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Identification and characterization of volatile attractants for the flower thrips, (*Frankliniella intonsa*), from the host *Hemerocallis citrina*

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Introduction: Flower thrips (*Frankliniella intonsa* Trybom) is a widespread pest threatening vegetables globally, with severe infestations in daylily (*Hemerocallis citrina* Baroni) planting regions in China.

Methods: Volatile compounds from *H. citrina* at leafing, bolting, and flowering stages were identified via gas chromatography-mass spectrometry (GC-MS). Behavioral assays using a Y-tube olfactometer and field trapping experiments were conducted to evaluate the attractiveness of key volatiles.

Results: A total of 60 volatile compounds were detected, with aromatic compounds (especially sesquiterpenes) prominent during peak thrip infestations. E- β -farnesene, nerol, and linalool attracted thrips at 100 mg/mL and 10 mg/mL in behavioral assays. Field tests showed nerol (160.0 ± 98.6 thrips/trap) and a mixed-component lure (182.5 ± 83.7 thrips/trap) had superior attractiveness; yellow sticky cards outperformed other colors. The three active components synergistically increased thrip capture on all card types.

Discussion: These findings provide a theoretical foundation for environmentally friendly control strategies of flower thrips using host plant volatiles.

KEYWORDS

host plant volatile, olfactory response, pest management, aggregation, thrip, *Frankliniella intonsa*, *Hemerocallis citrina*, volatile attractant

1 Introduction

Flower thrips (*Frankliniella intonsa* Trybom) are polyphagous pests that infest many crops, including solanaceous fruits, legumes, melons, and cruciferous vegetables (Jones, 2005). In China and other regions, this pest causes significant damage at both the adult and nymph stages, feeding on floral organs and petals, leading to severe whitening and yield

loss. Additionally, *F. intonsa* is a vector for various plant viruses, such as the tomato spotted wilt virus (TSMV), which exacerbates crop damage (Inoue et al., 2004; Jones, 2005). With a broad host range and high reproductive capacity, they pose a significant threat to various plants (Lim et al., 2013; Yang et al., 2024).

Daylily (*Hemerocallis citrina* Baroni), a perennial herbaceous plant of the Asphodelaceae family, has significant economic, nutritional and ornamental value, particularly in East Asia (Zhao et al., 2024). Its edible, medicinal and ornamental properties make it a vital crop in China and Korea (Wang et al., 2024). However, in recent years, China has faced substantial outbreaks of flower thrips, which severely impacted daylily cultivation (Zhang D, et al., 2021). The primary damage occurs when thrips feed on the undersides of leaves, flower stalks and buds, leading to a decrease in the quality and yield of daylily (Wu et al., 2018). Current control methods rely heavily on chemical insecticides, which, while effective, accelerate pesticide resistance and pose health risks to humans (Lim et al., 2013; Zhao et al., 2016). Consequently, there is an urgent need for sustainable pest management strategies.

Host plant volatiles are crucial in thrip aggregation and feeding behavior. Herbivorous insects often select host plants based on specific volatile signals, which can exhibit strong attractant properties (Bruce and Pickett, 2011; Cao et al., 2019). Previous studies have demonstrated the attraction effects of plant volatiles on various pests, such as the oriental fruit moth (*Cydia molesta*) to peach volatiles (Lu and Qiao, 2020), β -caryophyllene and limonene, to *Bactrocera dorsalis* (Liu et al., 2024; Ranaweera and Hee, 2024), whiteflies to volatiles from eggplants and tomatoes (Darshanee et al., 2017). The research on thrips and host plant volatiles primarily focuses on the following aspects. Volatile organic compounds emitted by host plants, including benzenoids, pyridines, terpenes, and esters, play a crucial role in modulating thrips behavior. For instance, benzenoid compounds such as benzaldehyde, cinnamaldehyde, eugenol, salicylaldehyde, 4-ethylbenzaldehyde, 2-acetophenonyl ethyl ester, eugenol phenol and geranyl bromide have demonstrated significant attractant effects on *Frankliniella occidentalis*, *Thrips tabaci*, *Thrips obscurus*, and *F. intonsa* (Qu et al., 2024; Han et al., 2015; Koschier, 2008; Kogel and Koschier, 2002; Avellaneda et al., 2021; Zhang Z, et al., 2021). Methyl isonicotinate in pyridine compounds exhibits attractive activity not only toward *F. occidentalis*, *T. tabaci*, and *T. obscurus*, but also against *Megalurothrips sjostedti*, *Thrips imaginis* and *Thrips major*. It has been successfully developed into commercial thrips attractants, including Lurem-TR (Koppert Biological Systems) and P178 (Chem Tica) (Nielsen et al., 2021; Andrews, 2011). Terpene compounds such as linalool, nerol and β -caryophyllene exhibit attractive activity toward *F. occidentalis*, *Megalurothrips usitatus* and *F. intonsa* (Cao et al., 2020; Avellaneda et al., 2021; Li et al., 2021). Additionally, ethyl isovalerate, α -pinene and geranial show attractive effects on *Thrips palmi* (Li et al., 2021; Qu et al., 2024).

