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Research Article

Effects of Organic and Conventional Farming on Lady Beetle Diversity, Dominance, and Temporal Stability in Indian Jujube Orchards

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Abstract

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Enhancing our understanding of how lady beetle biodiversity responds to organic and conventional farming is essential for sustainable pest management in tropical fruit systems. This study aims to compare the composition and interannual variation of lady beetle assemblages across different farming practices to assess the long-term differences in natural enemy assemblages in tropical orchards under organic and conventional management. From 2020 to 2024, lady beetle assemblages were surveyed in organically cultivated (OC) and conventionally cultivated (CC) Indian jujube orchards in Yanchao, Kaohsiung. A total of 20 species were recorded in OC orchards and 11 species in CC orchards. *Sasajiscymnus tainanensis* was the dominant species in both systems, and several species, including *Cheilomenes sexmaculata* and *Cryptogonus orbiculus*, were more abundant in OC orchards. The mycophagous species *Illeis koebelei* occurred exclusively in OC orchards. Mean species richness and total abundance per survey were significantly higher in OC orchards ($P < 0.05$ for both metrics). Shannon diversity was significantly greater in OC orchards, whereas Berger-Parker dominance did not differ between systems. Annual total abundance was consistently higher in OC orchards, with a significant OC-CC difference detected only in 2021. Temporal variability at the community level was higher in OC orchards (coefficient of variation; CV = 0.753) than in CC orchards (CV = 0.424), indicating lower interannual stability under organic management, reflecting the natural response of the population to changes in prey resources under low pesticide disturbance. These results provide multi-year empirical evidence of distinct community patterns of lady beetles under different farming systems in subtropical fruit orchards, which can serve as a basis for ecological monitoring and planning pest management strategies.

Key words: Coccinellidae, Biological control, Predator assemblages, Agricultural intensification, Ecosystem services.

INTRODUCTION

Organic and other eco-friendly farming practices have gained increasing attention worldwide as viable strategies to enhance farmland biodiversity and support ecological functions (Reganold & Wachter 2016). Reduced pesticide input, vegetation management, and

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habitat diversification promote the abundance and activity of natural enemies in agricultural landscapes, thereby strengthening ecosystem services such as biological control (Heimpel & Mills 2017). In Taiwan, the promotion of organic agriculture and the development of biodiversity-friendly farming systems have further highlighted the importance of multi-year ecological monitoring and indicator species for evaluating agroecosystem health.

Lady beetles (Coleoptera: Coccinellidae) are key predatory natural enemies in agricultural ecosystems, significantly contributing to the suppression of soft-bodied pests, including aphids, whiteflies, and scale insects. In perennial orchard systems, these predators help stabilize pest populations and reduce reliance on chemical insecticides, thereby supporting sustainable production (Obrycki & Kring 1998; Koch 2003; Tscharntke *et al*. 2005). Studies in temperate regions have demonstrated higher arthropod diversity and abundance under organic management compared to conventional systems (Wyss *et al*. 1995; Bengtsson *et al*. 2005; Tuck *et al*. 2014). In contrast, relatively little is known about the multi-year dynamics of lady beetle communities in tropical fruit orchards, particularly in Southeast Asia, where regional research remains limited and often short-term (Obrycki & Kring 1998; Koch 2003). In Taiwan, research has likewise concentrated on annual crops such as rice, with limited attention to predator assemblages in tropical and subtropical fruit orchards (Dong *et al*. 2023). Field surveys have identified several dominant species in local agroecosystems, including *Sasajiscymnus tainanensis* (Ohta, 1929) and *Illeis koebelei* Timberlake, 1943, reflecting the unique community structure of subtropical orchard systems (Sung *et al*. 2010; Hsu & Tsai 2024). These findings highlight the need for multi-year, system-level comparisons to understand how farming practices shape predator assemblages and their ecological functions in tropical perennial crops.

The Indian jujube (*Ziziphus mauritiana* Lam.) is a significant tropical fruit crop in Southern Taiwan, with Kaohsiung Yanchao District being a major production area (Saran *et al*. 2006; Awasthi & More 2009; Razi *et al*. 2013; Guo *et al*. 2022). These orchards are managed under either organic or conventional farming systems, which differ markedly in pesticide use, vegetation management, and habitat complexity. International research suggests that reduced pesticide inputs and more diverse ground vegetation in organic orchards can enhance natural enemy diversity and stability (Miñarro & Prida 2013; Porcel *et al*. 2018; Muneret *et al*. 2019); however, comparable evidence from tropical orchard systems remains scarce. This knowledge gap is particularly evident for the multi-year responses of lady beetle communities to different management practices- including changes in species composition, dominance structure, and temporal stability. Clarifying these patterns is essential for improving ecological management strategies, optimizing the conservation of natural enemies, and supporting sustainable fruit production in Taiwan's tropical orchard systems. We hypothesize that organic orchards support higher lady beetle diversity, more complex assemblages, distinct dominance patterns, and different temporal stability than conventionally managed orchards. Accordingly, this study conducts multi-year comparisons of Coccinellidae communities in organically cultivated (OC) and conventionally cultivated (CC) Indian jujube orchards to assess how farming practices shape predator assemblages, their community dynamics and temporal patterns, and their ecological functions.

