PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–11
https://doi.org/10.14719/pst.5022

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REVIEW ARTICLE

Integrated pest management strategies for the invasive orchid blossom midge (*Contarinia maculipennis* Felt.)

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OPEN ACCESS

ARTICLE HISTORY
Received: 11 September 2024
Accepted: 01 November 2024
Available online
Version 1.0 : 21 December 2024
Version 2.0 : 10 April 2025

Check for updates

Additional information

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

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CITE THIS ARTICLE
Minnu VJ, Allwin L, Elanchezhyan K, Manivannan MI, Rajinimala N. Integrated pest management strategies for the invasive orchid blossom midge (*Contarinia maculipennis* Felt.). Plant Science Today.2024;11(sp4):01-11. https://doi.org/10.14719/pst.5022

Abstract

Orchid blossom midge (*Contarinia maculipennis* Felt.) is a tiny Cecidomyiid fly that infests cut flowers such as orchids, jasmine, and tuberose. As a small insect, the midge can adapt to various environments, evolving new survival strategies, including overcoming climatic barriers. Midge has recently been identified as a major pest for cut-flower cultivators, posing substantial harm, especially to tuberose, reducing their attractiveness to customers. In orchid farms, it infests and damages the flower buds of *Dendrobium*, especially during the early stages, resulting in substantial yield loss. Abiotic conditions, in conjunction with orchid species, facilitate midge's access to its host plants; yet gaps in comprehending these relationships have impeded research. A major concern is its infestation within flower buds, which has prompted scientists to prioritize management strategies. Despite efforts toward sustainable management, controlling this pest remains a challenge. This review covers the host range, geographic distribution, molecular taxonomy, biology, seasonal occurrence, the influence of lunar phases on adult emergence, volatile studies, and various approaches for managing the orchid blossom midge.

Keywords

botanicals; cecidomyiid fly; *Dendrobium* spp.; lunar phases; polyphagous; taxonomy

Introduction

Orchids, members of the Orchidaceae family, are among the most coveted categories in floriculture, comprising approximately 8,000 genera and 35,000 species, both naturally occurring and hybridized (1). India alone has approximately 1,350 species within 185 orchid genera (2). Of these, 55 species have medicinal significance, over 150 are ornamental, and the remaining species hold ecological importance as biological curiosities (2, 3). Orchids hold global relevance, with products derived from orchids, such as vanilla, adding substantial value in local and national markets. Historically, orchids were also used as botanical extracts to treat coughs and various ailments. Although renowned for medicinal purposes, orchids have gained immense popularity for their aesthetic appeal and long-lasting blooms, making them highly desirable.

However, the 1990s saw a marked decline in orchid production due to the emergence of a new pest, orchid blossom midge (*C. maculipennis* Felt). The pest attracted attention in 1993–1994 when large-scale orchid cultivators reported substantial yield reductions. The adult *C. maculipennis* was first identified on the blossoms of *Hibiscus* species cultivated in Hawaii, USA (4). As an invasive gall midge (Diptera: Cecidomyiidae), *C. maculipennis* typically inhabits greenhouses and feeds on the flower buds of orchids, posing a considerable threat to the Orchidaceae family.

The orchid blossom midge is mainly confined to greenhouses containing *Dendrobium* orchids. However, in Japan, it has also been observed infesting open fields of cash crops such as *Jasminum sambac* and *Momordica charantia* (5). The increased occurrence of this pest has been linked to its introduction from Thailand during orchid imports into Tamil Nadu, together with the lack of efficient natural predators. Additionally, favorable agro-climatic conditions have led to an unusual rise in the pest's reproductive capacity. Infested orchid flower buds lose all commercial value, and the frequency of insecticide applications has doubled (6).

Geographic distribution of orchid blossom midge (*C. maculipennis*)

Infestations of *C. maculipennis* have been documented in orchid plantations in Japan, Singapore, Thailand, China, South Africa, Australia, and the Indian subcontinent (6). The emergence of this pest is represented in Table 1, whereas Table 2 presents details on its tuberose infestation. Between 1997 and 1999, Japan imported an average of 135 million cut blooms and six million plants of *Dendrobium* spp, annually from Southeast Asia, which may have facilitated the spread of *C. maculipennis*. The geographic spread of this midge is comparable to that of *Anopheles* spp. (7). Additionally, the insect has reached Okinawa Island and Florida, likely via orchid blooms imported from Thailand (8, 9). More recently, it has been recorded in India (Tamil Nadu) on *Jasminum* sp. (9) and *Dendrobium* sp. (10). The infestation sites for rynco orchids and the affected *Dendrobium* species are depicted in Fig. 1 and 2, respectively. Also, the particular flower infested with blossom midge is shown in Fig. 3.

