AGRIVITA Journal of Agricultural Science. 2024. 46(1): 78-95

AGRIVITA
Journal of Agricultural Science
www.agrivita.ub.ac.id

Comparative Study of Integrated Pest Management and Farmer's Standard Practices for Controlling Chrysanthemum Thrips under Plastic House

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ARTICLE INFO

Keywords:
Chrysanthemum
Economics
Integrated Pest Management
Plastic house
Thrips

Article History:
Received: December 28, 2022
Accepted: December 15, 2023

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ABSTRACT

Thrips is an important worldwide cause of severe damage to various host plants, especially chrysanthemums. Current management still relies on synthetic insecticides to control thrips. However, these pesticides harm the environment and promote thrips resistance. The study aimed to compare integrated pest management (IPM) and farmer's standard practices to control *Thrips parvispinus* on two chrysanthemum varieties and calculate the cost-benefit ratio of both pest control practices. Two chrysanthemum cultivars were planted in plastic houses to compare IPM and farmer's standard practices. The observed variables included thrips density, attack and damage rates, cut flower yield, and natural enemies abundance. Data were analyzed using ANOVA, and Tukey's HSD test identified significant differences at a 5% level. The results showed that the population of *T. parvispinus* nymphs was higher (78%) than adults. The highest adult thrips population emerges when chrysanthemums achieve the flowering phases. This study reveals that the control effects of IPM were not different from farmer's standard practices. A holistic approach integrating several management strategies successfully controlled the thrips population while producing high-quality crops with minimal aesthetic damage. The IPM strategy against thrips showed a competitive cost and reduced synthetic insecticide applications without decreasing the quality and productivity of chrysanthemums.

INTRODUCTION

Chrysanthemum (*Chrysanthemum morifolium* Ramat) is one of the attractive cut flowers that are in great demand by markets and consumers around the world (X.Chen et al., 2020). Chrysanthemums come in various sizes, shapes, and coloring hues, making them very popular with consumers (Ohmiya, 2018; Darras, 2021). In Indonesia, this crop grows widely in the highlands and is used as cut flowers and potted plants for decoration and landscape plants (Sanjaya et al., 2018). In the domestic market until now, chrysanthemums have been ranked first to replace roses as the most widely marketed fresh cut flowers (Statistics Indonesia, 2021). In practice, chrysanthemum cultivation in Indonesia is generally carried out in protected houses such as greenhouses or plastic houses (Budiarto et al., 2006; Sanjaya et al., 2018). Furthermore, chrysanthemum cultivation is usually a monoculture, and just a tiny proportion of plastic house construction has closed sides to keep pests from the surrounding area (Hutapea et al., 2021). These conditions are highly favorable for many pest species and threaten chrysanthemum plants because harmful pest species enter the plastic house. Thrips could penetrate the plastic house either directly through the opening side or indirectly through contaminated plant matter

ISSN: 0126-0537

Cite this as: Hutapea, D., Sartiami, D., Dadang, & Hidayat, P. (2024). Comparative study of integrated pest management and farmer's standard practices for controlling chrysanthemum thrips under plastic house. *AGRIVITA Journal of Agricultural Science, 46*(1), 78-95. http://doi.org/10.17503/agrivita.v46i1.4018

(Messelink et al., 2021; Silva-Castaño & Brochero, 2021). After the pest colonized inside the plastic house, the plant system provides ideal conditions for its growth and causes rapid population growth (Sutherland & Parrella, 2011). On the other hand, natural enemies of pests could also enter the plastic house and control pest populations that attack chrysanthemums (van Lenteren et al., 2020). However, such variations in the plastic house ecosystem have limited farmers' ability to predict pest suppression on their crops and pest control by natural enemies (Rhainds et al., 2005; Silva-Castaño & Brochero, 2021).

One insect pest that could impact the marketing quality of chrysanthemums and is considered a quarantine pest whose presence must be monitored is *Thrips parvispinus* Karny (Setyawan et al., 2016; Mouden et al., 2017). It is also known as a challenging to control pest due to its short life cycle, small size, difficult to recognize behavior and high female reproductive potential (Rhainds et al., 2005; Yusuf et al., 2010; Silva-Castaño & Brochero, 2021). In particular, females of *T. parvispinus* were able to produce offspring of 25 individuals in 11 days (Hutasoit et al., 2017). Thrips adults and nymphs are the most harmful because they insert their stylets into the tissues of chrysanthemum leaves, buds, and flowers (Reitz et al., 2020; Rogge & Meyhofer, 2021a). *T. parvispinus* has direct feeding and egg-laying activity in plant tissues, resulting in the malformation of affected plant parts (Steenbergen et al., 2018). The aesthetic damage could make chrysanthemums unmarketable (G. Chen et al., 2020; Reitz et al., 2020) and quarantine issues for international trade (Setyawan et al., 2016). In addition, their behavior that prefers to live in narrow crevices helps thrips avoid exposure to insecticides and natural enemies (Sutherland & Parrella, 2011; Reitz et al., 2020). Because of their low damage tolerance, synthetic insecticide applications have been the most commonly used technique for thrips management. Chrysanthemum growers heavily use insecticides; in some cases, spraying occurs 3-4 times per week (Hutapea et al., 2021). It has the potential to cause insecticide resistance and pose a significant risk to human health and the environment. Therefore, alternative crop protection methods are required, such as applying different control strategies in integrated pest management (Steenbergen et al., 2018).

Integrated pest management is a comprehensive strategy that employs multiple types of tactics to manage pests without disrupting the ecosystem (Mouden et al., 2017; van Lenteren et al., 2020. The approach pertains to enhancing the health of plants and includes cultural control, host plant resistance, biocontrol, continuous detection and monitoring, and chemical control (Daughtrey & Benson, 2005; Reitz et al., 2020). IPM approach provides for the actual needs of plants, minimizes the need for unnecessary regular applications of pesticides, and ensures that pesticides can be applied at the proper times of pests life cycles to optimize their efficacy (Pecenka et al., 2021). It has been demonstrated in various countries that employing IPM tactics helps farmers develop more sustainable chrysanthemum production systems. Among the IPM control tactics utilized for chrysanthemum production are the following: Application of entomopathogenic fungus (Brownbridge & Buitenhuis, 2019), resistant chrysanthemum cultivars (Rogge & Meyhofer, 2021b), natural enemies (van Lenteren et al., 2020; Lin et al., 2021), the yellow sticky trap (Rhainds et al., 2005), and silica fertilizers (Jeong et al., 2012), which could control and prevent the buildup of resistant thrips populations in chrysanthemum greenhouses. Thus, this approach simultaneously reduces environmental problems and improves worker health and safety (Brownbridge & Buitenhuis, 2019). In addition, the global market is increasingly demanding floriculture products with low chemical residues. It is evident from the willingness of consumers to pay more for cut flower products with environmentally friendly pest control practices (Shabozoi et al., 2011; Hassen, 2016).

Implementing environmental friendly pest management and other pest control strategies to substitute synthetic insecticides has become the primary program for sustainable agriculture in this century. As a result, the Indonesian government has established rules for integrated pest management techniques to be used in good agriculture practices for floriculture and sustainable agricultural cultivation systems (Undang-Undang No. 22, 2019). The development of IPM is also supported by the Directorate General of Horticulture program of the Indonesian Ministry of Agriculture, through the policy to encourage competitive and environmental friendly floriculture production. Thus, an integrated pest management approach to control thrips on chrysanthemums is critical to implementing government programs. The objective of the present study was to compare IPM practices and farmer's standard practices in controlling *Thrips parvispinus* on chrysanthemums under plastic house conditions.

