BIODIVERSITAS
Volume 26, Number 11, November 2025
Pages: 5671-5678

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d261126

Companion flowering plants enhance the preference and fitness of *Trichogramma* sp. in biological control

MUHAMMAD USMAN[1], WILDAN MUHLISON[1,♥], IRWANTO SUCIPTO[1], HARI PURNOMO[2]

[1]Department of Agrotechnology, Faculty of Agriculture, Universitas Jember. Jl. Kalimantan 37, Jember 68121, East Java, Indonesia.
Tel./fax.: +62-331-330224. ♥email: wildan.muhlison@unej.ac.id

[2]Department of Plant Protection, Faculty of Agriculture, Universitas Jember. Jl. Kalimantan 37, Jember 68121, East Java, Indonesia

Manuscript received: 17 August 2025. Revision accepted: 4 November 2025.

Abstract. *Usman M, Muhlison W, Sucipto I, Purnomo H. 2025. Companion flowering plants enhance the preference and fitness of* Trichogramma *sp. in biological control. Biodiversitas 26: 5671-5678. Trichogramma* sp. is a polyphagous egg parasitoid widely applied in biological control of lepidopteran pests. Its performance in the field depends on floral resources that provide nutrition. Flowering plants provide nectar, pollen, and odor that influence the behavior of parasitoids. Identifying compatible flowering plants will be essential for enhancing the efficacy of *Trichogramma* sp. This study aims to determine the preferences and fitness of *Trichogramma* sp. on eight flowering plants: *Tagetes erecta*, *Arachis pintoi*, *Wedelia trilobita*, *Melampodium divaricatum*, *Lantana camara*, *Zinnia peruviana*, *Turnera subulata*, and *Turnera ulmifolia*. The tests included an olfactory test using a Y-tube olfactometer and analyzed with a chi-square test, and a test of the effect of flowering plants on the fitness of *Trichogramma* sp. imagoes, analyzed with ANOVA. The olfactory test showed that *Trichogramma* sp. preferred *A. pintoi*, *T. ulmifolia*, and *T. subulata*. *T. subulata* can increase the longevity of males and females by 2.4 and 2.3 times, respectively. In contrast, *T. ulmifolia* can increase the longevity of males by 2.4 times and females by 1.8 times compared to the negative control. Both species can also increase total fecundity and imago emergence. These findings indicate that *T. subulata* and *T. ulmifolia* are promising flowering plants for improving *Trichogramma* sp. performance and can be used as companion plants in sustainable integrated pest management (IPM) systems, strengthening the conservation of natural enemies and supporting long-term pest control strategies.

Keywords: Biological control, conservation, insectary plants, olfactory, *Trichogramma* sp.

INTRODUCTION

Trichogramma sp. is an egg parasitoid of the order Hymenoptera used as a biological control agent (Navik et al. 2023; Sampaio et al. 2024). The potential of *Trichogramma* sp. in pest control is significant as it is polyphagous, commonly referred to as a generalist egg parasitoid (Wu et al. 2016; Ulya et al. 2023). Generalist egg parasitoids provide quick control by attacking eggs before pests develop into the larval stage, the most destructive phase for plants (Jin et al. 2021). *Trichogramma* sp. is widely used in pest control of the Lepidoptera order on economically valuable crops such as rice, corn, sugarcane, cotton, and other horticultural commodities (Xu et al. 2016; Sari et al. 2021). *Trichogramma* sp. is applied augmentatively (inundative or inoculative) annually in 40 countries (Pandi et al. 2021). However, it should be noted that most parasitoid of the order Hymenoptera are synovigenic, meaning that parasitoid imagoes require a food source to support their fitness and egg production (Barloggio et al. 2019). Access to suitable food sources is therefore essential to maintain imago longevity, fecundity, and effectiveness in the field. Nectar and pollen are critical for parasitoid imagoes and can significantly increase their longevity and parasitizing rates (Géneau et al. 2013; Mátray and Herz 2022). A study by Witting-Bissinger et al. (2008) showed that *Trichogramma* sp. performed better and lived longer when provided with nectar and pollen compared to water alone. This emphasizes the importance of floral resources in enhancing the efficiency of biological control.

Flowering plants can provide food sources for imago parasitoid (Balzan et al. 2016). They offer nectar, pollen, and volatile compounds that attract and sustain parasitoid populations. Flowering plants also positively influence biological control agents by supplying energy, increasing longevity, and enhancing parasitizing capacity (Arnó et al. 2018; Pandey et al. 2018; Fataar et al. 2019). Parasitoids generally perform more efficiently when such floral resources are readily available (Patt and Rohrig 2017). However, not all flowering plants are suitable for parasitoids. Odor, nectar, and pollen suitability, as well as accessibility, are factors that determine the suitability of flowering plants for parasitoids (Fiedler et al. 2008; Wäckers and Van Rijn 2012). For example, *Rorippa indica* and *Apium graveolens* were preferred by *Diadegma semiclausum* and improved its fitness, while *Portulaca oleracea* was not (Asmoro et al. 2021). Similarly, *Cotesia rubecula* prefers *Centaurea cyanus* over *Vicia sativa* and *Fagopyrum esculentum* (Fataar et al. 2019). The difficulty of accessing suitable flowering plants will cause parasitoids to focus on finding food sources rather than controlling pests on plants (Webster and Cardé 2017). Therefore, selecting compatible flowering plants is critical to attract biological control agents and enhance their fitness (Foti et al. 2017). These considerations highlight that the choice of

flowering plants is not only a matter of nutrition but also affects the behavioral ecology of parasitoids in crop fields.

However, current agricultural practices are dominated by monoculture systems with few flowering resources, which impacts biological control (Arnó et al. 2018). Despite the recognized benefits of flowering plants for biological control, research on their interaction with *Trichogramma* sp. particularly in Southeast Asia, remains limited. The tropical floral presents diverse options that could support parasitoid populations, yet few studies have evaluated their effectiveness. Understanding which local flowering plants can enhance adult survival, longevity, and reproductive capacity of *Trichogramma* sp. is crucial for improving IPM strategies in these agricultural systems. Therefore, this study aims to identify flowering plants that are beneficial in attracting the presence and influencing the fitness of the *Trichogramma* sp. egg parasitoid. The results are expected to provide recommendations for flowering plants that align with their preferences and enhance the fitness of *Trichogramma* sp. thereby supporting biological control and serving as a form of conservation in the field.