Table 1. Influx of orchid blossom midge from various outstations

Introduced to	Introduced from	Year	Natural reproduction	References
Florida	Thailand	1995	yes	(8)
Hawaii	Thailand	1945	yes	(8)
Netherland	Thailand	2001	no	(9)

Table 2. Midge fly infestation of tuberose at different locations in India (32)

Localities of the survey	Tuberose variety	Midge infestation (%)
Vannepudi locality in Kakinada district, Andhra Pradesh	Hyderabad local (single type)	35.00
Girgetpalle locality of Vikrabad district, Telangana	Arka Prajwal (single type)	82.33
Zaheerabad locality of Sangareddy district, Telangana	Arka Prajwal (single type)	83.00

Domain: Eukaryota
Kingdom: Metazoa
Phylum: Arthropoda
Subphylum: Uniramia
Class: Insecta
Order: Diptera
Family: Cecidomyiidae
Genus: *Contarinia*
Species: *maculipennis*

Fig. 1. Taxonomic tree of orchid blossom midge.

Fig. 2. Rhynco orchid site where blossom midge was identified (South India).

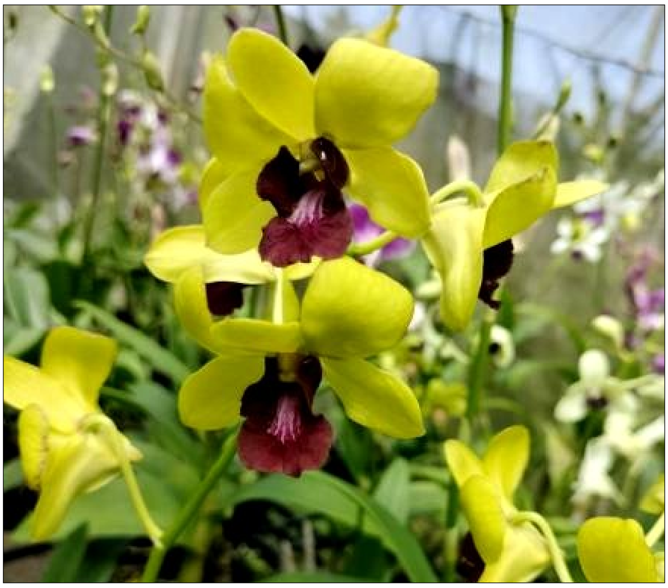

Fig. 3. *Dendrobium* spp. where midge gets attracted.

Host range of *C. maculipennis*

The incidence of the blossom midge, *C. maculipennis*, has been recorded on a range of host plants, including orchids, *Hibiscus* (*Malvaceae*), tomato, eggplant, potato, Paraguay nightshade (*Solanaceae*), pepper (*Piperaceae*), pak-choi (*Brassicaceae*), bitter gourd (*Cucurbitaceae*), and pikake (*Oleaceae*) (8). The midge damages flower buds on tuberose and hibiscus, causing scarring and reduced blooming, which diminishes these plants' aesthetic and commercial value. For crops such as tomato, eggplant, potato, and Paraguay nightshade, *C. maculipennis* reduces yields and quality, directly affecting profitability by causing bud abortion and fruit scarring. In pepper, it reduces flower set and yields; bitter gourd and pak-choi distort leaves and fruits, rendering them unmarketable. Additionally, infestations have been recorded on ornamental plants like *Plumeria* and various weed species (11).

The recent identification of this pest on cut tuberose blooms highlights concerns regarding its polyphagous nature (12). Phylogenetic and molecular evidence strongly supports the idea that the diversification of phytophagous insects is linked to their evolutionary host-switching history (13). While *C. maculipennis* likely originated in Southeast Asia, the global trade of *Dendrobium* spp. as cut blooms has contributed to its spread worldwide (13, 14). Fortunately, using insect-proof screens in greenhouses has reduced midge populations, minimizing the need for chemical treatments (15).

The orchid blossom midge, classified under the order Diptera, is part of the suborder Nematocera and is noted for its long, slender antennae. It is classified in the family Cecidomyiidae, commonly known as gall midges or itonidids. It includes numerous small fly species often associated with forming plant galls or feeding on plant tissues. Within this family, *C. maculipennis* falls under the subfamily Cecidomyiinae and the genus *Contarinia*, which includes several pest species affecting crops like sunflowers, cereals, and grasses. The taxonomic classification of *C. maculipennis* provides insight into its evolutionary relationships, aiding in understanding its morphological and ecological traits and facilitating the development of targeted management strategies. *C. maculipennis* Felt., has also been studied alongside *Contarinia lycopersici*, with advancements made in dichotomous keys to differentiate between the two (4).

Taxonomical and molecular confirmation of *C. Maculipennis*

The key taxonomical characters of adult female and male midges of *C. maculipennis* have been detailed by examining type specimens (4). The anatomical terminology for adult and larval stages has been thoroughly explored (7, 16). By examining this species' maternal and paternal specimens, researchers identified distinguishing antennal features that confirmed the specimens as *C. maculipennis*. They observed that this insect-infested the flower buds of *Dendrobium* spp. on Okinawa Island (7, 17). The taxonomic classification is illustrated in Fig. 1.

Adult sex outlook

Research on male and female *C. maculipennis* reveals that they are comparable in size, each measuring roughly 1.5 mm long, characterized by a black head and a yellowish-brown body (18). Females are distinguishable by the presence of a distinct ovipositor. Both sexes possess moniliform antennae adorned with whorls of hairs, though the antennal segments differ in females, the segments are long and cylindrical, whereas in males, they are short and spherical.