Flower thrips (*F. intonsa*) are important pollinating insect. Preliminary field investigations revealed that the flower thrips primarily damage buds and flowers in daylily plants. The infestation rate of infected plants was 100% during the flowering period. In severe cases, more than 50 flower thrips per flower were

observed. Consequently, does the aggregation and damage of *F. intonsa* in daylily flowers depend on the attraction of host flower-specific volatile substances? This study identified and analyzed the volatile components that specifically appeared during the pest infestation period of flower thrips, and screened for volatile substances with attractive activity toward flower thrips. The research findings not only enhance the understanding of the interaction between thrips and their host plants, but also establish a theoretical foundation for developing more precise and effective technologies for regulating thrip behavior.

2 Materials and methods

2.1 Insects and field population dynamics

The flower thrips were collected from Daylily plants grown in the Yunzhong District, Datong, China (longitude 113°32', latitude 40°30'), and used to establish a laboratory colony. The colony had been continuously reared, for over two generations, on kidney bean (*Phaseolus vulgaris* Linn) in insect collection tube (85mm $\times$ 25mm). They were kept in a controlled environment chamber (PRX-450C, Beijing Haitian Youcheng Technology Co., Ltd., China) under a 16:8 light-dark cycle, at $25 \pm 1^\circ\text{C}$, and $60 \pm 5\%$ relative humidity.

To assess the population dynamics of *F. intonsa* on *H. citrina*, weekly monitoring was conducted in the same daylily field in Yunzhong District, Datong, China, from early June to October 2023. This period spanned the entire phenological cycle of daylily, encompassing vegetative growth, flowering, and senescence stages. Thirty randomly selected daylily plants were examined each week. Thrips were sampled using a fine brush and aspirator, then preserved in 70% ethanol. Identification and counting were performed under a stereomicroscope (Olympus SZX16, Olympus). Thrips were counted on three distinct parts of *H. citrina* plant: leaves, stems, and floral organs, to assess their distribution. The proportion of thrips on each plant part (leaves, stems, floral organs) was calculated as the mean percentage of the total thrips population per plan.

2.2 Chemicals

The plant odorants β -Pinene ($\geq 98\%$), Linalool ($\geq 98\%$), Nerol ($\geq 97\%$) were purchased from Shanghai Aladdin Biochemical Technology Co. (Shanghai, China), (E)- β -Farnesene ($\geq 98\%$) was purchased from Shanghai Bide Pharmaceutical Technology Co. (Shanghai, China), β -ocimene ($\geq 98\%$) and α -Curcumene ($\geq 98\%$) were purchased from J&K Scientific Ltd.(Beijing, China). All chemicals were diluted with n-hexane (Sigma-Aldrich), and the chemical concentrations for the dose responses were 100, 10, 1, and 0.1 $\mu\text{g}/\mu\text{L}$.

