucurbitae* (Coquillett) (Diptera: Tephritidae) is one of the most destructive pests of cucurbit crops worldwide and is recognised as a quarantine pest in numerous countries due to its ability to disperse rapidly and inflict severe economic losses (1). Its quarantine status restricts the international trade of host crops and necessitates rigorous phytosanitary measures (2, 3). The pests' global importance is underpinned by its exceptionally high reproductive potential, remarkable adaptability to diverse climatic zones and a broad host range exceeding 125 plant species (4-6). Nevertheless, *Z. cucurbitae* continues to cause alarming yield losses across its range. In India, crop damage varies from 30 % to 100 %, depending on the crop species, growing season and prevailing environmental conditions (4,7). Several recent regional studies confirm this high impact and document heavy infestations in major cucurbit-growing states: for example, intensive melon-fly outbreaks and damage have been reported from multiple locations in Uttar Pradesh (including Varanasi and the eastern plain zone), where cucurbit fruit infestation and maggot loads were shown to reach very high levels during peak seasons. Comparable high losses have also been documented from Madhya Pradesh (Mandsaur region), with seasonal fruit-damage records for cucurbits frequently reaching tens of percent and sometimes exceeding 50 % in untreated plots (8-12). Comparable levels of devastation have been reported elsewhere: 53–100 % losses in Mozambique, 10–100 % in Kazakhstans' Kyzylorda region and 80–90 % in Central Asia due to the Baluchistan melon fly, *Myiopardalis pardalina*, a species distinct from *Zeugodacus cucurbitae* (13-17). Furthermore, widespread infestations throughout Southeast Asia, Africa and the Pacific Islands have repeatedly led to near-total crop failures (2, 15, 18). Among cucurbits, bitter gourd (*Momordica charantia*) is especially susceptible, owing to its volatile attractants and nutrient profile, which enhance pest development (4). Infestation not only diminishes marketable yield but also predisposes fruits to secondary

infections and rapid decay, resulting in significant economic losses. Consequently, understanding the pests' biology on this host is essential for devising sustainable management strategies. Critical parameters such as developmental duration, morphometrics and fecundity play a decisive role in shaping population dynamics (19). Morphometric traits, including egg, larva, pupa and adult size, provide insight into host suitability and nutritional adequacy, while fecundity reflects reproductive potential (20).

Despite considerable advances in pest control, chemical insecticides remain the principal tool for managing *Z. cucurbitae*. However, indiscriminate use has accelerated the development of resistance, led to residue accumulation and adversely affected non-target organisms. This underscores the urgency of transitioning toward integrated pest management (IPM) approaches (21). Recent investigations have identified newer chemistries such as chlorantraniliprole, cyantraniliprole, thiamethoxam, imidacloprid, indoxacarb and azadirachtin as promising alternatives. These compounds exhibit diverse modes of action, ranging from ovicidal and larvicidal to neurotoxic and repellent and have demonstrated considerable efficacy in suppressing fruit fly populations (22-28). Chlorantraniliprole and cyantraniliprole impair insect muscle contraction; neonicotinoids such as thiamethoxam and imidacloprid disrupt neural transmission; indoxacarb inhibits sodium channel function; and azadirachtin, a neem-derived compound, acts as an antifeedant and growth regulator. Their repellency potential, particularly when applied at varying concentrations, offers a pathway to safer and more ecologically compatible pest control strategies.

For these reasons, the present investigation was designed to elucidate the biology of *Z. cucurbitae* on bitter gourd, with emphasis on developmental duration, morphometric characteristics and fecundity under exposure to chlorantraniliprole, cyantraniliprole, thiamethoxam, imidacloprid, indoxacarb and azadirachtin at different concentrations. By integrating biological data with insecticide performance, the study aims to identify effective agents for behavioural disruption and to contribute to an IPM-based, crop-specific strategy. The ultimate goal is to reduce dependency on conventional insecticides while enhancing the efficacy, sustainability and environmental compatibility of control measures for *Z. cucurbitae* in bitter gourd cultivation.

Materials and Methods

Rearing technique of melon fruit fly in bitter gourd

The respective rearing method was developed with necessary modifications, adhering to the methodology established (29). Infested bitter gourd (*Momordica charantia*) fruits harbouring melon fruit fly (*Zeugodacus cucurbitae* Coquillett) larvae were collected from the experimental farm of ICAR-IIVR, Varanasi, during *Kharif*, 2024. The extracted maggots were transferred into petri dishes containing a layer of moist sand to regulate moisture levels, which was covered with tissue paper in order to avoid fungal contamination. Fresh, tender bitter gourd slices were placed atop the tissue paper and housed within a rearing cage to facilitate larval development. To sustain larval feeding, fresh bitter gourd slices were provided at 48 h intervals. Fully developed maggots were allowed to pupate within the sand substrate. Pupae were readily identifiable due to the presence of white tissue paper, strategically placed for contrast against the sand. Upon pupation, the pupae were carefully collected and transferred to a separate container with the provision of sand before being introduced into the rearing cage for adult emergence. Emerging adult flies were captured manually using insect collection tubes within the rearing setup, ensuring minimal disturbance. Subsequently, male and female flies were sexed and paired before being transferred into a wooden oviposition cage. Due to their tendency to settle inside the tubes immediately upon capture, removing the tubes without escape risk proved challenging. To mitigate fly loss, the tubes were left inside the cage until the flies acclimatised. Adult flies were sustained on cotton soaked in a 20 % honey solution as adult food. For oviposition, fresh, tender bitter gourds every 48 h intervals were introduced into the oviposition cage (45 cm × 45 cm × 45 cm), allowing females to lay eggs. As the larvae emerged, they were relocated to the rearing cage, where they continued their life cycle, ultimately pupating in the sand, thus perpetuating the life cycle (Fig. 1). The experiment was conducted at 25 ± 2ºC, 65 ± 5 % relative humidity and a 12:12 h (light: dark) photoperiod.

Observations taken

The present study investigated the effects of selected insecticidal treatments on key biological parameters of *Zeugodacus cucurbitae* infesting bitter gourd. Parameters assessed included the duration of developmental stages, morphometric traits such as length, width and wing span (adult), as well as fecundity. The insecticides evaluated are given in Table 1, each tested at three concentrations (4, 8 and 16 ppm).

Fecundity assessment

Each insecticide was tested with three replications. Five mating pairs of melon fruit flies were introduced into an experimental cage. A 20 % honey solution, serving as adult food, was applied to cotton swabs and affixed to the inner walls of the cage. Additionally, moist tissue papers were placed on petri plates to maintain optimal humidity. Fresh bitter gourd (*Momordica charantia*) fruits were procured, sliced and subjected to insecticidal treatment by immersion in solutions at concentrations of 4, 8 and 16 ppm for 15 min. The treated fruits were then air-dried and positioned on the tissue paper. Following the ingestion of the honey solution, copulation occurred among the flies, with females initiating oviposition on the treated bitter gourd slices. Mating was observed predominantly during the evening, aligning with the species' natural reproductive behaviour. The subsequent day, the bitter gourd pieces were meticulously examined for egg deposition. The eggs were quantified using a trinocular microscope (COSLAB). Egg counts were recorded daily for five pairs per replication across all treatments and concentration groups.

Table 1. Insecticides used in the experiment and their applied concentrations

Insecticide (Formulation)	Recommended dose	Test concentrations (ppm)
Chlorantraniliprole 18.50 % SC	0.2 mL L^{-1}	4, 8, 16
Cyantraniliprole 10.26 % OD	1.8 ML L^{-1}	4, 8, 16
Thiamethoxam 25 % WG	0.33 g L^{-1}	4, 8, 16
Imidacloprid 17.80 % SL	0.33 g L^{-1}	4, 8, 16
Indoxacarb 14.50 % SC	1.0 ML L^{-1}	4, 8, 16
Azadirachtin 300 ppm	5.0 mL L^{-1}	4, 8, 16