PCR-based confirmation

Cytochrome oxidase I gene-specific primers were used in PCR to amplify a specific region of mitochondrial DNA from the *C. maculipennis* Felt. species (19). Blossom midge larvae collected from *J. sambac* Linn. and *Momordica charantia* were utilized for DNA sequencing using these primers. The *C. maculipennis* specimen was confirmed to contain a 439 base pair fragment of the Cytochrome oxidase I gene (20, 21).

Morphological observation and molecular analysis

After confirmation, the 439 base pair DNA sequences were compared to those of *C. maculipennis* Felt. and its congeners using registered sequences in DNA databases. Additionally, sequence information for *C. maculipennis* was obtained from Okinawa. The existing morphology-based classification of gall midges (subfamily Cecidomyiinae) is predominantly validated by this group's first credible phylogenetic inference derived from multi-gene analyses (12).

Adult morphology

C. maculipennis are small flies, typically measuring about 2 -3 mm in length. They are reddish-brown or orange in color. As members of the Nematocera suborder, they possess long, thin antennae. Their slender bodies further contribute to their distinctive appearance (10).

Larval morphology

The larvae are legless maggots, generally measuring 2-3 mm in length, and exhibit coloration from pale yellow to white. They have a tapered body with a distinct head capsule (10). The duration of the first instar larvae ranged from 1.50 to 1.85 days, while the second instar larvae lasted from 2.30 to 3.30 days. The third instar larvae took between 3.60 and 4.70 days to develop. Upon reaching adulthood, the larvae can curl their bodies, flip themselves several centimeters, and pupate in the ground (10). The half-moon stage of infested buds with maggots is also shown in Fig. 4.

Fig. 4. Infested buds at half moon stage.

Pupal morphology

Pupae are located in the soil, exhibiting a reddish-brown coloration, and encased in a protective cocoon or puparium. The optimal conditions for pupation were damp or moist soil, although flooded or dry conditions can also have a significant impact. The adults emerged from the soil once the healthy pupae were partially exposed, with the pupal skins remaining visible (10).

Molecular analysis

DNA barcoding and phylogenetics

Specific gene regions, including cytochrome c oxidase I and 28S rRNA, were analyzed for species identification and to examine phylogenetic relationships. These regions help distinguish *C. maculipennis* from closely related or cryptic species complexes. They also offer valuable insights into the evolutionary history and biogeography of the species (10).

Population genetics and genomics

Genomic analyses help identify genetic variation both within and among populations. A key aspect of this research is identifying potential sources of infestation and migration patterns (12). These analyses also provide insights into population structure, gene flow, and adaptation to different environments or host plants.

Molecular diagnostics

Molecular markers, particularly PCR-based assays and DNA probes, have been developed to rapidly and accurately identify *C. maculipennis* (10). These tools are valuable for early detection and monitoring of infestations, and they also aid in differentiating other potential pests or non-target species.

Combining morphological observations with molecular analysis enables a more comprehensive understanding of the biology, taxonomy, and population dynamics of *C. maculipennis*. This knowledge is essential for developing effective management strategies, monitoring programs, and pest control measures in orchid production systems.

DNA analysis - polyphagous pest of orchids

The amplified Cytochrome oxidase I gene fragment in the mitochondria was 439 base pairs long. A bootstrap value of 100% was used to support the monophyly of the clade, including *C. maculipennis* Felt. from Thailand, Hawaii, and Okinawa. The sequences of *C. maculipennis* Felt. and the outgroup species, such as *C. okadai* and *T. japonensis*, showed distinct differences, with variations ranging from 35 to 46 base pairs. Additionally, the 146 base pairs of deduced amino acid residues displayed fluctuations, ranging from three (2.05%) to seven (4.79%). This highlights how DNA analysis can be informative in identifying the host plant ranges of cecidomyiid species that share similar morphology but are currently distinguished by differences in their host plants (22). Following this, a poll of 53 *C. maculipennis* larvae's mitochondrial DNA revealed the cytochrome oxidase subunit.

The analysis included the collection of flower buds from diverse host plants in Hawaii, Japan, and Thailand. It was found that the clade comprising *C. maculipennis* Felt. from Hawaii, Thailand, and Japan formed a monophyletic group (11). Specimens from Hawaii and Japan differed by only six base pairs (1.37%) and showed no sequential variation. Specimens from Thailand possessed three haplotypes, though these did not significantly differ from those from Hawaii and Japan. Among the 146 amino acid residues, most were identical across the population (23). Therefore, it can be concluded that *C. maculipennis* Felt. is a polyphagous species capable of growing on plants from at least seven distinct botanical families (4).

Biology of orchid blossom midge *C. Maculipennis*

A study on the biology of *C. maculipennis* in *Jasminum sambac* Linn. was conducted, revealing that the egg, larval, pupal, and total lifespan durations were 1-2 days, 4-5 days, 7-8 days, and 13-18 days, respectively (24). The developmental stages of the orchid blossom midge are detailed in Table 3 and 4. Female adults of *C. maculipennis* Felt. lay elongate, cylindrical eggs at night by piercing the petals of *J. sambac* Linn. in the inner 1-3 whorls of petals, with egg clusters ranging from 10 to 14 (18). The eggs hatch within 1-2 days, and the larval stage lasts 4-5 days. Pupation occurs in the top layer of soil within a thin, papery white pupal case. The adults emerge after 7-8 days and live for 1-3 days. The entire developmental cycle takes 13-18 days. The egg, larval, pupal, and adult longevity are 1.67 ± 0.39, 8.50 ± 0.89, 9.37 ± 0.70 days (for males), and 3.0 ± 0.55 days (for females), respectively, with a total life cycle duration of 21.45 ± 3.60 days. Each female has a fecundity of 8.73 ± 0.80 eggs (25). Morphometric studies of the blossom midge at various life stages have been conducted, and the results are summarized below. The life cycle of the orchid blossom midge, with a duration of approximately 3 to 4 weeks (25, 26).

