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Seasonal fluctuation and spatial variability of three major thrips species (Thysanoptera: Thripidae) in heated mango (Mangifera indica L.) greenhouse cultivation

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Abstract

Protected cultivation of tropical crops in temperate regions creates unique microclimatic niches that alter pest overwintering and outbreak dynamics. This study investigated the seasonal fluctuation and spatial distribution of total thrips populations and three major thrips species—*Scirtothrips dorsalis*, *Frankliniella occidentalis*, and *Frankliniella intonsa*—across four commercial heated mango (*Mangifera indica* L.) greenhouses in southern South Korea over a 17-month period from April 2023 to August 2024. Composite monitoring from April 2023 to August 2024 revealed recurring spring outbreaks across consecutive years, while species-level monitoring (July 2023 to August 2024) demonstrated that population density and species dominance varied significantly among individual greenhouses depending on local microclimates and management practices ($p < 0.001$). In three coastal greenhouses (Tongyeong 1–3), *S. dorsalis* was overwhelmingly dominant, exhibiting an explosive single-peak outbreak reaching up to 14,000 individuals per trap in late June. Conversely, in an inland greenhouse (Miryang), *F. occidentalis* predominated, forming a sharp spring peak exceeding 1,500 individuals per trap in late May. Although *F. intonsa* generally maintained low densities, a significant mid-winter spike (~ 1,500 individuals/trap) occurred in February under heated conditions (> 15°C), demonstrating that winter heating creates a thermal refuge enabling continuous, non-diapausing reproduction. Box-and-whisker plot analyses revealed pronounced spatial aggregation and within-greenhouse population deviations during outbreak periods, with numerous outliers indicating localized hot-spots ($p < 0.05$). These findings highlight that pest management in temperate greenhouse mango systems must be tailored to site-specific species dominance rather than uniform calendar spraying: proactive control before summer surges (mid-May) and winter heating monitoring are critical in *S. dorsalis*-dominant greenhouses, whereas intensive control during spring flowering (April–May) is essential in *F. occidentalis*-dominant facilities.

1. Introduction

Driven by rising average temperatures due to climate change and agricultural policies promoting farm income diversification, the cultivation area of subtropical and tropical fruit crops in temperature regions such as South Korea has steadily expanded (KOSIS 2023; Jeong et al. 2020). Among these, mango (*Mangifera indica* L.) has seen active expansion in protected greenhouse cultivation across southern areas due to its high market value and consumer preference (Jeong et al. 2020). However, greenhouse mango cultivation requires maintaining year-round warm and humid microclimatic conditions to produce high-quality fruit, which inadvertently provides an optimal environment for pest proliferation compared to open-field cultivation, a phenomenon also observed in protected pepper production (Lee et al. 2022). Furthermore, while mango is traditionally a tropical crop, its cultivation in heated greenhouses within temperate regions creates unique microclimatic niches that alter pest overwintering and outbreak dynamics.

Thrips (Thysanoptera) represent one of the most economically damaging pest groups in greenhouse mango orchards (Waite 2002; Choi et al. 2013; Gill et al. 2024). These minute insects primarily feed on young shoots, blossoms, and fruitlets by piercing and sucking plant sap. Feeding injury on mango fruits

results in silvery scarring and corky tissue formation on the skin, severely degrading marketability (Fig. 1). While *Scirtothrips dorsalis* Hood, *Frankliniella occidentalis* (Pergande), and *Frankliniella intonsa* (Trybom) have been reported as major thrips species in domestic protected horticulture (Choi et al. 2013; Hyun et al. 2012), and species complexes in subtropical fruit orchards are increasingly documented (Alarcón-Utrera et al. 2025), detailed information regarding their interspecific ecological divergence and seasonal occurrence dynamics across diverse greenhouse microclimates remains limited.

To achieve effective pest suppression, management must transition from routine calendar-based chemical applications—which frequently lead to insecticide resistance (Bielza et al. 2007; Gao et al. 2012; Li et al. 2016; IRAC 2019)—to monitoring-driven integrated pest management (IPM) grounded in seasonal population dynamics and spatial distribution patterns (Salas 2004; RDA 2019). Colored sticky traps are widely utilized as practical visual monitoring tools for early detection and mass trapping of phytophagous thrips across diverse cropping systems (Cho et al. 1995; Hoddle et al. 2002; Demirel and Cranshaw 2005; Natwick et al. 2007; Demirel and Yildirim 2008; Devi and Roy 2017; Carrillo-Arámbula et al. 2022; Santer and Allen 2024; Rind et al. 2025). Furthermore, because greenhouse interiors are insulated from external weather while subjected to artificial heating and ventilation, pest densities often vary markedly across different zones within a single structure (Taylor 1984). Consequently, statistical approaches that quantify both temporal fluctuations and spatial aggregation across trap locations are essential (Tukey 1977). Therefore, this study monitored the weekly occurrence of total thrips populations and three major thrips species across four commercial heated mango greenhouses over 17 months (including a 14-month species-level survey) to elucidate their interspecific ecological divergence, quantify within-greenhouse spatial variability, and establish site-specific, tailored optimal control timings.