MATERIALS AND METHODS

Equipment

The equipment used in this study consisted of laboratory instruments, behavioral test devices, and supporting tools. Laboratory instruments included an autoclave, UV lamp, stereoscopic microscope and digital caliper. Behavioral assays were conducted using a Y-tube olfactometer connected to an air pump (model 9970, JEBO Co. China) with activated charcoal filters. Supporting tools included reaction tubes, Petri dishes, brushes, acrylic cages, and software (IBM SPSS 25 and OriginLab 2024) for data analysis and visualization.

Propagation of flowering plants

The criteria for flowering plants used were plants commonly found in various ecosystems and reported to be attractive to biological control agents (adapted from Adedipe and Park (2010)). Flowering plants were grown from seeds at the Plant and Natural Medicine Laboratory, Universitas Jember. Seeds were sown in pot trays and then transferred to polybags with a planting medium composition of soil, husks, and compost (1:1:1). The plants were checked daily and watered until they flowered. The flowering plants used in the study included eight species: *Tagetes erecta*, *Arachis pintoi*, *Melampodium divaricatum, Lantana camara Wedelia trilobita*, *Zinnia peruviana*, *Turnera subulata*, and *Turnera ulmifolia*.

Rearing of *Corcyra cephalonica*

Corcyra cephalonica eggs were obtained from the Sukosari Research Center of PTPN XI Jatiroto, Lumajang. *C. cephalonica* was propagated on a medium of coarse corn bran and rice with a composition of (1:2) that was sterilized using an autoclave (Ulya et al. 2023). The medium was placed in a 40 cm x 30 cm x 15 cm plastic box, and *C. cephalonica* eggs were placed on the surface of the medium. The box was covered with gauze and placed in a storage room until the imago emerged. The room temperature was 25±2°C, and the humidity was 76%. The imago that emerged was placed in an egg-laying tube. The eggs were harvested after 24 hours using a brush. The eggs were collected in a Petri dish and stored in a refrigerator. *C. cephalonica* egg plates were made using 1 cm x 4 cm manila paper; the paper's surface was coated with glue, and the eggs were scattered on the surface of the plate. The egg plates were exposed to UV light using the method of Edwin et al. (2016) for 9 minutes to sterilize the *C. cephalonica* embryos without altering the nutrients in the eggs before they were used as hosts for *Trichogramma* sp.

Rearing of *Trichogramma* sp.

Eggs of *C. cephalonica* parasitized by *Trichogramma* sp. were obtained from the Sukosari Research Center of PTPN XI Jatiroto, Lumajang, East Java, Indonesia. According to Raven and Nahrung (2020), *Trichogramma* sp. was reared in reaction tubes with honey provided as food for the imago. Unparasitized *C. cephalonica* eggs were placed in tubes. The tubes were covered with gauze and secured with rubber bands. The temperature was maintained at 25±2°C and the humidity at 76%. Parasitizing was conducted for 24 hours. Parasitized eggs turned black. *Trichogramma* sp. imagoes will appear 3-4 days after the color change. The newly emerged *Trichogramma* sp. imagoes were used in the test. The sex of the parasitoids was observed under a stereoscopic microscope using a fine brush, distinguishing males and females based on antenna morphology (Nascimento et al. 2021).

Olfactory test of *Trichogramma* sp. imago on flowering plants

Testing the olfactory response of *Trichogramma* sp. imagoes to flowering plants using a Y-tube olfactometer. Female imagoes were used in the test (Barloggio et al. 2019), as female imagoes directly control pests. The testing method was based on Belz et al. (2013) with modifications. Each arm of the glass Y-tube olfactometer was connected to an odor source chamber containing flowering plants. The odor chambers were connected to an air delivery system supplied by an air pump (model 9970, JEBO Co. China) at a calibrated airflow rate of 1000 mL/min. The air pump, which specifically has two air outlet channels. These two channels are designed to release airflow at the same rate and are equipped with flow rate control, allowing for adjustment and calibration of the airflow before the experiment is conducted. Air was filtered through activated charcoal before entering the odor chambers to maintain purity. The test was conducted at a room temperature of 25±2°C and a humidity of 76%. Female *Trichogramma* sp. imagoes were placed at the end of the Y-tube olfactometer. The imagoes were given 10 minutes; if they did not choose a scent source after 10 minutes, they were considered unresponsive and replaced with new individuals. The testing consisted of two experiments: flowers with air and flowers with flowers. The flowers with air experiment utilized the best flowering plants based on their results. Each experimental set consisted of 15 randomly selected

females, with total samples of flowers with air n: 120 and flowers with flowers n: 90. After each test, the Y-tube and connecting parts were cleaned with 90% ethanol and dried to eliminate residual odors.

Measurement of *Trichogramma* sp. and flower morphology

Morphological measurements were conducted to determine the accessibility of *Trichogramma* sp. to flowers. Morphological measurement parameters were adapted from Vattala et al. (2006). *Trichogramma* sp. imagoes were frozen and placed under a stereoscopic microscope with 40x magnification, then head width was measured using Image Raster software. Corolla aperture in each flower that showed high attractiveness in the olfactory test were measured using a digital caliper.

Tests the effect of flowering plants on the fitness of *Trichogramma* sp.

The test aims to determine the effect of flowering plants as food sources on the fitness of *Trichogramma* sp. imagoes. The flowering plants in this experiment showed high attractiveness in previous olfactory tests. The testing method refers to Witting-Bissinger et al. (2008), which has been modified. Each flower was placed in a tube with a diameter of 6 cm and a height of 10 cm (Figure 1). A pair of *Trichogramma* sp. imagoes was placed in the tube. Fifty *C. cephalonica* eggs were placed in the tube and replaced daily until the imagoes died. Honey was used as a positive control, while the negative control had no additional food source. Honey was dripped into the tube wall using a needle at six points with a diameter of less than 2 mm. The room temperature was 25±2°C, and the humidity was 76%. The fitness parameters observed were the longevity of the imago, total fecundity, and the emergence of the imago. Each treatment consisted of five replicates, with one pair of *Trichogramma* sp. imagoes per replicate (n: 5 pairs per treatment) selected at random.