Table 3. Measurement of different stages of orchid blossom midge (10)

Stage	Width (mm)	Length (mm)
Egg	0.06 ±0.01	0.26 ±0.04
Larva	0.40±0.05	1.69 ±0.11
Pupa	0.31±0.05	1.63±0.06

Table 4. Life stages of blossom midge (9)

Life stages of midge	Duration of different life stages of *C. maculipennis* in four *Jasminum* species, mean ± SD (in days)			
	J. sambac	*J. auriculatum*	*J. grandiflorum*	*J. nitidum*
Egg period	1.30 ± 0.483	1.20 ± 0.421	1.10 ± 0.31	1.10 ± 0.31
Larval period	4.40 ± 0.737	4.10 ± 0.42	4.10 ± 0.32	3.90 ± 0.32
Pupal period	7.50 ± 0.674	7.30 ± 0.52	7.20 ± 0.42	7.00 ± 0.00
Adult period	2.03 ± 0.874	1.90 ± 0.88	1.80 ± 0.79	1.90 ± 0.57
Total life cycle	15.20 ± 14.24	14.3 ± 1.004	13.3 ± 1.441	13.40 ± 1.07

Ecology

The ecology of the midge focuses on understanding how each life stage interacts with the floral environment. The blossom midge on orchids reproduced year-round in Hawaii, with a total life cycle from egg to adult lasting approximately 21–28 days. The rearing of the larval stage is shown in Fig. 5.

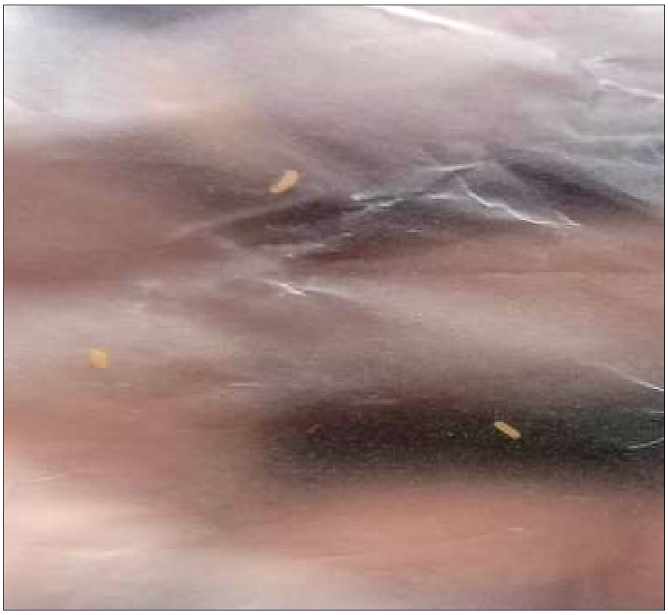

Fig. 5. Larval image on rearing.

Eggs

The newly hatched maggots entered the bud and fed on fluids from the damaged plant tissue. The eggs, which were elongated and cylindrical, were laid in groups of 10-13 on the inner whorls of the petals during dusk. This behavior was well-documented in studies on blossom midge egg crowds (10). The white or cream-colored eggs hatched into maggots within one to two days. The average egg duration was 1.3, 1.2, 1.1, and 1.1 days for *J. sambac*, *J. auriculatum*, *J. grandiflorum*, and *J. nitidum*, respectively (27).

Maggot

The percent discoloured buds caused by the maggots of *C. maculipennis* ranged from 11.24 to 23.81 (28). The maggots were observed within the buds at the base of the corolla, and the attack caused swelling at the base of the bud (29). The buds became discolored and dropped in large numbers. The newly hatched maggots are white, turning yellow with a pink tinge as they age before pupating in the soil. The adults have bright orange-colored abdomens. An ecological inspection of *C. maculipennis* Felt. was conducted on hibiscus hosts, revealing a life cycle of approximately 3 to 4 weeks (30). The maggots can flip several inches into the air to escape the bloom. The larval phase endures for four to five days. The average duration of the larval stage in *J. sambac*, *J. auriculatum*, *J. grandiflorum*, and *J. nitidum* was found to be 4.4, 4.2, 4.1, and 3.9 days, respectively (27).

Pupae

The pupae live in moist soil, changing color from yellowish -white to brown as they develop. They then move closer to the soil surface, where they will emerge as adults 14 to 21 days after penetrating the soil. A study on the biology of the blossom midge was conducted in orchids, revealing that, except for the adult stage, the larvae and pupae are sheltered within the buds and soil, respectively (12). The total developmental period ranged from approximately 21 to 28 days. The pupal stage lasted for 7 to 8 days. The average pupal duration was 7.5, 7.3, 7.2, and 7.0 days in *J. sambac*, *J. auriculatum*, *J. grandiflorum*, and *J. nitidum*, respectively (27).

