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Intercropping insect repellent plants (irps): a promising strategy for sustainable pest management

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Abstract. In current intensive crop production, the utilization of natural biological control in pest management is not fully maximized, resulting in a significant dependency on the application of insecticides. Insect-repellent plants (IRPs) have become a prominent subject of research and a widely implemented strategy for reducing both pest damage and reliance on chemical insecticides. In this study, intercropping three IRP species, coriander (*Coriandrum sativum* L.; Apiaceae), celery (*Apium graveolens* L.; Apiaceae), and bunching onion (*Allium fistulosum* l.; Amaryllidaceae), in two intercropping systems were assessed for controlling insect pests in chilli pepper. The research was carried out in the experimental field of the Indonesian Vegetable Research Institute (IVegRI) in 2022. The results revealed that intercropping systems of chilli pepper with coriander, celery, and bunching onion significantly reduced plant damage over sole crops. Among the various intercrop combinations, chili pepper intercropped with coriander resulted in the lowest damage of three major pest species on chili pepper, *Thrips parvispinus* (51.77%), *Helicoverpa armigera* (47.67%), and *Bactrocera dorsalis* (40.35%). Furthermore, this effect enhanced the productivity of chili pepper yield (43.27%).

Key words: intercropping, pest management, chili pepper, natural biological control, insecticide reduction, sustainable agriculture.

INTRODUCTION

In Indonesia, the production of chili pepper (*Capsicum annuum* L.), indeed faces challenges due to insect pests, which can significantly impact the quality and quantity of yield. Globally, yield losses in chili pepper production can range from 25% to 100%, primarily due to pest infestations. In Indonesia, chili pepper production also face similar challenges. Various pests have significantly impacted chili pepper production, causing yield losses of up to 50% (Setiawati et al., 2022). Notably, a comprehensive study has identifield 53 insect pests affecting chili peppers in both nurseries and fields. Major pests include aphids (*Myzus persicae* Sulzer, *Aphis gossypii* Glover, and *Aphis craccivora*

Koch), thrips (*Thrips parvispinus* Karny), yellow mites (*Polyphagotarsonemus latus* Banks), and whiteflies (*Bemisia tabaci* Gennadius), all of which are identified as sucking pests of chili. Additionally, certain insects directly damage chili fruits, such as fruit borers (*Helicoverpa armigera*), armyworms (*Spodoptera litura*), and the oriental fruit fly (*Bactrocera dorsalis*) (Gurlaz & Sangha, 2016; Shivalingaswamy et al., 2022).

The extensive application of chemical pesticides as a conventional method of controlling pests frequently has detrimental effects on agroecosystems. These include the development of resistance to primary pests, the resurgence of secondary pests, the eradication of natural enemies, toxic residue in food, long residual effects, and increased environmental pollution, which can adversely affect human health. This can disrupt ecosystems and lead to a decrease in biodiversity (Devi, 2018; Isman, 2020; Adeleye et al., 2022; Lishchuk et al., 2024). These factors have played to implementing environmentally friendly methods for controlling insect pests in chili peppers. Intercropping, a conventional method in agriculture and horticulture, has been investigated in several studies for its potential effects on the behavior and abundance of herbivores, their natural enemies, as well as to increase productivity and yield stability (Järvinen et al., 2023; Dubey et al., 2023). Intercropping is a farming technique that involves cultivating multiple crops in the same field simultaneously (Martin-Guay et al., 2018). This practice offers several benefits, including increased crop yield, cost savings in crop production, higher income, reduced pest infestation, and minimized reliance on broad-spectrum insecticides (Mahfudz et al., 2019; Huss et al., 2022; Mir et al., 2022; Lepse & Zeipiņ, 2023). Additionally, intercropping contributes to weed suppression, improved soil fertility, conservation of natural enemies, mitigating climate change, and efficiently reducing agriculture's negative effects on the environment (Sujay & Giraddi, 2015; Lauren et al., 2020; da Silva et al., 2021; Adeleyea et al., 2022). Furthermore, Zhang et al. (2024) reported that intercropping affects plant chemistry and enhances resistance mechanisms, which supports sustainable agriculture. According to their research, intercropping can change a plant's metabolic profiles and boost its defenses, leading to increase against herbivorous pests. This is accomplised by altering the chemistry of the leaves, which can deter pests and improve the plant's overall defense mechanisms