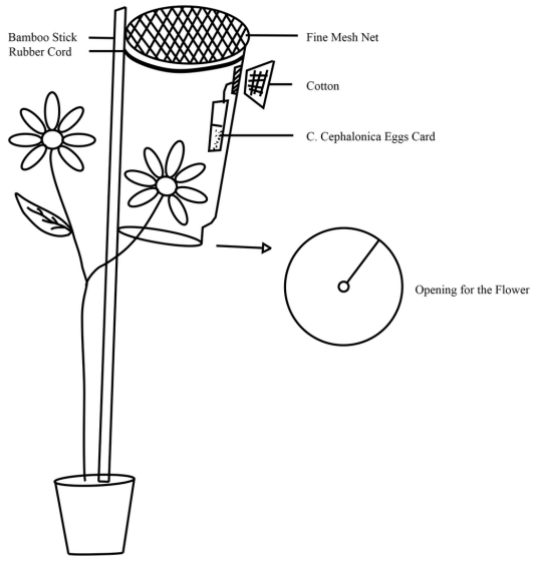

Figure 1. Set up of the cage used to test the effect of flowering plants on the fitness of *Trichogramma* sp.

Data analysis

Analysis of significant differences in the preference of odor sources in flowers with air and flowers with flowers olfactory tests was conducted using the chi-square test (χ^2). Data analysis of the longevity of *Trichogramma* sp. imagoes, total fecundity, and emergence of imagoes was conducted using ANOVA and post hoc analysis using Duncan's Multiple Range Test (DMRT) at a 5% level in IBM SPSS 25 software. Data on the longevity of *Trichogramma* sp. imagoes was visualized using the Kaplan-Meier curve in OriginLab software.

RESULTS AND DISCUSSION

Olfactory test of *Trichogramma* sp. imago on flowering plants

Flower with air experiments

Female *Trichogramma* sp. imagoes in flowers with air olfactory test preferred odor sources in several flowering plants rather than air. The percentage shows that *T. subulata* had the highest preference response (P<0.01), followed by *T. ulmifolia*, *T. erecta*, and *A. pintoi* (P<0.05). The highest percentage of response to air odor was found in *L. camara* and *W. trilobita* (P<0.05) (Figure 2).

The flowers with air olfactory test analysis results showed that female *Trichogramma* sp. imagoes preferred the odor of flowering plants (*T. subulata*, *T. ulmifolia*, *T. erecta*, and *A. pintoi*) rather than air. This preference indicates that the flowering plants used have the potential to attract *Trichogramma* sp. This is important as biological control programs need to attract natural enemies to agricultural fields using natural resources, such as floral scents (Balmer et al. 2014). The attraction of parasitoids is likely mediated by volatile compounds emitted from flowers. According to Fataar et al. (2019), parasitoids in searching for food sources can be influenced by olfactory cues and the odor of flowering plants. Food sources found in flowering plants include nectar and pollen (Géneau et al. 2013). Nectar and pollen are part of the flower, which also contains volatile compounds released by the plant (Raguso 2004; Desurmont et al. 2020). The olfactory organs of parasitoids can detect volatile compounds from a distance. This contrasts with visual signals, which are detected from shorter distances. The chromatic vision resolution of parasitoids is restricted, allowing them to find and distinguish targets only at close range (de Ibarra et al. 2015). Therefore, flowering plants that emit strong and detectable volatile cues are more likely to attract parasitoids effectively. The intensity and combination of volatile cues likely influence detectability and antennal stimulation, thereby contributing to the differences in preference among odor sources. Chen et al. (2020) further stated that volatile compounds can have a positive effect as attractants or an adverse effect, such as repelling and driving away parasitoids or acting as repellents.

Flower with flower experiments

The flowers with flowers olfactory test showed significant differences in odor source preferences in *A. pintoi* (P<0.05),

T. ulmifolia ($P<0.05$), and *T. subulata* ($P<0.01$) when compared to *T. erecta*. However, there were no significant differences between *T. ulmifolia* and *A. pintoi*, *A. pintoi* and *T. subulata*, and *T. subulata* and *T. ulmifolia* (Figure 3).

In the flowers with flowers olfactory test, *T. subulata* showed a high preference response, while *T. erecta* showed a low preference. This difference in preference might be influenced by the quality and quantity of volatile compounds released by the plants. Volatile emission profiles can enhance detectability and stimulate antennal receptors in parasitoids, affecting orientation behavior and foraging efficiency. According to studies by Belz et al. (2013), the lack of preference for *Fagopyrum esculentum* is due to the low quality of volatile compounds released compared to *Centaurea cyanus* and *Iberis amara*. This causes the compounds to be less detectable by *Microplitis mediator* (Hymenoptera: Braconidae). Another factor is that the volatile compounds in *F. esculentum* are lower in quantity when compared to *C. cyanus* and *I. amara*, even though they are of the same quality. According to Bianchi and Wäckers (2008), flower attractiveness is important when selecting flowering plants. Selecting suitable flowering plants implies that they can function as attractants to lure parasitoids that are biological control agents (Turlings and Erb 2018). Furthermore, the overall strength and combination of volatile cues may enhance olfactory perception, allowing parasitoids to detect and respond more effectively to attractive flowers. This highlights that both qualitative and quantitative aspects of floral scent play critical roles in mediating *Trichogramma* sp. attraction and foraging behavior.

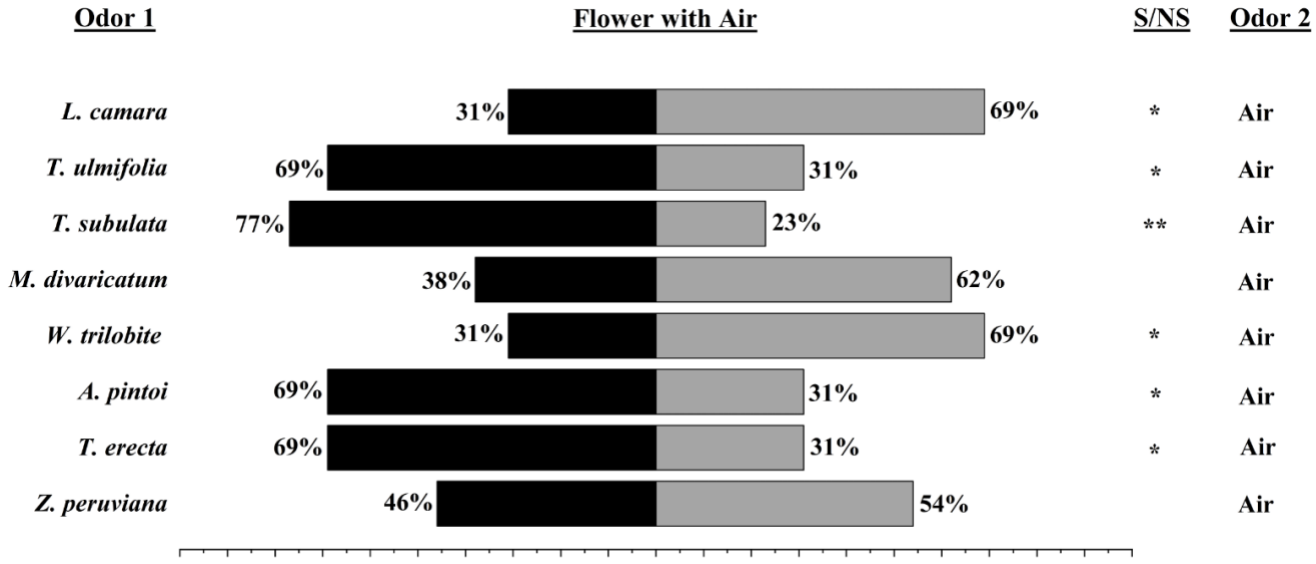

Figure 2. Olfactory response of *Trichogramma* sp. in flowers with air experiments. Pearson's χ^2 test, **: $P<0.01$, *: $P<0.05$