This study reports not only on the thrips control effect of IPM versus farmer's standard practices but also on the costs-benefit ratio of the two practices.

MATERIALS AND METHODS

Research Site Location and Experimental Design

The field study was carried out in the plastic house of the Indonesian Ornamental Crops Research Institute (IOCRI), Cianjur, West Java (6^o 45' 34'' S, 107^o 3' 5'' E, elevation 1100 masl) from April to September 2021. The plastic house was internally divided into three experimental plots based on the treatment of control technique. A split-plot design with a randomized block design was used to carry out the study. The main plot was the chrysanthemum varieties, and the subplots were the control techniques. The variables tested in this experiment were control treatment: IPM, farmer's standard practice, and untreated as a subplot. The main plots were two varieties of chrysanthemum, namely 'Jimba' and 'Jayanti'. Each experimental plot was designed by installing a plastic partition as a barrier for each management technique. The experimental plots were isolated from each other to avoid the movement of insecticide spraying from one plot to another. Each experimental plot consisted of 30 plots with the size of 1 m x 1 m for each plot. The distance between plot was 0.5 meter. For IPM treatment, 270 basil seeds were planted in a single row in a pot surrounding the plot. In addition, 72 seroja species of ornamental pepper were planted in four rows and arranged evenly amongst the plots.

Land Preparation and Plant Maintenance

The planting site was prepared by tillage and manure application. A mixture of horse and goat manure was added at an amount of 30 t/ha to improve the physical properties of the soil. Especially for IPM treatment, gliocompost fertilizer was added with a dose of 100 g/m^2. At the same time, to neutralize soil acidity, 3.1 t/ha of dolomite was added, and 300 kg/ha of SP36 fertilizer was added as basic fertilizer. Specifically for IPM treatment, PGPR was applied when the plants reached 1, 2, 3, and 4 weeks after planting (WAP), and liquid silica (SiO_2) fertilizer was also applied at 1-10 WAP by spraying on the plant canopy.

The planting materials were rooted cuttings after 12 days the rooting process. The rooted cuttings were planted with the density of 100 cuttings per meter^2 in each bed with a plant net installed. Once planted, the cuttings were watered with water to facilitate moisture and avoid plant stress. Water supply was provided by the sprinkling system every 1-2 days until harvest time. Long day condition was stimulated by supplemental lighting at night for 4 hours from 07.00 pm to 11.00 pm during the first 35 days planting. The 15-watt LED lamps were installed for these additional lighting and arranged with a distance between lamps of 2 m and 1.5 m above the plant canopy. After 35 days, the long day condition was stopped, and the plants were forced to flower in neutral day conditions. Fertilization was done by giving urea fertilizer (200 kg/ha) at 7 days after planting (DAP); NPK 16-16-16 (250 kg/ha) was given twice at 10, and 35 DAP and KCl (350 kg/ha) was given at 40 DAP. All experimental plots were sprayed with fungicide with active ingredient of mancozeb fungicides during vegetative phase and azoxystrobin during generative phase to prevent the chrysanthemum white rust development.

Pest Management Treatment

The chrysanthemum IPM strategy was developed based on the literature review and was evaluative, with tactics adapted to the seasons and local conditions. Details of the experimental design of the chrysanthemum production system with IPM, farmer's standard practices, and untreated were implemented as shown in Table 1. The time of application of insecticides for the control of chrysanthemum thrips is listed in Table 2. The concentrations of application of insecticide treatments were as follows: imidacloprid (5% WP), emamectin benzoate (5% SG), imidacloprid; spirotetramat (120 g/l; 120 g/l SC), chlorpyrifos (200 g/l SC), diafenthiuron (500 g/l SC), chlorfenapyr (100 g/l SC), abamectin (18 g/l EC) with 1 g(ml)/l of each. Meanwhile, the insecticide cyromazine (75 WP) was 0.75 g/l. Then concentration of neem oil (50% azadirachtin) was 2 ml/l and *Beauveria bassiana* was 7.5 g/l, silica 5 ml/l. The amount of sprayed liquid per application was 10 l per plot up to 5 WAP and 15 l per plot from 6 WAP until harvest. All chemicals were applied with a manual knapsack sprayer (Swan Brand; Golden Agin).

Monitoring of Thrips Population

Monitoring was carried out to observe the number of populations and the level of damage caused by thrips. Weekly observations were carried out on ten sample plants in each replication, selected diagonally at 2-14 weeks after planting. Two methods are used: plant taping with a beating tray (nondestructive sampling) and destructive sampling (Hollingsworth et al., 2002). The first method of sampling using plant tapping was carried out by pushing the plant into the beating tray for ten seconds. The thrips obtained were then put into a clear plastic bag measuring 40 cm x 60 cm. The second method of monitoring thrips on chrysanthemum leaves was picking three leaves per plant from ten sample plants in one plot. The chrysanthemum leaves were selected representing the upper, middle, and lower leaves of ten sample plants in one plot. Five leaf sampling plots were determined diagonally in each treatment plot. Each selected leaf was placed inside a 10 cm x 15 cm plastic ziplock clip, and observation date and sample code were recorded. Furthermore, for thrips nymphs observation, chrysanthemum leaves were stored in a 500 ml plastic container with a top opening, which was sealed with a net. The container was stored in the Laboratory of Entomology of the Indonesian Ornamental Crops Research Institute at 20°C, with 12 hours of light and 70% RH. The leaves were incubated for five days under these circumstances, and the number of developing nymphs was counted. Ten buds or flowers per plot were harvested from 12 diagonally chosen plots in each replication and treatment every seven days for three weeks to monitor the thrips population in chrysanthemums were recorded. The picked flowers were immediately placed in bottles containing 70% ethanol, and the nymphs and adults of thrips were counted while dissecting the flowers in Petri dishes under a stereo microscope. All monitoring of thrips was carried out one day before insecticide application. In addition, the collected thrips are identified based on the available keys for thrips identification (Sartiami & Mound, 2013).

Evaluating the Existence of Natural Enemies

During the experiment, natural enemies observations (parasitoids and predators) were performed four times at four-week intervals since the plants reached 4 WAP. Sampling was conducted using insect nets, a beating tray, a yellow pan trap, and a hand vacuum. All natural enemies obtained were preserved in a 70% ethanol solution and identified based on morphological characteristics.

Damage and Yield Rate Assessment

The level of thrips damage was calculated based on observations of attack symptoms from 60 sample plants in every cultivar in each treatment plot. The plant samples in each plot were selected randomly from a number of no more than ten plants and labeled. The level of damage due to thrips attack on chrysanthemum leaves was recorded once a week for ten weeks, while the level of damage to flowers was observed three times. The size of all individual feeding spots on completely exposed leaves was added to calculate the total area of "silver" damage per plant. A severity index was categorized with the level of damage through a modification of Aristizábal et al. (2016), where 0 = no damage, 1 = mild (1-2 scars), 2 = moderate (3-4 scars or curls), and 3 = severe (> 4 scars/curls per leaf).