2.3 Volatile extraction and identification

Volatiles were extracted from *H. citrina* seedlings, buds, and flowers using dynamic headspace sampling. Plant tissues (leaves,

stems, flowers) were carefully excised using sterile scalpels to minimize mechanical damage and collected within 5 minutes to reduce wounding-induced volatile emissions. Plant tissues (120g) were enclosed in glass jar (ϕ 20cm, H:28cm) and connected via polytetrafluoroethylene tubing to stainless steel adsorption tubes packed with Tenax-TA adsorbent (60/80 mesh, Sigma-Aldrich, St. Louis, MO, USA). Thrips exhibited distinct olfactory responses to six volatile compounds emitted by daylily. E- β -farnesene, nerol, and linalool demonstrated significant attractiveness to thrips, whereas α -curcumene, β -pinene, and β -ocimene elicited no discernible olfactory reaction. Notably, nerol at 100 μ g/ μ L induced the highest attraction rate, reaching 88%, significantly outperforming the other tested volatiles (Figure 3). Purified air, passed through a drying tower and activated carbon column, was pumped into the sampling bag at a flow rate of 500 mL/min using an atmospheric sampling instrument (TY-08A, Tianyu Instrument Co., Ltd., China). Each sample was collected for 8 hours, with three biological replicates per tissue type. The attraction of thrips to the same compound varies significantly across different concentrations. *F. intonsa* exhibits a highly significant preference for higher concentrations of nerol (100 μ g/ μ L and 10 μ g/ μ L) and linalool (10 μ g/ μ L), with responses markedly greater than those of the control group. Additionally, the species shows a significantly stronger attraction to a lower concentration of E- β -farnesene (1 μ g/ μ L) compared to the control (Figure 4).

After collection, the adsorption tubes were thermally desorption with a TD-30 (Shimadzu, Kyoto, Japan), using the following settings for tube desorption: 3 min at 250°C, the cold trap collection temperature is -10°C for 3 minutes; the cold trap desorption temperature is 280°C, splitless flow of 20ml/min into GC-MS (QP-2020NX, Shimadzu, Kyoto, Japan). Volatiles were separated under the following conditions: helium (99.999% purity) served as the carrier gas with pulsed splitless injection port temperature of 270°C, the oven temperature program began at 45°C (held for 2 minutes), increasing at 6°C/min to 240°C, and then held for 5 minutes, totaling 40 minutes. A Rtx-5 MS capillary column (30m $\times$ 0.25 mm $\times$ 0.25 μ m, Restek Corporation, US) was used for separation. For mass spectrometry, the interface and ion source temperatures were set at 280°C, electron impact (EI) ionization was applied at 70eV, and spectra were acquired in full scan mode over a mass range of 45–600 AMU. The retention indices of compounds were calculated relative to n-alkane standards (C8-18) and compared with NIST20 MS library, corresponding to retention indices on <https://webbook.nist.gov/>, the relative contents of these compounds were calculated from their peak areas.

2.4 Host plant volatile activity assay

The olfactory response of flower thrips to daylily volatile compounds: (E)- β -Farnesene, Nerol, Linalool, α -Curcumene, β -Pinene, and β -ocimene was tested using a Y-tube olfactometer (10 cm arms, 22 cm base, 2.9 cm diameter, 60°angle between arms), covered with a cardboard box (50 cm $\times$ 48 cm $\times$ 33 cm) that was opened at the top. Among all tested treatments, the combination of

the yellow sticky trap and the mixed-component lure achieved the highest capture efficacy, numbered 203.2 ± 48.8 thrips (Figure 5, ANOVA, $df = 2$, $F = 63.0$, $P < 0.05$). The olfactometer arena was illuminated from above by a 40 lux light source. The thrips used in the experiment were of the same generation reared on green bean pods. After 2-hour starvation, 30 thrips were individually introduced into the Y-tube using a soft brush. A thrip was considered to have made a choice when it crossed 2/3 of one arm within 5 min. Otherwise, the thrips was considered to be non-responding. All bio-assays were conducted between 8:00 am and 10:00 am in a room under 26°C, 65% RH, during which time thrips exhibited active behavior. Airflow was maintained at 250 mL/min, and arms were swapped after each trial to eliminate potential bias. For the treatment arm, 10 μ L of test solution was applied to a piece of Whatman[®] filter paper (5 cm in length and 5 mm in width). For the control arm, filter paper containing 10 μ L n-hexane was provided.