Intercropping of insect-repellent plants (IRPs) alongside crops has emerged as an alternative method in pest management (Rahman et al., 2020). Many types of intercropping have been identified based on the temporal and spatial overlap of plant species. Previous studies have examined the effectiveness of Coriander (*Coriandrum sativum* L.) (Sujay & Giraddi, 2015; da Silva et al., 2021) and Celery (*Apium graveolens*) (Moekasan & Prabaningrum, 2017; Wang et al., 2021) as intercrops for chili pepper, but the impact of bunching onion (*Allium fistulosum*) has yet to be explored. Järvinen et al. (2023) reported that *Allium* sp. has shown repellency against a wide range of arthropods. Bunching onions are highly suitable for intercropping due to their sulfur compounds, like allicin, which effectively deter pests. Their perennial nature and adaptability make them sustainable for long-term use. Additionally, they offer culinary benefits and are excellent for companion planting, enhancing both agricultural productivity and economic value.

The purpose of the study was to evaluate the effects of different IRP species, such as coriander, celery, and bunching onions, as well as the type of intercropping on insect pests and the natural enemies of chili peppers. The overall goal was to improve yields, reduce pesticide usage, and promote eco-friendly pest management practices toward natural pest control.

MATERIALS AND METHODS

The research was conducted in Margahayu, an experimental field of the Indonesian Vegetables Research Institute (107° 30’ EL, 60° 30’ SA; 1,250 m above sea level) located in Lembang, West Bandung, Province of West Java, Indonesia, from October 2022 to February 2023. During the experiment, the averageannual rainfall was 7.24 mm year^{-1}, and the average annual temperature ranged between 24 °C and 26 °C, with humidity ranging between 84% and 88%. The soil at the experimental site was categorized as Andisol with a pH of 5.0. From an initial study conducted based on the literature, three insect-repellent plant species (IRPs) cultivated in two intercropping systems: interrow cropping (IRC) and interplant cropping (IPC) were chosen for incorporation into chili pepper cultivation as intercrops. The following seven intercropping treatments were used: A) Intercropped chili pepper + coriander (IRC); B) Intercropped chili pepper + coriander (IPC); C) Intercropped chili pepper + celery (IRC); D) Intercropped chili pepper + celery (IPC); E) Intercropped chili pepper + bunching onion (IRC); F) Intercropped chili pepper + bunching onion (IPC); and G) Sole chili pepper (without any IRPs species) (Fig. 1). The experimental treatments were arranged following a randomized complete block design (RCBD) with four replicates. Plot sizes were 10 by 1 meter. There were forty chili plants on each plot. During the experiment, no pesticides were used in the experimental area.

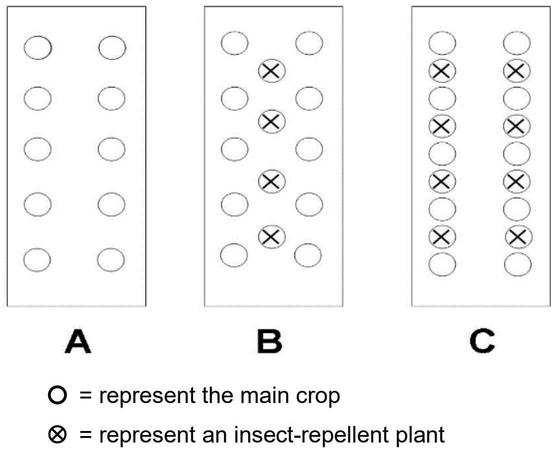

Figure 1. A schematic drawing of (A) a monoculture, (B) inter-row cropping (IRC) with ratio (100%: 50%), and (C) inter-plant cropping (IPC) with a ratio (100%:100%).