Table 1. Lists of the treatment to control thrips on chrysanthemum

Treatments	Untreated	Farmers' Standard Practices	IPM
Land preparation	Horse and goat manure, dolomite	Horse and goat manure, dolomite	Horse and goat manure, dolomite, gliocompost
Fertilizer	Urea, SP36, KCl, NPK	Urea, SP36, KCl, NPK	Urea, SP36, KCl, NPK, Silica
Seed treatment	Mancozeb	Mancozeb	PGPR
Variety	'Jimba' and 'Jayanti'	'Jimba' and 'Jayanti'	'Jimba' and 'Jayanti'
Border crops	-	-	Basil (Moekasan, 2018)
Yellow sticky trap	-	-	*Yellow sticky trap*
Companion plants	-	-	Ornamental pepper (Xiao et al., 2012)
Insecticide application timing	-	1-8 WAT* : twice a week 9-14 WAT: thrice a week	Once a week (Table 2)
Insecticide mixture	-	Two type of insecticides	Single spray
Entomopathogens	-	-	*Beauveria bassiana*
Botanical insecticides	-	-	Azadirachtin

Remarks: * WAT: Weeks after transplanting

Data Analysis

The data was analyzed using analysis of variance (ANOVA) in a split-plot design to determine the effect of treatment, variety, and interaction of treatment with varieties using the software-based package R "Agricolae" (Mendiburu & Yaseen, 2020). The normality of the data collected was determined using the Shapiro-Wilkinson test after the square root transformation (x +0.5) was performed on all calculated data before analysis. Significant differences were identified using Tukey's HSD test at the 5% significance level.

The total yield of chrysanthemum was calculated by adding up the undamaged and damaged chrysanthemums after being sorted according to the Indonesian National Standard of chrysanthemum cut flowers and then tied up with ten plants per bunch. Due to price fluctuations, the average price per bunch of cut flowers is set at Rp. 15,000 (grade A), Rp. 12,000 (grade B), and Rp. 5,000 (grade C) per bundle for calculating the cost-benefit ratio. Then, the benefit-cost ratio (B/C) was calculated for farmer's standard practices and IPM packages for control plots using the formula 1:

$$\text{B/C Ratio} = \frac{\text{Total income on IPM} - \text{Total income on untreated}}{\text{Total cost of thrips management}} \quad .....1)$$

where B/C Ratio = Cost benefit ratio (Shabozoi et al., 2011).

Table 2. Schedule of insecticide application treatment for thrips management

Week after transplanting	Farmers' standard practices	IPM
2	Imidacloprid + Emamectin benzoate	*Beauveria bassiana*
2	Imidacloprid + Emamectin benzoate	Silica
3	Imidacloprid + Emamectin benzoate	Emamectin benzoate
3	Imidacloprid;Spirotetramat + Emamectin benzoate	Silica
4	Imidacloprid;Spirotetramat + Emamectin benzoate	*Beauveria bassiana*
4	Imidacloprid;Spirotetramat + Emamectin benzoate	Silica
5	Chlorpyrifos + Cyromazine	Azadirachtin
5	Chlorpyrifos + Cyromazine	Silica
5	Cyromazine + Emamectin benzoate	-
6	Chlorfenapyr + Diafenthiuron	Chlorfenapyr
6	Chlorfenapyr + Diafenthiuron	Silica
6	Chlorfenapyr + Diafenthiuron	-
7	Imidacloprid + Emamectin benzoate	Azadirachtin
7	Imidacloprid + Emamectin benzoate	Silica
7	Imidacloprid + Emamectin benzoate	-
8	Abamectin + Imidacloprid;Spirotetramat	Diafenthiuron
8	Abamectin + Imidacloprid;Spirotetramat	Silica
8	Abamectin + Imidacloprid;Spirotetramat	-
9	Abamectin + Imidacloprid;Spirotetramat	Azadirachtin
9	Abamectin + Chlorpyrifos	Silica
9	Abamectin + Chlorpyrifos	-
10	Abamectin + Chlorfenapyr	Abamectin
10	Abamectin + Chlorfenapyr	Silica
10	Abamectin + Imidacloprid;Spirotetramat	-
11	Abamectin + Imidacloprid;Spirotetramat	Abamectin
11	Abamectin + Imidacloprid;Spirotetramat	Silica
11	Abamectin + Imidacloprid;Spirotetramat	-
12	Abamectin + Chlorpyrifos	Imidacloprid
12	Abamectin + Chlorpyrifos	-
12	Abamectin + Chlorpyrifos	-
13	Abamectin + Imidacloprid;Spirotetramat	Abamectin
13	Abamectin + Imidacloprid;Spirotetramat	-
13	Abamectin + Imidacloprid;Spirotetramat	-
14	Abamectin + Chlorfenapyr	Abamectin
14	Abamectin + Chlorfenapyr	-
14	Abamectin + Chlorfenapyr	-

RESULTS AND DISCUSSION

Chrysanthemum Thrips Densities

As expected, thrips were commonly found in the plastic houses experimental station of the Indonesian Ornamental Crops Research Institute, even though synthetic pesticides were frequently utilized to manage pests. In this study, a thrips species that infested two chrysanthemum cultivars was identified as *Thrips parvispinus* of the Thripidae family. This species is mostly widespread in horticulture crops, particularly vegetables (Hutasoit et al., 2017). Due to its cosmopolitan and polyphagous behavior, we also found it also attacks the chrysanthemum. Throughout the observation period, *T. parvispinus* was found in all tested chrysanthemum cultivars. However, the majority of the population were boosted when the plants reached the generative stage. Weekly population densities of adults and nymphs were assessed for 12 weeks under IPM, farmer's standard practices, and untreated (Fig. 1). Based on the observation, thrips began infesting chrysanthemums since the first week of planting. The adult population was generally consistent in all treatments at two weeks after planting, 1–2 thrips per plant, until the density peaked at 4 WAP. Meanwhile, the population density of nymphs varied by 3, 2, and 5 thrips per plant for IPM, farmer's standard practices, and untreated treatments, respectively. The density of thrips nymphs peaked at 7 WAP for IPM and farmer's standard practices and 9 WAP for the control treatment. Generally, the number of thrips steadily increases along the plant ages. However, the average number of adults per plant does not exceed five until harvest in IPM and farmers' standard practice treatments. Meanwhile, in untreated plots, the increase in the number of adults and nymphs and the density were significantly different from the IPM and farmer's standard practices treatments (F=5.56, p=0.003).