2.5 Field testing

Field tests were conducted in a daylily field in Yunzhou District, Datong, China (40°30' N, 113°32' E), from 11 to 14 July 2023. Volatile compounds, including (E)- β -Farnesene, Nerol, Linalool, α -Curcumene, β -Pinene, and β -ocimene, were diluted to 10 μ g/ μ L and 100 μ L of the solution were loaded onto bell-shaped green rubber septa (ϕ 0.7 cm, Qinghe Dingye Rubber and Plastic Products Co., Hebei, China) as bait. The bait was suspended at the center of yellow sticky traps.

To further verify the synergistic effect of the three active components on sticky insect boards commonly used in production, the solution (with a ratio of (E)- β -farnesene: nerol: linalool = 4.8:21.3:73.9, consistent with their proportion in *H. annuus* flowers) was prepared following the same method described above, and then suspended at the center of yellow, blue, and yellow-black striped sticky traps (Caoxian Agricultural Production Materials Co., Ltd., Shandong, China). The sticky insect boards of the three colors were placed randomly.

Wooden stakes 1.2 m in height were used to deploy sticky traps. Sticky traps were hung 1m in height and 5m apart along daylily rows. The total thrips captured on each trap were counted, with 80 replicates for each attractant. The average number of thrips per card, including both sides, were counted every three days, with 80 replicates for volatile components and 20 replicates for different color sticky cards.

2.6 Data analysis

Differences in thrips distribution among plant parts and the efficacy of different volatile compound combinations in attracting flower thrips under field conditions were analyzed using one-way analysis of variance (ANOVA). For the behavioral results, the proportion of thrips which chose the treatment and control was calculated. Chi-squared tests were used to determined significant

differences. The thrip that did not make a definitive choice were not used in the statistical analysis.

3 Result

3.1 Population dynamics of flower thrips

Flower thrips were first observed in early June in Datong, China, coinciding with the onset of the daylily growing season. As the daylily progressed through its developmental stages, thrips migrated to the stems by late June. With the emergence of flower buds from late June to early July, thrips shifted their feeding preference to these reproductive structures. By late September, as floral availability diminished, thrips dispersed to alternative hosts, including *Saussurea japonica*. Overwintering commenced in October, marking the end of their active season on daylily (Figure 1). The distribution of flower thrips across different daylily parts significantly (Figure 2, ANOVA $df = 3$, $F = 48.4$, $P < 0.05$). During the growing season, thrips were most abundant on floral organs, comprising $53.91 \pm 4.25\%$ of the population, followed by stems ($27.58 \pm 3.18\%$) and leaves ($14.60 \pm 1.46\%$), and the least number on leaves, at $3.89 \pm 1.26\%$.

3.2 Identification and analysis of volatiles in *H. citrina*

Sixty volatile compounds emitted from different anatomical parts of daylily (leaves, stems, and flowers) were detected and classified into eight chemical categories: alcohols, aldehydes, ethers, phenols, terpenes, carboxylic acids, esters, aromatic compounds, and hydrocarbons. Notably, six volatile compounds namely E- β -farnesene, nerol, linalool, α -curcumene, β -pinene, and β -ocimene, were exclusively present in buds and flowers. The LRT values of 31 compounds were compared with the corresponding

retention indices on <https://webbook.nist.gov/chemistry/> determine their chemical structures (see Supplementary Table).

3.3 Olfactory response of thrips to different plant volatiles

Thrips exhibited distinct olfactory responses to six volatile compounds emitted by daylily. E- β -farnesene, nerol, and linalool demonstrated significant attractiveness to thrips, whereas α -curcumene, β -pinene, and β -ocimene elicited no discernible olfactory reaction. Notably, nerol at 100 $\mu\text{g}/\mu\text{L}$ induced the highest attraction rate, reaching 88%, significantly outperforming the other tested volatiles.

The attraction of thrips to the same compound varies significantly across different concentrations. *F. intonsa* exhibits a highly significant preference for higher concentrations of nerol (100 $\mu\text{g}/\mu\text{L}$ and 10 $\mu\text{g}/\mu\text{L}$) and linalool (10 $\mu\text{g}/\mu\text{L}$), with responses markedly greater than those of the control group. Additionally, the species shows a significantly stronger attraction to a lower concentration of E- β -farnesene (1 $\mu\text{g}/\mu\text{L}$) compared to the control.