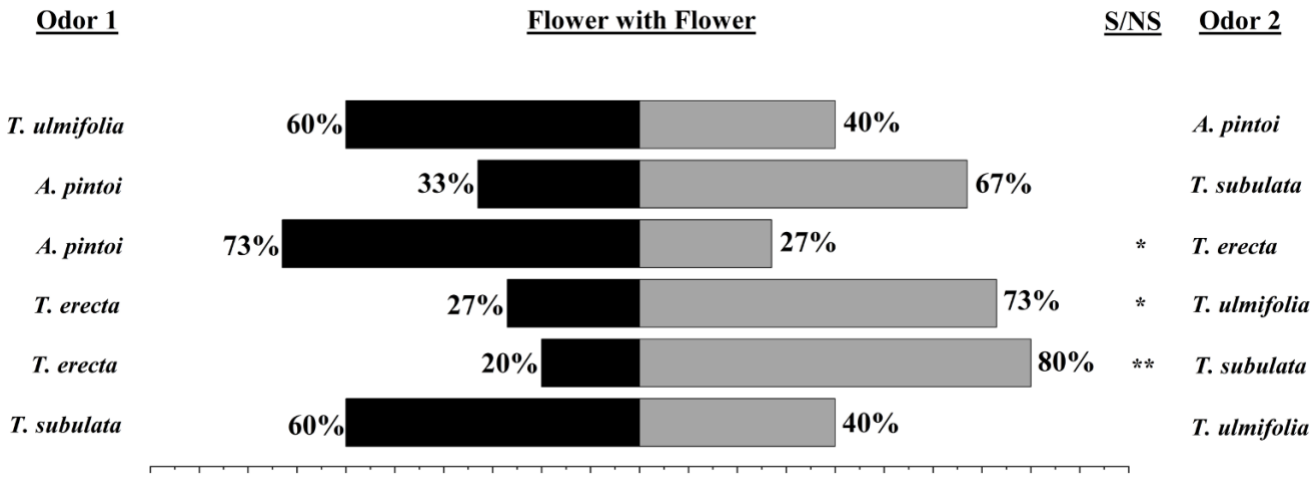

Figure 3. Olfactory response of *Trichogramma* sp. in flowers with flower experiments. Pearson's χ^2 test, **: $P<0.01$, *: $P<0.05$

Measurement of Trichogramma *sp. and flower morphology*

Measurements showed that *Trichogramma* sp. had an average head width of 0.22±0.04 mm. Corolla aperture ranged from 1.35±0.41 mm (*A. pintoi*) to 11.33±0.36 mm (*T. ulmifolia*) (Figure 4). *T. subulata* and *T. ulmifolia* have a broader flower structure than *A. pintoi*. All three flowers are theoretically accessible to parasitoids based on the width of the head of *Trichogramma* sp. The accessibility of parasitoids to food sources is closely related to flower morphology; therefore, flower morphology plays a role in supporting the survival of *Trichogramma* sp. imagoes (Nafziger Jr and Fadamiro 2011; Wäckers and Van Rijn 2012). Flowers with more open structures, such as *T. subulata* and *T. ulmifolia*, are thought to provide better accessibility to food sources and provide microhabitat conditions that support parasitoid activity (van Rijn and Wäckers 2016; Asmoro and Winasa 2021). Open corolla structures may also reduce handling time, allowing parasitoids to feed more efficiently and allocate energy to reproduction. This factor makes it easy for parasitoids to feed on nectar or pollen in these flowers.

Tests the effect of flowering plants on the fitness of *Trichogramma* sp.

Longevity of imago Trichogramma *sp.*

The flowering plants used in the test were three plants with significant responses in the flowers with flowers olfactory test. The negative control treatment showed the lowest longevity of the imago of *Trichogramma* sp. followed by *A. pintoi*. The positive control treatment showed the highest longevity. *T. subulata* and *T. ulmifolia* showed similar results in males but different results in females (Male: F: 22.462, df: 4, P<0.01; Female: F: 19.333, df: 4, P<0.01) (Table 1).

The results showed that the treatment of flowering plants overall had a better effect on increasing *Trichogramma* sp. imago's longevity than the negative control. However, this effect did not exceed the effect of the positive control. The positive effect of flowering plants on the longevity of *Trichogramma* sp. imago was also evident from the probability of survival (Figure 5).

Table 1. Longevity of imago *Trichogramma* sp. in flowering plant treatment

Treatments	Sex (Mean±SD)	
	Male	Female
Negative control	1.4±0.55 a	1.8±0.45 a
Positive control	3.8±0.45 b	4.6±0.55 c
Arachis pintoi	1.8±0.45 a	2.4±0.55 a
Turnera subulata	3.4±0.55 b	4.2±0.45 c
Turnera ulmifolia	3.4±0.55 b	3.4±0.89 b

Note: Numbers in the same column followed by the same letter indicate no significant difference based on Duncan's test at α: 5%