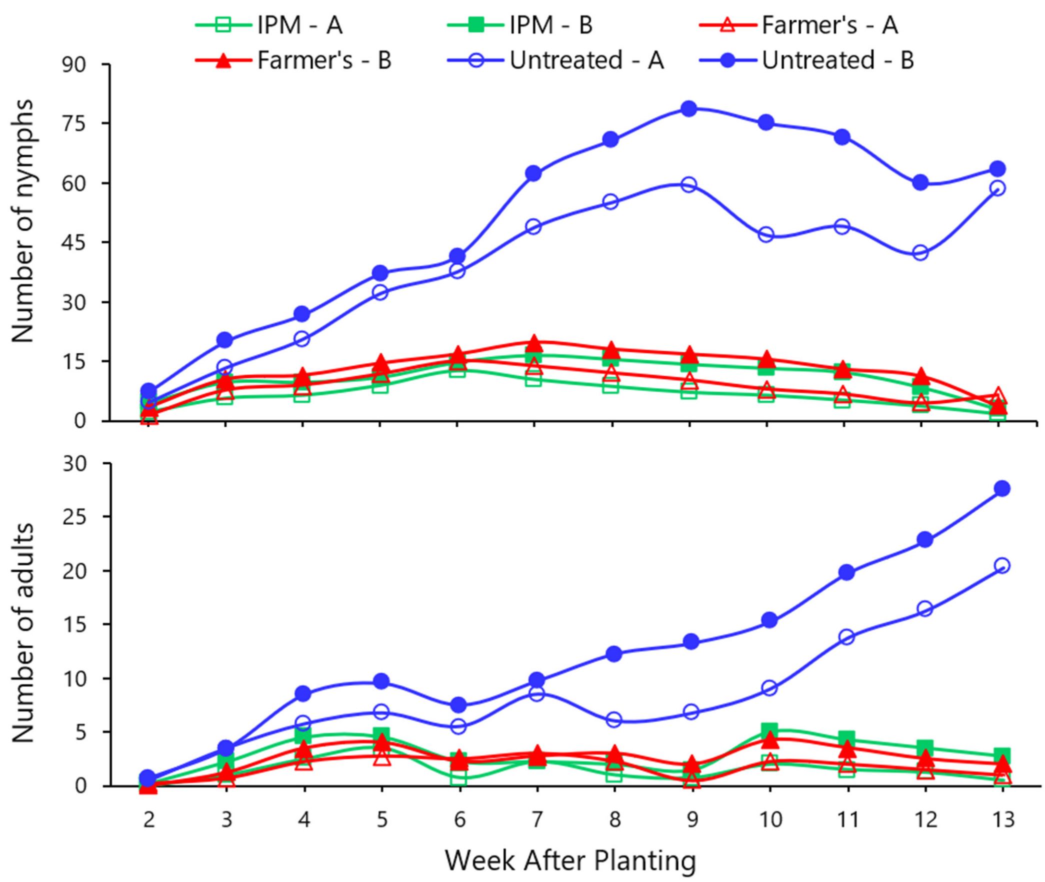

Fig. 1. Number of thrips nymphs and adults collected from two chrysanthemum cultivars: Jimba (A), and Jayanti (B). Period of observation of thrips on leaves 2-10 WAT; while on buds/flowers on 11-13 WAT

The research findings revealed that the thrips population density declined to its lowest level after six weeks of IPM treatment, whereas farmers' standard practices the decrease occured after five weeks (Fig. 1). However, the number of thrips population density between IPM and farmer's standard practices was not significantly different (adults: F=1.13, p=0.377; nymphs: F=0.54, p=0.664). Furthermore, from the 4th week until the chrysanthemums were harvested, the treatments of IPM and farmers' standard practice demonstrated a significant reduction in the thrips population (P 0.05) in comparison to the control treatment (Table 3). The highest number of thrips was found in the control treatment because there was no pest management treatment, and as a result, their growth was faster. The average thrips number in the IPM and farmer's standard practices treatment was 0-3 individuals per plant, while the untreated was 10-14 individuals. The number of thrips found was relatively high because the weather conditions during the study were in the dry season, which promoted an increase in the pest population. The dry season and temperatures in plastic houses which tend to be high, also trigger an increase in the thrips population (Hutasoit et al., 2017; Park & Lee, 2020; Messelink et al., 2021). In addition to temperature, plant age is a variable that could affect thrips numbers. According to Rogge & Meyhofer (2021a), thrips population density was higher on chrysanthemum crops after the appearance of the flowering phase. Chrysanthemum flowers are known to attract thrips due to their semiochemical compounds and color, which is why they are frequently spotted on them (Rogge & Meyhofer, 2021b).

The total population of nymph and adult thrips in the two chrysanthemum cultivars did not show significant differences, and there was no interaction between the pest control treatment and the chrysanthemum cultivars [adult (F=2.01, p=0.170), nymph (F=1.04, p=0.319)]. The results showed that the number of nymph and adult thrips was higher in the 'Jayanti' compared to the 'Jimba' (Table 3). It suggests that the 'Jayanti' is a susceptible cultivar and a suitable host for thrips. These less resistant characteristics is an impotant information for growers to give more attention during the plant maitenance to produce higher marketable yields. Previous studies have shown that chrysanthemum cultivars can be used to control thrips in greenhouses. 'Jimba' and 'Jayanti' cultivars are popular in Indonesia widely grown commercially. Generally, the flower appearance of the two cultivars were similar, white in color, but differs in decorative flower shape. Several studies reported the role of factors such as flavonol content, flower shape, and flower color of chrysanthemum affected thrips preference (Rogge & Meyhofer, 2021b), while leaf trichome density has no significant impact on chrysanthemum defense against thrips (G.Chen et al., 2020). 'Jimba' is a snow-white chrysanthemum cultivar that is the most popular since it is an exported variety, whereas 'Jayanti' is a mutant cultivar that is now being sold domestically with limited success (Ohmiya, 2018; Sanjaya et al., 2018). Furthermore, besides the chrysanthemum flower color, it is likely that *T. parvispinus* also responds during the vegetative phase, especially in the green parts of the appropriate plant (Rogge & Meyhofer, 2021a). In contrast, the number of thrips nymphs and adults in the untreated plot increased until harvest period. It is indicated that *T. parvispinus* was the primary pest of chrysanthemums, and if it was not controlled, its activities persisted throughout the growing season (Tasmin et al., 2018; Iglesias, Havey et al., 2021).

Table 3. Mean total of numbers (± SE) of *Thrips parvispinus* on chrysanthemum during the study period

Cultivar	Treatments	Mean numbers (± SE) of *T. parvispinus**	
		Adult	Nymph
'Jimba'	IPM	1.42 ± 0.28 b	6.67 ± 0.94 b
	Farmers' practices	1.75 ± 0.27 b	8.90 ± 1.12 b
	Untreated	8.54 ± 1.61 a	38.92 ± 5.19 a
'Jayanti'	IPM	2.91 ± 0.42 b	11.08 ± 1.22 b
	Farmers practices	2.58 ± 0.35 b	12.90 ± 1.49 b
	Untreated	12.52 ± 2.25 a	51.15 ± 6.88 a

Remarks: * Means (± SE) followed by the same letter at the each column are not significantly different at the p ≤ 0.05 level

During the observation period, the maximum adult population of thrips occurred when the plant reached the generative stage (10 WAT), and the number was lower than that of nymphs. Generally, the nymph stage contributed to 78% of the total average thrips per plant. The average number of thrips adults sampled at 2-13 WAT ranged from 1.42 - 2.91 per plant in the IPM and 1.75 - 2.58 per plant in the farmer's standard practices. However, the average number of thrips nymphs was lower in the IPM treatment than in the farmer's standard practices, but with negligible differences (t=1.32, df=20, p=0.402). Weekly nymph counts in IPM plots were consistently lower than in farmer's standard practices plots. The results of the study confirm that nymphs are the most dangerous life stage of thrips in chrysanthemums and the most important to control. Furthermore, IPM control tactics that have been implemented induce the existence of natural enemies of thrips such as *Ceranisus* sp., *Menochilus sexmaculatus*, *Macrocheles* sp., *Atheta* sp., *Amblyseius spp*, and *Neoseiulus spp*. Although the population is relatively low, the presence of natural enemies in IPM plots is thought to have contribution in suppressing the thrips population, especially the nymph phase (Fig. 2). Meanwhile, in the farmer's standard practice plot, the frequency of insecticide application 2-3 times per week actually inhibited the presence of natural enemies of thrips. Scheduled application of insecticides, like imidacloprid, chlorpyrifos, chlorfenapyr, diafenthiuron, emamectin benzoate, abamectin, and imidacloprid; spirotetramat with high frequency is detrimental to predators and parasitoids. On the other hand, in untreated plots, the exceptionally high population density of thrips cannot be controlled by natural enemies, so the damage rate is even higher. Thus, it is also proven that without integrated control with other appropriate control techniques, thrips cannot be controlled in chrysanthemum production.