2. Materials and Methods

2.1. Study Sites and Survey Period

The field survey was conducted in four commercial heated mango greenhouses located in distinct climatic settings in southern South Korea: three farms in a warm, humid coastal area (Tongyeong 1, 2, and 3) and one farm in a drier inland basin (Miryang) (Table 1).

Table 1
Geographic locations and characteristics of the surveyed mango greenhouses in Gyeongnam Province, South Korea, from April 2023 to August 2024

Farm ID	GPS coordinates	Area (m^2)	Winter temp. (℃)
Tongyeong 1(A)	34.937283, 128.359786	3300	≥ 15
Tongyeong 2(B)	34.938038, 128.35906	3300	≥ 15
Tongyeong 3(C)	34.937855, 128.358694	3300	≥ 15
Miryang (D)	35.529583, 128.769753	2600	≥ 15

Cultivar and tree age: All surveyed greenhouses cultivated 'Irwin' mango (*Mangifera indica* L.) trees aged 5 years in plastic multi-span greenhouses.

Heating period: Heating systems were operated from November to February of the following year to maintain a minimum internal greenhouse temperature above 15°C.

Trap installation: Five sticky traps (15 × 25 cm; yellow) were installed per greenhouse at the upper canopy height and replaced weekly.

Weekly monitoring was carried out over approximately 17 months from April 10, 2023, to August 30, 2024. The monitoring program was structured into two consecutive phases: an initial 3-month survey (April 10 to July 6, 2023) assessing overall pest pressure as a total thrips complex, followed by a 14-month species-level monitoring phase (July 13, 2023, to August 30, 2024) to determine species-specific seasonal dynamics. All surveyed greenhouses were equipped with heating systems operated during the winter season (November to February) to maintain minimum internal temperatures above 15°C, and all farms followed conventional commercial management practices registered for protected crops (RDA 2019).

2.2. Target Pests and Monitoring Procedure

Total thrips populations and three economically important species—*S. dorsalis*, *F. occidentalis*, and *F. intonsa*—were monitored using yellow sticky traps, which are widely recognized as effective visual cues for capturing diverse phytophagous thrips taxa in orchards and greenhouses (Cho et al. 1995; Hoddle et al. 2002; Carrillo-Arámbula et al. 2022). Five yellow sticky traps (15 × 25 cm) were suspended at the upper canopy level (near growing shoots) evenly distributed across the front, middle, and rear sections of each greenhouse. Traps were collected and replaced at 7-day intervals. Retrieved traps were transported to the laboratory and examined under a stereomicroscope. During the initial phase (April–July 2023), all adult thrips captured were counted collectively as the total thrips complex; during the subsequent 14-month phase (July 2023–August 2024), adult thrips were morphologically identified to the species level and counted separately. Trap catch data were standardized as the weekly mean number of individuals per trap (n = 5 per farm) for subsequent analysis.

2.3. Statistical Analysis and Data Visualization

All weekly trap catch data were analyzed using SAS software (version 9.4, SAS Institute, Cary, NC, USA). To quantitatively evaluate spatiotemporal population fluctuations and localized density concentrations (hot-spots) across trap locations within each greenhouse, box-and-whisker plot analyses were performed (Tukey 1977). Median values, interquartile ranges (IQR), and statistical outliers were derived for each sampling date to assess spatial aggregation (Taylor 1984).

One-way analysis of variance (ANOVA) was performed separately to compare mean trap catches among individual greenhouses at each sampling date and across sampling dates within each greenhouse. Prior to ANOVA, raw trap catch counts (x) were transformed using $\ln(x + 1)$ to satisfy the assumptions of normality and homogeneity of variance. When significant differences were detected, means were separated using Duncan's Multiple Range Test (DMRT) at $\alpha = 0.05$.

3. Results and Discussion

3.1. Spatiotemporal Dynamics of the Total Thrips Complex

Weekly monitoring of the total thrips complex over the 17-month period revealed highly significant site-specific differences in overall pest pressure and seasonal outbreak timing across the four commercial mango greenhouses ($p < 0.001$, Fig. 2). Notably, the two-year spring monitoring dataset demonstrated clear inter-annual recurrence of spring outbreaks in specific facilities. In the inland greenhouse (Miryang), total thrips catches surged sharply during the spring flowering and early fruiting period in both years, peaking at ~ 1,500 individuals/trap on May 24, 2023, and recurring with a comparable spring surge of ~ 1,500 individuals/trap between late April and May 2024. Similarly, coastal Tongyeong 3 exhibited recurrent spring peaks in both April 2023 (800–1,000 individuals/trap on April 10) and spring 2024 (~ 350 individuals/trap in late March to early April), alongside a late-summer increase in August 2023 (~ 400 individuals/trap).