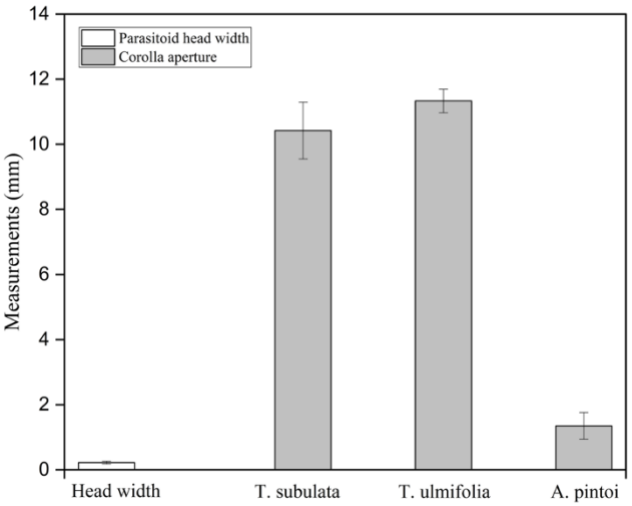

Figure 4. Measurement of *Trichogramma* sp. and flower morphology

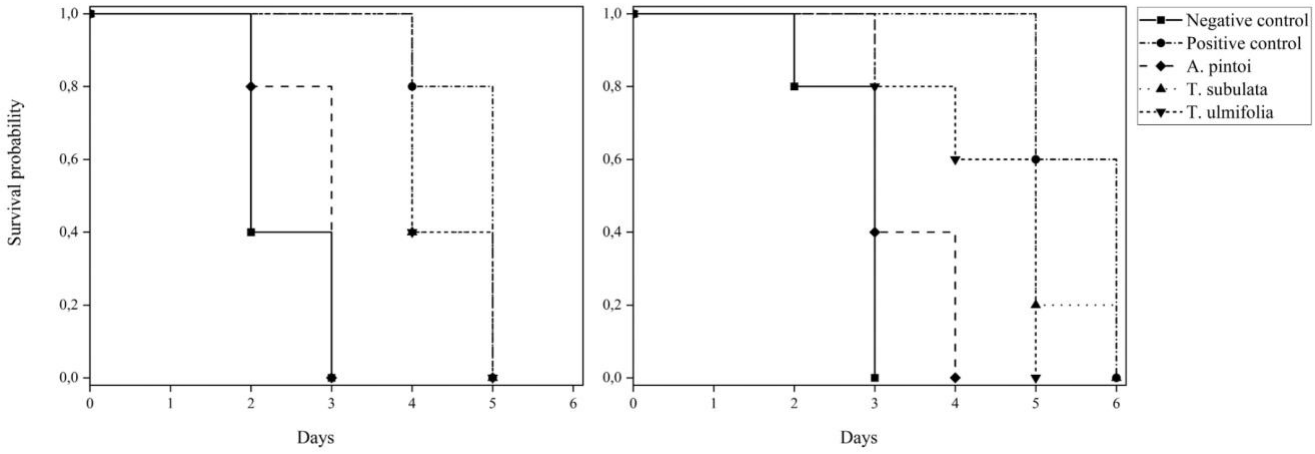

Figure 5. Survival probability of *Trichogramma* sp. imago (A: Male, B: Female)

The *T. subulata* treatment increased the longevity of imagoes to 2.4 times (males) and 2.3 times (females) that of the negative control, while the *T. ulmifolia* treatment increased longevity to 2.4 times (males) and 1.8 times (females). These results suggest a link between corolla accessibility and imago longevity: flowers with larger corolla openings allow easier access to nectar and pollen, directly contributing to extended survival. Food sources, including nectar, pollen, and other carbohydrate sources, can increase the longevity of parasitoids in laboratory and field tests (Asmoro et al. 2021). Global comparisons show similar trends, the longevity of the parasitoid *Diaeretiella rapae* (Hymenoptera: Braconidae) can increase by 3.4 times with *Leptospermum* sp. as a food source, *Diadegma semiclausum* can increase by 4.3 times with *Myoporum parvifolium* as a food source, and *Cotesia glomerata* (Hymenoptera: Braconidae) can increase by 6 times with *Grevillea* sp. as a food source compared to water as a control (Pandey et al. 2018). Nectar and pollen contain water, carbohydrates, and amino acids required by parasitoids (Heil 2011). Carbohydrates particularly influence the longevity of parasitoids, while fats and proteins are needed in egg production or maturation (Williams III and Roane 2007; Benelli et al. 2017). Buckwheat plants can enhance the fitness of the parasitoid *Microctonus hyperodae* (Hymenoptera: Braconidae) and have a higher sucrose/(glucose+fructose) ratio compared to phacelia, coriander, and white mustard (Vattala et al. 2006). Moreover, the quantity and composition of nutrients contained in each flower are different, leading to differences in the benefits obtained by parasitoids from different flowers (Irvin and Hoddle 2021).

The presence of nectar and pollen in flowers plays an important role as a source of nutrition that affects the survival of parasitoids (Balzan et al. 2016; Mátray and Herz 2022). Parasitoids typically emerge from their hosts with limited energy reserves, enabling them to survive for only 1-2 days without food intake (Wäckers 2004; Asmoro et al. 2021). *Trichogramma* sp. imagoes have an average longevity of 0.8±0.6 (Mean±SE) without access to food sources such as nectar or honey A study conducted by (Witting-Bissinger et al. 2008). This condition causes the parasitoid to prioritize searching for food sources after emerging from its host before switching to host search (Takasu and Lewis 1995; Asmoro et al. 2021). This underscores the ecological importance of providing flowering plants in crop systems to sustain parasitoid populations.

Total fecundity and imago emergence

The negative control treatment showed the lowest total fecundity and imago emergence, followed by *A. pintoi*. The positive control treatment showed the highest total fecundity and imago emergence, followed by *T. subulata* and *T. ulmifolia* (Total fecundity: F: 64.397, df: 4, P<0.01; Total imago emergence: F: 64.548, df: 4, P<0.01) (Table 2).

Positive control treatments used honey, nectar, or pollen from flowering plants, providing an important food source for parasitoids. This food source improved the fitness of parasitoids, as reflected in higher total fecundity compared to negative control treatments without food sources. The results highlight that flower morphology and nectar accessibility directly influence reproductive output, consistent with previous studies where flower structure and nutrient content affect parasitoid fecundity. Berndt and Wratten (2005) investigated the effect of sweet alyssum flowers (*Lobularia maritima*) on the leaf miner parasitoid *Dolichogenidea tasmanica*, showing a significant increase in total fecundity when flowers were present compared to when they were absent. Leatemia et al. (1995) found similar results when investigating *Trichogramma minutum* (Hymenoptera: Trichogrammatidae) provided with different food sources. Total fecundity increased significantly in females fed honey compared to those not fed. *Trichogramma* sp. is synovigenic parasitoids, which require continuous egg maturation during their reproductive period (Boivin 2010; Wang et al. 2025). Therefore, the presence of nectar or pollen as nutritional source helps extend the parasitoid's longevity and enhances fecundity and reproductive capacity (Zhu et al. 2015; Barloggio et al. 2019).