This study aims to address this knowledge gap by conducting a multi-year ecological survey of lady beetle assemblages in organic and conventional Indian jujube orchards in Kaohsiung, Southern Taiwan. We compared species richness, abundance, dominant species structure, and temporal variation between management types to evaluate how farming practices influence predator communities. The findings provide multi-year empirical evidence for how organic management shapes predator diversity and temporal community patterns in tropical orchard systems and offer insights for integrating biodiversity conservation into sustainable fruit production strategies in Taiwan's tropical fruit production systems.

MATERIALS AND METHODS

Study sites and experimental design

This study was conducted from 2020 to 2024 in Indian jujube (*Z. mauritiana* Lam.) orchards located in Yanchao District, Kaohsiung, Southern Taiwan. Four organically managed orchards (OC) and four conventionally managed orchards (CC) were selected for comparison. All orchards were planted with the same commercial cultivar ('Honey jujube'), and each study block was larger than 0.2 ha.

The OC orchards were located in Guanshui and Andong Sections (22.771424°N, 120.335748°E; 22.773791°N, 120.334799°E; 22.774300°N, 120.334652°E; 22.780247°N, 120.328120°E), while the CC orchards were situated in adjacent areas of Guanshui Section (22.770677°N, 120.335624°E; 22.770298°N, 120.335828°E; 22.770458°N, 120.335381°E; 22.780712°N, 120.325730°E). Selecting nearby orchards minimized differences in climate, soil, and landscape features. Kaohsiung has a tropical monsoon climate typical of Southern Taiwan, generally characterized by hot, wet summers and drier winters. Organic management followed the Organic Agriculture Promotion Act, which prohibits the use of synthetic fertilizers, chemical pesticides, genetically modified organisms (GMOs), and their by-products. In contrast, conventional orchards followed standard regional practices, including the application of chemical fertilizers and pesticides for pest and crop management.

Insect sampling and field collection

Lady beetle surveys were conducted during four crop growth stages- flowering, early fruiting, mid-fruiting, and harvest- and sampling was repeated throughout each growing season from 2020 to 2024. Each sampling date was treated as a separate sampling event for analysis.

In each orchard, four sampling subplots were established, and one yellow sticky trap (33 cm × 28 cm) was deployed on one randomly selected tree within each subplot, at each sampling event, resulting in four traps per orchard per sampling occasion. Trap installation followed standardized procedures described by Dong *et al*. (2023), with traps mounted 1.2–1.3 m above ground on black grid frames (36 cm × 28 cm), either attached to trunks or suspended from branches.

Traps were deployed for ~14 d before collection and replacement. Samples were transported to the laboratory, where lady beetles were sorted, identified to species, and counted. All records were entered into standardized datasheets to ensure consistency across sampling dates and orchards. All recorded species belonged to the family Coccinellidae, including both predatory and mycophagous species, and functional group classification followed established descriptions of feeding traits reported in regional and international literature (Sung *et al*. 2010; Hsu & Tsai 2024).

Orchard management and tree characteristics

The surveyed orchards had established production histories under either conventional or organic management. All orchards were maintained by experienced local growers following consistent annual cultivation practices. Trees selected for sampling were mature (> 10 years old), regularly pruned, and maintained with consistent annual fruit production. All trees were planted at a spacing of 6 m × 6 m and grown inside nylon mesh houses commonly used for commercial Indian jujube production in the region, primarily for fruit protection and pest exclusion. Only trees with similar vigor and canopy structure were included based on visual assessment to ensure consistent sampling conditions across orchards. Management practices in both systems followed standard local cultivation routines appropriate for Indian jujube production, including routine pruning, fertilization, irrigation, and pest management.

Statistical analyses

Statistical analyses were conducted using Python 3.10 and R 4.3.2. Analyses in Python used the SciPy, statsmodels, and pandas packages, whereas analyses conducted in R employed the vegan and car packages. The orchard ($n = 4$ per management type) was used as the statistical replicate. Data were aggregated at the orchard level for all analyses to avoid pseudoreplication and ensure independence among replicates. Nonparametric tests were used because the abundance and diversity variables violated the normality and equal-variance assumptions (Shapiro-Wilk and Levene's tests, $P < 0.05$). To quantify interannual stability, we compared the magnitude of year-to-year fluctuations in each response variable between organic and conventional orchards. Temporal variability (i.e., lower variance over time) is commonly interpreted as greater ecological stability. Therefore, Levene's test was applied to evaluate whether interannual variances differed between farming systems (Ives & Carpenter 2007); lower interannual variance indicates greater temporal stability in predator populations. Thus, this test directly evaluates whether one farming system supports more stable year-to-year predator dynamics. Because most variables did not meet normality assumptions ($P < 0.05$), comparisons between organic and conventional orchards were performed using the Mann-Whitney *U* test.

Annual comparisons between organic (OC) and conventional (CC) orchards involved only one independent test per year (OC vs CC), and therefore false discovery rate (FDR) correction was not applied. Applying FDR to small and independent two-group samples ($n = 4$ orchards per management type) would substantially reduce statistical power and is not recommended for independent annual contrasts. Unadjusted *P*-values were therefore retained for the OC-CC comparisons following standard practice for independent annual tests in ecological field studies.