In contrast, Tongyeong 1 maintained relatively low densities throughout 2023—aside from a moderate peak in late August (~ 2,500 individuals/trap)—before experiencing an explosive early-summer outbreak on June 20, 2024, where total catches reached a weekly mean of ~ 12,000 individuals/trap (up to 16,000 in individual traps). Meanwhile, Tongyeong 2 displayed a distinct multi-peak fluctuation across the 17 months, characterized by late-summer surges in August 2023 (~ 2,000 individuals/trap) and August 2024 (1,500–2,000 individuals/trap), as well as a pronounced mid-winter outbreak in February 2024 (~ 2,000 individuals/trap, with outliers exceeding 4,500). Box-and-whisker plots across all four greenhouses showed markedly expanded interquartile ranges and extended whiskers during these peak periods, confirming strong within-greenhouse spatial aggregation (Taylor 1984; Tukey 1977). Crucially, although total trap catches revealed recurring spring and summer surges across facilities, composite counts alone could not distinguish whether these outbreaks were driven by different taxa, underscoring the necessity of species-level identification in subsequent analyses.

3.2. Spatiotemporal Dynamics of *Frankliniella occidentalis*

Weekly monitoring of *F. occidentalis* during the 14-month species-level phase (July 2023–August 2024) revealed highly significant differences in outbreak timing and population density driven by local microclimates and greenhouse management practices (Fig. 3). Across the three coastal greenhouses (Tongyeong 1–3), weekly catches generally remained low (< 100 individuals/trap) throughout the year, though minor farm-specific peaks occurred: Tongyeong 1 exhibited a small summer peak (10–20 individuals/trap) in July–August 2023, whereas Tongyeong 2 showed a slight winter increase (~ 40 individuals/trap) on February 15, 2024, reflecting continuous reproduction enabled by winter heating (Ullah and Lim 2015; Park et al. 2020). Tongyeong 3 experienced a brief spring increase coinciding with greenhouse ventilation and mango flowering, peaking at 60–80 individuals/trap on April 11 before declining rapidly.

In stark contrast, *F. occidentalis* in the inland greenhouse (Miryang) remained suppressed for most of the year before surging into a sharp, single-peak outbreak exceeding 1,500 individuals/trap on May 24, 2024. Although the inland site comprised a single commercial greenhouse, its distinct dry spring microclimate and management regime clearly illustrated how localized environmental conditions shift species dominance toward *F. occidentalis*. This pattern aligns with the ecological preference of *F. occidentalis*, whose fecundity and survival peak under warm, relatively dry spring conditions (20–25°C) rather than hot and humid summer environments (Cho et al. 2000; Kirk and Terry 2003; Jeong et al. 2018; Reitz et al. 2020). Box-and-whisker plots demonstrated dramatic expansions in both the IQR and whisker lengths during the peak periods in Miryang (May 24) and Tongyeong 3 (April 11), confirming severe within-greenhouse spatial aggregation and localized hot-spots (outliers) near vents or entryways (Taylor 1984). One-way ANOVA confirmed highly significant differences across greenhouses ($p < 0.001$), with DMRT separating the May outbreak in Miryang and the April peak in Tongyeong 3 into statistically distinct groups ($p < 0.05$). Given that *F. occidentalis* rapidly develops field resistance to key insecticides such as spinosad (Bielza et al. 2007; Gao et al. 2012; Li et al. 2016; Jeong et al. 2018), targeting this spring flowering window with mode-of-action rotation (IRAC 2019) and soil-applied entomopathogenic fungi like *Beauveria bassiana* (Lee et al. 2017; Zhang et al. 2019) is strongly recommended.

3.3. Spatiotemporal Dynamics of *Scirtothrips dorsalis*

Scirtothrips dorsalis was overwhelmingly dominant in the coastal greenhouses (Tongyeong1 − 3), accounting for over 90% of total thrips catches during the 14-month species-level survey, while remaining negligible in the inland greenhouse (Miryang) (Fig. 4). Tongyeong 1 maintained low baseline densities before experiencing an explosive single-peak outbreak on June 20, 2024, reaching a weekly mean of ~ 12,000 individuals/trap (up to 14,000 in individual traps). Conversely, Tongyeong 2 exhibited a multi-peak pattern with summer surges in late August 2023 (~ 2,000 individuals/trap) and mid-to-late August 2024 (1,000–1,500 individuals/trap), alongside a notable winter peak (> 500 individuals/trap) in mid-February 2024. Tongyeong 3 maintained stable densities below 600 individuals/trap throughout the study, while Miryang recorded only a minor peak (~ 400 individuals/trap) on April 26, 2024.