The emergence of female and male imago

The negative control treatment showed the lowest total imago emergence, followed by *A. pintoi*. The positive control treatment showed the highest total imago emergence. *T. subulata* and *T. ulmifolia* showed no significant difference in total emergence (Female: F: 40.473, df: 4, P<0.01; Male: F: 39.341, df: 4, P<0.01). The percentage of female imagoes showed no significant differences between most treatments, although there were variations in values (F: 1.522, df: 4, P>0.05). The negative control tended to produce more females than other treatments, but only differed significantly from some treatments (Table 3).

Table 2. Total fecundity and imago emergence

Treatments	Total (Mean±SD)	
	Fecundity	Imago emergence
Negative control	20.00±3.67 a	16.20±3.03 a
Positive control	56.20±3.77 d	47.80±3.35 d
Arachis pintoi	29.20±5.63 b	23.40±4.04 b
Turnera subulata	47.20±3.70 c	39.20±3.56 c
Turnera ulmifolia	46.00±3.32 c	37.60±3.71 c

Note: Numbers in the same column followed by the same letter indicate no significant difference based on Duncan's test at α:5%

Table 3. The emergence of female and male imago

Treatments	Total imago emergence (Mean±SD)		Percentage of females (%) (Mean±SD)
	Female	Male	
Negative control	9.60±1.95 a	6.60±1.52 a	59.25±4.57 b
Positive control	24.80±1.92 d	23.00±2.12 d	51.91±2.34 a
A. pintoi	12.80±3.03 b	10.60±1.82 b	54.47±5.15 ab
T. subulata	20.40±2.07 c	18.80±2.05 c	52.05±2.63 a
T. ulmifolia	20.20±1.64 c	17.40±3.65 c	54.06±6.23 ab

Note: Numbers in the same column followed by the same letter indicate no significant difference based on Duncan's test at α:5%

The success of biological control conservation programs depends on the potential reproduction rate, which is the number of female imago offspring (Kean et al. 2003). The percentage of female *Trichogramma* sp. imago emergence was good in the negative control treatment, which was 59.25±4.57. The positive control treatment and flowering plants had a percentage of female imago emergence of 51.91±2.34 to 54.47±5.15. Witting-Bissinger et al. (2008) stated that this difference could be influenced by sperm depletion in older females. *Trichogramma* sp. in the negative control treatment showed a short longevity and low total fecundity. In contrast, the positive control treatment and flowering plants showed a long longevity and high total fecundity. This shows that although the percentage of female imago emergence was good in the negative control treatment, the total female offspring was highest in the positive control (24.80±1.91), followed by *T. subulata* (20.40±2.07) and *T. ulmifolia* (20.20±1.63).

The availability of floral resources directly affects the longevity of parasitoids, their fecundity, and the number of female offspring, indirectly enhancing their performance in pest control (Foti et al. 2019; Irvin and Hoddle 2021). Parasitoids *Cotesia rubecula* (Hymenoptera: Braconidae) that lack food sources spend more time searching for food sources than hosts, while parasitoids that are fed more spend more time searching for hosts (Witting-Bissinger et al. 2008). Female parasitoids *T. cacoeciae*, *T. dendrolimi*, and *T. evanescens* fed honey as a food source spend more time parasitizing host eggs than females without honey (Khafagi and Hassan 2001).

In conclusion, this study shows that *Trichogramma* sp. has an olfactory preference for *A. pintoi*, *T. subulata*, and *T. ulmifolia*. However, flower morphology alone does not necessarily translate into increased fitness. Only *T. subulata* and *T. ulmifolia* significantly enhanced longevity, fecundity, and imago emergence, highlighting that effective floral resources require a combination of detectable odor, accessible morphology, and nutritional content. Wäckers and van Rijn (2012) state that positive interactions between parasitoids and flowering plants are described when parasitoids find flowering plants and obtain benefits from the plants. These findings suggest that *T. subulata* and *T. ulmifolia* have strong potential as companion plants in integrated pest management programs, contributing both to the conservation of biological control agents and to sustainable crop protection. Future research should validate these functional relationships under field conditions, assess the long-term ecological impacts, and explore interactions with other natural enemies to ensure practical applicability in diverse agricultural landscapes.

ACKNOWLEDGEMENTS

We want to express our sincere gratitude to the Institute for Research and Community Service (*Lembaga Penelitian dan Pengabdian kepada Masyarakat*) of Universitas Jember, Indonesia, for supporting this research through the Research Group (KeRis-DiMas) 2024 grant.

REFERENCES

Adedipe F, Park YL. 2010. Visual and olfactory preference of *Harmonia axyridis* (Coleoptera: Coccinellidae) adults to various companion plants. J Asia-Pacific Entomol 13 (4): 319-323. DOI: 10.1016/j.aspen.2010.07.004.

Arnó J, Oveja MF, Gabarra R. 2018. Selection of flowering plants to enhance the biological control of *Tuta absoluta* using parasitoids. Biol Control 122: 41-50. DOI: 10.1016/j.biocontrol.2018.03.016.

Asmoro PP, Dadang D, Pudjianto P, Winasa IW. 2021. Screening insectary refugia plants that increase the performance of *Diadegma semiclausum* Hellen (Hymenoptera: Ichneumonidae) against diamondback moth larvae. Biodiversitas 22 (10): 4254-4260. DOI: 10.13057/biodiv/d221016.

Asmoro PP, Winasa IW. 2021. The effect of flower morphology on the longevity of *Diadegma semiclausum* (Hymenoptera: Ichneumonidae). IOP Conf Ser: Earth Environ Sci 694 (1): 012049. DOI: 10.1088/1755-1315/694/1/012049.

Balmer O, Géneau CE, Belz E, Weishaupt B, Förderer G, Moos S, Ditner N, Juric I, Luka H. 2014. Wildflower companion plants increase pest parasitation and yield in cabbage fields: Experimental demonstration and call for caution. Biol Control 76: 19-27. DOI: 10.1016/j.biocontrol.2014.04.008.

Balzan MV, Bocci G, Moonen A. 2016. Utilisation of plant functional diversity in wildflower strips for the delivery of multiple agroecosystem services. Entomologia Experimentalis et Applicata 158 (3): 304-319. DOI: 10.1111/eea.12403.

Barloggio G, Tamm L, Nagel P, Luka H. 2019. Selective flowers to attract and enhance *Telenomus laeviceps* (Hymenoptera: Scelionidae): A released biocontrol agent of *Mamestra brassicae* (Lepidoptera: Noctuidae). Bull Entomol Res 109 (2): 160-168. DOI: 10.1017/S0007485318000287.