To assess species abundance structure within each farming system, we compared abundance patterns across species using the Kruskal-Wallis *H* test. When the overall test was significant ($P < 0.05$), post hoc pairwise comparisons were conducted using Mann-Whitney *U* tests. In this analysis, multiple pairwise comparisons among species were performed following a significant Kruskal-Wallis test. Because these comparisons originate from the same dataset and involve repeated testing across species, the probability of type I error increases. Therefore, the Benjamini-Hochberg FDR procedure was applied to control for inflated false-positive rates while maintaining reasonable statistical power in multi-species comparisons. *P*-values were adjusted using the Benjamini-Hochberg FDR procedure to control the type I error rate under multiple testing.

To compare mean species richness and total abundance between organic (OC) and conventional (CC) orchards, we used the Mann-Whitney *U* test because the variables did not meet normality assumptions. For dominant-species responses, we compared the five most abundant species identified separately for OC and CC using Mann-Whitney *U* tests to evaluate species-specific differences between organic and conventional orchards.

Diversity, dominance, and stability metrics included Shannon diversity (H'), Berger-Parker dominance (d), and the coefficient of variation (CV). Differences in H' and d between farming systems were analyzed using Mann-Whitney *U* tests. Temporal variability was quantified using the CV for both the total community and dominant species, with annual mean abundance and CV calculated for each orchard. The CV is widely used as an index of interannual stability, with lower CV values indicating more stable year-to-year population dynamics (Wolda 1988). Differences in interannual variability between OC and CC were examined using Levene's test, which evaluates variance differences independent of mean effects.

All tests were two-sided, and statistical significance was set at $P < 0.05$. Replication at the orchard level was necessarily limited by field logistics (n = 4 per farming system), a constraint that is common in long-term ecological monitoring of perennial orchard systems. To address this limitation, inference in this study relied on repeated observations across multiple years, with the five-year sampling framework (2020–2024) providing substantial temporal replication to support comparisons between farming systems.

Because this study was based on fixed, long-term monitoring sites rather than experimentally replicated plots, a formal a priori power analysis was not feasible. Nevertheless, the multi-year temporal design increased the robustness of statistical comparisons and allowed consistent management-related patterns to be evaluated across years, despite modest spatial replication.

RESULTS

Species composition and dominant species

From 2020 to 2024, a total of 20 lady beetle species were recorded in organic (OC) Indian jujube orchards and 11 species in conventional (CC) orchards (Tables 1 and 2). Among these, 9 species were exclusive to OC, and 2 to CC. *Sa. tainanensis* (Ohta, 1929) was the dominant species in both systems, with consistently higher mean per-survey abundance in OC orchards. Furthermore, other frequently encountered species included the predatory species *Cryptogonus orbiculus* (Gyllenhal, 1808) and *Cheilomenes sexmaculata* (Fabricius, 1781),

Table 1. Lady beetle species and their mean abundance in organic Indian jujube orchards from 2020 to 2024 (ranked by abundance).

Scientific name	Trophic guild	Mean abundance (mean ± *SE*)[z]
Sasajiscymnus tainanensis (Ohta, 1929)	Predatory	5.12 ± 1.38 a
Cryptogonus orbiculus (Gyllenhal, 1808)	Predatory	2.19 ± 0.46 b
Cheilomenes sexmaculata (Fabricius, 1781)	Predatory	1.45 ± 0.50 c
Illeis koebelei Timberlake, 1943	Mycophagous	0.27 ± 0.14 d
Sasajiscymnus fuscus (Yang, 1971)	Predatory	0.06 ± 0.03 d
Scymnus quadrillum Motschulsky, 1858	Predatory	0.05 ± 0.03 d
Scymnus ovimaculatus Sasaji, 1968	Predatory	0.04 ± 0.02 d
Jauravia limbata Motschulsky, 1858	Predatory	0.04 ± 0.02 d
Axinoscymnus nigripennis Kamiya, 1965	Predatory	0.03 ± 0.02 d
Propylea japonica (Thunberg, 1781)	Predatory	0.03 ± 0.02 d
Sasajiscymnus parenthesis (Weise, 1923)	Predatory	0.03 ± 0.02 d
Sticholotis taiwanensis Miyatake, 1982	Predatory	0.03 ± 0.02 d
Scymnus yangi Yu et Pang, 1993	Predatory	0.01 ± 0.01 d
Lemnia saucia (Mulsant, 1850)	Predatory	0.01 ± 0.01 d
Lemnia biplagiata (Swartz, 1808)	Predatory	0.01 ± 0.01 d
Sticholotis formosana Weise, 1923	Predatory	0.01 ± 0.01 d
Rodolia okinawensis Miyatake, 1959	Predatory	0.01 ± 0.01 d
Platynaspidius maculosus (Weise, 1910)	Predatory	0.01 ± 0.01 d
Scymnus hoffmanni Weise, 1879	Predatory	0.01 ± 0.01 d
Platynaspidius quinquepunctatus Miyatake, 1961	Predatory	0.01 ± 0.01 d

[z] Differences in species abundance were tested using Kruskal-Wallis with post hoc Mann-Whitney *U* tests (false discovery rate (FDR)-adjusted). Species sharing the same letter are not significantly different at $P < 0.05$.

both of which were more abundant in OC orchards (Table 3). The mycophagous species *I. koebelei* Timberlake, 1943, occurred exclusively in OC orchards. *Cr. ohtai* Sasaji, 1968, was detected only in CC orchards. Species-level abundances varied significantly among species within each farming system as indicated by Kruskal-Wallis tests (OC: H = 850.04, P < 0.0001; CC: H = 210.71, P < 0.0001).