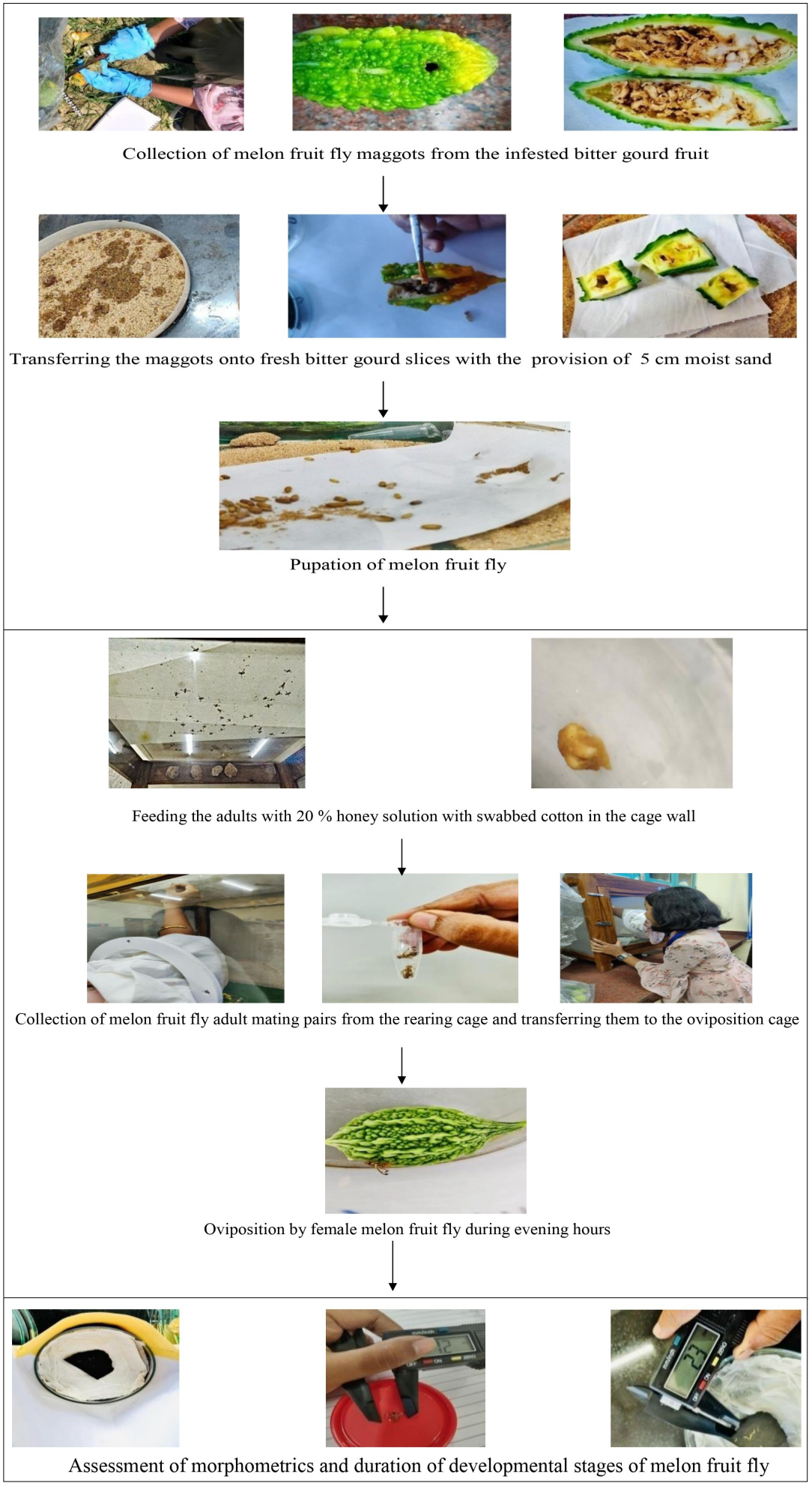

Fig. 1. Rearing procedure of the melon fruit fly.

Morphometrics of all developmental stages

Morphometric measurements of all the life stages were conducted using Vernier callipers and a trinocular microscope integrated with COSLAB software. Mean values were calculated from 5 individuals per replication for each concentration and treatment (Fig. 2).

Duration of all the developmental stages of the melon fruit fly

Infested bitter gourd fruits containing *Zeugodacus cucurbitae* larvae were collected from the field and reared as per the established protocol. Tender bitter gourd slices were treated with six insecticides (Table 1), each replicated thrice. Treated slices were placed in the petri dishes to allow adult flies to lay eggs. The durations of egg, larval, pupal and adult stages were recorded, with means calculated from 5 individuals per replicate per treatment.

Statistical analysis

The experimental data on morphometrics, developmental durations at each life stage and fecundity of female adults of *Zeugodacus cucurbitae* were subjected to statistical analysis using SAS software (version 9.3) by using the procedure generalised linear model (PROC GLM). The experiment was conducted in a completely randomised design (CRD) set-up with six insecticidal treatments, each tested at three concentrations, with three replications, along with a control. An analysis of variance (ANOVA) was performed for each parameter based on the design adopted. Treatment means were compared using tukeys' honest significant difference (HSD) test at $P = 0.05$. The square root data transformation $\sqrt{(x + 0.5)}$ was applied to the parameter fecundity to meet the normality assumption.

Results

Fecundity

The fecundity of melon fruit fly was significantly influenced by the tested insecticides ($F = 17.97$; $P < 0.0001$). Tukeys' HSD test (MSD = 0.77) revealed that azadirachtin (7.28) recorded the lowest fecundity, significantly lower than all other treatments and control (9.05), making it the most effective in reducing oviposition. In contrast, indoxacarb (8.68) showed the highest fecundity among insecticide treatments, statistically similar to control and, thus, being the least effective (Table 2).

Table 2. Effect of different insecticidal treatments on the fecundity of melon fruit fly

Insecticides	Fecundity*
Chlorantraniliprole	8.08^{bc}(64.79)
Cyantraniliprole	7.40^{cd} (54.26)
Thiamethoxam	8.10^{bc}(65.11)
Imidacloprid	7.48^{cd}(55.45)
Indoxacarb	8.68^{ab}(74.84)
Azadirachtin	7.28^{d} (52.50)
Control	9.05^{a}(81.40)

Means followed by the same letters in a column are not significantly different at $P = 0.05$ based on Tukeys' honest significant difference (HSD); *Data were subjected to square root transformation $\sqrt{(x + 0.5)}$, values in parentheses represent original values.

The interaction between insecticides and concentrations was also highly significant ($F = 7.72$, $P < 0.0001$). Tukeys' HSD test (MSD =1.27) revealed that imidacloprid 16 ppm (6.77) followed by azadirachtin 16 ppm (7.14) achieved the greatest reduction in fecundity, significantly lower than the control, whereas indoxacarb 4 ppm (8.96) had the highest value amongst all the insecticides (Table 3).

Morphometrics

The morphometric traits of *Zeugodacus cucurbitae* were significantly affected by insecticidal treatments across developmental stages. Both egg length and width differed among treatments (ANOVA: length $df = 6$, $F = 6.03$, $P = 0.0027$; width $df = 6$, $F = 41.22$, $P < 0.0001$). Tukeys' HSD (Length MSD = 0.10; Width MSD = 0.03, $\alpha = 0.05$) showed that chlorantraniliprole (1.19 mm) and cyantraniliprole (1.22 mm) produced significantly shorter eggs than the control (1.32 mm). Cyantraniliprole produced the narrowest eggs (0.19 mm) (significant vs control; Table 4). The insecticide × concentration interaction also affected both traits (interaction ANOVA significant); for example, azadirachtin 16 ppm gave the smallest length observed (1.18 mm), though this value was not significantly different from the control at the tested MSD. Cyantraniliprole 16 ppm and imidacloprid 16 ppm produced the narrowest widths (0.16 mm each), both significantly smaller than the

Table 3. Interaction effect of different insecticidal treatments and their concentrations on the fecundity of melon fruit fly

Insecticides	Concentration	Fecundity*
	4ppm	8.66^{abc}(74.99)
Chlorantraniliprole	8ppm	7.90^{abcde}(61.91)
	16ppm	7.64^{bcde}(57.87)
	4ppm	7.50^{cde} (55.75)
Cyantraniliprole	8ppm	7.35^{de}(53.52)
	16ppm	7.34^{de}(53.38)
	4ppm	8.15^{abcd}(65.92)
Thiamethoxam	8ppm	8.11^{abcd}(65.27)
	16ppm	7.97^{abcde}(63.02)
	4ppm	8.28^{abcd}(68.06)
Imidacloprid	8ppm	7.30^{de}(52.79)
	16ppm	6.77^{e}(45.33)
	4ppm	8.96^{a}(79.78)
Indoxacarb	8ppm	8.86^{ab}(78.00)
	16ppm	8.21^{abcd}(66.90)
	4ppm	7.44^{cde}(54.85)
Azadirachtin	8ppm	7.26^{de}(52.21)
	16ppm	7.14^{de}(50.48)
Control		9.05^{a}(81.40)

Means followed by the same letters in a column are not significantly different at $P = 0.05$ based on Tukeys' honest significant difference (HSD); *Data were subjected to square root transformation $\sqrt{(x + 0.5)}$, values in parentheses represent original values.

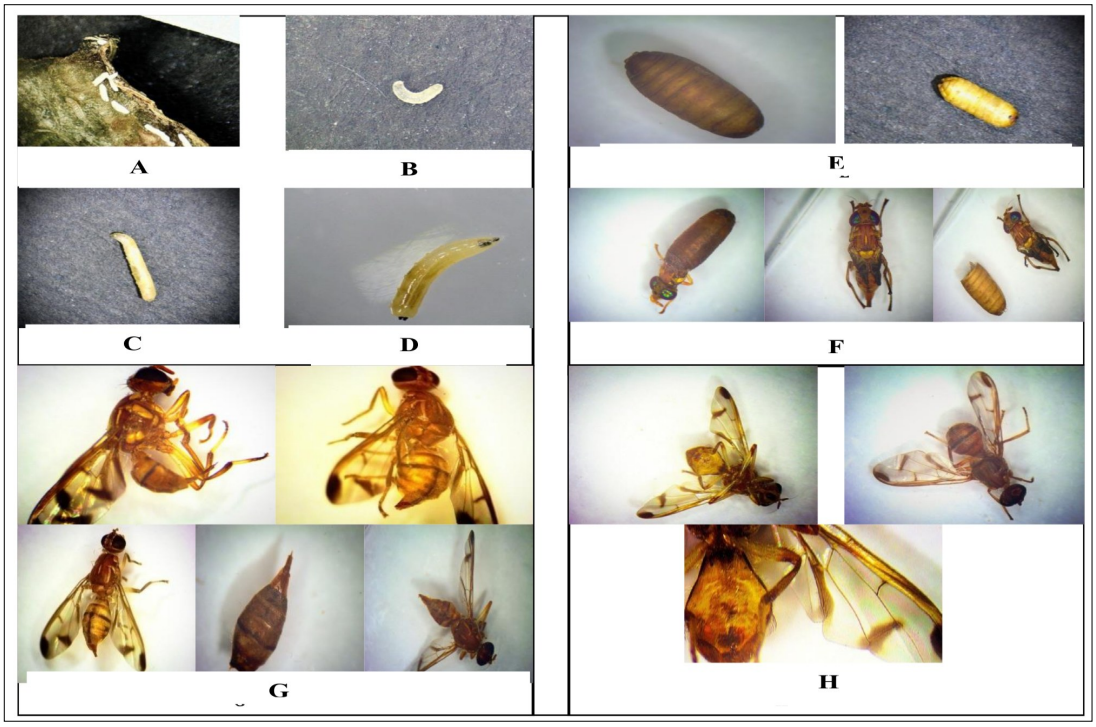

Fig. 2. Developmental stages of melon fruit fly. **A.** Egg stage; **B.** 1st instar maggot; **C.** 2nd instar maggot; **D.** 3rd instar maggot; **E.** Pupa; **F.** Adult emerging from pupal case**; G.** Female adult, **H.** Male adult.

control (Table 5).