Adult

The adults of *C. maculipennis* Felt. are small flies with long, slender legs, an orange-colored abdomen, and transparent wings with a few veins (29). They typically live for one to two days, with rare cases extending up to three days. The average adult lifespan for *J. sambac*, *J. auriculatum*, *J. grandiflorum*, and *J. nitidum* was 2.0, 1.9, 1.8, and 1.9 days, respectively. The duration from egg to adult stage was 15.4, 14.3, 13.3, and 13.4 days for *J. sambac*, *J. auriculatum*, *J. grandiflorum*, and *J. nitidum*, respectively (27). The total life cycle from egg to adult lasting approximately 21–28 days (29).

Adult longevity and fecundity

Recently emerged, unexposed adults were used in experiments to determine adult longevity. The newly emerged adults were placed in glass bottles with fresh flower buds and a small amount of honey diluted and supplemented with a vitamin solution. Their lifespan was carefully monitored and recorded every six to eight hours. Two adult male and female insects were released into separate glass bottles containing twenty fresh buds of *Dendrobium* spp., where they were observed for up to seven days. The flower buds were replaced every 24 hours. Fertility was assessed by counting the total number of eggs laid by each female insect (11). The data on adult longevity is shown in Table 5.

Table 5 . Adult longevity of blossom midge, *C. maculipennis* on orchids (10)

Months	Adult period		Temperture	Relative humidity
	Female	Male		
November-December	3.40 ± 0.5	1.90 ± 0.5	25.9	68.3
January-February	3.00 ± 0.6	1.40 ± 0.5	27.3	71.6
March-April	2.70 ± 0.4	1.40 ± 0.5	32.3	77.4

Impact

The *Dendrobium* midge has significantly impacted orchid farmers, particularly those with large cultivation areas. Infested blossom buds remain closed, disfigured, and discolored. The petals show visible symptoms even when slightly damaged buds open, rendering the plants unsellable. Infestations have been reported in Hawaii, Japan, and Fiji. Some growers have stopped cultivating orchids in Japan, and the remaining farmers have increased their pesticide applications (6). For example, on Okinawa Island, the frequency of pesticide applications has doubled since the introduction of the *Dendrobium* midge. In Hawaii, infestation levels are often very high, making them difficult to control (11). While the effects on other hosts are still unresolved, the midge was initially considered a nuisance in Hawaii before attacks on *Dendrobium* species were observed. No damage has been reported on other hosts in fields or greenhouses, although bitter gourd has been affected in Japan (5). However, these volatiles of these orchids and jasmines can be used against midges as an attractant with a maximum merit (30). Also, midge prone vegetables like egg plants and various other vegetables can be raised as a trap crop (31).

Midge behaviour

Adults of blossom midges are nocturnal, a behavior recently observed on the *Ryncho* orchid farm near Thuckkalay, India (25).

Seasonal incidence of blossom midge, C. maculipennis

The incidence of *C. maculipennis* in Hawaii led to a severe outbreak on various host plants, with infestations reported as particularly intense. However, the incidence was sporadic on agave, pepper, tomato, and eggplant, occurring mainly in September, October, and November (32). Most infestations, often attributed to fruit midge damage, were observed during the spring and early summer months, particularly in May and June. Extremely heavy infestations were reported on hibiscus and *J. sambac* in January (27). The first observation of *C. maculipennis* in India occurred in Andhra Pradesh on *J. sambac* (32, 33). Severe infestations on *Jasminum auriculatum* were recorded in July and August in the Coimbatore district of Tamil Nadu (18).

The impact of *C. maculipennis* on jasmine was significant from June 2000 to May 2001, with the highest damage (24.60%) occurring in October 2000 (34). The outbreak of *C. maculipennis* on jasmine began in the first fortnight of April and continued until the second fortnight of December (31). The highest infestation rate (58.40%) was recorded in the first fortnight of December, while the lowest damage (4.74%) occurred in the second fortnight of August.

$$\text{Blossom midge infestation} = \frac{\text{Number of discoloured buds}}{\text{Total number of buds}} \times 100$$

The equation represents the Blossom midge infestation index, a standardized method used to calculate the percentage of orchid buds damaged by *C. maculipennis* in a given sample or population (28). The formula divides the number of discolored buds (indicating visible midge damage) by the total number of buds on the orchid plant. Pretreatment observations of blossom midge incidence were made one day before spraying. Post-treatment counts were taken on the first, third, seventh, and fourteenth days following the start of treatment (28).

C. maculipennis on hibiscus is present year-round, although populations tend to be higher during the warmer months (30). The infestation of *C. maculipennis* on jasmine was significantly higher (22.33%) during the first fortnight of March and lower (10.33% and 10.48%) during the first and second fortnights of June (34, 35). Similarly, the incidence began to increase from November onwards, reaching a peak during the second fortnight of March to the first half of April, after which the incidence showed a declining trend (34, 35).