Species richness, abundance, and diversity indices

Mean species richness per survey was significantly higher in OC orchards (1.94 ± 0.11 species) than in CC orchards (1.43 ± 0.10 species) (Mann-Whitney U = 3,168.5, P = 0.0033). Total abundance per survey was also higher in OC (11.37 ± 1.76 individuals) than in CC orchards (4.49 ± 0.60 individuals) (U = 3,585.0, P < 0.0001) (Table 4).

Shannon diversity (H') was significantly greater in OC orchards (0.385 ± 0.043) than in CC orchards (0.240 ± 0.052) (U = 3,018.5, P = 0.0243). Berger-Parker dominance (d) did not differ significantly between farming systems (U = 2,059.5, P = 0.0567), reflecting the consistently high relative abundance of the dominant predator *Sa. tainanensis* in both orchard types (Table 5). Annual patterns of Shannon diversity are presented in Fig. 1.

Table 2. Lady beetle species and their mean abundance in conventional Indian jujube orchards from 2020 to 2024 (ranked by abundance).

Scientific name	Trophic guild	Mean abundance (mean ± *SE*)[z]
Sasajiscymnus tainanensis (Ohta, 1929)	Predatory	1.78 ± 0.52 a
Cheilomenes sexmaculata (Fabricius, 1781)	Predatory	0.90 ± 0.28 b
Propylea japonica (Thunberg, 1781)	Predatory	0.08 ± 0.04 c
Cryptogonus ohtai Sasaji, 1968	Predatory	0.06 ± 0.03 c
Cryptogonus orbiculus (Gyllenhal, 1808)	Predatory	0.06 ± 0.03 c
Scymnus quadrillum Motschulsky, 1858	Predatory	0.04 ± 0.00 c
Sasajiscymnus fuscus (Yang, 1971)	Predatory	0.04 ± 0.03 c
Axinoscymnus nigripennis Kamiya, 1965	Predatory	0.04 ± 0.03 c
Rodolia okinawensis Miyatake, 1959	Predatory	0.02 ± 0.02 c
Olla v-nigrum (Mulsant, 1866)	Predatory	0.02 ± 0.02 c
Rodolia cardinalis (Mulsant, 1850)	Predatory	0.02 ± 0.02 c

[z] Differences in species abundance were tested using Kruskal-Wallis with post hoc Mann-Whitney U tests (false discovery rate (FDR)-adjusted). Species sharing the same letter are not significantly different at P < 0.05.

Table 3. Comparison of dominant lady beetle species between organically cultivated (OC) and conventionally cultivated (CC) jujube orchards based on mean abundance per survey.

Species	Organic[z] (mean ± *SE*)	Conventional (mean ± *SE*)	*U*-value	*P*-value
Sasajiscymnus tainanensis (Ohta, 1929)	5.12 ± 1.38	1.78 ± 0.52	3,257.5	0.0020*
Cryptogonus orbiculus (Gyllenhal, 1808)	2.19 ± 0.46	0.06 ± 0.03	3,621.0	< 0.0001*
Cheilomenes sexmaculata (Fabricius, 1781)	1.45 ± 0.50	0.90 ± 0.28	2,254.0	0.2131
Illeis koebelei Timberlake, 1943	0.27 ± 0.14	0.00 ± 0.00	2,677.5	0.0521
Sasajiscymnus fuscus (Yang, 1971)	0.06 ± 0.03	0.04 ± 0.03	2,505.0	0.9485
Propylea japonica (Thunberg, 1781)	0.03 (0.02)	0.08 ± 0.04	2,379.5	0.1939
Cryptogonus ohtai Sasaji, 1968	0.00 ± 0.00	0.06 ± 0.03	2,352.0	0.0160*

[z] Mean values represent abundance per survey (mean ± *SE*). Differences between OC and CC were evaluated using the Mann-Whitney U test. Asterisks (*) indicate significant differences at the P < 0.05.

Table 4. Comparison of mean species richness and total abundance of lady beetles per survey between organically cultivated (OC) and conventionally cultivated (CC) jujube orchards from 2020 to 2024.

Variable	Organic (mean ± *SE*)	Conventional (mean ± *SE*)	*U*-value	*P*-value
Mean richness (species/survey)[z]	1.94 ± 0.11	1.43 ± 0.10	3,168.5	0.0033
Mean abundance (individuals/survey)[z]	11.37 ± 1.76	4.49 ± 0.60	3,585.0	< 0.0001

[z] Mann-Whitney *U* tests were used to compare mean species richness and total abundance per survey between OC and CC jujube orchards. All comparisons were significant at $P < 0.05$.

Table 5. Comparison of lady beetle diversity (Shannon *H′*), dominance (Berger-Parker *d*), and interannual stability (coefficient of variation; CV) between organically cultivated (OC) and conventionally cultivated (CC) jujube orchards.