The strong dominance of *S. dorsalis* in the Tongyeong greenhouses reflects its ecological adaptation to warm, humid environments combined with surrounding subtropical evergreen host orchards (e.g., citrus) that serve as external reservoirs (Hyun et al. 2012; Gill et al. 2024). Similar to *F. occidentalis*, box-and-whisker plots during peak periods (June 20 in Tongyeong 1; August 24 in Tongyeong 2) revealed markedly elongated boxes, extended whiskers, and numerous outliers, demonstrating intense spatial clustering during rapid population growth. ANOVA confirmed highly significant differences across sites ($p < 0.001$), classifying the early-summer outbreak in Tongyeong 1 as an independent statistical group ($p < 0.05$).

3.4. Spatiotemporal Dynamics of *Frankliniella intonsa*

Although *F. intonsa* exhibited lower overall densities than *S. dorsalis* and *F. occidentalis* over the 14-month species-level monitoring, it displayed statistically significant fluctuations tied to seasonal and heating-induced thermal shifts (Fig. 5).

Tongyeong 1 recorded a distinct early-summer peak averaging ~ 600 individuals/trap (maximum > 1,200) on June 20, 2024. Most notably, Tongyeong 2 experienced an unusual mid-winter surge around February 15, 2024, reaching a weekly mean of ~ 1,500 individuals/trap (maximum > 4,000). This winter outbreak indicates that maintaining temperatures above 15°C with restricted ventilation during cold months creates a thermal refuge that prevents winter diapause and accelerates continuous reproduction alongside early mango shoot and blossom flushing (Ullah and Lim 2015; Liu et al. 2026). Tongyeong 3 showed minor activity (100–150 individuals/trap) in spring and early summer, whereas Miryang remained below 30 individuals/trap year-round.

Consistent with the other two species, expanded IQRs and outliers during the February 15 (Tongyeong 2) and June 20 (Tongyeong 1) peaks verified strong spatial aggregation during density surges. ANOVA showed highly significant variation among sites ($p < 0.001$), isolating the winter outbreak in Tongyeong 2 as a statistically distinct group ($p < 0.05$).

4. Conclusion

This 17-month investigation (incorporating a 14-month species-level analysis) demonstrated that while total thrips complexes exhibit recurring spring and summer surges across consecutive years, species composition, interspecific ecological divergence, and outbreak dynamics in heated greenhouse mango orchards differ substantially depending on site-specific microclimates and greenhouse management ($p < 0.001$). The coastal greenhouses (Tongyeong) were overwhelmingly dominated by *S. dorsalis*, whereas the inland greenhouse (Miryang) experienced a spring-concentrated outbreak of *F. occidentalis*. Box-and-whisker plot analyses consistently revealed that population surges are accompanied by extreme spatial aggregation (hot-spots), underscoring the need for targeted spot-treatments guided by weekly visual trap monitoring rather than uniform calendar spraying (Carrillo-Arámbula et al. 2022; Santer and Allen 2024).

Furthermore, the mid-February surges of *F. intonsa* and *S. dorsalis* under heated conditions prove that winter heating supports continuous, non-diapausing reproduction in temperate protected systems. To enhance future IPM efficacy in protected mango cultivation, combining color-optimized sticky traps with host-derived volatile attractants or push-pull strategies (Cook et al. 2007; Khan et al. 2016; Cao et al. 2020; Ren et al. 2020; Makhlouf et al. 2024; Acebes-Doria et al. 2026; Liu et al. 2026; Ouvrard et al. 2026), exploiting host plant resistance mechanisms (Sadafale et al. 2025), and cultural or biological controls (Salas 2004; Lee et al. 2017; Rind et al. 2025) will be highly beneficial. Consequently, management strategies in temperate greenhouse mango systems must be tailored to site-specific species dominance: in *S. dorsalis*-dominant greenhouses, continuous winter monitoring during heating periods and proactive control starting in mid-May prior to the summer surge are essential; in *F. occidentalis*-dominant facilities, intensive short-term control during the spring flowering and fruitlet stages (April–May) is critical to ensure high-quality fruit production.

Declarations

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Ethics Approval

Not applicable. This study involved field monitoring of agricultural insect pests using non-invasive sticky traps and did not involve human participants or vertebrate animals.

Consent to Participate

Not applicable.

Consent to Publish

Not applicable.

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Author Contribution

All authors contributed to the study conception and design. Material preparation, field monitoring, and data collection were performed by DK, SL, and IH. Statistical analysis and data visualization were

performed by DK and SL. The first draft of the manuscript was written by DK and JK, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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Figures



Figure 1

Typical feeding damage symptoms caused by thrips on mango fruit (A) and young leaves (B) in surveyed greenhouses.