Blossom midge towards Tamil Nadu

The incidence of jasmine blossom midge was observed across all surveyed districts of Tamil Nadu, with varying intensity (10). Investigating pest population dynamics is crucial for developing season-based integrated pest management strategies and forecasting the severity of pest infestations (36). The highest incidence of these pests was recorded in Madurai district, with 34.27% of midges, followed by Tirunelveli district, which recorded a 33.19% midge incidence (22).

Resistant host breeds

It is likely that some orchid species and species from various host plant families are more susceptible to the midge than *Dendrobium* spp. and *Vanda* species. Cattleya orchids from the Rynco Orchids farm also exhibited a certain degree of resistance to midge fly attacks.

Lunar phases on emergence of adult midges

The swarming behavior of some *Chironomus* spp. and *Chaoborus* species shortly after a new moon and the influence of lunar phases on the biology of these species has been studied (37). The development of *Chironomus brevibucca* Kief. closely followed moon phases, with adults emerging in greater numbers after a full moon (38). An analysis of 10 years of data on adult emergence revealed that 80% of the midge population emerged within three days of a new or full moon. The first generation coincided with the lunar periodicity, while the second generation emerged 43.4 days (1.5 lunar cycles) after the first emergence (39, 40).

Additionally, the matured rice gall midge, *Orseolia oryzae* Wood-Mason, showed a strong attraction to light traps, with the highest numbers recorded during a full moon (39, 40). A similar approach was applied for midge control, yielding positive results to some extent. Fig. 4 shows the half-moon infestation stage.

Natural enemies on blossom midge, C. maculipennis

Although there has been ongoing research on predators and parasitoids, *Systasis* spp. has been reported to exhibit predatory behavior towards the maggots of *Contarinia* spp. in Tamil Nadu (41, 42). Hymenopteran parasitoids such as *Microdontomerus* spp. (Torymidae), *Elasmus anticles* Walker (Elasmidae), *Tetrastichus* spp., *T. gala* Walker (Eulophidae), and *Bracon* spp. (Braconidae) have also been recorded as parasitoids of *C. maculipennis* (18).

Management of blossom midge

Botanical oils

Olfactometer tests indicated that DEET (N,N-diethyl-meta-toluamide) (1 µg/µL) was the most effective synthetic repellent, but filter paper landing bioassays revealed that plant-based oils performed better. DEET, currently the industry standard for insect repellents, was no more effective than light traps fitted with polyester mesh impregnated with a 10% and 25% concentration of a combination of octanoic, decanoic, and nonanoic fatty acids. These traps captured 2.2 to 3.6 times fewer midges compared to control traps. Lemon eucalyptus oil emerged as the best plant -based repellent. A study showed that DEET and the combination of organic fatty acids are more effective and have a longer half-life despite claims that they are safe substitutes (43).

Among various plant-based products tested, neem oil at 500 mL/ha reduced the incidence of blossom midge on jasmine (43, 44). Palmarosa oil (0.1%) and jatropha oil (0.5%) were also effective in lowering bud damage caused by *C. maculipennis* (42). A comprehensive study on palmarosa oil at 0.1% concentration showed it to be one of the most effective botanicals in reducing *C. maculipennis* incidence, comparable to jatropha oil at 0.5% (30). However, plants sprayed with azadirachtin 3000 ppm at 1 mL/L had fewer discolored flower buds. Neem and pungam oil formulations were also effective against *C. maculipennis* under *in vitro* conditions. Several other liquid formulations also contributed to the study of the behavior of midges toward attractants and deterrents (10). In Table 6, the maximum advantage of botanical oils is mentioned in comparison with chemicals.

Cultural control of blossom midge

A unique tomato variety has been found to have a flower structure that facilitates easier oviposition by blossom midges, making it more susceptible to infestation. In contrast, host plant varieties with petals that remain tightly closed until the bud is almost fully opened may be less vulnerable to these pests. A key cultural practice involves eliminating and disposing of fallen, infested buds still attached to the plant. Flower buds containing midge larvae should be placed in a sealed container or plastic bag to prevent maggots from escaping. Due to significant climatic fluctuations, orchid growers have adapted by shifting plants to shaded areas or using greenhouses. Moreover, microorganisms significantly diminish crop resistance in certain areas, prompting the increased use of greenhouse settings (45).

Light traps

Since orchid blossom midges are most active at night, their nocturnal behavior significantly influences control strategies. Light traps can help manage the population by exploiting the midge's attraction to light. These traps attract adult midges, capturing or killing them. However, light traps have limitations as they only target adults and do not affect the larvae responsible for the most damage by feeding on orchid blossoms. Although light traps effectively reduce adult populations in certain environments (46), their efficacy as a control method may be reduced if they attract non-target species. Combining light traps with other strategies, such as biological controls or botanical oils, can enhance effectiveness.