Index	Mean ± *SE*[z] (OC)	CV (OC)	Mean ± *SE* (CC)	CV (CC)	*U*-value	*P*-value
Shannon *H′*	0.385 ± 0.043	1.113	0.240 ± 0.052	1.558	3,018.5	0.0243
Berger-Parker *d*	0.826 ± 0.021	0.254	0.867 ± 0.029	0.238	2,059.5	0.0567

[z] Shannon diversity (*H′*) and Berger-Parker dominance (*d*) were compared between OC and CC orchards using the Mann-Whitney *U* test. Interannual stability was evaluated using the CV, which was not subjected to significance testing. Statistical significance was set at $P < 0.05$.

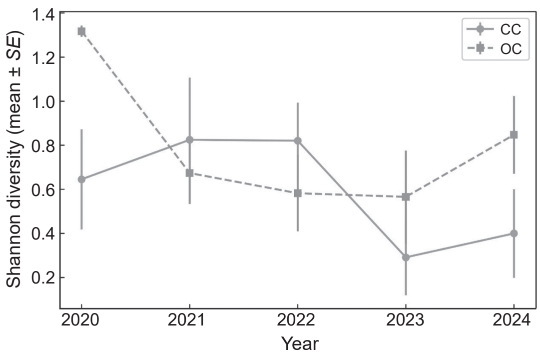

Fig. 1. Shannon diversity (mean ± *SE*) of lady beetle assemblages under organically cultivated (OC) and conventionally cultivated (CC) management in jujube orchards from 2020 to 2024. No significant differences were detected between OC and CC in any year (Mann-Whitney *U* tests; all $P \geq 0.05$).

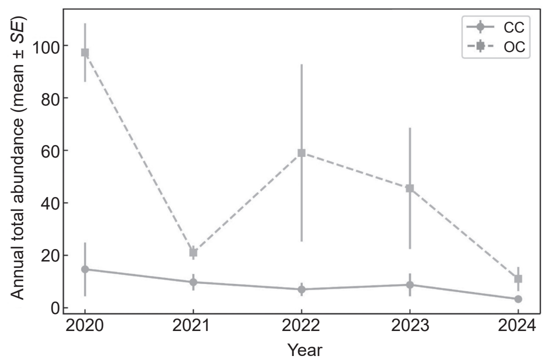

Fig. 2. Annual total abundance of lady beetles (mean ± *SE*) under organically cultivated (OC) and conventionally cultivated (CC) management in jujube orchards from 2020 to 2024. Significant differences between OC and CC were detected in 2021 ($P < 0.05$), whereas in all other years, no significant differences were observed ($P \geq 0.05$).

Annual abundance patterns

Annual total abundance of lady beetles was higher in OC orchards than in CC orchards throughout the five-year period (Fig. 2). A significant OC-CC difference was observed only in 2021 ($P < 0.05$), consistent with the annual summary in Table 4, whereas all other years showed no significant differences ($P \geq 0.05$).

Annual abundance of *Sa. tainanensis*, the dominant species, did not differ significantly between OC and CC orchards in any year (Fig. 3). *Ch. sexmaculata* exhibited a similar pattern, with no significant OC-CC differences across years and two borderline comparisons (2020 and 2024; Fig. 4). These temporal patterns correspond with the overall abundance differences summarized in Table 4.

Temporal variability and community stability

Annual total abundance from 2020 to 2024 averaged 184.80 ± 62.26 individuals per year in OC orchards and 31.20 ± 5.91 individuals per year in CC orchards (Table 6). Interannual variance differed significantly between the two systems (Levene's stat = 6.515, $P = 0.0340$).

Community-level temporal variability (CV) was 0.753 in OC orchards and 0.424 in CC orchards (Fig. 5), indicating greater temporal instability in OC orchards compared with CC orchards. Species-level CV values for both dominant species were relatively high, indicating considerable interannual fluctuations in their populations.

For *Sa. tainanensis*, the difference in interannual variance between farming systems was marginally non-significant ($P = 0.0551$), suggesting a trend toward greater year-to-year fluctuations in OC orchards.

DISCUSSION

Community patterns under different management systems

Lady beetle assemblages in this study showed consistently higher species richness, abundance, and functional heterogeneity in organic (OC) orchards than in conventional (CC) orchards, reflecting the well-established pattern that reduced pesticide input and greater vegetation heterogeneity promote natural enemy communities in agroecosystems (Bengtsson *et al*. 2005; Tuck

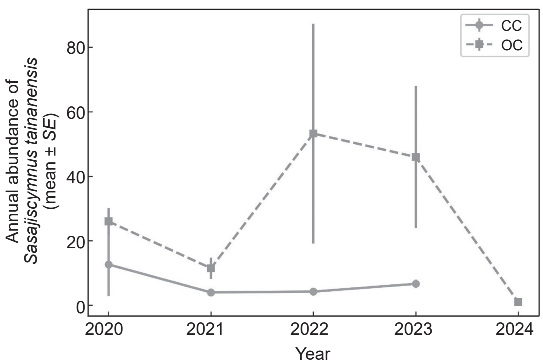

Fig. 3. Annual abundance of *Sasajiscymnus tainanensis* (Ohta, 1929) (mean ± *SE*) under organically cultivated (OC) and conventionally cultivated (CC) management in jujube orchards from 2020 to 2024. No significant differences between OC and CC were detected in any year (Mann-Whitney *U* tests; all $P \geq 0.05$).