Belz E, Kölliker M, Balmer O. 2013. Olfactory attractiveness of flowering plants to the parasitoid *Microplitis mediator*: potential implications for biological control. BioControl 58: 163-173. DOI: 10.1007/s10526-012-9472-0.

Benelli G, Giunti G, Tena A, Desneux N, Caselli A, Canale A. 2017. The impact of adult diet on parasitoid reproductive performance. J Pest Sci 90: 807-823. DOI: 10.1007/s10340-017-0835-2.

Berndt LA, Wratten SD. 2005. Effects of *Alyssum* flowers on the longevity, fecundity, and sex ratio of the leafroller parasitoid *Dolichogenidea tasmanica*. Biol Control 32: 65-69. DOI: 10.1016/j.biocontrol.2004.07.014.

Bianchi FJ, Wäckers FL. 2008. Effects of flower attractiveness and nectar availability in field margins on biological control by parasitoids. Biol Control 46 (3): 400-408. DOI: 10.1016/j.biocontrol.2008.04.010.

Boivin G. 2010. Reproduction and immature development of egg parasitoids. In: Consoli FL, Parra JRP, Zucchi RA (eds). Egg Parasitoids in Agroecosystems with Emphasis on *Trichogramma*. Springer, Netherlands.

Chen Y, Mao J, Reynolds OL, Chen W, He W, You M, Gurr GM. 2020. Alyssum (*Lobularia maritima*) selectively attracts and enhances the performance of *Cotesia vestalis*, a parasitoid of *Plutella xylostella*. Sci Rep 10 (1): 6447. DOI: 10.1038/s41598-020-62021-y.

de Ibarra NH, Langridge KV, Vorobyev M. 2015. More than colour attraction: Behavioural functions of flower patterns. Curr Opin Insect Sci 12: 64-70. DOI: 10.1016/j.cois.2015.09.005.

Desurmont GA, Von Arx M, Turlings TC, Schiestl FP. 2020. Floral odors can interfere with the foraging behavior of parasitoids searching for hosts. Front Ecol Evol 8: 148. DOI: 10.3389/fevo.2020.00148.

Edwin ES, Vasantha-Srinivasan P, Ponsankar A, Thanigaivel A, Selin-Rani S, Mankin RW, Senthil-Nathan S, Kalaivani K, Murali-Baskaran RK, Duraipandiyan V. 2016. Effects of temperature and nonionizing ultraviolet radiation treatments of eggs of five host insects on production of *Trichogramma chilonis* Ishii (Hymenoptera: Trichogrammatidae) for biological control applications. J Asia-Pacific Entomol 19 (4): 1139-1144. DOI: 10.1016/j.aspen.2016.09.011.

Fataar S, Kahmen A, Luka H. 2019. Innate and learned olfactory attraction to flowering plants by the parasitoid *Cotesia rubecula* (Marshall, 1885) (Hymenoptera: Braconidae): Potential impacts on conservation biological control. Biol Control 132: 16-22. DOI: 10.1016/j.biocontrol.2019.01.009.

Fiedler AK, Landis DA, Wratten SD. 2008. Maximizing ecosystem services from conservation biological control: The role of habitat management. Biol Control 45 (2): 254-271. DOI: 10.1016/j.biocontrol.2007.12.009.

Foti MC, Peri E, Wajnberg E, Colazza S, Rostás M. 2019. Contrasting olfactory responses of two egg parasitoids to buckwheat floral scent are reflected in field parasitism rates. J Pest Sci 92: 747-756. DOI: 10.1007/s10340-018-1045-2.

Foti MC, Rostás M, Peri E, Park KC, Slimani T, Wratten SD, Colazza S. 2017. Chemical ecology meets conservation biological control: Identifying plant volatiles as predictors of floral resource suitability for an egg parasitoid of stink bugs. J Pest Sci 90: 299-310. DOI: 10.1007/s10340-016-0758-3.

Géneau CE, Wäckers FL, Luka H, Balmer O. 2013. Effects of extrafloral and floral nectar of *Centaurea cyanus* on the parasitoid wasp *Microplitis mediator*: Olfactory attractiveness and parasitization rates. Biol Control 66 (1): 16-20. DOI: 10.1016/j.biocontrol.2013.02.007.

Heil M. 2011. Nectar: Generation, regulation and ecological functions. Trends Plant Sci 16: 191-200. DOI: 10.1016/j.tplants.2011.01.003.

Irvin NA, Hoddle MS. 2021. The effects of floral nectar, extrafloral nectar and hemipteran honeydew on the fitness of *Tamarixia radiata* (Hymenoptera: Eulophidae), a parasitoid of *Diaphorina citri*. Biol Control 163: 104753. DOI: 10.1016/j.biocontrol.2021.104753.

Jin T, Lin Y, Ma G, Liu J, Hao Z, Han S, Peng Z. 2021. Biocontrol potential of *Trichogramma* species against *Spodoptera frugiperda* and their field efficacy in maize. Crop Prot 150: 105790. DOI: 10.1016/j.cropro.2021.105790.

Kean J, Wratten S, Tylianakis J, Barlow N. 2003. The population consequences of natural enemy enhancement, and implications for conservation biological control. Ecol Lett 6 (7): 604-612. DOI: 10.1046/j.1461-0248.2003.00468.x.

Khafagi W, Hassan SA. 2001. Studies on three species of *Trichogramma*. I. Foraging behaviour for food or hosts. J Appl Entomol 124: 145-149. DOI: 10.1046/j.1439-0418.2000.00454.x.

Leatemia JA, Laing JE, Corrigan JE. 1995. Effects of adult nutrition on longevity, fecundity, and offspring sex ratio of *Trichogramma minutum* Riley (Hymenoptera: Trichogrammatidae). Can Entomol 127 (2): 245-254. DOI: 10.4039/Ent127245-2.

Mátray S, Herz A. 2022. Flowering plants serve nutritional needs of *Ascogaster quadridentata* (Hymenoptera: Braconidae), a key parasitoid of codling moth. Biol Control 171: 104950. DOI: 10.1016/j.biocontrol.2022.104950.

Nafziger JTD, Fadamiro HY. 2011. Suitability of some farmscaping plants as nectar sources for the parasitoid wasp, *Microplitis croceipes* (Hymenoptera: Braconidae): effects on longevity and body nutrients. Biol Control 56 (3): 225-229. DOI: 10.1016/j.biocontrol.2010.11.005.