Treatments reduced both length and width for first-instar larvae (ANOVA: length $F = 11.91$, $P < 0.0001$; width $F = 6.73$, $P = 0.0016$). Tukeys' HSD (length MSD = 0.16; Width MSD = 0.04) identified chlorantraniliprole (1.49 mm) as producing the shortest larvae compared to the control (1.85 mm) (Table 4). Interaction effects were significant (interaction ANOVA); e.g., azadirachtin 16 ppm also yielded a short length (1.49 mm) and chlorantraniliprole 16 ppm the narrowest width (0.19 mm), both significantly reduced versus the control. By contrast, lower-dose thiamethoxam (4 ppm) and azadirachtin (4 ppm) produced the largest larvae and were statistically comparable to the control (Table 5).

Length differed among treatments while width did not for second-instar larvae in the main-effect ANOVA (length $F = 4.50$, $P = 0.0096$; width $F = 1.30$, $P = 0.3179$). Tukeys' HSD (length MSD = 0.58) showed that chlorantraniliprole (5.66 mm) and azadirachtin (5.51 mm) gave significantly shorter larvae than the control (6.25 mm) (Table 4). Interaction effects were significant for both traits (interaction ANOVA); at 16 ppm, chlorantraniliprole (4.78 mm) and azadirachtin (5.03 mm) were the shortest lengths and chlorantraniliprole 16 ppm (1.04 mm), cyantraniliprole 16 ppm (1.06 mm) and azadirachtin 16 ppm (1.09 mm) produced the narrowest widths (Table 5).

No main-effect difference was detected for third-instar larvae length ($F = 1.79$, $P = 0.1740$), but width varied significantly ($F = 3.77$, $P = 0.0191$). Tukeys' HSD (width MSD = 0.20) indicated thiamethoxam (1.82 mm) and chlorantraniliprole (1.85 mm) produced significantly narrower larvae than the control (2.08 mm) (Table 4). Interaction effects were significant; notably, chlorantraniliprole 16 ppm showed strong size reduction (length 8.02 mm reported under interaction) and narrowest widths for chlorantraniliprole 16 ppm (1.68 mm) and cyantraniliprole 16 ppm (1.73 mm) (Table 5).

Pre-pupal morphometrics showed that length, but not width, was significantly influenced by treatment (length $F = 4.15$, $P = 0.0133$; width $F = 2.37$, $P = 0.0862$). Tukeys' HSD (length MSD = 0.57) identified chlorantraniliprole (6.11 mm), cyantraniliprole (6.12 mm) and azadirachtin (6.14 mm) as significantly shorter than the control (6.79 mm) (Table 3). Interaction effects were present (interaction ANOVA); chlorantraniliprole 16 ppm (6.00 mm) and imidacloprid 16 ppm (5.99 mm) were the shortest and chlorantraniliprole 16 ppm (1.73 mm) and imidacloprid 16 ppm (1.75 mm) the narrowest pre-pupae (all significant vs control; Table 4).

Pupal length did not differ among main treatments ($F = 0.23$,

Table 4. Effect of different insecticidal treatments on the morphometrics of all developmental stages of melon fruit fly

Insecticides	gEL (mm)	hEW (mm)	i1IL (mm)	j1IW (mm)	k2IL (mm)	l2IW (mm)	m3IL (mm)	n3IW (mm)	oPPL (mm)	pPPW (mm)	qPL (mm)	rPW (mm)	sFL (mm)	tFW (mm)	uML (mm)	vMW (mm)
aCh	1.19^{c}	0.20^{de}	1.49^{c}	0.24^{c}	5.66^{b}	1.09^{a}	9.15^{a}	1.85^{b}	6.11^{b}	1.84^{a}	5.68^{a}	2.32^{b}	9.45^{a}	14.25^{ab}	7.99^{a}	10.31^{b}
bCy	1.22^{bc}	0.19^{e}	1.61^{bc}	0.28^{ab}	5.91^{ab}	1.14^{a}	9.19^{a}	1.92^{ab}	6.12^{b}	1.89^{a}	5.89^{a}	2.40^{ab}	9.46^{a}	14.42^{ab}	8.10^{a}	10.36^{b}
cTh	1.29^{ab}	0.24^{bc}	1.69^{b}	0.30^{a}	5.97^{ab}	1.20^{a}	9.53^{a}	1.82^{b}	6.19^{b}	1.91^{a}	5.94^{a}	2.44^{ab}	9.47^{a}	15.25^{ab}	8.28^{a}	10.94^{ab}
dImi	1.22^{bc}	0.22^{cd}	1.58^{bc}	0.26^{abc}	6.04^{ab}	1.17^{a}	9.11^{a}	1.93^{ab}	6.15^{b}	1.85^{a}	5.86^{a}	2.38^{ab}	9.37^{a}	14.65^{ab}	8.16^{a}	10.80^{ab}
eIndo	1.31ab	0.24^{b}	1.71^{ab}	0.28^{abc}	6.07^{ab}	1.20^{a}	9.46a	1.91^{ab}	6.22^{ab}	1.88^{a}	5.96^{a}	2.46^{ab}	9.54^{a}	15.29^{ab}	8.24^{a}	11.06^{ab}
fAza	1.24^{abc}	0.23^{bcd}	1.69^{b}	0.28^{ab}	5.51^{b}	1.17^{a}	9.03^{a}	1.91^{ab}	6.14^{b}	1.89^{a}	5.73^{a}	2.34^{b}	9.36^{a}	14.13^{b}	8.08^{a}	10.43^{b}
Control	1.32^{a}	0.29^{a}	1.85^{a}	0.24^{bc}	6.25^{a}	1.22^{a}	10.05^{a}	2.08^{a}	6.79^{a}	2.06^{a}	5.72^{a}	2.66^{a}	9.97^{a}	15.79^{a}	8.78^{a}	11.82^{a}

Means followed by same letters in a column are not significantly different at P=0.05 based on Tukeys' Honest Significant Difference (HSD) ([a]Ch-Chlorantraniliprole, [b]Cy-Cyantraniliprole, [c]Thi-Thiamethoxam, [d]Imi-Imidacloprid, [e]Indo-Indoxacarb, [f]Aza- Azadirachtin, [g]EL-Egg Length, [h]EW-Egg Width, [i]1IL-1st Instar length, [j]1IW- 1st Instar Width, [k]2IL-2nd Instar Length, [l]2IW- 2nd Instar Width, [m]3IL- 3rd Instar Length, [n]3IW- 3rd Instar Width, [o]PPL-Prepupal length, [p]PPW-Prepupal Width, [q]PL-Pupal Length, [r]PW-Pupal Width, [s]FL- Female Length, [t]FW- Female Wing span, [u]ML- Male Length, [v]MW- Male Wing span)

Table 5. Interaction effect of different insecticidal treatments and their concentrations on the morphometrics of all developmental stages of melon fruit fly

Insecticides	Concentration (ppm)	[g]EL (mm)	[h]EW (mm)	[i]1IL (mm)	[j]1IW (mm)	[k]2IL (mm)	[l]2IW (mm)	[m]3IL (mm)	[n]3IW (mm)	[o]PPL (mm)	[p]PPW (mm)	[q]PL (mm)	[r]PW (mm)	[s]FL (mm)	[t]FW (mm)	[u]ML (mm)	[v]MW (mm)
	4ppm	1.34[a]	0.24[cdef]	1.75[abcd]	0.29[cde]	6.58[ab]	1.16[abcd]	9.90[ab]	2.03[abcd]	6.24[ab]	1.99[ab]	6.06[abc]	2.50[abcd]	9.76[ab]	15.18[abcd]	8.31[ab]	11.37[abc]
[a]Ch	8ppm	1.14[ab]	0.20[fghi]	1.56[cde]	0.24[fgh]	5.95[bcd]	1.07[cd]	9.53[ab]	1.85[cde]	6.13[b]	1.80[ab]	5.93[abcde]	2.29[bcd]	9.56[ab]	14.03[bcd]	7.92[ab]	9.86[e]
	16ppm	1.09[b]	0.17[hi]	1.16[f]	0.19[i]	4.78[g]	1.04[d]	8.02[e]	1.68[ef]	6.00[b]	1.73[b]	5.05[e]	2.17[d]	9.03[b]	13.55[cd]	7.76[b]	9.70[e]
	4ppm	1.25[ab]	0.20[efgh]	1.82[ab]	0.33[abc]	6.55[ab]	1.20[abcd]	9.83[ab]	2.12[abc]	6.28[ab]	1.99[ab]	6.25[ab]	2.56[abc]	9.82[ab]	14.86[abcd]	8.41[ab]	11.40[abc]
[b]Cy	8ppm	1.21[ab]	0.17[hi]	1.66[abcd]	0.26[defg]	5.80[cde]	1.14[abcd]	9.35[abcd]	1.85[cde]	6.17[ab]	1.84[ab]	5.73[abcde]	2.31[abcd]	9.18[ab]	13.76[cd]	7.98[ab]	9.92[e]
	16ppm	1.16[ab]	0.16[i]	1.23[f]	0.22[ghi]	5.59[def]	1.06[cd]	8.04[e]	1.73[ef]	6.03[b]	1.79[ab]	5.15[cde]	2.22[cd]	9.06[b]	13.50[d]	7.80[b]	9.75[e]
	4ppm	1.32[a]	0.29[ab]	1.85[a]	0.36[a]	6.55[ab]	1.27[a]	10.23[a]	2.21[a]	6.33[ab]	1.96[ab]	6.30[a]	2.6[ab]	9.87[ab]	15.79[ab]	8.43[ab]	11.53[ab]
[c]Thi	8ppm	1.28[ab]	0.23[defg]	1.69[abcd]	0.29[cde]	6.38[abc]	1.21[abcd]	9.33[abcd]	1.71[ef]	6.20[ab]	1.91[ab]	5.87[abcde]	2.47[abcd]	9.34[ab]	15.20[abcd]	8.32[ab]	11.27[abcd]
	16ppm	1.26[ab]	0.19[ghi]	1.52[de]	0.25[efgh]	4.98[fg]	1.12[abcd]	9.02[abcde]	1.53[f]	6.06[b]	1.88[ab]	5.65[abcde]	2.27[bcd]	9.21[ab]	14.75[abcd]	8.09[ab]	10.04[de]
	4ppm	1.32[a]	0.27[abcd]	1.79[abc]	0.30[bcd]	6.87[a]	1.23[abc]	9.91[ab]	2.08[abc]	6.29[ab]	1.99[ab]	6.23[ab]	2.53[abcd]	9.81[ab]	15.37[abc]	8.39[ab]	11.52[ab]
[d]Imi	8ppm	1.20[ab]	0.23[defg]	1.65[abcd]	0.25[efgh]	6.31[abc]	1.18[abcd]	9.45[abc]	2.01[abcd]	6.17[ab]	1.80[ab]	5.96[abcd]	2.42[abcd]	9.26[ab]	14.97[abcd]	8.21[ab]	11.28[abcd]
	16ppm	1.15[ab]	0.16[i]	1.30[ef]	0.21[hi]	4.94[g]	1.11[abcd]	8.10[de]	1.69[ef]	5.99[b]	1.75[b]	5.38[bcde]	2.20[d]	9.04[b]	13.60[cd]	7.86[ab]	9.62[e]
	4ppm	1.34[a]	0.28[abc]	1.85[a]	0.32[abc]	6.79[a]	1.26[ab]	10.25[a]	2.20[ab]	6.34[ab]	1.99[ab]	6.30[a]	2.61[ab]	9.78[ab]	16.09[a]	8.44[ab]	11.50[ab]
[e]Indo	8ppm	1.30[ab]	0.25[bcde]	1.70[abcd]	0.27[def]	6.24[abc]	1.20[abcd]	9.55[ab]	1.81[de]	6.24[ab]	1.84[ab]	6.04[abc]	2.47[abcd]	9.54[ab]	15.22[abcd]	8.24[ab]	11.26[abcd]
	16ppm	1.29[ab]	0.20[fghi]	1.58[bcd]	0.24[fgh]	5.17[efg]	1.14[abcd]	8.91[bcde]	1.72[ef]	6.07[ab]	1.79[ab]	5.87[abcde]	2.30[bcd]	9.31[ab]	14.55[abcd]	8.05[ab]	10.09[cde]
	4ppm	1.34[a]	0.27[abcd]	1.86[a]	0.34[ab]	6.34[abc]	1.23[abc]	9.58[ab]	2.08[abc]	6.30[ab]	1.97[ab]	6.18[ab]	2.52[abcd]	9.59[ab]	14.97[abcd]	8.29[ab]	11.27[abcd]
[f]Aza	8ppm	1.20[ab]	0.22[efg]	1.72[abcd]	0.27[def]	5.17[efg]	1.18[abcd]	9.27[abcde]	1.94[bcde]	6.13[b]	1.93[ab]	5.90[abcde]	2.29[bcd]	9.42[ab]	13.81[cd]	8.14[ab]	10.29[bcde]
	16ppm	1.18[ab]	0.19[ghi]	1.49[de]	0.23[fghi]	5.03fg	1.09[bcd]	8.23[cde]	1.71[ef]	6.01[b]	1.76[b]	5.10[de]	2.22[cd]	9.08[b]	13.60[cd]	7.82[b]	9.73[e]
Control		1.32[a]	0.30[a]	1.85[a]	0.24[fgh]	6.25[abc]	1.22[abcd]	10.05[ab]	2.08[abc]	6.79[a]	2.06[a]	5.72[abcde]	2.66[a]	9.97[a]	15.79[ab]	8.78[a]	11.82[a]