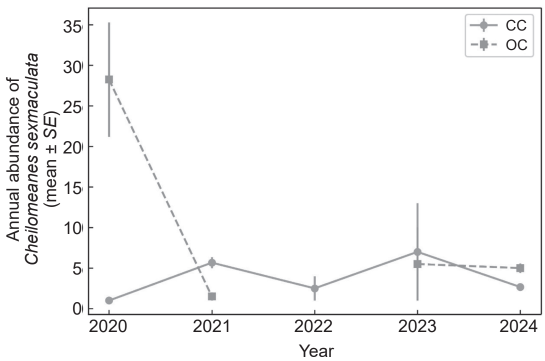

Fig. 4. Annual abundance of *Cheilomenes sexmaculata* (Fabricius, 1781) (mean ± *SE*) under organically cultivated (OC) and conventionally cultivated (CC) management in jujube orchards from 2020 to 2024. No significant differences between OC and CC were detected in any year (Mann-Whitney *U* tests; all $P \geq 0.05$). Two years (2020 and 2024) showed borderline differences (2020: $P = 0.10$; 2024: $P = 0.08$), but neither reached statistical significance.

Table 6. Comparison of mean abundance, temporal stability (coefficient of variation; CV), and interannual variance (Levene's test) of dominant lady beetle species and total community under organically cultivated (OC) and conventionally cultivated (CC) jujube orchard management.

Species/Community	Mean (*SE*)[z] (OC)	Mean (*SE*) (CC)	Levene's stat	*P*-value	CV (OC)	CV (CC)
Sasajiscymnus tainanensis (Ohta, 1929)	100.40 ± 36.71	22.75 ± 5.15	5.283	0.0551	0.817	0.453
Cheilomenes sexmaculata (Fabricius, 1781)	35.50 ± 25.95	9.20 ± 2.78	1.265	0.2977	1.462	0.676
Total (all species)	184.80 ± 62.26	31.20 ± 5.91	6.515	0.0340	0.753	0.424

[z] Annual mean abundance (mean ± *SE*) and interannual stability (CV) were calculated for dominant species and the total community from 2020 to 2024. Interannual variance between OC and CC orchards was compared using Levene's test; *P*-values shown in the table correspond to Levene's test. Interannual stability based on CV was not subjected to significance testing. Statistical significance was set at $P < 0.05$.

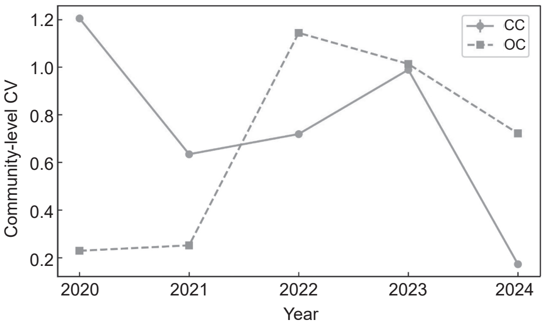

Fig. 5. Community-level temporal variability (coefficient of variation; CV) of lady beetle abundance under organically cultivated (OC) and conventionally cultivated (CC) management in jujube orchards from 2020 to 2024. No significant differences were detected between OC and CC across years ($P \geq 0.05$).

et al. 2014). The distinct species composition observed between management systems underscores this pattern. While *Sa. tainanensis* (Ohta, 1929) remained the dominant predator under both systems- indicating strong ecological adaptability and a broad prey range- several other predators, including *Cr. orbiculus* (Gyllenhal, 1808) and *Ch. sexmaculata* (Fabricius, 1781), were more abundant in OC orchards (Table 3). The exclusive occurrence of the mycophagous species *I. koebelei* Timberlake, 1943, in OC orchards further suggests that organic management supports more functionally diverse assemblages. Similar trends have been documented across Taiwanese agroecosystems, where *Sa. tainanensis* and other predatory Coccinellidae consistently respond positively to reduced pesticide disturbance (Sung *et al*. 2010; Dong *et al*. 2023; Hsu & Tsai 2024). Together, these patterns indicate that organic orchards maintain not only higher predator richness but also a broader functional spectrum within predator assemblages than conventionally managed orchards. Overall, these findings demonstrate that organic management promotes both taxonomic and functional diversification within lady beetle communities, strengthening the ecological basis for sustained natural pest suppression.

Ecological mechanisms underlying diversity and stability

Several mechanisms may explain why organic orchards supported richer, more dynamic lady beetle communities than conventional systems. Reduced pesticide disturbance is likely the primary driver, as broad-spectrum insecticides used in conventional orchards can suppress predator survival, impair reproduction, and disrupt population recovery following seasonal fluctuations (Porcel *et al*. 2018; Muneret *et al*. 2019). In contrast, organic orchards maintain higher structural heterogeneity through groundcover vegetation, flowering weeds, and leaf-litter layers, which collectively provide alternative prey, microhabitats, and refuges that sustain predator activity even during periods of low pest density. These habitat-mediated processes are consistent with the ecological principles of conservation biological control, where diverse vegetation promotes prey availability and stabilizes predator populations (Heimpel & Mills 2017).