The high number of nymphs means that adult thrips may contribute less to crop damage and production loss. Several studies have reported that the nymph stage is higher in number than the adults. Steenbergen et al. (2018) reported that the nymph ratio of thrips reached more than 57% of the total thrips, while according to Silva-Castaño & Brochero (2021), the proportion of nymphal stages could reach 2.5 times more than adult thrips during the chrysanthemum growing season. Similarly, Rogge & Meyhofer (2021a) stated that thrips nymphs could be the most accurate indicator of plant damage and loss. Management tactics applied in IPM plots are able to bring in natural enemies and contribute in reducing thrips populations. Planting companion plants such as basil and ornamental pepper directly or indirectly supplies natural enemies with supporting resources such as food and shelter. Companion plant systems provide sources of food and refugia for parasitoids and predators of thrips such as *Amblyseius barkeri*, *Macrocheles* sp, *Atheta* sp. (Xiao et al., 2012; Knapp et al., 2018). Scheduled application of insecticides with high frequency is an ineffective for long production process. Besides causing pest resistance to insecticides, it also has a detrimental impact on natural enemies (van Lenteren et al., 2020). Meanwhile, the presence of natural enemies in uncontrolled plots could not suppress the high population density of thrips. In this case, environmental influences are due to foreign natural enemies and ineffective natural enemies of thrips (Messelink et al., 2021).

Chrysanthemum Damage

During the observation period, thrips damage on chrysanthemums appeared as curling leaves with silver spot on the top side of the leaves. These symptoms are more dominantly found in young shoots and leaves. In addition to attacking leaves, thrips have also been found to attack flower buds and opened flower. Symptoms of damage by thrips on leaves began to appear two weeks after planting, while attacks on flowers occured ten weeks after planting. The results showed that the level of damage began to appear three weeks after planting, and the control treatment plots was observed to have severely damage. The average damage rates on 'Jimba' were 0.0 to 1.9% (IPM), 0.0 to 1.9% (farmer's standard practices), and 1.0 to 76.1% (untreated). The damage rate of the 'Jayanti' reached 0.0-4.5% (IPM), 0.0-4.9% (farmer's standard practices), and 1.0-89.9% (untreated). Based on the analysis of variance, there was no interaction effect between chrysanthemum cultivars and thrips control techniques ($F = 40.88$; $p < 0.05$). However, it is only influenced by pest control treatments, namely IPM and farmer's standard practice ($F = 82.47$; $p < 0.05$). The untreated plot recorded the most severe damage on the leaves and flowers. As shown in Table 4, the level of thrips damage on the untreated plot increased from the fourth week of observation until the generative phase, and both cultivars showed a similar reaction pattern. Therefore, the rate of flower damage on ‘Jayanti’ was higher and significantly different than that ‘Jimba’. The level of damage on chrysanthemums treated with IPM was not significantly different from the farmer’s standard practices treatment, which was spraying with synthetic insecticides on a scheduled basis.

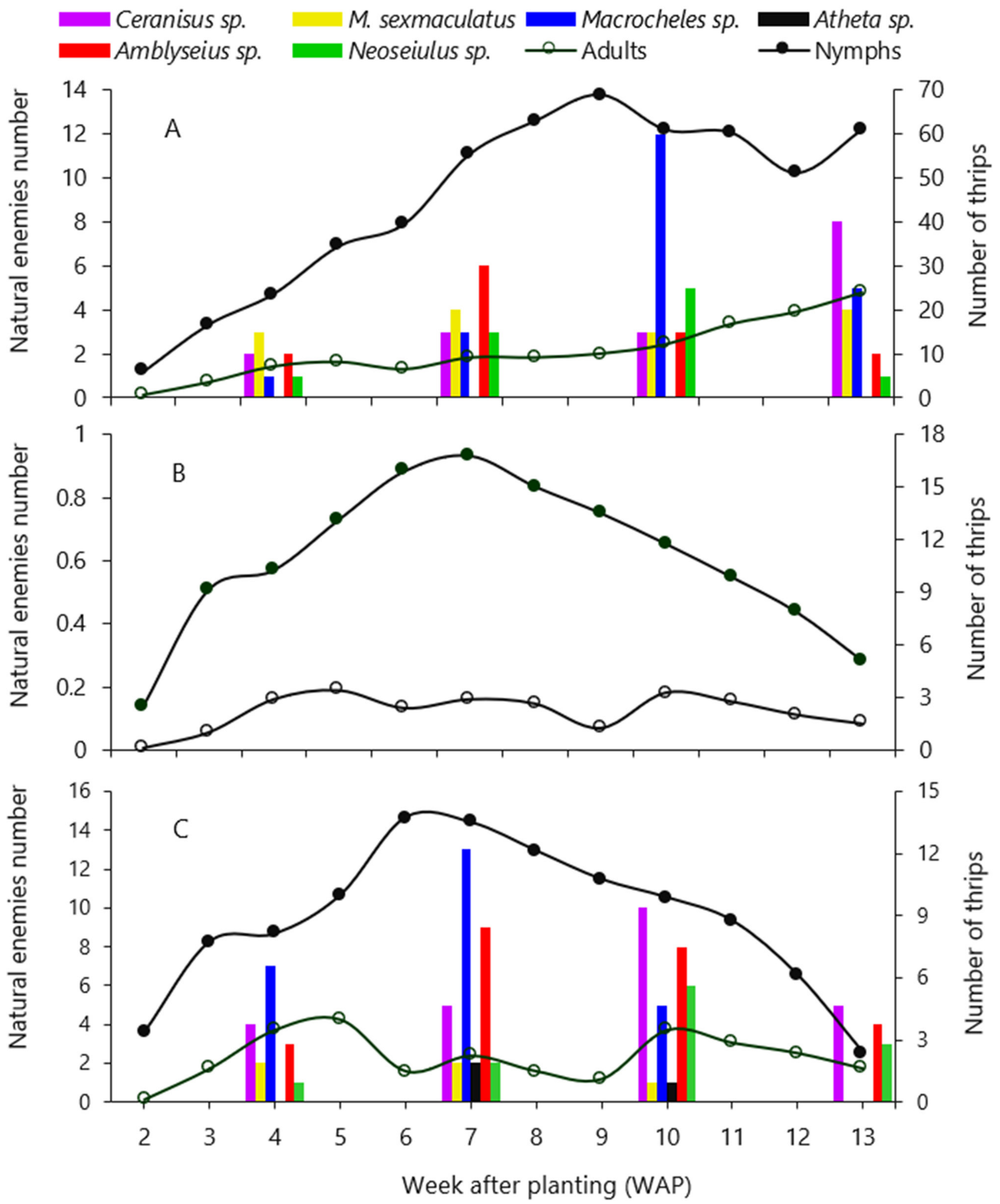

Fig. 2. The average number of nymphs and adults of *Thrips parvispinus* and their natural enemies collected on untreated (A), farmer standard practices (B), and IPM plots (C)

The population density of nymph and adult thrips was closely related to damage in chrysanthemum crops. Thrips feeding activity on leaves is most common during the vegetative phase of chrysanthemums, particularly during terminal growth (Rogge & Meyhofer, 2021a). Within a few days after feeding activity occurs, the leaves will shine silvery as a result of air replacing the cell contents in damaged cells (Rhainds et al., 2005). The level of thrips damage is crucial for successful *T. parvispinus* management on chrysanthemum crops under plastic house conditions. Thrips are challenging to control due to their polyphagous behavior and wide range of insecticide resistance (Mouden et al., 2017; Setyawan et al., 2016). The research findings also revealed that the damage rate of thrips increased more than fivefolds as they approached the blooming period. Moreover, the most critical phase of *T. parvispinus* infestation was early blooming. Given the high attack spike, farmers must employ an intensive scouting program to detect and assess thrips population density. Scouting thrips populations since the beginning of chrysanthemum growth is much better for determining the action of insecticide application (Aristizábal et al., 2016; Hollingsworth et al., 2002). Another critical thing to consider is how challenging it can be to control thrips when the population has grown to high numbers. Thrips are pests that are challenging to control because of their small size, and their population is complicated to estimate (Aristizábal et al., 2016; Mouden et al., 2017).