Means followed by the same letters in a column are not significantly different at P =0.05 based on Tukeys' Honest Significant Difference (HSD). ([a]Ch- Chlorantraniliprole, [b]Cy-Cyantraniliprole, [c]Thi-Thiamethoxam, [d]Imi-Imidacloprid, [e]Indo-Indoxacarb, [f]Aza- Azadirachtin, [g]EL-Egg Length, [h]EW- Egg Width, [i]1IL-1st Instar length, [j]1IW- 1st Instar Width, [k]2IL-2nd Instar Length, [l]2IW- 2nd Instar Width, [m]3IL- 3rd Instar Length, [n]3IW- 3rd Instar Width, [o]PPL-Prepupal length, [p]PPW-Prepupal Width, [q]PL-Pupal Length, [r]PW-Pupal Width, [s]FL- Female Length, [t]FW- Female Wing span, [u]ML- Male Length, [v]MW- Male Wing span)

P = 0.9595), whereas pupal width did (*F* = 3.50, *P* = 0.0251). Tukeys' HSD (Width MSD = 0.29) indicated chlorantraniliprole (2.32 mm) and azadirachtin (2.34 mm) were significantly narrower than the control (2.66 mm) (Table 4). Interaction effects were significant for both traits; chlorantraniliprole 16 ppm produced among the shortest pupal lengths reported under interaction (5.05 mm) and the narrowest pupae (chlorantraniliprole 16 ppm 2.17 mm; imidacloprid 16 ppm 2.20 mm) relative to control (Table 5).

In female adults, length did not differ among main treatments (*F* = 1.96, *P* = 0.1403), but wing span did (*F* = 3.80, *P* = 0.0186); azadirachtin-treated females were significantly narrower winged (14.13 mm) than controls (15.79 mm) (Table 4). Interaction effects indicated chlorantraniliprole 16 ppm and azadirachtin 16 ppm produced the shortest females (lengths reported under interaction: chlorantraniliprole 16 ppm 9.03 mm; azadirachtin 16 ppm 9.08 mm), while cyantraniliprole 16 ppm produced the narrowest winged females (13.50 mm) (Table 5). In males, significant interaction effects were found for both length and wing span; chlorantraniliprole 16 ppm produced the shortest males (7.76 mm) and imidacloprid 16 ppm the narrowest winged males (9.62 mm) compared with the control (length 8.78 mm; width 11.82 mm).

In summary. chlorantraniliprole, cyantraniliprole and azadirachtin consistently and significantly produced the largest and most concentration-dependent reductions in length and width across immature stages. Imidacloprid showed size-suppressing effects at higher concentrations, whereas lower-dose thiamethoxam and indoxacarb generally produced minimal or no significant reductions relative to control.

Duration

Results demonstrated that insecticidal treatments significantly affected the egg stage duration of *Zeugodacus cucurbitae*, both as a main effect (*F* = 33.15, *P* < 0.0001 and through their interaction with concentration (*F* = 37.86, *P* < 0.0001) Tukeys' HSD test (main effect: MSD = 0.09; Interaction effect: MSD = 0.13, α = 0.05) confirmed that, under the main effect, indoxacarb (1.07) recorded the shortest durations and was statistically comparable with control (1.08) and significantly lower than chlorantraniliprole (1.36), which exhibited the longest duration (Table 6). In the interaction analysis, chlorantraniliprole 16 ppm (1.64) remained significantly superior to all treatments, while the control (1.08) and indoxacarb 16 ppm (1.10) showed the shortest durations, statistically at par with each other. Thus, chlorantraniliprole 16 ppm was most effective in extending the egg stage, whereas indoxacarb showed the least effect, being at par with the control (Table 7).

Significant treatment effects were observed for 1st instar larval duration (main effect: *F* = 32.62, *P* < *0.0001*; Interaction effect: *F* = 36.80, *P* < *0.0001*). According to Tukeys' HSD (main effect MSD = 0.09; Interaction effect MSD = 0.12), chlorantraniliprole (1.31), followed by cyantraniliprole (1.27) and azadirachtin (1.27), were at par with each other and recorded the longest duration under the main effect, significantly exceeding the control (1.03) and the rest of the treatments. Indoxacarb (1.06) was statistically similar to the control, showing the shortest durations (Table 6). In the interaction effect, chlorantraniliprole 16 ppm (1.56) was the longest, significantly outperforming all others, while indoxacarb treatments (1.04–1.10) remained equivalent to the control, indicating minimal impact (Table 7).

ANOVA indicated a strong influence of treatments on 2nd instar duration (main effect: *F* = 46.16, *P* < 0.0001, MSD=1.30; Interaction effect: *F* = 90.87, *P* < 0.0001, MSD=0.13). Under the main effect, cyantraniliprole (2.57) followed by azadirachtin (2.53) and chlorantarniliprole (2.50), which were at par with each other, recorded the longest duration, significantly exceeding the control (2.08) and all other treatments. Indoxacarb (2.21) and control were the shortest and statistically similar (Table 6). In the interaction analysis, chlorantraniliprole 16 ppm and cyantraniliprole 16 ppm (both ~2.81) recorded the maximum durations, significantly higher than all others, while indoxacarb 4 ppm (2.05) and control remained the shortest and at par (Table 7).

Treatment effects were also significant for 3rd instar duration (main effect: *F* = 10.97, *P* = 0.0001, MSD=0.25; Interaction effect: *F* = 42.91, *P* < 0.0001, MSD=0.19). Under the main effect, cyantraniliprole (3.09) achieved the longest duration, significantly exceeding the control (2.58) and other treatments. Indoxacarb (2.61) was statistically comparable with the control, recording the shortest duration (Table 6). In the interaction effect, cyantraniliprole 16 ppm (3.26) remained significantly superior, while indoxacarb treatments (2.51-2.76) were the shortest and statistically similar to the control (Table 7).

For the pre-pupal stage, significant differences were observed (*F* = 20.47, *P* < 0.0001, Interaction effect: *F* = 28.69, *P* < 0.0001). Main effect analysis (MSD = 0.11) revealed that indoxacarb (1.10), being statistically comparable with control (1.03), produced the shortest duration, significantly lower than azadirachtin (1.28), chlorantraniliprole (1.27) and cyantraniliprole (1.27), which formed the top statistical group (Table 6). In the interaction effect (MSD = 0.12), cyantraniliprole 16 ppm (1.45) followed by chlorantarniliprole (1.37) showed significantly longer duration than all others, while indoxacarb treatments matched the control for the shortest duration (Table 7).