Prey dynamics may also contribute to the observed patterns. Mobile generalist predators such as *Ch. sexmaculata* and *Cr. orbiculus* are known to rapidly track aphid and soft-scale outbreaks, a behavior well-documented for aphidophagous Coccinellidae (Obrycki & Kring 1998; Kindlmann & Dixon 1999). Such prey-tracking responses often generate strong interannual fluctuations when prey resources appear in short pulses rather than continuously, which is consistent with the higher CV observed in organic orchards. Although our field survey did not directly quantify prey populations (e.g., aphids, whiteflies, scale insects), previous work in Taiwanese rice systems provides important dietary evidence that helps explain the observed patterns. Stable-isotope analyses have revealed that predator dietary composition differs markedly between organic and conventional fields, with predators consuming a higher proportion of pest-derived prey in conventional systems and exhibiting broader prey spectra in organic systems (Hsu *et al*. 2025). These dietary shifts reflect underlying differences in prey availability and resource heterogeneity between farming systems and may similarly influence the dynamics of lady beetle assemblages in jujube orchards. Temporal stability is ecologically important because more stable predator populations can provide more reliable and sustained biological control services in perennial fruit systems, where pest outbreaks vary substantially from year to year.

Seasonal climatic variation may further influence these patterns. Taiwan's tropical-subtropical rainfall regime produces pronounced seasonal shifts that shape insect phenology and population size (Wolda 1988). Under such conditions, reduced chemical disturbance in organic orchards likely allows predator populations to fluctuate with environmental and prey-driven cues rather than being suppressed by pesticide use, resulting in predator communities that fluctuate more strongly but maintain long-term presence and functional roles despite interannual variation.

Although the difference in interannual variance of *Sa. tainanensis* between farming systems was only marginally significant (P = 0.0551), this pattern suggests a biologically meaningful trend in which the dominant predator responds to reduced pesticide disturbance yet still exhibits notable year-to-year fluctuations. Such borderline significance is common in long-term ecological datasets with limited replication, and the observed effect remains consistent with the broader pattern of heightened predator activity and community dynamism in organic orchards.

Cross-system and regional comparisons

The patterns observed in this study are consistent with findings from other Taiwanese agroecosystems, where organic and low-input management typically support richer predator assemblages and more heterogeneous community structures. Similar trends have been documented in pomelo, citrus, and rice systems, in which predatory Coccinellidae- particularly *Sa. tainanensis*, *Cr. orbiculus*, and *Ch. sexmaculata*- respond positively to reduced pesticide use and increased groundcover vegetation (Sung *et al*. 2010; Hsu & Tsai 2024). These cross-crop similarities suggest that the mechanisms identified here, including prey-tracking behavior, habitat heterogeneity, and minimized chemical disturbance, operate broadly across subtropical orchard and field systems.

The patterns identified in this study are not unique to Taiwan but reflect broader ecological responses observed in diverse farming systems worldwide. Comparable outcomes have also been reported internationally. A synthesis from Brazil highlighted that predatory Coccinellidae consistently exhibit higher diversity and functional importance in low-input and heterogeneous farming systems (de Paula Malheiros *et al*. 2025). Field experiments in India have demonstrated that organic vegetable farms support significantly higher lady beetle richness and abundance compared to conventional fields, primarily due to reduced pesticide pressure and increased vegetation diversity (Jesu Rajan *et al*. 2019). Similarly, studies in Eastern Europe revealed that organic wheat, oat, and buckwheat systems support more diverse and structurally connected predatory Coccinellidae communities than conventionally managed fields (Grabovska *et al*. 2021).

These case studies align with global meta-analyses, which demonstrate that organic and low-input farming systems consistently support higher natural enemy diversity, stronger biological control potential, and more resilient predator communities (Bengtsson *et al*. 2005; Letourneau *et al*. 2009; Tuck *et al*. 2014). Although dominant species vary among regions, the ecological processes shaping predator assemblages- reduced disturbance, increased vegetation complexity, and enhanced resource heterogeneity- remain widely consistent across agroecosystems. Collectively, these cross-system comparisons indicate that the advantages of organic management for sustaining diverse and dynamic lady beetle assemblages represent a generalizable and widely observed ecological pattern across low-input farming systems.

Management and policy implications

The clearer separation of lady beetle assemblages between organic and conventional orchards provides important insights for orchard management and biodiversity-based pest regulation. The consistently higher richness and functional diversity observed in organic orchards suggest that maintaining groundcover vegetation, reducing pesticide disturbance, and allowing natural vegetation structure to develop can strengthen predator communities and, in turn, enhance biological control services. This interpretation aligns with global assessments of biodiversity-friendly farming, which consistently show that reducing chemical inputs and increasing habitat complexity promote resilient natural enemy communities across diverse agroecosystems (Bengtsson *et al*. 2005; Letourneau *et al*. 2009; Tuck *et al*. 2014).