The results showed that IPM strategies consistently lowered chrysanthemum damage by thrips. The suppression of chrysanthemum damage leads to the production of chrysanthemums on an equal level with farmer's standard practices. Various control strategies are applied to the IPM approach that has proven effective in the chrysanthemum production system under the plastic house to reduce the number of synthetic pesticides within the thrips pest management strategy. There were nine control tactics applied, namely: gliocompost (*Gliocladium* sp, and *Trichoderma* sp), silica, PGPR, border crop (basil), yellow sticky trap, companion plant (ornamental pepper), *B. bassiana*, azadirachtin, and synthetic insecticides. Thrips management on chrysanthemums requires a holistic approach that combines multiple tactic to reduce pest numbers and create high-quality plants with little cosmetic impact (Messelink et al., 2021; Iglesias, Havey et al., 2021). This approach enriches the IPM strategy by promoting plant health improvement to suppress thrips in greenhouse crops effectively.

Table 4. The average damage rate percentage of *Thrips parvispinus* (mean ± SD) in two chrysanthemum cultivars with IPM treatment, farmer standard practices, and untreated

Observation Dates	IPM		Farmer Practices		Untreated	
	Jimba*	Jayanti*	Jimba*	Jayanti*	Jimba*	Jayanti*
Leaves (n=30)						
2	0.30 ± 0.48 b	0.86 ±0.19 ab	0.36 ± 0.60 b	0.84 ±0.54 ab	1.14 ± 0.42 ab	1.54 ± 0.61 a
3	0.42 ± 0.32 b	1.08 ± 0.36 bc	0.67 ± 0.66 b	0.91 ± 0.32 bc	1.80 ± 0.65 b	3.68 ± 0.58 a
4	0.63 ± 0.42 b	1.29 ± 0.74 b	0.73 ± 0.51 b	1.25 ± 0.21 b	2.97 ± 0.16 a	3.75 ± 0.61 a
5	1.00 ± 0.16 c	1.43 ± 0.54 c	0.77 ± 0.43 c	1.20 ± 0.44 c	3.40 ± 0.40 b	5.20 ± 0.69 a
6	0.87 ± 0.53 c	1.53 ± 0.44 c	0.61 ± 0.25 c	0.87 ± 0.16 c	5.12 ± 0.62 b	8.33 ± 1.23 a
7	0.49 ± 0.14 c	1.09 ± 0.20 c	0.31 ± 0.23 c	0.68 ± 0.28 c	7.07 ± 1.04 b	10.56 ± 1.86 a
8	0.40 ± 0.23 c	1.00 ± 0.21 c	0.26 ± 0.14 c	0.80 ± 0.19 c	10.21 ± 1.34 b	14.04 ± 2.20 a
9	0.32 ± 0.11 b	0.71 ± 0.15 b	0.25 ± 0.14 b	0.80 ± 0.15 b	14.72 ± 2.38 a	16.56 ± 2.35 a
10	0.17 ± 0.13 b	0.67 ± 0.13 b	0.20 ± 0.13 b	0.74 ± 0.16 b	19.20 ± 2.78 a	20.03 ± 1.65 a
11	0.11 ± 0.12 b	0.32 ± 0.13 b	0.09 ± 0.10 b	0.33 ± 0.16 b	23.85 ± 3.50 a	25.42 ± 3.11 a
Buds (n=10)						
10	0.56 ± 1.36 b	2.78 ±1.72 b	0.56 ± 1.36 b	2.22 ± 2.72 b	27.72 ± 3.26 a	30.00 ± 5.96 a
11	0.00 ± 0.00 b	1.67 ± 1.51 b	0.00 ± 0.00 b	1.67 ± 1.51 b	35.83 ± 7.73 a	44.44 ± 8.61 a
12	0.00 ± 0.00 c	1.11 ± 1.36 c	0.00 ± 0.00 c	0.56 ± 1.36 c	54.44 ± 5.84 b	62.22 ± 6.89 a
13	-	-	-	-	72.50 ± 3.65 a	82.17 ± 7.77 b

Remarks: * Means (± SD) followed by the same letter at the same row are not significantly different under the HSD test at the p ≤ 0.05 level; (-) = harvested

Plant health is critical for crop protection as it plays a vital role in suppressing yield losses caused by pests. Efforts are being made to provide soil amendments in the form of gliocompost and PGPR. Both strategies could potentially improve the growth of chrysanthemum crops by improving nutrient uptake and stimulating the plant's immune system (Perez-De-Luque et al., 2017). Meanwhile, applying silica fertilizer to the leaves once a week for ten weeks promoted the health of chrysanthemums. Silica plays a protective role in plant cell walls by strengthening them. Silica fertilizer effectively controls pests and diseases in chrysanthemum crops cultivated in greenhouses (Jeong et al., 2012).

In this study, monitoring the thrips population in the early phase of chrysanthemum growth was also carried out by installing yellow sticky traps in each IPM plot. Thrips are generally detected in traps after a few days or at the same time as trapping. During the early stages of thrips colonization on chrysanthemums, the number of flying thrips caught in traps significantly dominated the collected amount thrips from plants. Trapping adult thrips is a technical baseline in population estimation to determine the application of synthetic insecticides. The weekly average number of adult thrips caught is 7-12 individuals per trap (Fig. 3). At the same time, this amount reduces *T. parvispinus* infestations on chrysanthemums and minimizes damage. The weekly catch of thrips on the yellow sticky trap showed the size of the thrips population on chrysanthemums, whose numbers fluctuated throughout the growing season. These findings indicate that yellow sticky traps effectively monitor thrips in chrysanthemum plastic houses and could be used easily for the early detection of thrips. Field scouting is an important part of IPM and is at least twice as efficient as other monitoring methods (Hollingsworth et al., 2002; Aristizábal et al., 2016). Thus, the yellow sticky trap can be used as an effective, easy, and practical monitoring technique for further developing IPM programs on chrysanthemums. These findings could help farmers to better monitor and manage thrips on chrysanthemums.