3.4 Field attraction of thrips to different plant volatiles

Field experiment revealed that nerol was the most effective attractant, capturing an average of 160.0 ± 98.6 thrips per sticky trap, though this was surpassed by a mixed-component lure, which captured 182.5 ± 83.7 thrips per trap. However, the difference between them is not statistically significant. Both treatments significantly outperformed individual components (E- β -farnesene, linalool, α -curcumene, β -pinene, β -ocimene) and the control (ANOVA, $df = 7$, $F = 100.7$, $P < 0.05$).

Different colored sticky traps exhibit varying efficacy in attracting *F. intonsa*. The yellow trap demonstrates the highest

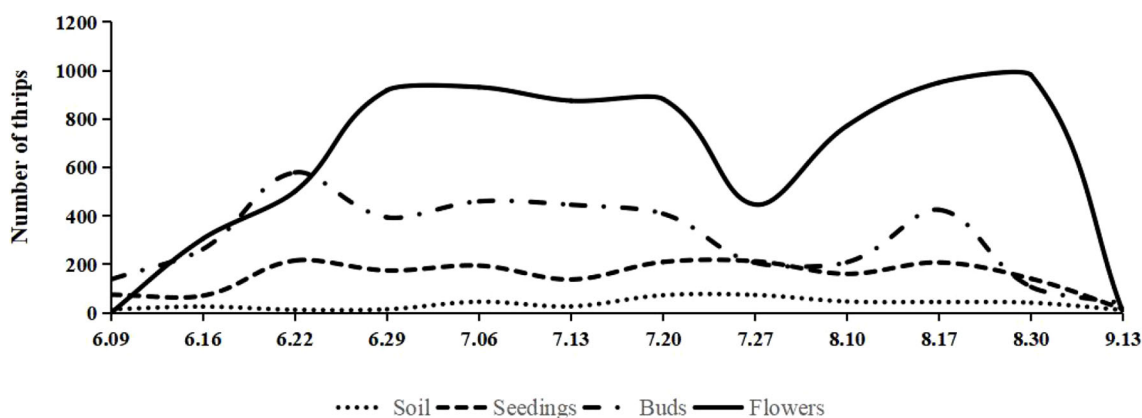


FIGURE 1

The population dynamics of flower thrips (*Frankliniella intonsa*) on daylily (*Hemerocallis citrina*). As daylilies grows, thrips migrate to the buds and cause damage in late June. Upon the emergence of flower from the end of June through early July, the pests shift to the flowers for feeding; they enter the overwintering stage in October.

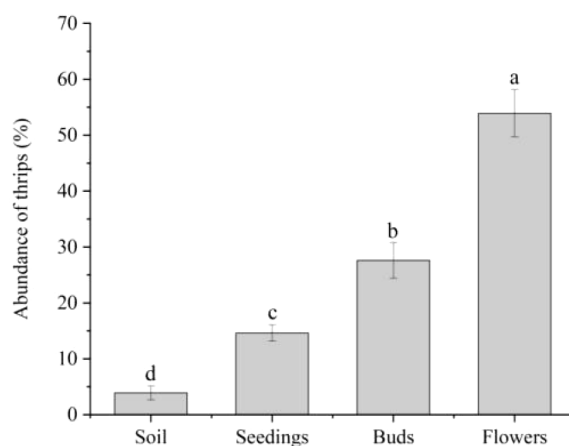


FIGURE 2

Distribution of flower thrips (*Frankliniella intonsa*) on daylily (*Hemerocallis citrina*) parts during the growing season in Datong, China. Thrips abundance was highest floral organs (53.91 ± 4.25%), followed by stems (27.58 ± 3.18%) and leaves (14.60 ± 1.46%), lowest in soil (3.89 ± 1.26%). Significant differences in thrip distribution among plant parts were detected (df = 3, F = 58.4, P < 0.05).