These findings also provide practical guidance for ecological orchard management in subtropical systems. Practices such as maintaining flowering weeds within inter-rows, conserving leaf-litter layers, and minimizing broad-spectrum insecticide use during peak predator activity periods align with established principles of conservation biological control. Foundational synthesis work has shown that groundcover vegetation and habitat complexity can enhance predator foraging efficiency, survival, and persistence by supplying alternative prey, shelter, and favorable microclimates (Bugg & Waddington 1994; Landis *et al*. 2000). Empirical studies further demonstrate that native flowering plant strips can increase natural enemy abundance and activity in perennial fruit systems, highlighting the value of floral resources as part of habitat-management strategies (Walton & Isaacs 2011). Importantly, our results suggest that temporal variability in predator abundance- often interpreted as instability- should instead be viewed as a natural ecological response to prey fluctuations under conditions of low chemical disturbance. This interpretation is consistent with evidence showing that reduced pesticide inputs mitigate sublethal and behavioral disruptions to beneficial arthropods (Desneux *et al*. 2007) and support more resilient natural enemy communities at the landscape scale (Geiger *et al*. 2010). Collectively, these insights underscore the potential of organic orchards to function as reservoirs of natural enemies within mixed agricultural landscapes.

From a policy perspective, these results support Taiwan's ongoing efforts to expand organic and low-pesticide farming systems. Global syntheses have shown that organic agriculture consistently enhances biodiversity and associated ecosystem functions across a wide range of production landscapes (Bengtsson *et al*. 2005; Ponisio *et al*. 2015). By demonstrating that predator communities respond predictably and positively to reduced chemical disturbance, our study provides empirical evidence that biodiversity-oriented management can strengthen ecological stability and long-term pest regulation- a finding consistent with broader evaluations of ecosystem service provisioning in diversified farming systems (Garibaldi *et al*. 2017). These insights may help inform regional habitat management programs, certification standards, and incentive schemes designed to promote functional biodiversity and ecological resilience in fruit orchards.

Study limitations

This study focused on long-term patterns of lady beetle assemblages under contrasting farming systems but did not directly quantify prey populations, climatic variables, or detailed pesticide application records at each orchard. As a result, the mechanisms underlying observed differences in diversity, abundance, and temporal variability were inferred from community-level patterns rather than being explicitly tested. Future studies integrating concurrent monitoring of prey dynamics, local climatic conditions, and management inputs would provide stronger mechanistic insights into the drivers of predator community stability in tropical orchard systems.

CONCLUSIONS

Organic Indian jujube orchards in Southern Taiwan supported significantly higher lady beetle species richness, greater abundance, and higher interannual variability than conventional orchards. The dominant predator *Sa. tainanensis* (Ohta, 1929) responded strongly to organic management, a pattern consistent with the combined effects of reduced pesticide disturbance and increased vegetation heterogeneity. These results provide robust empirical evidence that organic practices enhance predator diversity and community resilience in subtropical orchard ecosystems. Moreover, the distinct species assemblages observed in Taiwan- compared to temperate and subtropical jujube systems abroad- highlight the importance of region-specific biodiversity baselines when evaluating the impacts of management.

In practical terms, integrating organic farming principles with habitat-enhancing actions-such as maintaining ground cover, conserving floral resources, and minimizing pesticide inputs-can simultaneously reduce chemical dependency and strengthen natural enemy communities. Embedding these strategies into Taiwan's fruit integrated pest management (IPM) guidelines and pesticide-reduction programs would promote ecological sustainability and reinforce the long-term resilience of biological control services in subtropical fruit production systems.

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有機與慣行農法對印度棗果園瓢蟲多樣性、優勢度與時間穩定性的影響

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摘要

郝秀花、董耀仁、許北辰、李奇峯、石憲宗。2026。有機與慣行農法對印度棗果園瓢蟲多樣性、優勢度與時間穩定性的影響。台灣農業研究 75(2):217–230。

增進我們對瓢蟲生物多樣性如何應對有機與慣行農法的瞭解，對於熱帶果樹系統的永續性害蟲管理至關重要。本研究旨在比較不同耕作方式下瓢蟲群聚 (assemblages) 之組成與年際變動特性，以評估熱帶果園天敵群聚在有機 (organically cultivated; OC) 與慣行 (conventionally cultivated; CC) 管理下之長期差異。2020−2024 年於高雄燕巢印度棗園進行調查，OC 園共記錄 20 種瓢蟲，顯著高於 CC 園之 11 種。兩類型園區的優勢種皆為臺南方瓢蟲 (*Sasajiscymnus tainanensis*)，而變斑隱勢瓢蟲 (*Cryptogonus orbiculus*) 與六條瓢蟲 (*Cheilomenes sexmaculata*) 在 OC 出現較高豐度，食菌性的黃瓢蟲 (*Illeis koebelei*) 則僅見於 OC 園。每次調查之平均物種豐富度與總豐度在 OC 園皆顯著高於 CC 園 ($P < 0.05$)。OC 園之 Shannon 多樣性 (H') 亦高於 CC 園，而 Berger-Parker 優勢度指數在兩類型間無顯著差異。年總豐度在五年間皆以 OC 園較高，僅 2021 年兩者差異達顯著水準。年際變動方面，OC 園之群聚變異係數 (coefficient of variation; CV = 0.753) 高於 CC 園 (CV = 0.424)，顯示其瓢蟲群聚具有較大的年際波動，反映在低藥劑干擾下族群對獵物資源變化的自然回應。本研究提供熱帶果樹系統中不同耕作管理對瓢蟲群聚多年期差異之實證資料，可作為生態監測及害蟲管理策略規劃之基礎。

關鍵詞：瓢蟲科、生物防治、捕食者群聚、農業集約化、生態系服務。

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