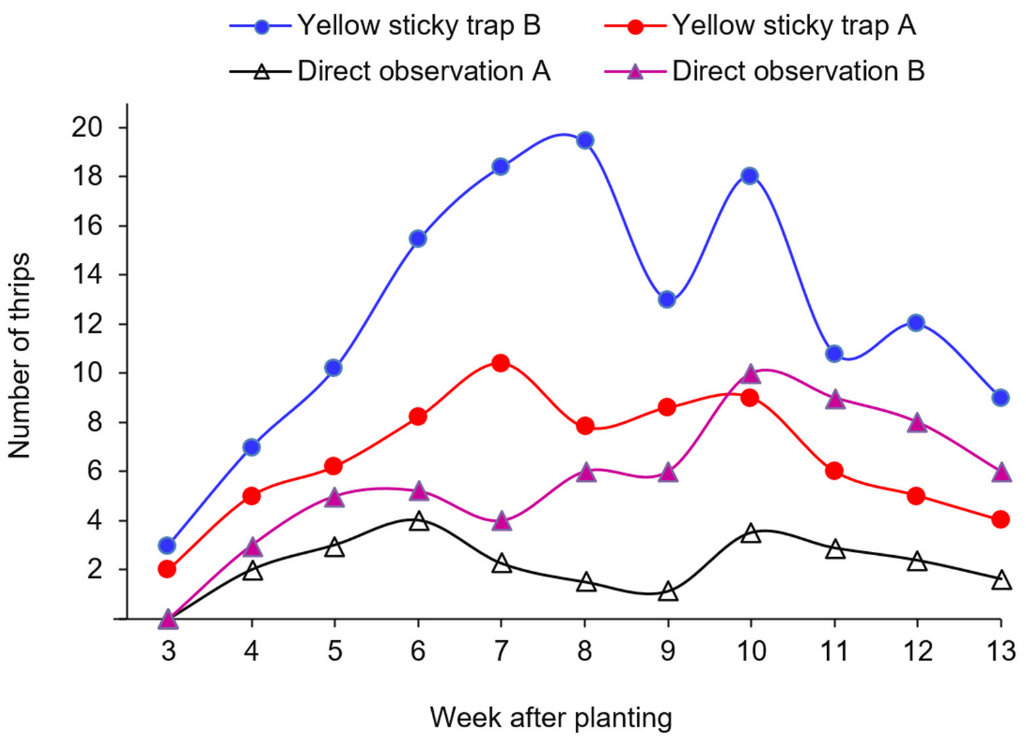

Fig. 3. The average number of thrips in the yellow sticky trap and direct observations on the IPM plots from (A) 'Jimba', and (B) 'Jayanti'

Natural Enemies Abundance

The total number of natural enemies collected from all treatment plots was 661 individuals, representing 36 species, 25 families, and nine orders. In the untreated plots and farmer's standard practices, the parasitoid population had the highest proportion, whereas predators had the highest proportion in the IPM plots. The existing natural enemy population is the original natural enemies in the chrysanthemum plastic house. Based on observations, the number of natural enemies in the untreated plot was 2.14 times greater than that of IPM and 9.79 times greater than farmer's standard practices. In contrast, natural enemies in IPM plots were 4.58 times more prevalent than in conventional farming methods (Table 5). As predicted, integrated pest control used in plastic houses for chrysanthemums could promote and protect the natural enemies of thrips and restore ecosystem activities. It indicates that limiting synthetic insecticides and ecosystem engineering increases the population of natural enemies in the field. Predator *Hemerobius* sp. (Neuroptera: Hemerobiidae) was found to be the dominant group in the control treatment, while in IPM plot and farmer's standard practices, *Amblyseius* sp. (Acarina: Phytoseiidae) and *Camponotus* sp. (Hymenoptera: Formicidae) were more dominant, respectively. The parasitoid species *Opius chromatomyia* (Hymenoptera: Braconidae) was dominant in control plots and farmer's standard practices, as well as *Ceranisus* sp. (Hymenoptera: Eulophidae) in IPM plots.

Pest management in chrysanthemums generally relies on synthetic pesticides, but their existence is currently facing regulatory threats due to environmental and human health concerns, especially for residential landscape use (Mouden et al., 2017; Reitz et al., 2020). Therefore, it is essential to consider efficient management alternatives that could reduce pest attacks through ecosystem services and environmentally friendly pest control that does not harm human health. Through experiments in plastic houses, it was found that pest control by implementing integrated control had similar effects with those on farmer's standard practices against *T. parvispinus*. The IPM strategy has minimal effect on natural enemies. The generalist predators such as *Macrocheles* sp., *Amblyseius* sp., *Neoseiulus* sp., *M. sexmaculatus*, and the parasitoids *Ceranisus* sp. are detected in IPM plots and more likely impacted to the control of *T. parvispinus*. The population dynamics of the main natural enemy of thrips showed similar patterns with the population of thrips. The five natural enemies were the primary agents in reducing the number of *T. parvispinus* (Fig. 2). These natural enemies have been used in over 50 countries and are the most successful biocontrol agents in greenhouse farming (Sampson & Kirk, 2016; Xiao et al., 2012). Growing ornamental peppers alongside chrysanthemums as a refugia plant system promotes the establishment of natural enemies, particularly *Amblyseius* sp. (Xiao et al., 2012). The findings of this study show that an integrated pest management strategy has a minimal risk of harming natural enemies and is an effective technique for managing thrips in chrysanthemums.

Pest management techniques through cultural control in chrysanthemum production are essential to regulate the main pests of chrysanthemums in plastic houses. Planting ornamental peppers and basil at the same time with chrysanthemums has been proven to improve the diversity of natural enemies, even though synthetic insecticides in IPM plots are still used (Table 5). The ornamental pepper may be more attractive to thrips due to the less damage to chrysanthemums. Alternatively, it also acts as refugia and helps to develop natural enemies (Xiao et al., 2012). Furthermore, growing aromatic plants like basil also improved the population of beneficial arthropods and decreased pest infestation (Moekasan, 2018). Additionally, the thrips population was effectively suppressed as indicated from the low plant damage due to the application of *B. bassiana*, azadirachtin, and synthetic insecticides. Several studies have shown that *B. bassiana* effectively suppresses the population and reduces the level of *T. parvispinus* damage in chrysanthemum (Brownbridge & Buitenhuis, 2019; Yusuf et al., 2010). Neem oil, a botanical pesticide made from the seeds of *Azadirachta indica*, has no adverse effects but could avoid thrips' level of damage and population by influencing their eating behavior and egg-laying intensity (Amoabeng et al., 2014; Iglesias, Groves et al., 2021). In general, synthetic insecticides used are avermectin (abamectin and emamectin benzoate) and neonicotinoids (imidacloprid), which have low toxicity to mammals. Several studies have reported that these insecticides have minimal effects against non-target organisms, including predators and parasitoids (Lin et al., 2021). Thus, the results of this study reach the same level as farmer's standard practices through calendar-based spraying. This significant benefit of implementing the IPM has resulted in a significant reduction in synthetic insecticides through the optimization of biopesticide application, technical culture, and monitoring (Mouden et al., 2017; Pecenka et al., 2021). Furthermore, the tactic of using companion plants needs to be implemented further, given its essential role in IPM (Reitz et al., 2020; Pecenka et al., 2021). However, it was realized that further validation was needed for promotion and large-scale adoption by adding the frequency of chrysanthemum planting with different test locations.