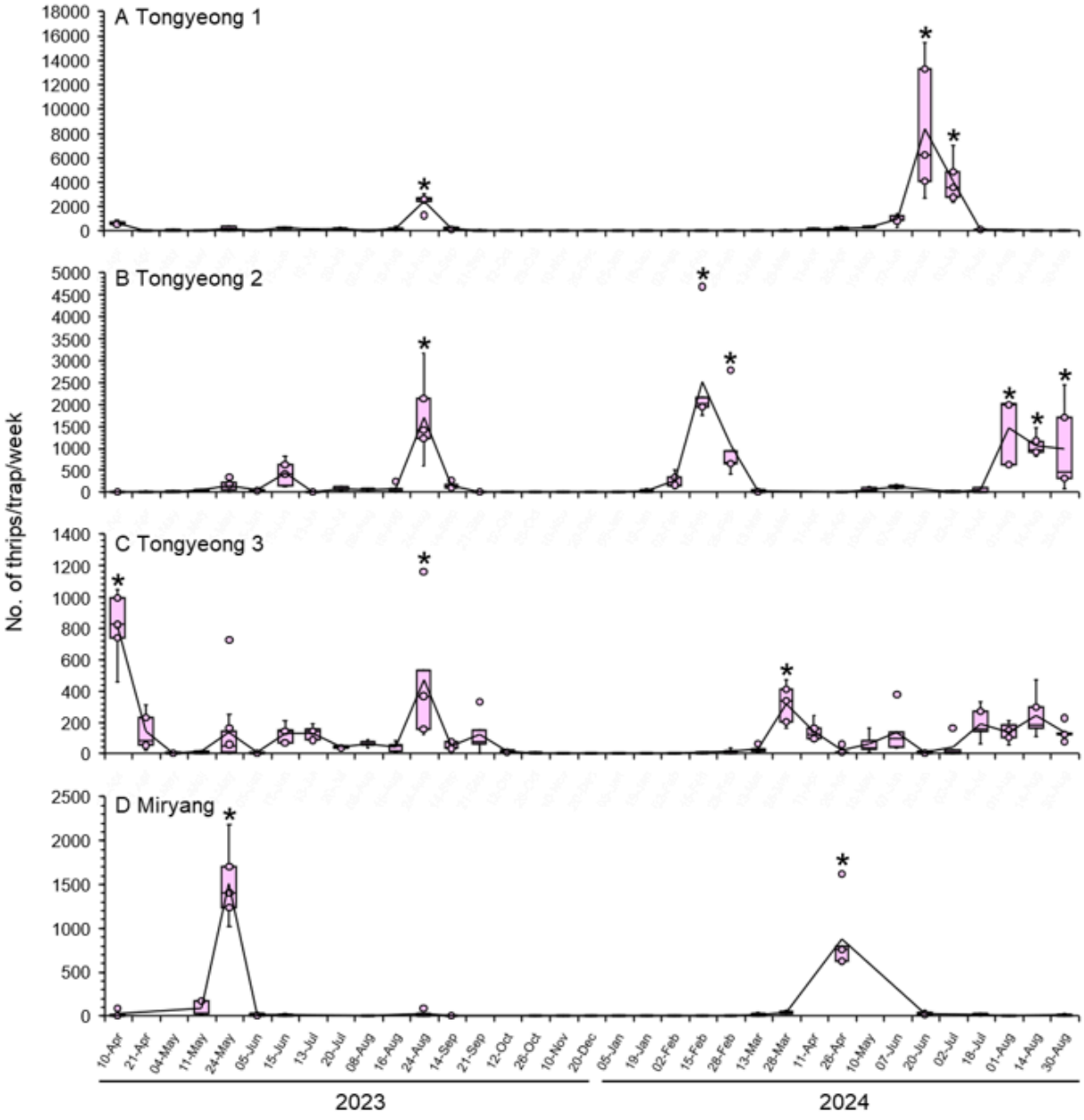

Figure 2

Weekly occurrence dynamics of the total thrips complex in heated mango greenhouses over a 17-month period from April 2023 to August 2024. Data points represent the weekly mean of total thrips catches per trap (n = 5 traps per greenhouse), overlaid with box-and-whisker plots indicating the median, 25th, and 75th percentiles. Vertical whiskers denote the non-outlier range, and individual dots represent statistical outliers. Asterisks (*) above specific peaks indicate major outbreak periods that were statistically separated into distinct groups from baseline periods by Duncan's Multiple Range Test (DMRT, $p < 0.05$). Note the distinct variations in the Y-axis scales among the sites [A: Tongyeong 1 (0–18,000); B: Tongyeong 2 (0–5,000); C: Tongyeong 3 (0–1,400); D: Miryang (0–2,500)], reflecting highly

significant site-specific differences and inter-annual recurrence in overall pest pressure ($p < 0.001$, One-way ANOVA).