Pupal duration was significantly affected (main effect: *F* = 29.55, *P* < 0.0001; Interaction effect: *F* = 68.43, *P* < 0.0001). Under the main effect (MSD = 0.31), indoxacarb (6.64) recorded the shortest duration, while cyantraniliprole (7.33), imidacloprid (7.14) and chlorantraniliprole (7.11) recorded significantly longer durations than control (Table 6). Interaction analysis (MSD = 0.22) identified chlorantraniliprole 16 ppm (7.57) and cyantraniliprole 16 ppm (7.56)

Table 6. Effect of different insecticidal treatments on the duration of all developmental stages of melon fruit fly

Insecticides	Egg (days)	1st instar larva (days)	2nd instar larva (days)	3rd instar larva (days)	pre-pupa (days)	Pupa (days)	Female (days)	Male (days)	Oviposition (days)
Chlorantraniliprole	1.36^{a}	1.31^{a}	2.50^{ab}	2.81^{bcd}	1.27^{a}	7.11^{ab}	37.23^{a}	32.29^{a}	19.27^{ab}
Cyantraniliprole	1.33^{a}	1.27^{ab}	2.57^{a}	3.09^{a}	1.27^{a}	7.33^{a}	33.76^{b}	30.42^{a}	20.20^{a}
Thiamethoxam	1.12^{bc}	1.09^{c}	2.27^{c}	2.76^{bcd}	1.10^{bc}	6.80^{c}	25.22^{d}	23.14^{cd}	17.95^{bc}
Imidacloprid	1.22^{b}	1.18^{b}	2.40^{b}	2.91^{ab}	1.18^{ab}	7.14^{ab}	26.70^{d}	24.81^{bc}	19.96^{a}
Indoxacarb	1.07^{c}	1.06^{c}	2.21^{cd}	2.61^{cd}	1.10^{c}	6.64^{c}	22.71^{e}	21.08^{d}	16.65^{cd}
Azadirachtin	1.21^{b}	1.27^{ab}	2.53^{ab}	2.84^{abc}	1.28^{a}	6.84^{bc}	27.09^{d}	27.06^{b}	17.95^{bc}
Control	1.08^{c}	1.03^{c}	2.08^{d}	2.58^{d}	1.03^{c}	6.30^{d}	30.82^{c}	26.78^{b}	16.25^{d}

Means followed by the same letters in a column are not significantly different at P=0.05 based on Tukeys' honest significant difference (HSD)

Table 7. Interaction effect of different insecticidal treatments and their concentrations on the duration of all developmental stages of melon fruit fly

Insecticides	Conc.	Egg (days)	1st instar larva (days)	2nd instar larva (days)	3rd instar larva (days)	pre-pupa (days)	Pupa (days)	Female (days)	Male (days)	Oviposition (days)
Chlorantraniliprole	4ppm	1.12^{defgh}	1.10^{fghi}	2.15^{gh}	2.55^{hi}	1.19^{cde}	6.79^{efgh}	34.63^{d}	28.05^{bcd}	19.05^{de}
	8ppm	1.31^{c}	1.24^{cde}	2.61^{bc}	2.67^{ghi}	1.26^{bcd}	6.97^{def}	36.25^{c}	31.58^{abc}	19.21^{cde}
	16ppm	1.64^{a}	1.56^{a}	2.81^{a}	3.21^{ab}	1.37^{ab}	7.57^{a}	41.48^{a}	37.23^{a}	19.53^{bcd}
Cyantraniliprole	4ppm	1.24^{cd}	1.20^{defg}	2.40^{de}	2.91^{de}	1.14^{defg}	7.24^{bc}	30.97^{e}	27.83^{bcd}	19.33^{bcde}
	8ppm	1.32^{c}	1.27^{bcd}	2.51^{cd}	3.11^{abc}	1.27^{bc}	7.36^{ab}	34.23^{d}	30.35^{abc}	20.60^{ab}
	16ppm	1.48^{b}	1.37^{b}	2.81^{a}	3.26^{a}	1.46^{a}	7.56^{a}	37.87^{b}	35.65^{ab}	21.10^{a}
Thiamethoxam	4ppm	1.12^{defgh}	1.04^{i}	2.11^{gh}	2.61^{ghi}	1.04^{fg}	6.67^{ghi}	23.15^{hi}	20.98^{de}	17.18^{gh}
	8ppm	1.12^{defgh}	1.09^{ghi}	2.31^{ef}	2.67^{ghi}	1.09^{efg}	6.72^{ghi}	26.18^{g}	24.20^{cde}	18.13^{efg}
	16ppm	1.13^{defgh}	1.13^{efghi}	2.41^{de}	3.01^{cd}	1.16^{cdef}	7.01^{de}	26.32^{g}	24.25^{cde}	18.53^{defg}
Imidacloprid	4ppm	1.21^{cdefg}	1.09^{ghi}	2.31^{ef}	2.76^{efg}	1.09^{efg}	7.01^{de}	26.45^{g}	23.48^{cde}	18.75^{def}
	8ppm	1.22^{cdef}	1.22^{def}	2.36^{e}	2.87^{def}	1.19^{cde}	7.07^{cd}	26.53^{fg}	24.60^{cd}	20.50^{abc}
	16ppm	1.23^{cde}	1.24^{cde}	2.56^{bc}	3.11^{abc}	1.27^{bc}	7.36^{ab}	27.08^{fg}	26.35^{cd}	20.63^{ab}
Indoxacarb	4ppm	1.04^{h}	1.04^{i}	2.05^{h}	2.51^{i}	1.04^{fg}	6.51^{ij}	21.78^{i}	15.78^{e}	16.12^{h}
	8ppm	1.07^{h}	1.05^{hi}	2.21^{fg}	2.56^{hi}	1.04^{fg}	6.57^{hi}	23.22^{hi}	19.80^{de}	16.70^{h}
	16ppm	1.10^{efgh}	1.09^{ghi}	2.36^{e}	2.76^{efg}	1.11^{efg}	6.86^{defg}	23.80^{h}	21.32^{de}	17.47^{fgh}
Azadirachtin	4ppm	1.09^{fgh}	1.17^{defgh}	2.31^{ef}	2.71^{fgh}	1.19^{cde}	6.77^{fgh}	25.99^{g}	25.85^{cd}	17.22^{gh}
	8ppm	1.21^{cdefg}	1.27^{bcd}	2.61^{bc}	2.76^{efg}	1.32^{b}	6.81^{efg}	27.28^{fg}	27.28^{bcd}	18.13^{efg}
	16ppm	1.32^{c}	1.36^{bc}	2.66^{b}	3.06^{bcd}	1.32^{b}	6.96^{def}	28.02^{f}	28.05^{bcd}	18.52^{defg}
Control		1.08^{gh}	1.03^{i}	2.08^{gh}	2.58^{ghi}	1.03^{g}	6.30^{j}	30.82^{e}	26.78^{cd}	16.25^{h}

Means followed by the same letters in a column are not significantly different at P=0.05 based on Tukeys' honest significant difference (HSD)

as top performers, while indoxacarb at 4 ppm (6.51) remained statistically similar to the control (Table 7).

Highly significant differences were recorded for female longevity (main effect: $F = 155.49$, $P < 0.0001$; Interaction effect: $F = 383.85$, $P < 0.0001$). Under the main effect (MSD = 1.98), indoxacarb recorded (22.71) the shortest duration, significantly lower than chlorantraniliprole (37.23) and all other treatments (Table 6). Interaction analysis (MSD = 1.50) confirmed chlorantraniliprole 16 ppm (41.48) as significantly superior to all others, while indoxacarb treatments (21.78–23.80) were the shortest and at par with each other (Table 7).

Male longevity was also significantly affected (main effect: $F = 49.00$, $P < 0.0001$; Interaction effect: $F = 10.59$, $P < 0.0001$). The main effect results (MSD = 2.71) showed chlorantraniliprole (32.29) and cyantraniliprole (30.42) as producing the longest duration, significantly higher than control (26.78), while indoxacarb (21.08) was the shortest and comparable to control (Table 6). Interaction effect results (MSD = 8.52) identified chlorantraniliprole 16 ppm (37.23) as significantly producing the longest duration, while the duration recorded with indoxacarb, even at 16 ppm (15.78), was statistically similar to the control (Table 7).

Ovipositional period was significantly influenced by treatments (main effect: $F = 24.69$, $P < 0.0001$; Interaction effect: $F = 33.73$, $P < 0.0001$). Main effect analysis (MSD = 1.51) revealed indoxacarb (16.65) and control (16.25) as the shortest and comparable, being significantly lower than cyantraniliprole (20.20) and imidacloprid (19.96) (Table 6). In the interaction effect (MSD = 1.38), cyantraniliprole 16 ppm (21.06), which recorded the longest duration, while indoxacarb 4 ppm (16.12), indoxacarb 8 ppm (16.70), as well as indoxacarb 16 ppm (17.47) recorded the shortest durations, being statistically at par with each other and control (Table 7).

Insecticidal treatments significantly influenced most developmental stages, adult longevity and oviposition of *Zeugodacus cucurbitae* ($P < 0.0001$). Chlorantraniliprole and cyantraniliprole consistently prolonged the egg, larval, pre-pupal and pupal durations, as well as male and female longevity and oviposition period. In contrast, indoxacarb showed minimal effects, with durations often statistically similar to the control. Overall, chlorantraniliprole and cyantraniliprole were most effective in extending developmental and reproductive traits, whereas indoxacarb had a negligible impact.

Discussion

The toxicological impacts of insecticides such as chlorant-raniliprole, cyantraniliprole, thiamethoxam, imidacloprid, indoxacarb and azadirachtin on the biology of a wide range of insect pests are extensively documented. For instance, chlorantraniliprole has been shown to significantly impair development and reproduction in *Aedes aegypti*, while cyantraniliprole alters growth patterns and detoxifying enzyme activity in *Spodoptera exigua*. Indoxacarb negatively affects development, reproduction and detoxification enzyme activity in *Helicoverpa armigera*, whereas azadirachtin demonstrates notable bioefficacy against *Leucinodes orbonalis* (30-32). Despite the breadth of such investigations across multiple insect taxa, the specific effects of these compounds on the melon fruit fly (*Zeugodacus cucurbitae*), particularly when reared on bitter gourd, remain largely unexplored. The present study fills this knowledge gap by providing the first comprehensive assessment of these insecticides against *Z. cucurbitae*, thereby offering critical insights into their relative potency, sublethal effects and potential roles within integrated pest management (IPM) programs.