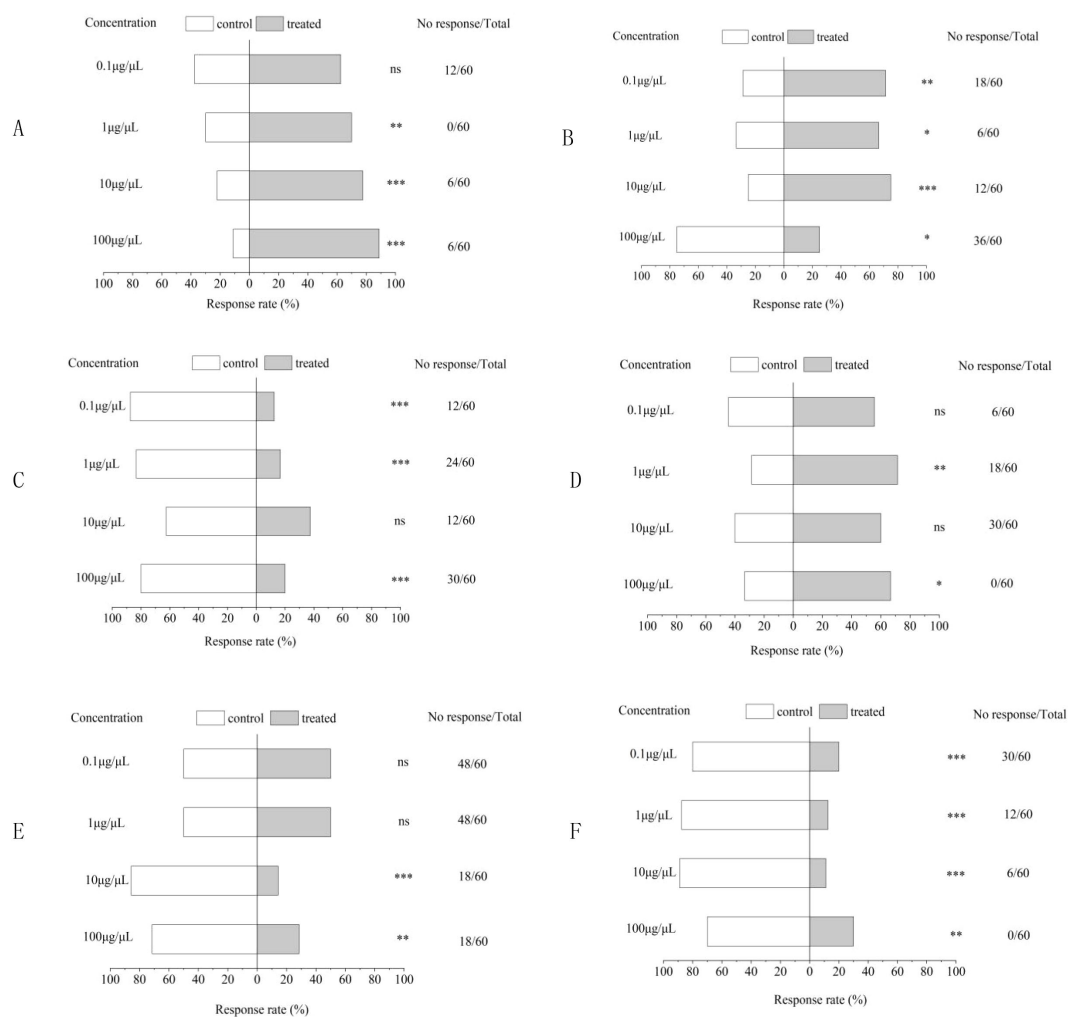


FIGURE 3

Behavioral responses of *Frankliniella intonsa* to six volatile compounds emitted by daylily in a Y-tube olfactometer. Bars represent the percentages of choice (n = 60) treated arm [linalool (A), linalool (B), β-ocimene (C), E-β-farnesene (D), β-pinene (E) and α-curcumen (F) at four concentrations] or the control arm. Asterisks indicate significant differences (*p < 0.05, **p < 0.01, ***p < 0.001, χ^2 test; ns, not significant).