Nascimento PT, Fadini MA, Rocha MS, Souza CS, Barros BA, Melo JO, Von Pinho RG, Valicente FH. 2021. Olfactory response of *Trichogramma pretiosum* (Hymenoptera: Trichogrammatidae) to volatiles induced by transgenic maize. Bull Entomol Res 111 (6): 674-687. DOI: 10.1017/S0007485321000341.

Navik O, Yele Y, Kedar SC, Sushil SN. 2023. Biological control of fall armyworm *Spodoptera frugiperda* (JE Smith) using egg parasitoids, *Trichogramma* species (Hymenoptera: Trichogrammatidae): A review. Egypt J Biol Pest Control 33 (1): 118. DOI: 10.1186/s41938-023-00759-z.

Pandey S, Rahman A, Gurr GM. 2018. Australian native flowering plants enhance the longevity of three parasitoids of brassica pests. Entomol Exp Appl 166 (4): 265-276. DOI: 10.1111/eea.12668.

Pandi GG, Ullah F, Patil NB, Sahu M, Adak T, Pokhare S, Yadav MK, Mahendiran A, Mittapelly P, Desneux N. 2021. Performance of *Trichogramma japonicum* under field conditions as a function of the factitious host species used for mass rearing. PLos One 16 (8): e0256246. DOI: 10.1371/journal.pone.0256246.

Patt JM, Rohrig E. 2017. Laboratory evaluations of the foraging success of *Tamarixia radiata* (Hymenoptera: Eulophidae) on flowers and extrafloral nectaries: Potential use of nectar plants for conservation biological control of Asian citrus psyllid (Hemiptera: Liviidae). Fla Entomol 100 (1): 149-156. DOI: 10.1653/024.100.0121.

Raguso RA. 2004. Why are some floral nectars scented? Ecology 85 (6): 1486-1494. DOI: 10.1890/03-0410.

Raven C, Nahrung HF. 2020. *Trichogramma* spp. as potential augmentative biocontrol agents of Poinciana looper, *Pericyma cruegeri* (Butler) (Lepidoptera: Noctuidae). Urban For Urban Green 50: 126656. DOI: 10.1016/j.ufug.2020.126656.

Sampaio F, Marchioro CA, Takahashi TA, Foerster LA. 2024. A new biocontrol agent against old enemies: The potential of *Trichogramma foersteri* for the control of *Spodoptera frugiperda* and *Spodoptera eridania*. Biol Control 192: 105504. DOI: 10.1016/j.biocontrol.2024.105504.

Sari L, Maryana N, Hidayat P. 2021. Biology and life table of *Trichogramma chilotraeae*, Egg parasitoids of *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae). IOP Conf Ser Earth Environ Sci 948 (1): 012044. DOI: 10.1088/1755-1315/948/1/012044.

Takasu K, Lewis WJ. 1995. Importance of adult food sources to host searching of the larval parasitoid *Microplitis croceipes*. Biol Control 5 (1): 25-30. DOI: 10.1006/bcon.1995.1003.

Turlings TC, Erb M. 2018. Tritrophic interactions mediated by herbivore-induced plant volatiles: Mechanisms, ecological relevance, and application potential. Ann Rev Entomol 63 (1): 433-452. DOI: 10.1146/annurev-ento-020117-043507.

Ulya Q, Muhlison W, Purnomo H, Sucipto I. 2023. Pengaruh pemberian media pakan *Corcyra Cephalonica* S. terhadap parasitasi *Trichogramma* sp. Jurnal Agrotek Tropika 12 (1): 138-145. DOI: 10.23960/jat.v12i1.6455. [Indonesian]

van Rijn PC, Wäckers FL. 2016. Nectar accessibility determines fitness, flower choice and abundance of hoverflies that provide natural pest control. J Appl Ecol 53: 925-933. DOI: 10.1111/1365-2664.12605.

Vattala HD, Wratten SD, Phillips CB, Wäckers FL. 2006. The influence of flower morphology and nectar quality on the longevity of a parasitoid biological control agent. Biol Control 39 (2): 179-185. DOI: 10.1016/j.biocontrol.2006.06.003.

Wäckers FL. 2004. Assessing the suitability of flowering herbs as parasitoid food sources: flower attractiveness and nectar accessibility. Biol Control 29 (3): 307-314. DOI: 10.1016/j.biocontrol.2003.08.005.

Wäckers FL, van Rijn PC. 2012. Pick and mix: Selecting flowering plants to meet the requirements of target biological control insects. In: Gurr GM, Wratten SD, Snyder WE, Read DMY (eds). Biodiversity and Insect Pests: Key Issues for Sustainable Management. CABI, Wallingford.

Wang J, Huang HX, Trumble JT, Wang C, Zhu ZY, Zang LS, Desneux N, Di N, Li YX. 2025. Ecological risks of cadmium-contaminated non-prey food on three *Trichogramma* egg parasitoids. J Pest Sci 98: 1519-1527. DOI: 10.1007/s10340-025-01888-0.

Webster B, Cardé RT. 2017. Use of habitat odour by host-seeking insects. Biol Rev 92 (2): 1241-1249. DOI: 10.1111/brv.12281.

Williams III L, Roane TM. 2007. Nutritional ecology of a parasitic wasp: Food source affects gustatory response, metabolic utilization, and survivorship. J Insect Physiol 53 (12): 1262-1275. DOI: 10.1016/j.jinsphys.2007.06.017.

Witting-Bissinger BE, Orr DB, Linker HM. 2008. Effects of floral resources on fitness of the parasitoids *Trichogramma exiguum* (Hymenoptera: Trichogrammatidae) and *Cotesia congregata* (Hymenoptera: Braconidae). Biol Control 47 (2): 180-186. DOI: 10.1016/j.biocontrol.2008.07.013.

Wu LH, Hoffmann AA, Thomson LJ. 2016. *Trichogramma* parasitoids for control of Lepidopteran borers in Taiwan: Species, life-history traits and *Wolbachia* infections. J Appl Entomol 140 (5): 353-363. DOI: 10.1111/jen.12263.

Xu J, Yang X, Lin Y, Zang L, Tian C, Ruan C. 2016. Effect of fertilized, unfertilized, and UV-irradiated hosts on parasitism and suitability for *Trichogramma* parasitoids. Entomol Exp Appl 161 (1): 50-56. DOI: 10.1111/eea.12485.

Zhu P, Wang G, Zheng X, Tian J, Lu Z, Heong KL, Xu H, Chen G, Yang Y, Gurr GM. 2015. Selective enhancement of parasitoids of rice Lepidoptera pests by sesame (*Sesamum indicum*) flowers. BioControl 60: 157-167. DOI: 10.1007/s10526-014-9628-1.