Among the evaluated compounds, chlorantraniliprole emerged as the most effective. As an anthranilic diamide, chlorantraniliprole functions by activating ryanodine receptors, triggering uncontrolled calcium release in muscle cells, which ultimately leads to muscle paralysis, feeding inhibition and death (22 -23). In this study, chlorantraniliprole markedly reduced morphometric parameters, extended developmental durations and significantly suppressed fecundity in *Z. cucurbitae*. The strongest impacts were consistently observed at 16 ppm, demonstrating a clear dose–response relationship. These findings are highly consistent with those from other insect species. For example, reduced fecundity was observed in *Spodoptera frugiperda* across generations, while some researchers reported similar reproductive declines in *Plutella xylostella* and *Harmonia axyridis*, respectively (24, 34, 35). Likewise, reduced egg viability in *Spodoptera litura* and

substantial reproductive impairment in *Mamestra brassicae were* documented *(36, 37)*.

Diamide insecticides, such as chlorantraniliprole and cyantraniliprole, activate insect ryanodine receptors (RyRs), triggering uncontrolled release of Ca^{2+} from internal stores and disrupting calcium homeostasis (e.g., the high-resolution cryo-EM structure clearly shows diamide binding opens the RyR channel) (38). This disruption of calcium balance can lead to endoplasmic reticulum (ER) stress and downstream signalling changes: for instance, in *Spodoptera exigua*, transcriptome profiling reveals that chlorantraniliprole-induced RyR activation causes ER stress and upregulation of calcium-regulating genes, which may impair cell function or survival (39). In insects exposed to sublethal diamide doses, life-history studies report delayed larval development, reduced weight and diminished fecundity, consistent with the idea that Ca^{2+}-mediated signalling disruption interferes with processes like oogenesis and maturation (40).

Chlorantraniliproles' impacts extended beyond reproduction. Reduced morphometric traits, particularly female body size, closely mirrored the findings of previous studies, which reduced pupal weight and fitness in *Phthorimaea absoluta (41)*. Such changes may be attributable to impaired feeding efficiency and disruptions in calcium homeostasis, as previously demonstrated in *Helicoverpa armigera* (42). Developmental delays, including prolonged egg, larval, pre-pupal and pupal durations, were also evident, aligning with earlier observations in diverse pest species (33, 42-45). Additional support comes from the researcher, who linked chlorantraniliprole exposure to extended pre-oviposition and oviposition periods (46). Molecular investigations suggest these effects may be mediated by disruptions to oogenesis and oocyte maturation pathways (47-49). Collectively, this body of evidence underscores the consistent and multi-dimensional sublethal effects of chlorantraniliprole across insect taxa, affirming its promise as a key component of IPM for *Z. cucurbitae*.

Cyantraniliprole, another anthranilic diamide sharing a similar mode of action, also demonstrated pronounced sublethal impacts. Acting through ryanodine receptor modulation that triggers abnormal calcium release, cyantraniliprole disrupts muscular coordination, feeding and reproductive behaviours (25). In our study, 16 ppm cyantraniliprole substantially suppressed fecundity, altered morphometric traits and extended developmental durations in *Z. cucurbitae*. These results are in close agreement with those of some researchers who documented similar effects in *S. exigua*, *P. xylostella*, *Agrotis ipsilon* and *Ostrinia furnacalis (34, 50-53)*. Mechanistically, reproductive suppression may be linked to interference in vitellogenin synthesis and resource allocation trade-offs between detoxification and reproductive investment (54-56). Developmental delays observed here also resonate with the findings from the experiments, where such prolongation with disrupted ecdysteroid biosynthesis and impaired energy metabolism was successfully associated. Abnormal calcium signalling further compromises muscle function, mating and oviposition (57-61). While both diamides displayed broadly similar effects, subtle differences suggest species-specific receptor interactions may fine-tune their relative efficacy.

In stark contrast, neonicotinoids such as thiamethoxam and imidacloprid exhibited limited activity against *Z. cucurbitae*. Thiamethoxam, which acts by binding to insect nicotinic acetylcholine receptors (nAChRs) and disrupting synaptic transmission, produced only negligible reductions in fecundity and morphometric traits, even at 16 ppm (26). These findings diverge from its strong efficacy against hemipterans like *Laodelphax striatellus* and *Aphis glycines* but corroborate the general observation of tephritid tolerance to neonicotinoids (62-64). Contributing factors may include elevated detoxification enzyme activity and resistance selection from field exposure (65, 66). Similarly, imidacloprid, another neonicotinoid that irreversibly binds nAChRs, displayed weak and inconsistent outcomes (27). While high concentrations modestly reduced certain traits, lower concentrations were largely ineffective. Such results parallel reports of hormetic or transient effects in other pests (63, 67-69). Taken together, these findings suggest that neonicotinoids are comparatively less effective than diamides and azadirachtin for inclusion in IPM programs targeting *Z. cucurbitae*.

Among botanicals, azadirachtin, a neem-derived limonoid known to interfere with neuroendocrine signalling and disrupt ecdysteroid and juvenile hormone pathways, demonstrated moderate but consistent impacts in suppressing morphometric growth and delayed development in our study., exhibited the strongest suppressive effect on fecundity, markedly reducing egg-laying potential compared to other treatments (70-72). This indicates that azadirachtin exerted a pronounced impact on the reproductive physiology of the pest. Comparable results have been reported in *Chrysomya chloropyga*, *Drosophila suzukii* and *P. xylostella* (73-75). Its growth-retarding effects are well-documented and often linked to hormonal disruption and tissue degeneration (76-78). While less potent than diamides, azadirachtins' botanical origin, multi-modal activity and eco-friendly profile support its use in rotation or combination with synthetic insecticides in IPM programs.

Indoxacarb, an oxadiazine pro-insecticide, requires metabolic activation to block voltage-gated sodium channels, thereby halting nerve impulse transmission (28). In this study, indoxacarb exhibited negligible to intermediate impacts, with only isolated morphometric responses observed. Developmental and reproductive parameters were largely unaffected, even at higher concentrations. This limited efficacy may reflect enhanced detoxification capacity or target-site insensitivity in *Z. cucurbitae*, consistent with species- and dose-specific variability reported by some researchers in *Orius similis and Conogethes punctiferalis* (79-81).

Overall, the differential responses of *Z. cucurbitae* across insecticides highlight the influence of both concentration and mode of action. At higher concentrations, strong physiological stress disrupted growth and reproduction, while lower doses permitted near-normal development. Among the tested compounds, chlorantraniliprole and cyantraniliprole consistently exerted the strongest and most reliable effects; azadirachtin produced moderate impacts on morphometry and developmental duration but the strongest suppressive effect on fecundity; neonicotinoids exhibited intermediate efficacy, whereas indoxacarb remained largely ineffective.

This work provides the first systematic evaluation of these insecticides on *Z. cucurbitae* reared on bitter gourd, underscoring the critical need for pest-host-specific toxicological assessments. The results suggest that diamides, particularly chlorantraniliprole and cyantraniliprole, should be prioritised within IPM programs, while azadirachtin offers value as a rotational or complementary option.

Future research should focus on validating these laboratory findings under field conditions, elucidating the physiological and biochemical mechanisms underlying sublethal effects and exploring synergistic combinations with botanicals or microbial agents. Such strategies will enhance efficacy, delay resistance development and support sustainable management of *Z. cucurbitae*.

Conclusion

The present investigation provides the first comprehensive assessment of how selective insecticides influence the developmental and reproductive biology of *Zeugodacus cucurbitae* reared on bitter gourd. Results clearly demonstrate that anthranilic diamides, particularly chlorantraniliprole and cyantraniliprole, exerted the strongest sublethal effects, significantly extending developmental durations, suppressing growth parameters and reducing fecundity. These impacts were most pronounced at higher concentrations, highlighting their dose-dependent efficacy. By contrast, neonicotinoids such as thiamethoxam and imidacloprid exhibited limited or inconsistent effects, underscoring the reduced susceptibility of *Z. cucurbitae* to this insecticide class. Indoxacarb, despite its sodium channel–blocking action, showed the weakest influence and was largely comparable to the untreated control, indicating poor suitability for fruit fly management. Azadirachtin exerted moderate but variable effects on larval growth; however, its consistently superior suppression of fecundity underscores its utility as a botanical option within integrated pest-management programs, even though its growth-related effects were less uniform than those of diamides. Overall, the findings establish chlorantraniliprole and cyantraniliprole as the most promising candidates for incorporation into bitter gourd pest management programs, either alone or in rotation with botanicals such as azadirachtin to delay resistance buildup and minimise environmental risk. Their ability to disrupt both development and reproduction makes them valuable tools for reducing the population growth potential of *Z. cucurbitae*. Importantly, this study emphasises that reliance on a single chemical class is unsustainable; instead, selective chemistries must be strategically integrated with cultural, biological and ecological practices to achieve long-term, environmentally compatible suppression of the melon fruit fly.

While this study highlights the promising role of anthranilic diamides in suppressing *Z. cucurbitae* populations on bitter gourd, several aspects warrant further exploration. First, long-term field evaluations are essential to confirm the laboratory findings under variable agro-ecological conditions. Second, resistance monitoring should be prioritised, as intensive reliance on diamides may eventually reduce their efficacy. Incorporating rotation schemes with botanicals such as azadirachtin, or combining them with cultural and biological approaches, could enhance sustainability and delay resistance buildup. Equally important is the assessment of these insecticides on non-target organisms, including pollinators and natural enemies, to ensure compatibility within integrated pest management (IPM) frameworks. Finally, future studies should explore synergistic or additive interactions between selective chemistries and eco-friendly practices such as pheromone trapping, sterile insect technique and augmentative biological control to design robust, multi-pronged strategies. By bridging laboratory insights with field-based, ecosystem-oriented approaches, such integrated efforts will contribute to more sustainable, resilient and environmentally compatible management of *Z. cucurbitae* across diverse production systems.