Data were collected by randomly selecting ten plants from each plot (U Shape) to collect pest intensity, natural enemies, growth performance (plant height, canopy diameter), number of chili pepper fruits, and yield. Three weeks after transplanting, weekly records of growth performance, pest intensity, and natural enemies were recorded, while the fresh weight of chili pepper fruits was recorded after harvest. The abundance of predators was determined by the average number of individuals per plant over the weeks of sampling. The intensity of plant damage due to pest infestation was calculated using Eq. 1 (Moekasan & Prabaninggrum 2017):

$$P = \frac{\sum(n\ x\ v)}{N\ x\ Z}\ x\ 100\% \qquad (1)$$

where P is the percentage of damage level; v is the value of the damage category; n is the number of plants that have the same v value; Z is the highest value of the damage category (which is 9), and N is the number of observed plants. The value of v is based on the percentage of leaf area damage, with: 0 indicating no damage; 1 indicating >0 – ≤20% damage; 3 indicating >20 – ≤40% damage; 5 indicating >40 – ≤60% damage; 7 indicating >60 – ≤80% damage, and 9 indicating >80 – ≤100% damage.

The intensity of fruit bored due damage was calculated using Eq. 2 (Moekasan & Prabaningrum 2017):

$$\text{Fruit damage intensity (\%)} = \frac{\text{Number of infected fruits per plot}}{\text{Total number of fruits per plot}} \text{ x } 100\% \quad (2)$$

The percent increase in yield over control in each of treatments was calculated as using the Equation follows:

$$\text{\% Increase in yield over control} = \frac{\text{Yield in treatment} - \text{Yield in control}}{\text{Yield in control}} \text{ x } 100\% \quad (3)$$

Variables related to plant growth, such as plant height and canopy length, were measured once every week. The number of fruits per sample plant and yield per plot were recorded for each harvest, the average was determined and the yield per hectare was calculated. Data regarding fruit morphology parameters were recorded starting from the first harvest of the fruits. The fruits of each treatment harvested separately were used to record phenotypic parameters like fruit weight (g) fruit length (cm) and fruit diameter (cm).

A one-way analysis of variance (ANOVA) was used to examine the differences in all parameters for each of the seven treatments. A post hoc test called Tukey's honestly significant difference (HSD) was employed to separate the means to compare the variations between the seven treatments at a level of 5%.

RESULTS AND DISCUSSION

Throughout the growing season, three insect pest species were observed in chili pepper plots., namely, thrips (*T. parvispinus*), oriental fruit flies (*B. dorsalis*), and fruit borer (*H. armigera*). In most cases, intercropping with IRPs significantly affected reducing pests and relative abundances of the pests in chili peppers, but the effects varied across IPR species. Plant and fruit damages were lower in intercropped plots than in sole chili peppers. These results corroborate with other previous studies on the pest-suppressive effect of intercropping with IRPs. Fig. 2 illustrates the influence of intercrop effects on thrips damage. The statistical analysis revealed that the average amount of damage between the various dates of damage evaluation varied significantly. The percentage of thrips damage varied depending on the treatment. Plant damage caused by thrips attacks was most severe in sole chili pepper plots where there were no IRPs. Chili pepper plants intercropped with coriander had significantly less damage, with only 6.94% damage observed. This was followed by that for bunching onion (IPC), which had 8.33% damage. These damage levels represent reductions of 51.77% and 42.11%, respectively, compared to the control plots. This finding suggests that thrips damage increases with plant age. In contrast to sole chili pepper, intercropping with IRPs does not show a significant increase in thrips damage when plant age increases.