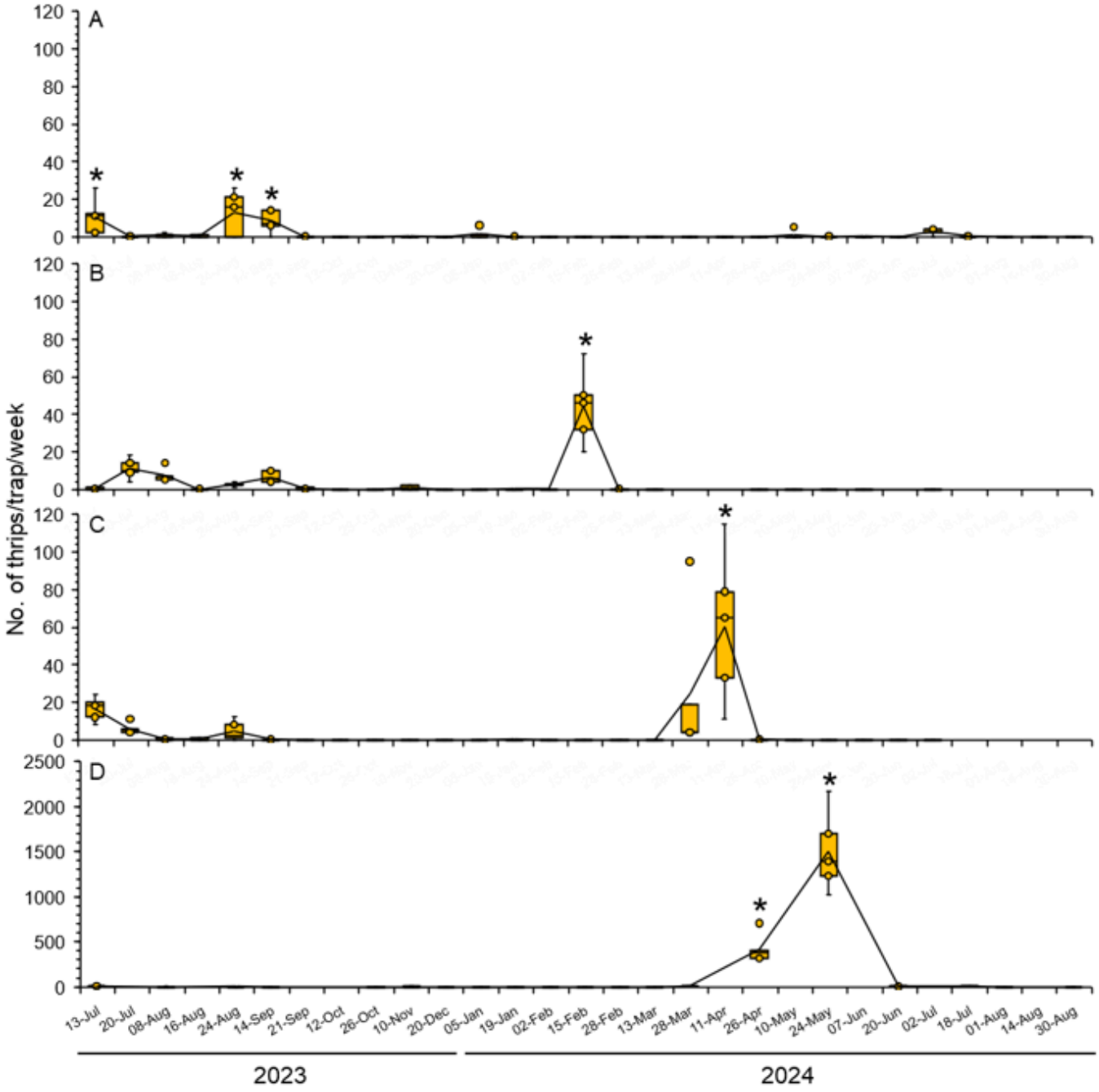

Figure 3

Weekly occurrence dynamics of *Frankliniella occidentalis*in greenhouse mango cultivation areas during the 14-month species-level survey from July 2023 to August 2024. Data points represent the weekly mean of thrips catches per trap (n = 5 traps per greenhouse), overlaid with box-and-whisker plots indicating the median, 25th, and 75th percentiles. Vertical whiskers denote the non-outlier range, and individual dots represent statistical outliers. Asterisks (*) above specific peaks indicate major outbreak periods that were statistically separated into distinct groups from baseline periods by Duncan's Multiple

Range Test (DMRT, $p < 0.05$). Note the distinct variations in the Y-axis scales among the sites [A: Tongyeong 1 (0–120); B: Tongyeong 2 (0–120); C: Tongyeong 3 (0–120); D: Miryang (0–2,500)], reflecting a highly significant localized and situational variation in population density ($p < 0.001$, One-way ANOVA).