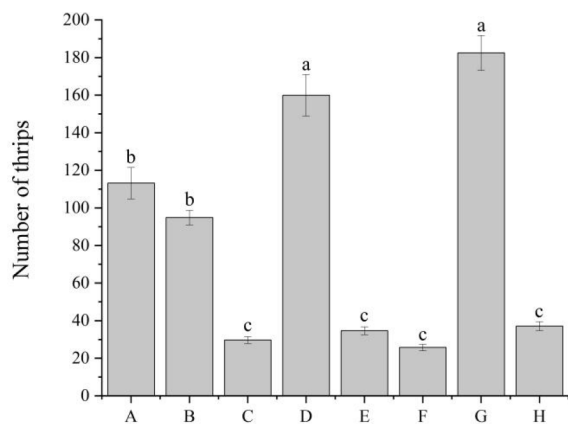


FIGURE 4

Comparative field attraction of *Frankliniella intonsa* to volatile components. The mixed-component lure (G) captured 182.5 ± 83.7 thrips per trap, exceeding nerol (D) captured 160.0 ± 98.6 thrips per trap. Both outperformed E- β -farnesene (B), linalool (A), α -curcumin (E), β -pinene (C), β -ocimene (F), and the control (H). Statistical analysis (ANOVA, $df = 7$, $F = 100.7$, $P < 0.05$) confirmed superior attraction by nerol and the mixed lure. X-axis, Treatment; Y-axis, Thrips per Trap.

attraction efficiency, followed by blue and yellow-black striped cards (ANOVA, $df = 2$, $F = 59.2$, $P < 0.05$). On average, the yellow sticky trap captured 111.5 ± 24.1 thrips, representing approximately 1.32-fold and 2.34-fold higher catches compared to the blue and yellow-black striped cards, respectively. When supplemented with a mixed-component lure, the attractiveness of yellow, blue, and yellow-black striped cards to flower thrips was enhanced. Compared to the unlured treatments, the number of captured thrips increased by 82.3%, 43.3%, and 72.1% for yellow, blue, and yellow-black striped cards, respectively. Among all tested treatments, the combination of the yellow sticky trap and the

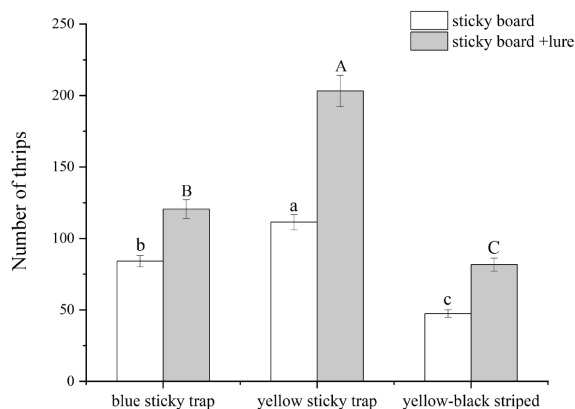


FIGURE 5

Mean number of *Frankliniella intonsa* caught on yellow, blue and yellow-black striped traps with and without a mixed-component ((E)- β -farnesene: nerol: linalool = 4.8:21.3:73.9) in daylily field. Yellow traps with a mixed-component lure captured 203.2 ± 48.8 thrips per trap (ANOVA, $df = 2$, $F = 63.0$, $P < 0.05$).

mixed-component lure achieved the highest capture efficacy, numbered 203.2 ± 48.8 thrips (ANOVA, $df = 2$, $F = 63.0$, $P < 0.05$).

4 Discussion

The color, morphology, and volatile secondary metabolites of plants play an important role in the host location of thrips (Teulon et al., 1993, 1999). Among these factors, volatile secondary metabolites released by plant leaves and flowers play a pivotal role in guiding thrips host-seeking behavior (Lewis, 1997). The survey results show that the flower thrips population in the soil remains consistently low throughout the entire growth period of daylily, indicating that thrips do not reproduce locally but rather migrate from alternative host plants. In this process, volatile chemicals emitted by host plants play a critical role in mediating the long-distance, directional movement of thrips. The distribution of *F. intonsa* in daylily is significantly greater in buds and flowers than in leaves and soil, suggesting that secondary metabolites present in floral structures of daylily exert an attractive effect on thrips populations. A total of 60 volatile compounds were detected across three distinct tissues of daylily in this study. Among these, E- β -farnesene, nerol, linalool, α -curcumin, β -pinene, and β -ocimene were exclusively detected in the primary sites of thrips aggregation, buds and flowers. Further behavioral experiments demonstrated that, among the six compounds, E- β -farnesene, nerol, and linalool exhibited strong attractant activity toward flower thrips at a high concentration (100 $\mu\text{g}/\mu\text{L}$ and 10 $\mu\text{g}/\mu\text{L}$). Research has demonstrated that low concentrations of nerol exert significant attractant effects on *F. occidentalis*, *Thrips hawaiiensis*, and *Megalurothrips usitatus* (Koschier et al., 2000; Han et al., 2015; Tang et al., 2015). Linalool and its derivatives also exhibit attractant properties toward various thrips species. For example, 10% linalool and linalool oxide pyran significantly attract *F. occidentalis* (Hooper et al., 1999; Koschier et al., 2000), while linalool at a volume ratio concentration of 10^{-6} attracts *T. hawaiiensis* (Han et al., 2015), 10^{-2} attracts *M. usitatus* (Tang et al., 2015), and at a concentration of $10^{-3} \mu\text{L}/\mu\text{L}$ has been shown to attract *T. palmi* (Cao et al., 2020). Additionally, (E)- β -farnesene at concentrations of 1% and 10% exhibits attractive activity toward *F. occidentalis* (Koschier et al., 2000; Katerinopoulos et al., 2005).