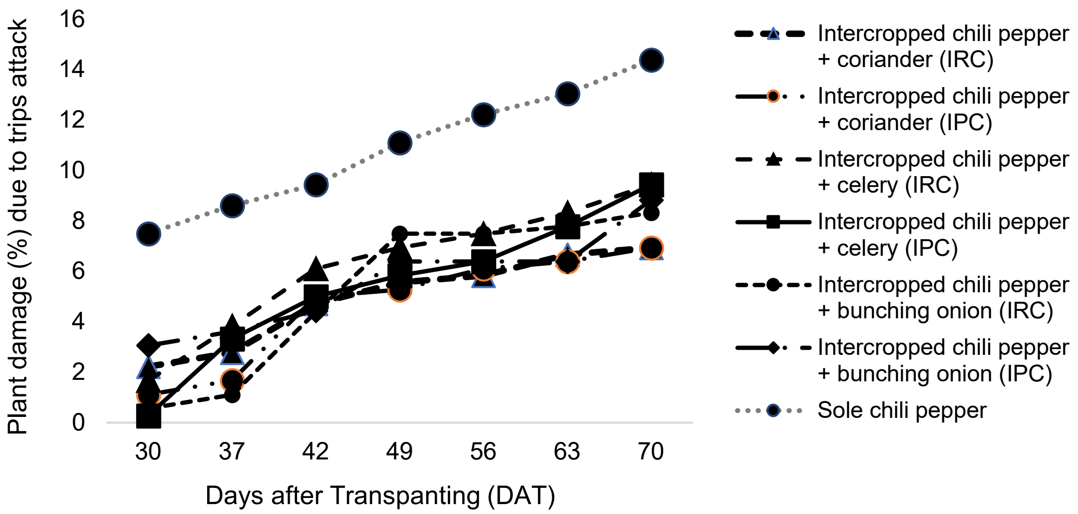

Figure 2. Plant damage due to thrips attack.

The presence of intercropping plants (IRPs) significantly affected the abundance of thrips, their predators, and the predator to thrips ratio. Although the overall number of thrips was similar across different types of intercropping (as shown in Table 1), the impact varied depending on the IRP species. Specifically, coriander intercropped plots (IRC) and bunching onion plots (IPC) had the lowest thrips populations, with reductions of 51.12% and 47.66%, respectively.

Table 1. Cumulative numbers of thrips and the total predator in chili pepper during the experiment under different treatments

No.	Treatments	Total no. of thrips/leaves	Total no. of predator/plants	Ratio of predators to thrips
A	Intercropped chili pepper + coriander (IRC)	26.75^{b}	47.08^{a}	1.76:1
B	Intercropped chili pepper + coriander (IPC)	30.64^{b}	45.26^{a}	1.51:1
C	Intercropped chili pepper + celery (IRC)	30.59b	45.88^{a}	1.50:1
D	Intercropped chili pepper + celery (IPC)	30.54b	49.17^{a}	1.61:1
E	Intercropped chili pepper + bunching onion (IRC)	31.01b	42.79^{a}	1.38:1
F	Intercropped chili pepper + bunching onion (IPC)	29.63b	40.29^{a}	1.36:1
G	Sole chili pepper	83.25a	32.47^{b}	0.39:1
	CV (%)	19.40	17.70	

*The means in each row of a parameter followed by different letters are significantly difference ($P < 0.05$) according to the honestly significant difference (HSD) test.

A recent field study conducted by Salamanca et al. (2018) found that in control plots (sole of chili pepper), there are 2.68–3.11 times more counted thrips. Rakotomalala et al. (2023) reported that intercropping decreased arthropod pest density and abundance by 41% and 38%, respectively. The intercropped treatment exhibits lower pest densities than the sole chili pepper, which is consistent with the repellent chemical theory, which contends that VOCs from non-host plants prevent herbivores from finding and feeding on hosts. Coriander contains significant amounts of linalool, geranyl acetate, α-pinene and β-pinene, eucalyptol, borneol, camphor, and terpinene which may be why fewer insects are present on plots where coriander is grown as an intercrop (Woldemelak, 2020). The primary active ingredients in celery that appeared to have an impact on pest selection behavior may have been D-Limonene, β-myrcene, and (E)-β-ocimene (Tu & Qin, 2017). VOCs from nonhost plants regularly affect the behavior of pests and their natural enemies, according to Yousefi et al. (2024). According to certain reports, intercropping can enhance the natural enemies of pests in agroecosystems by increasing crop biodiversity (Batista, 2017). When different intercrops are employed, however, the impact of intercrops on natural enemies differs. Our findings demonstrated that thrip population densities in both intercropping and sole chili pepper treatments decrease as predator population densities increase. The populations of predators were 51.14% and 45% higher, respectively, in the celery and coriander plots than in the sole chili pepper plots, where the populations were most numerous. The decrease in pest incidence in intercropped chili peppers may be attributed to either the low concentration of resources or the abundance of natural enemies. Natural enemies were high in okra (*Abelmoschus esculentus* L.) plots intercropped with coriander (Sujayanand et al., 2016). The same result was obtained by (Breitenmoser et al., 2022). Additionally, it was discovered that there were 53% more natural enemies of pests in the intercrop and that the number of pests had decreased from 33.5% to 53.5. The highest numbers of Coccinellidae and Syrphidae were observed on plots where carrots were intercropped with coriander. Natural enemies were unaffected by the increased plant diversity brought about by intercropping, which is advantageous for the biological control of a several of pests (da Silva et al., 2021; Li et al., 2021).