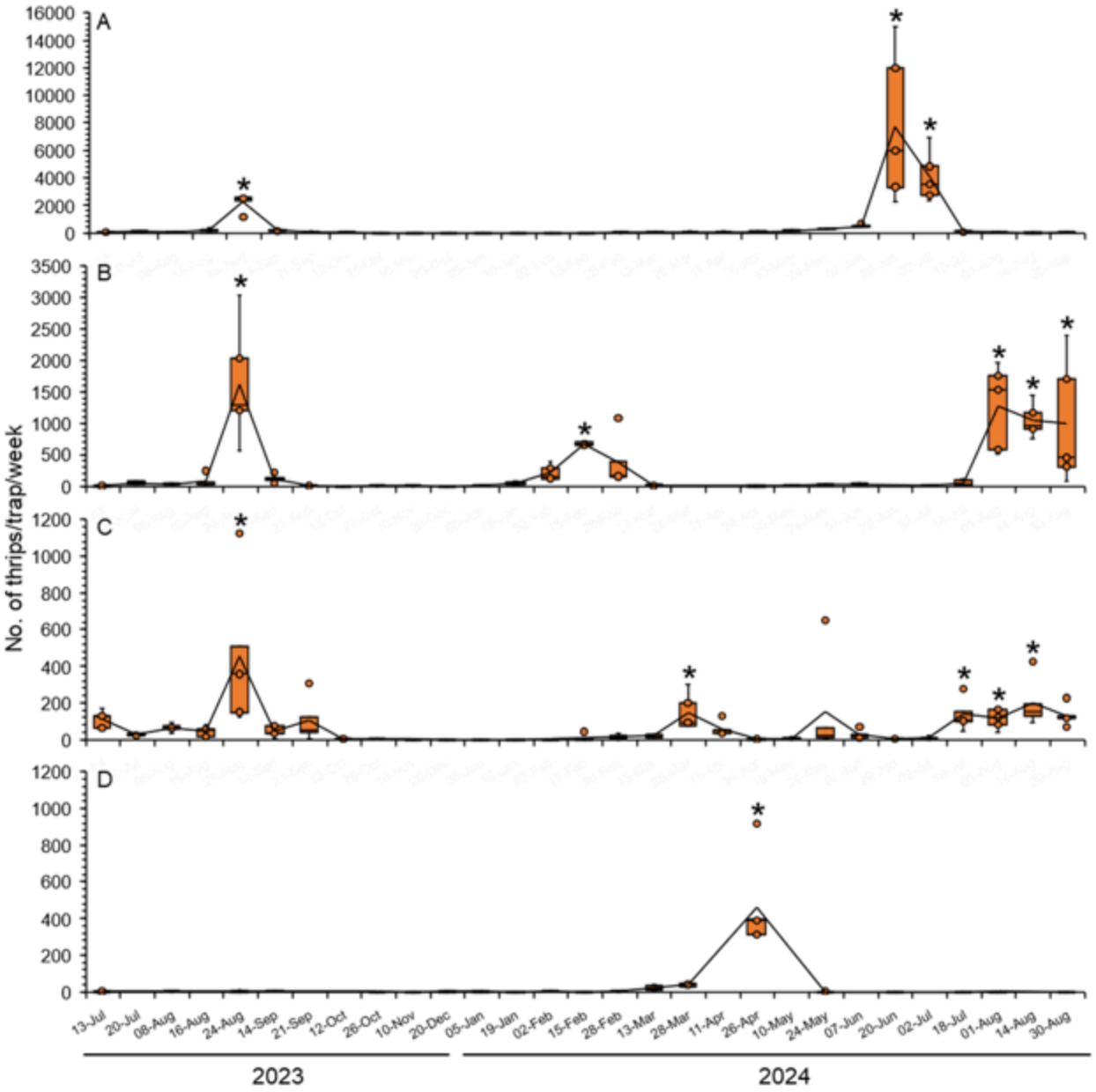

Figure 4

Weekly occurrence dynamics of *Scirtothrips dorsalis* in greenhouse mango cultivation areas during the 14-month species-level survey from July 2023 to August 2024. Data points represent the weekly mean of thrips catches per trap (n= 5 traps per greenhouse), overlaid with box-and-whisker plots indicating the median, 25th, and 75th percentiles. Vertical whiskers denote the non-outlier range, and individual dots represent statistical outliers. Asterisks (*) above specific peaks indicate major outbreak periods that

were statistically separated into distinct groups from baseline periods by Duncan's Multiple Range Test (DMRT, $p < 0.05$). Note the distinct variations in the Y-axis scales among the sites [A: Tongyeong 1 (0–16,000); B: Tongyeong 2 (0–3,500); C: Tongyeong 3 (0–1,200); D: Miryang (0–1,200)], reflecting a highly significant localized and situational variation in population density ($p < 0.001$, One-way ANOVA).