Table 5. The collected natural enemies by vacuum, yellow pan trap, sweep net, and beating tray on IPM, farmer practices, and untreated treatments during the period of study

Order	Family	Species	Untreated	Farmer practices	IPM
Predator					
Acarina	Macrochelidae	*Macrocheles* sp.	17	0	22
	Phytoseiidae	*Amblyseius* sp.	13	0	24
	Phytoseiidae	*Neoseiulus* sp.	10	0	12
Araneae	Araneidae	*Araneus* sp.	12	2	9
	Oxyopidae	*Oxyopes* sp.	8	0	1
	Salticidae	Salticidae sp1	4	0	2
	Theridiidae	*Coleosoma* sp.	0	0	2
Coleoptera	Coccinellidae	*Cryptolaemus montrouzieri*	7	0	1
		Harmonia axyridis	3	0	0
		Menochilus sexmaculatus	14	0	5
	Staphylinidae	*Atheta* sp.	0	0	3
		Paederus sp.	2	0	3
Diptera	Asilidae	Asilidae sp1	0	0	2
	Syrphidae	*Syrphus* sp.	13	0	0
	Tachinidae	*Eurithia* sp.	15	0	5
		Tachinidae sp1	9	5	4
Hemiptera	Geocoridae	*Geocoris* sp.	5	0	0
Mantodea	Mantidae	*Stagmomantis carolina*	6	0	1
Neuroptera	Hemerobiidae	*Hemerobius* sp.	21	0	7
Odonata	Libellulidae	*Orthetrum sabrina*	0	0	2
Hymenoptera	Formicidae	*Camponotus* sp.	16	5	3
		Monomorium sp.	10	0	0
		Polyrhachis dives	4	3	5
		Technomyrmex sp.	1	0	2
		Total	190	15	115
Parasitoid					
Hymenoptera	Aphelinidae	*Encarsia spp*	28	1	15
	Braconidae	*Binodoxys angelica*	38	8	1
		Doryctobracon sp.	7	2	1
		Opius chromatomyia	61	8	7
	Encyrtidae	*Ooencyrtus* sp.	13	0	0
	Eulophidae	*Asecodes* sp.	9	0	4
		Ceranisus sp.	16	0	24
		Hemiptarsenus varicornis	39	8	22
	Figitidae	*Gronotoma micromorpha*	3	1	0
	Mymaridae	*Anagrus* sp.	10	0	4
	Platygastridae	*Platygaster* sp.	2	0	0
	Scelionidae	*Telenomus* sp.	5	0	4
		Total	231	28	82

Cost Benefits

The results showed that implementing IPM practices was not significantly different from the farmer's standard practices in flower yields but significantly different from the control treatment (Table 6). Generally, the yield quality of IPM treatment is more excellent than typical farmer practice. According to the Indonesian National Standard grading measurement, number of grade A flower stalks was more significant in IPM treatment (68%) than in farmer's standard practices. In this study, various control strategies in the IPM approach for thrips management were successful in the plastic house chrysanthemum production system. Adopting IPM tactics delivered economic benefits such as continued growth, enhanced production, and minimized thrips infestations. Thrips management in ornamental plants requires a holistic approach that combines various control approaches to minimize pest populations while producing high-quality plants with minimal aesthetic damage (Brownbridge & Buitenhuis, 2019; Messelink et al., 2021). This approach enriches the IPM strategy with approaches to promote plant health improvement. Plant health is crucial for plant protection because it plays an essential role in reducing yield losses caused by pests. Efforts were applied by giving soil improvers like gliocompost and PGPR that could optimize the growth of chrysanthemum plants by promoting nutrient acquisition and inducing the plant's immune system (Perez-De-Luque et al., 2017). Meanwhile, applying silica fertilizer once a week for ten weeks could improve the health of chrysanthemums. Silica contributes to physical resistance by fortifying plant cell walls. Using silica to manage pests and diseases in chrysanthemum production in plastic houses is effective.

Table 6. Yield quality of chrysanthemum maintained by IPM, farmers' standard practices, and untreated plots

Variety	Treatment	Height of plant (cm)	Diameter of stem (mm)	Diameter of flower (cm)*	Grade (%)			Worth selling (%)
					A	B	C	
'Jimba'	IPM	79.01 a	11.93 a	5.02 a	68	17	10	95
	Farmers' standard practices	77.55 ab	11.86 ab	4.98 a	63	20	12	95
	Untreated	67.70 c	9.31 c	4.02 b	0	0	4	4
'Jayanti'	IPM	75.88 ab	11.62 ab	4.86 a	62	19	12	93
	Farmers' standard practices	73.84 b	11.30 b	4.76 a	60	17	15	92
	Untreated	65.14 c	8.34 d	3.81 b	0	0	2	2

Remarks: * The means followed by the same letter in the same column are not significantly different in the HSD test at the $p < 0.05$ level

Table 7. Chrysanthemum cut flower costs and income with the ratio of costs and benefits of IPM control and farmers standard practice

Treatment		Pest control cost (IDR)	Total income (IDR)	Benefit (IDR)	B/C ratio
IPM	Gliocompost	105,600			
	PGPR	280,500			
	Ornamental pepper	627,450			
	Basil	346,500			
	Yellow sticky trap	548,800			
	Beauveria bassiana	193,600			
	Silica	367,500			
	Azadirachtin	210,900			
	Insecticide	825,440			
	Fungicide	226,400	10,150,000	6,417,310	1:1.68
Farmers' standar practices	Insecticide	2,872,625			
	Fungicide	226,400	9,920,000	6,820,975	1:2.15
Untreated	-	-	150,000		

The results showed that implementing IPM practices cost Rp. 3,732,690 (245 USD), while the standard practice of farmers reached Rp. 3,099,025 (204 USD). The cost of controlling IPM pests is 17% higher than the farmers' standard practice, but there is an increase in the yield of grade A chrysanthemums in IPM by 5%. The competitive cost of IPM plots results from labor costs in implementing IPM services under plastic houses. In addition, based on the synthetic insecticide application, the cost of insecticides on IPM plots is Rp. 825,440 (54 USD), while the standard practice of farmers is Rp. 2,872,625 (188 USD). These results indicate that the IPM plot has an insecticide cost savings of 71% (Rp 2,047,185/134 USD) compared to farmer's standard practices. It confirms that although the cost of pest control on IPM plots is generally higher than farmer's standard practices, the cost of insecticides is much lower.

The cost-benefit ratio is a measure of the relative economic consequences of pest management treatment strategies. A ratio of more than one indicates the economic feasibility of the treatment compared to the control treatment. In the present study, the ratio of costs and benefits of IPM treatment was 1:1.68 and 1:2.15 for the farmer's standard practice treatment (Table 7). This ratio shows that both treatments are effective and provide a sizable return on crop protection investment. The cost-benefit ratio measured during this study is in line with Ahmed et al. (2020) but exceeding than that acquired by Amoabeng et al. (2014). Both of studies determine the cost-benefit ratio by examining only the costs of plant protection. The results reveal that farmer's standard practices are more economically viable than IPM, yet IPM is marginally better environmentally. However, because IPM and farmer's standard practice provide a cost-benefit ratio of more than one, farmers have the option to choose IPM as an enviromental friendly pest management measure. Although the value of the cost-benefit ratio of IPM plots is lower, IPM control is preferable ecologically because it is enviromental friendly, has low residue levels, is preferred by customers, and is economically viable. The results of this study also highlight the importance of environmentally friendly pest management in floriculture industry schemes as promoted by the Indonesian government through Undang-Undang No. 22 of 2019. Furthermore, various study findings indicate that ecological friendly ornamental plant production techniques influence customer preference for purchasing cut flowers, although they are relatively expensive (Hassen, 2016; Darras, 2021).

CONCLUSION

The species of thrips that infested chrysanthemums in plastic houses is *Thrips parvispinus*. Cultivar 'Jayanti' was more prone to thrips, particularly before blooming and until the flowers bloomed. A holistic approach integrating several management strategies proved successful in reducing the thrips population while producing high-quality crops with minimal aesthetic damage. The IPM strategy to control thrips on chrysanthemums shows a competitive cost and reduces the number of synthetic insecticide applications without reducing the quality and productivity of chrysanthemums.

ACKNOWLEDGEMENT

The author would like to thank the Agricultural Research and Development Agency, Indonesian Ministry of Agriculture, for supporting research with scholarship grants.

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