Biological control

The adults of blossom midges are vulnerable to common predators such as ants and web-spinning spiders, with ants potentially feeding on the underground pupae. Experiments aimed at achieving the right skewness were conducted using parasitoids and predators to maintain their predatory effectiveness on blossom midges. Evaluating the efficacy of a biological control agent against a pest species involves two key steps (43). First, it is necessary to demonstrate that the agents are sufficiently harmful to the target organism in the release areas. This can include effects such as reduced longevity, smaller maximum size, delayed reproduction, or stunted growth, which could alter the dynamics of the pest population. These parameters are typically measured in carefully controlled experimental settings by comparing the development of target plants with and without the presence of the agents. The second step is to determine if the damage caused by the agents results in practical benefits, such as slower spread rates, lower pest densities, or reduced biomass in infested areas (43). The association between the midge realeased components which is an allelopathic effect in the plant and the environmental impacts over the plant and the component can be studied well for the management aspects (47).

Table 6. Comparison table between botanical oils and chemical treatments

Factor	Botanical oils	Chemical treatments
Cost-effectiveness	Generally, it is more expensive upfront due to organic sourcing. However, they lower long-term costs as they may be reusable or mixed with other eco-friendly approaches.	Often cheaper initially, especially synthetic insecticides. Higher long-term costs due to the potential for resistance and the need for frequent reapplications.
Environmental impact	Low environmental impact. Biodegradable and often non-toxic to beneficial insects, birds, and aquatic life. Sustainable, eco-friendly option.	Higher environmental impact. Potential toxicity to non-target species. It can lead to soil and water contamination.
Ease of application	It is generally easy to apply but requires precision to cover all affected areas effectively. It may need more frequent application, especially after rain.	It is often easier to apply with standardized dosages. It requires fewer applications, but overuse can lead to pest resistance.

Entomopathogenic microbial

The excellent trend with the entomopathogenic fungi *B. bassiana* at 1x(10^8) cfu mg^-1 and *Lecanicillium lecanii* at 1x(10^8) cfu mg^-1 were recorded 80.1% and 71.2% mortality, respectively (48). Foliar applications of synthetic insecticides have effectively reduced damage caused by *C. nasturtii* on swede plants under laboratory and field conditions (49, 50). In trials, significant larval mortality was observed during the pre-and post-oviposition phases when using spinosad and pyrethrin organic formulations. These treatments were highly effective, achieving more than twice the mortality rate of azadirachtin and *Beauveria bassiana* in pre- and 1.5 times higher mortality in post-oviposition trials. The mortality rates caused by spinosad (76% and 78%) and pyrethrin (56% and 62%) showed more consistency between pre- and post-oviposition trials than those caused by azadirachtin (32% and 47%) and *B. bassiana* (32% and 44%). This suggests that spinosad and pyrethrin may have a longer residual activity on foliage, as they do not degrade as quickly as the latter treatments (50, 51). *Metarhizium anisopliae* at 1x(10^8) cfu mg^-1 also resulted in 82.3% mortality in *C. maculipennis* after 144 hours of treatment under *in vitro* conditions (10). Similarly, the entomopathogenic fungi *B. bassiana* at 1x(10^8) cfu mg^-1 and *Lecanicillium lecanii* at 1x(10^8) cfu mg^-1 recorded 80.1% and 71.2% mortality, respectively (48).

In the field testing of potential microbial against *C. maculipennis*, the jasmine blossom midge, profenophos at 50 EC (2 mL/liter) was found to be effective in controlling midge damage to orchid buds, achieving an 81.75% reduction compared to the control (10). Additionally, the green muscardine fungus demonstrated control over the blossom midge, with a 79.92% reduction in damage compared to the control (48).

Chemical control

Certain favorable chemical formulations were sprayed on the leaves to kill the larvae and mixed into the soil to target the pupal stages. Since the pupal cases of the orchid blossom midge are buried in the soil and the live maggots are protected within the buds, only the adult stage of the insect is vulnerable to contact insecticides. The lack of success in systemic insecticide trials on *Dendrobium* spp. may be attributed to the inability of the chemical to penetrate the flower buds and eliminate the maggots.

Vigor of insecticides in comparison with other dipteran midge flies

Twenty insecticides from twelve different classes were found effective against *C. nasturtii* through foliar application, soil drenching, or seed dressing (50). Systemic insecticides are those that spread throughout the entire plant from the site of application can be come along with the crop rotation and various cultural turn overs (51). Following this, acetamiprid proved more effective against adult midges than larvae. Soil drenching with acetamiprid, imidacloprid, and thiamethoxam showed a 100% reduction of larvae even after 7 weeks, while seed dressing with clothianidin and thiamethoxam effectively controlled *C. nasturtii* (52, 53). Flubendiamide 39.35 SC (4.64%) and chlorantraniliprole 18.5 SC (4.95%) were the most effective treatments, recording the lowest infestation rates, with a reduction in invasion of more than 84% compared to untreated plants, when considering both the spray rounds and the observation period (52).

Insecticides such as acephate, cyhalothrin, chlorpyrifos, and methomyl were effective against the larvae of *C. nasturtii* (53). Aerial application of esfenvalerate significantly reduced the populations of *C. origonensis* and *Megastigmus spermotrophus* in mature seed orchards of *Pseudotsuga menziesii* in Oregon (54). The mango blossom midge (*Erosomyia indica*) was managed by spraying fenitrothion (0.05%), dimethoate (0.045%), or diazinon (0.04%) at the bud bursting stage of the inflorescence (54, 55). Additionally, applying bifenthrin 25 EC at 70 mL/100 L of water, at an interval of 7-10 days during the flowering season up to the pinhead stage of the fruit, effectively controlled the blossom midge (55).