Further field experiments demonstrated that the three compounds, (E)- β -farnesene, nerol, and linalool at a ratio of 4.8:21.3:73.9, as well as each individual compound, exhibited significantly greater attraction toward flower thrips compared to other single components. To date, there have been no reports on the application of these three compounds in the field control of thrips. However, nerol serves as the primary precursor for the artificial synthesis of the flower thrips aggregation pheromone neryl-(S)-2-methylbutanoate (Zhang et al., 2011), suggesting that nerol may also function as a biosynthetic precursor in the natural production of this pheromone. This finding could provide a foundation for elucidating the biosynthetic pathway of the flower thrips aggregation pheromone.

Blue was reported to be the most attractive color to *F. intonsa* (Chen et al., 2017; Seo MiJa et al., 2006), followed in attractiveness by white (Mao et al., 2018) and pink (Chen et al., 2025). In this study, yellow cards were found here to have a significantly stronger attractive ability than blue and yellow-black striped cards for *F. intonsa* in daylily field. The experimental findings revealed that the color and material composition of sticky traps varied significantly across different manufacturers. Consequently, to precisely evaluate the attraction efficacy of color plates for thrips, it is imperative to determine the RGB values of the color plates and their material composition (e.g., corn fiber, polypropylene, or Polyethylene Coated Paper) for a comprehensive assessment.

The attractant exhibits synergistic effects on sticky traps of various colors, with the most pronounced enhancement observed on yellow traps. However, yellow sticky traps not only capture large quantities of thrips but also attract beneficial insects such as hoverflies and ladybugs. Moreover, in practical pest management applications, their use leads to the unintended removal of natural enemies and requires substantial labor and material inputs for frequent trap replacement. Yellow-black striped traps, which have demonstrated reduced adverse impacts on natural enemies and non-target organisms, have been increasingly adopted in pear orchards in recent years for the control of pests such as aphids and psyllids (Zhao et al., 2018). Nevertheless, in this study, the yellow-black striped traps exhibited limited efficacy in attracting thrips, indicating their unsuitability for effective thrips management.

In conclusion, E- β -farnesene, nerol, and linalool offer promising tools for monitoring and controlling *F. intonsa* in *H. citrina*. By integrating plant-derived volatiles into IPM, this study paves the way for sustainable thrips management, reducing pesticide reliance and enhancing agricultural sustainability. Future research should optimize volatile blends, develop slow-release formulations of insecticides adjuvant. Assessing impacts on beneficial insects is also critical for IPM integration.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

HL: Writing – original draft, Methodology, Data curation, Investigation. LL: Writing – original draft, Methodology, Formal Analysis, Resources. NS: Writing – review & editing, Validation, Data curation. JW: Writing – review & editing, Investigation. XZ: Formal Analysis, Writing – review & editing. ZL: Software, Writing – review & editing. GX: Supervision, Writing – review & editing, Funding acquisition, Project administration. JL: Funding acquisition, Project administration, Writing – review & editing.

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Conflict of interest

ZLv was employed by Shanxi Huashi Group Co., Ltd.

The remaining author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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