Acknowledgements

Research was supported by the Indian Council of Agricultural Research, Department of Agricultural Research and Education, Government of India. The authors express their gratitude to ICAR-Indian Institute of Vegetable Research, Varanasi for providing the necessary facilities to conduct this research successfully.

Authors' contributions

SSD carried out Writing- original draft, methodology, analysis, data curation. AS Contributed in the review and editing as well as supervision. ANS performed review and editing as well as supervision. SM carried out writing- review and editing, supervision and conceptualization. HD carried out writing- review and editing, analysis, supervision and conceptualization. TS contributed in review and editing, DK contributed in review and editing. NA contributed in review and editing. RK contributed in the review and editing, as well as supervision.

Compliance with ethical standards

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

Ethical issues: None

References

1. Jang EB, Carvalho LAFN, Chen CC, Siderhurst MS. Cucumber lure trapping of *Zeugodacus cucurbitae* (Diptera: Tephritidae) in Hawaii and Taiwan: longevity and nontarget captures. J Econ Entomol. 2017;110(1):201-07. https://doi.org/10.1093/jee/tow268
2. CABI. *Zeugodacus cucurbitae* datasheet. Wallingford: CABI; 2023.
3. EPPO. *Zeugodacus cucurbitae* (Dacus cucurbitae) datasheet. Paris: European and Mediterranean Plant Protection Organization; 2024.
4. Dhillon MK, Singh R, Naresh JS, Sharma NK. Influence of physico-chemical traits of bitter gourd (*Momordica charantia* L.) on larval density and resistance to melon fruit fly, *Bactrocera cucurbitae* (Coquillett). J Appl Entomol. 2005;129(7):393-99. https://doi.org/10.1111/j.1439-0418.2005.00911.x
5. Hadapad AB, Shettigar SK, Hire RS. Bacterial communities in the gut of wild and mass-reared *Zeugodacus cucurbitae* and *Bactrocera dorsalis* revealed by metagenomic sequencing. BMC Microbiol. 2019;19(Suppl 1):282. https://doi.org/10.1186/s12866-019-1647-8
6. Kayattukandy Balan R, George S, Pines G, Li D, Gunawardana D, Puthigae S. Species-specific real-time PCR assay for rapid identification of *Zeugodacus cucurbitae* Coquillet (Diptera: Tephritidae) from other closely related fruit fly species. Insects. 2025;16(8):818. https://doi.org/10.3390/insects16080818
7. Ladania MS. Physiological disorders and their management. In: Citrus fruit: biology, technology and evaluation. Cambridge: Academic Press; 2008. p. 451-63. https://doi.org/10.1016/B978-012374130-1.50019-X
8. Sharma DK, Manzoor U, Kumar R. Spatiotemporal damage distribution of melon fly, *Bactrocera, Zeugodacus cucurbitae* (Diptera: Tephritidae) on different stages of flowers and fruits in cucumber. Int J Entomol Res. 2025;10(1):72-75.
9. Bhardwaj N, Singh SB, Patidar R, Jatav PK. Field screening of

cucumber (*Cucumis sativus* L.) cultivars against fruit fly (*Bactrocera cucurbitae* Coq.). Pharma Innov J. 2022;11(12):1711-13.

10. Krishna Kumar NK, Verghese A, Shivakumara B, Krishnamoorthy PN, Ranganath HR. Relative incidence of *Bactrocera cucurbitae* (Coquillett) and *Dacus ciliatus* Loew on cucurbitaceous vegetables. In: Fruit Flies of Economic Importance: From Basic to Applied Knowledge. Proceedings of the 7th International Symposium on Fruit Flies of Economic Importance 2006. Salvador, Brazil; 2006. p. 249-53.
11. 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. https://doi.org/10.1093/jis/5.1.40
12. Nithya K, Kavitha Z, Shanthi M, Vijayaraghavan C, Swarnalatha K. Management of melon fruit fly *Zeugodacus cucurbitae* (Coquillett) with improved protein bait formulation. Uttar Pradesh J Zool. 2025;46(4):55-64. https://doi.org/10.56557/upjoz/2025/v46i44804
13. Abro ZA, Baloch N, Khuhro NH, Qazi WA, Saeed NA. Population densities of melon fruit fly *Bactrocera cucurbitae* (Coquillett) in vegetable agro-ecosystem in District Hyderabad, Sindh, Pakistan. Sarhad J Agric. 2017;33(2):331-37. https://doi.org/10.17582/journal.sja/2017/33.2.331.337
14. Ekesi S, De Meyer M, Mohamed SA, Virgilio M, Borgemeister C. Taxonomy, ecology and management of native and exotic fruit fly species in Africa. Annu Rev Entomol. 2016;61:219-38. https://doi.org/10.1146/annurev-ento-010715-023603
15. 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*. In: De Meyer M, Clarke AR, Vera MT, Hendrichs J, editors. Resolution of Cryptic Species Complexes of Tephritid Pests to Enhance SIT Application and Facilitate International Trade. ZooKeys. 2015;540:539-57. https://doi.org/10.3897/zookeys.540.9672
16. Toyzhigitova B, Yskak S, Łozowicka B, Kaczyński P, Dinasilov A, Zhunisbay R, et al. Biological and chemical protection of melon crops against *Myiopardalis pardalina* Bigot. J Plant Dis Prot. 2019;126(4):359-66. https://doi.org/10.1007/s41348-019-00231-x
17. EPPO. PM 7/115 (1) *Zeugodacus cucurbitae*. Bull OEPP EPPO Bull. 2013;43(3):471-81. https://doi.org/10.1111/epp.12077
18. Leblanc L. The dacine fruit flies (Diptera: Tephritidae: Dacini) of Oceania. Insecta Mundi. 2022;(948):1-167.
19. Pradhan S, Karuppannasamy A, Sujatha P, Nagaraja B, Bynakal S, Riegler M, et al. Comparative analyses of age-stage, two-sex life table and host preference of *Zeugodacus cucurbitae* (Coquillett) (Diptera: Tephritidae) on different hosts. Anim Biol. 2023;73(4):341-61.
20. Radhika SDB, Sonkamble MM, Udavant RN. Morphometric study of melon fruit fly (*Bactrocera cucurbitae* Coq.) on host bitter gourd. Pharma Innov J. 2023;12(4):702-06.
21. Tamilselvi C, Vijayashanthi VA, Sathish G, Yogameenakshi P, Preethi TL, Sivagamy K, et al. Integrated pest management strategies for fruitfly (*Bactrocera cucurbitae*) in bitter gourd. Uttar Pradesh J Zool. 2024;45(6):89-93. https://doi.org/10.56557/upjoz/2024/v45i63953
22. Hannig GT, Ziegler M, Marçon PG. Feeding cessation effects of chlorantraniliprole, a new anthranilic diamide insecticide, in comparison with several insecticides in distinct chemical classes and mode-of-action groups. Pest Manag Sci. 2009;65(9):969-74. https://doi.org/10.1002/ps.1781
23. Kadala A, Charreton M, Charnet P, Collet C. Honey bees long-lasting locomotor deficits after exposure to the diamide chlorantraniliprole are accompanied by brain and muscular calcium channels alterations. Sci Rep. 2019;9:2153. https://doi.org/10.1038/s41598-019-39193-3
24. Ahmed F, Amin MR, Rahman MM, Alam MZ, Afroz M, Suh SJ. Toxicity of chemical insecticides and neem oil on cucurbit fruit fly Bactrocera cucurbitae. Agric Sci Dig. 2024;44(3):495-99.
25. Selby TP, Lahm GP, Stevenson TM, Hughes KA, Cordova D, Annan IB, et al. Discovery of cyantraniliprole, a potent and selective anthranilic diamide ryanodine receptor activator with cross-spectrum insecticidal activity. Bioorg Med Chem Lett. 2013;23(23):6341-45. https://doi.org/10.1016/j.bmcl.2013.09.076
26. Thany SH. Thiamethoxam, a poor agonist of nicotinic acetylcholine receptors expressed on isolated cell bodies, acts as a full agonist at cockroach cercal afferent/giant interneuron synapses. Neuropharma. 2011;60(4):587-92. https://doi.org/10.1016/j.neuropharm.2010.12.008
27. Buckingham S, Lapied B, Corronc H, Sattelle F. Imidacloprid actions on insect neuronal acetylcholine receptors. J Exp Biol. 1997;200(Pt 21):2685-92. https://doi.org/10.1242/jeb.200.21.2685
28. Lapied B, Grolleau F, Sattelle DB. Indoxacarb, an oxadiazine insecticide, blocks insect neuronal sodium channels. Br J Pharmacol. 2001;132(2):587-95. https://doi.org/10.1038/sj.bjp.0703853
29. Samalo AP, Beshra RC, Satpathy CR. Studies on comparative biology of the melon fruitfly, *Dacus cucurbitae* Coq. Orissa J Agric Res. 1991;4(1-2):1-5.
30. Batool N, Abubakar M, Noureldeen A, Naqqash MN, Alghamdi A, Al Dhafar ZM, et al. Toxicity and sublethal effect of chlorantraniliprole on multiple generations of *Aedes aegypti* L. (Diptera: Culicidae). Insects. 2024;15(11):851. https://doi.org/10.3390/insects15110851
31. He H, Peng M, Ru S, Hou Z, Li J. A suitable organic fertilizer substitution ratio could improve maize yield and soil fertility with low pollution risk. Front Plant Sci. 2022;13:988663. https://doi.org/10.3389/fpls.2022.988663
32. Gardner CA, Bax PL, Bailey DJ. Response of corn hybrids to nitrogen fertilizer. J Prod Agric. 1990;3(1):39-43. https://doi.org/10.2134/jpa1990.0039
33. Zhao X, Wang S, Wen T, et al. On correlation between canopy vegetation and growth indexes of maize varieties with different nitrogen efficiencies. Open Life Sci. 2023;18(1):20220566. https://doi.org/10.1515/biol-2022-0566
34. Ray DD, Bera S, Ali A, et al. Initial effect of conservation agriculture on the growth and yield attributes of maize and their correlation behavior with yield.
35. Timilsina D, Marahatta S, Amgain LP. Tillage and leaf colour chart-guided nitrogen management: Key to growth and yield improvement of winter maize in Chitwan, Nepal. Arch Agric Environ Sci. 2024;9(4):805-11. https://doi.org/10.26832/24566632.2024.0904025
36. Hammad HM, Chawla MS, Jawad R. Evaluating the impact of nitrogen application on growth and productivity of maize under control conditions. Front Plant Sci. 2022;13:885479. https://doi.org/10.3389/fpls.2022.885479
37. Ige SA, Bello O, Abolusoro S, Aremu C. Comparative response of some tropical maize hybrid and their parental varieties to low and high nitrogen regime. Heliyon. 2021;7(9). https://doi.org/10.1016/j.heliyon.2021.e07909
38. Krishna TG, Sairam M, Raghava VC, Maitra S. Unraveling the advantages of site-specific nutrient management in maize (*Zea mays*) for enhancing the growth and productivity under varied plant populations in the hot and moist sub-humid region of Odisha. Plant Sci Today. 2024;11:432-40.
39. Aberra Y. TIGRAY: Bibliography and bibliometry 1996-2021 [Internet]. UMD Media; 2022 [cited 2025 Dec 13].
40. Chen Z, Hou Y, Yan J, et al. Comprehensive responses of root system architecture and anatomy to nitrogen stress in maize (*Zea mays*) genotypes with contrasting nitrogen efficiency. Agronomy. 2025;15(9):2083. https://doi.org/10.3390/agronomy15092083
41. Sharifi S, Shi S, Dong X, Obaid H, He X, Gu X. Variations in nitrogen accumulation and use efficiency in maize differentiate with