Insecticides

Various insecticides have been evaluated for controlling midges, and it was concluded that quinalphos (0.5% and 0.1%) and monocrotophos (0.5% and 0.1%) were highly effective in reducing infestation by the blossom midge on jasmine (52). Soil application of carbofuran 3G was also significantly effective in controlling purple discoloration (17.49%) and drying flower buds in *Jasminum sambac* (40). Monocrotophos at 0.1% and fenvalerate at 0.2% were superior in reducing the purple discoloration of flower buds caused by *C. maculipennis* (18).

Insecticides applied through soil drenching were particularly effective against the pupal stage of the orchid blossom midge (12). However, systemic insecticides proved ineffective against *C. maculipennis* due to their inability to translocate to the flower buds on orchids. The foliar application of flubendiamide, chlorantraniliprole, and triazophos three times resulted in a 100% reduction of the *C. maculipennis* larval population (52). Post-oviposition foliar applications of λ-cyhalothrin and spinosad, along with a silicone–polyether copolymer adjuvant, caused larval mortality of 97% and 92%, respectively, compared to a mean mortality of 56% for organic pyrethrin and 78% for organic spinosad (50). Applying thiacloprid 240 SC at 0.6 mL and flubendiamide 480 SC at 0.5 mL against *C. maculipennis* recorded cumulative mortalities of 92.83% and 87.8%, respectively (10).

Effective insecticides

Among organophosphates, chlorpyrifos is commonly used as a foliar spray or seed treatment to control *C. maculipennis* Felt. Phosmet has also effectively managed sunflower seed midge when applied during the crop's susceptible stage (51). Among pyrethroids, lambda-cyhalothrin is used in foliar applications and has proven effective in reducing midge populations. Bifenthrin is also applied as a foliar spray or seed treatment for midge control (52). Additionally, zeta-cypermethrin has been evaluated and shown to be effective against *C. maculipennis* Felt. when used during peak adult emergence (52).

Among neonicotinoids, imidacloprid is used as a seed treatment or foliar spray to manage sunflower seed midge infestations. Thiamethoxam is also applied as a seed treatment or foliar spray for midge control. Spinosad, a naturally derived insecticide, has demonstrated efficacy against *C. maculipennis* Felt. when used during the crop's susceptible stage (52).

Insect growth regulators (IGRs), such as novaluron, have been evaluated for their potential in controlling sunflower seed midge populations. It is important to note that the effectiveness of these insecticides can vary depending on factors such as application timing, insecticide resistance, and environmental conditions (6). Moreover, insecticide use should be part of an integrated pest management (IPM) strategy, including cultural practices, biological control, and monitoring techniques. Proper selection, rotation, and application of insecticides are essential to ensure effective control of *C. maculipennis* Felt., while minimizing potential risks to non-target organisms and the environment. Local guidelines and regulations should be followed when using insecticides for sunflower seed midge management.

Knockdown rate using translaminar chemicals

Insecticides known as translaminars, which move from the top lamina to the lower surface where they are applied, may be able to enter the bud and target the maggots. Avid, exhibiting translaminar activity, can infiltrate the buds to target the larvae.

Future directions for IPM

By identifying critical infestation thresholds, the quantitative data from the Blossom Midge Infestation Index provides valuable guidance to orchid growers in adjusting their cultivation practices. For instance, growers can modify greenhouse ventilation, humidity control, and irrigation schedules based on observed infestation patterns, as *C. maculipennis* requires specific environmental conditions for reproduction. Timing pesticide applications to target the midge's most vulnerable life stages can further enhance current management strategies (6). The index helps growers determine the optimal times for spraying by identifying discolored buds early, particularly during the crucial two- to three-day adult emergence period. Additionally, decisions regarding the removal and destruction of infested buds—before larvae drop into the soil to pupate—are informed by this data. These insights may also prove beneficial for managing other damaging pests (9).

Conclusion

This study addresses the challenges of controlling the orchid blossom midge, *C. maculipennis* Felt. Despite various methods being tested to manage this pest, the midge's high fecundity and efficiency pose significant barriers to the healthy growth of orchid flowers. While some strategies have provided valuable insights into controlling midge populations to some extent, further research is needed to refine these approaches for future success and to prevent neglecting midge control. The findings presented in this study cover the midge's life cycle, biology, the efficacy of certain botanical treatments, and other management strategies. Additional research is expected to identify threshold levels, improve cut flower cultivation, and offer effective control measures for orchid blossom midge management in orchid farming.

Acknowledgements

Tamil Nadu Agricultural University, Coimbatore is acknowledged with gratitude by the authors, for providing the platform to publish this article. Thanks to the Department of Entomology, V O C Agricultural College and Research Institute, Killikulam, for facilitating the work. We also express our heartfelt thanks to Mr. Ramakrishnan, Rynco Orchids farm, and Thuckkalay for his support in completing the article.

Authors' contributions

All the authors have contributed equally to data contribution, writing the original manuscript draft, editing, and reviewing.

Compliance with ethical standards

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

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

While preparing this manuscript, the authors used Grammarly to improve the language and readability. After using this tool/service, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

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