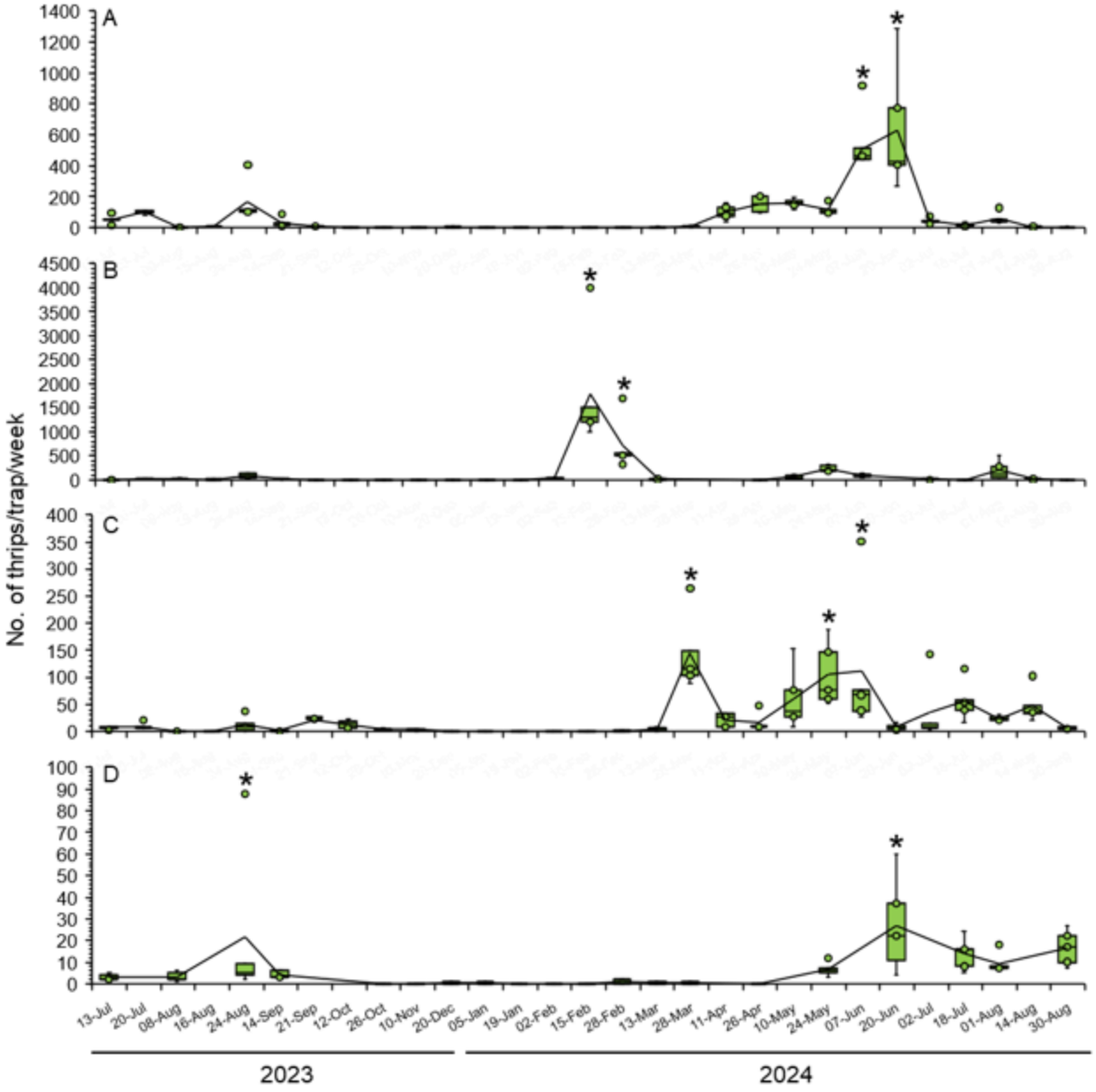

Figure 5

Weekly occurrence dynamics of *Frankliniella intonsa* in greenhouse mango cultivation areas during the 14-month species-level survey from July 2023 to August 2024. Data points represent the weekly mean of thrips catches per trap (n= 5 traps per greenhouse), overlaid with box-and-whisker plots indicating the median, 25th, and 75th percentiles. Vertical whiskers denote the non-outlier range, and individual dots represent statistical outliers. Asterisks (*) above specific peaks indicate major outbreak periods that were statistically separated into distinct groups from baseline periods by Duncan's Multiple Range Test

(DMRT, $p < 0.05$). Note the distinct variations in the Y-axis scales among the sites [A: Tongyeong 1 (0–1,400); B: Tongyeong 2 (0–4,500); C: Tongyeong 3 (0–400); D: Miryang (0–100)], reflecting a highly significant localized and situational variation in population density ($p < 0.001$, One-way ANOVA).