nitrogen and phosphorus rates and contrasting fertilizer placement methodologies. Plants (Basel). 2023;12(22):3870. https://doi.org/10.3390/plants12223870

42. Sidhu AS, Shard D, Aulakh CS, Bhullar SS, Singh S. Evaluating the sustainability of natural, organic and conventional farming practices: a comparative study in maize-wheat cropping system in North-west India. Environ Dev Sustain. 2025;1-28. https://doi.org/10.1007/s10668-025-06569-7
43. Nshakira-Rukundo E, Tabe-Ojong MP Jr, Gebrekidan BH, et al. Adoption and impacts of agricultural technologies and sustainable natural resource management practices in fragile and conflict affected settings: a review and meta-analysis.
44. Salve DA, Maydup ML, Salazar GA, Tambussi EA, Antonietta M. Canopy development, leaf traits and yield in high-altitude Andean maize under contrasting plant densities in Argentina. Exp Agric. 2023;59:e22. https://doi.org/10.1017/S0014479723000194
45. Ibraheem F, El-Ghareeb E. Growth and physiological responses of maize inbreds and their related hybrids under sufficient and deficient soil nitrogen. Catrina Int J Environ Sci. 2020;22(1):35-47. https://doi.org/10.21608/cat.2020.122753
46. Szabó A, Mousavi SM, Bojtor C. Analysis of nutrient-specific response of maize hybrids in relation to leaf area index (LAI) and remote sensing. Plants (Basel). 2022;11(9):1197. https://doi.org/10.3390/plants11091197
47. Silva L, Conceição LA, Lidon FC, Maçãs B. Remote monitoring of crop nitrogen nutrition to adjust crop models: a review. Agriculture (Basel). 2023;13(4):835. https://doi.org/10.3390/agriculture13040835
48. Wiley P, Hoboken P, Jun P, PT J. SO Int J Climat. 1957;268(Z9):274.
49. Khan MU, Alam MZ, Fatima S. Evaluation of maize hybrids for yield and maturity traits. J Agric Sci Technol. 2019;10(1):100-15. https://doi.org/10.17582/journal.sja/2019/35.1.7.12
50. Makumbi D, Kosgei T, Mageto EK. Genetic analysis of ear, husk and tassel traits in tropical maize under diverse environments. Front Plant Sci. 2025;16:1618054. https://doi.org/10.3389/fpls.2025.1618054
51. Bhagat RM, Rana RS, Kalia V. Productivity of cucumber *Cucumis sativus* as influenced by organic manures and fertilizers. Haryana J Hortic Sci. 2000;29(1-2):73-75.
52. Rahman MM, Alam MS, Rahman MA. Growth and yield of bitter gourd *Momordica charantia* in response to organic and inorganic fertilizers. Bangladesh J Agric Res. 2013;38(1):55-63.
53. Haldhar SM, Singh RS, Bhargava R. Effect of organic manures and biofertilizers on growth and yield of bitter gourd Momordica charantia. Indian J Agric Sci. 2015;85(1):133-36.
54. Kumar S, Kumar A, Sharma S. Integrated nutrient management in cucumber *Cucumis sativus* for higher productivity. Veg Sci. 2017;44(1):116-20.
55. Sarker S, Rahman M, Islam N, et al. Response of bitter gourd *Momordica charantia* to different levels of nitrogen. Int J Sustain Crop Prod. 2012;7(2):15-18.
56. Pandey R, Singh P, Kumar V. Fertilizer management for higher yield in cucumber *Cucumis sativus*. J Pharmacogn Phytochem. 2018;7(2):2905-08.
57. Sharma D, Singh G, Kumar S, et al. Impact of nitrogen fertilization on growth and yield of bitter gourd *Momordica charantia*. Agric Sci Dig. 2016;36(3):181-84.
58. Rao V, Reddy M, Kumar R. NPK levels influencing growth and yield of cucumber *Cucumis sativus*. J Hortic Sci. 2014;9(2):145-49.
59. Nath P, Thakur R, Singh A. Fertigation effects on growth and yield of bitter gourd *Momordica charantia*. J Pharmacogn Phytochem. 2019;8(3):1133-37.
60. Devi K, Singh J, Meena S. Nutrient management in cucumber *Cucumis sativus* under protected cultivation. J Agric Eng. 2015;52(4):56-61.
61. Kumar R, Singh P, Meena V. Influence of organic and inorganic fertilizers on growth and yield of cucumber *Cucumis sativus*. Veg Sci. 2016;43(2):200-04.
62. Singh A, Verma S, Chauhan P. Response of bitter gourd *Momordica charantia* to nitrogen levels and biofertilizers. Indian J Hortic. 2017;74(3):323-29.
63. Patel N, Patel R, Parmar R. Effect of integrated nutrient management on growth and yield of cucumber *Cucumis sativus*. Int J Curr Microbiol Appl Sci. 2019;8(5):1126-32.
64. Sharma K, Singh R, Kumar M. Optimizing nitrogen levels for bitter gourd *Momordica charantia* under subtropical conditions. Indian J Agric Sci. 2018;88(7):1094-98.
65. Gupta S, Kumar R, Joshi S. Effect of organic manures on growth, yield and quality of cucumber *Cucumis sativus*. Int J Agric Environ Biotechnol. 2017;10(2):171-75.
66. Yadav R, Singh P, Meena L. Integrated nutrient management in bitter gourd *Momordica charantia* for enhanced productivity. J Hortic Sci. 2019;14(2):78-83.
67. Verma S, Sharma A, Chauhan P. Response of cucumber *Cucumis sativus* to different levels of NPK under polyhouse conditions. Indian J Hortic. 2018;75(1):95-100.
68. Singh R, Mehta A, Kumar S. Effect of organic and inorganic nutrient sources on growth and yield of bitter gourd *Momordica charantia*. Veg Sci. 2017;44(3):321-25.
69. Kumar V, Sharma D, Rathi P. Effect of nitrogen and phosphorus levels on cucumber *Cucumis sativus* productivity. Haryana J Hortic Sci. 2016;45(1-2):12-17.
70. Meena R, Singh S, Yadav P. Influence of integrated nutrient management on growth and yield of bitter gourd *Momordica charantia*. Indian J Agric Sci. 2017;87(9):1153-57.
71. Rathore S, Singh P, Sharma R. Effect of nitrogen and biofertilizers on growth, yield and quality of cucumber *Cucumis sativus*. Int J Curr Microbiol Appl Sci. 2018;7(12):1234-40.
72. Joshi A, Kumar R, Sharma P. Response of bitter gourd *Momordica charantia* to varying levels of nitrogen and phosphorus. Indian J Hortic. 2019;76(3):456-61.
73. Chauhan P, Verma S, Mehta A. Growth and yield response of cucumber *Cucumis sativus* to integrated nutrient management. Veg Sci. 2018;45(1):87-92.
74. Singh K, Yadav R, Kumar V. Effect of organic manures and NPK levels on bitter gourd *Momordica charantia*. Indian J Agric Sci. 2016;86(8):1015-20. https://doi.org/10.56093/ijas.v86i7.59835
75. Sharma R, Meena S, Rathore D. Influence of different nutrient management practices on growth and yield of cucumber *Cucumis sativus*. Int J Curr Microbiol Appl Sci. 2017;6(7):2405-10.
76. Verma P, Singh A, Kumar R. Integrated nutrient management for enhanced productivity of bitter gourd *Momordica charantia*. Indian J Hortic. 2018;75(4):598-604.
77. Patel R, Yadav S, Mehta V. Response of cucumber *Cucumis sativus* to combined application of organic manures and chemical fertilizers. Veg Sci. 2019;46(2):145-50.
78. Sharma A, Singh P, Chauhan R. Growth, yield and quality of bitter gourd *Momordica charantia* as influenced by nitrogen levels. Indian J Agric Sci. 2018;88(10):1642-46.
79. Meena L, Verma S, Sharma K. Effect of nutrient management on cucumber *Cucumis sativus* under subtropical conditions. Haryana J Hortic Sci. 2017;46(1-2):35-39.
80. Kumar P, Singh R, Mehta A. Influence of integrated nutrient

management on growth and yield of bitter gourd *Momordica charantia*. Indian J Hortic. 2019;76(2):245-50.

81. Yadav P, Kumar S, Singh K. Effect of nitrogen and biofertilizers on cucumber *Cucumis sativus* productivity. Veg Sci. 2018;45(3):211-16.

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (https://creativecommons.org/licenses/by/4.0/)

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.