The ratio of predator-to-prey in all treatments was calculated. In general, the intercropped plots had a larger ratio of predators of thrips than the sole chili pepper plots, especially in the coliander and celery plots. When compared to the sole chili pepper plot, the ratio in these two intercropped plots increased by almost fourfold times. Thrip abundance was effectively reduced by intercropping, and the ratio of predators to pests was enhanced. In IRP intercropping, the ratio of predators to prey (pests) indicated an increased danger of predation and the possibility of improving biological control (Järvinen et al., 2023). By providing natural enemies with food, shelter, search capabilities, and oviposition sites, intercropping IRPs may improve the effectiveness of biological control by increasing the quantity and bolstering the rates of predation of these foes (Togni et al., 2016; Gurr et al., 2017; Talgre et al., 2023). Plants such as cabbage, tomatoes, carrots, eggplants, and roses attract predators such as ladybeetles (Coccinellidae), lacewings (Chrysopidae), and hoverflies (Syrphidae) when interplanted with cilantro. Plots of okra (*Abelmoschus esculentus* L.) interplanted with marigold (*Tagetes* spp.), mint (*Mentha* spp.), and coriander (*C. sativum* L.) (Sujayanand et al., 2016) had high levels of natural enemies. Furthermore, coriander flowers give their natural enemies a source of food in the form of nectar and pollen (da Silva et al., 2021).

Ladybeetles from the *Cheilomene* genus are not only the primary natural enemies for thrips but also contribute to manage the population of whiteflies (Sujayanand et al., 2016), aphids (Udiarto et al., 2023), and mites (Sumathi et al., 2019). These predators play a crucial role in managing insect pests. It is, therefore, probable that IPRs have attracted predator of thrips that could have contributed to reducing their populations in chili pepper intercropping plots. The result demonstrates the potential of IRP cropping systems to provide improved and sustainable insect pest management. Intercropping has been suggested as an important agronomic practice for mitigating pest infestation in primary crops. This practice involves manipulating habitats to maintain ecological balance and create favorable conditions for natural enemies as well as sustaining crop productivity.

A significant difference in fruit damage between the control and the intercrop treatments was found during the experiments (Table 2). Tukey test results ($\alpha = 5\%$) showed that the lowest fruit damage due to *B. dorsalis* (8.84%) and *H. armigera* (2.13%) was recorded from chili and coriander (IRC), which was statistically similar to another treatment. The maximum fruit damage due to *B. dorsalis* (14.82%) and *H. armigera* (4.07%) was recorded from sole chili. Hence, it was confirmed that coriander was superior with a 40.35% and 47.67% reduction in fruit damage over control. To maintain production and control pest populations in the main crop, natural enemies and beneficial insects (pollinators) may be drawn to the increased plant diversity (da Silva et al., 2021; Adeleye et al., 2022).

Table 2. Effect of different treatments on fruit damage (%) due to *Bactocera dorsalis*, and *Helicoverpa armigera*

No.	Treatments	Fruits damage (%)			
		Bactocera dorsalis	Reduction of *B. dorsalis* over sole chili (%)	*Helicoverpa armigera*	Reduction of *H. armigera* over sole chili (%)
A	Intercropped chili pepper + coriander (IRC)	8.84^{c}	40.35	2.13^{b}	47.67
B	Intercropped chili pepper + coriander (IPC)	9.74^{bc}	34.28	2.76^{b}	32.19
C	Intercropped chili pepper + celery (IRC)	9.22^{bc}	37.79	2.69^{b}	33.91
D	Intercropped chili pepper + celery (IPC)	10.99^{b}	25.84	2.73^{b}	32.92
E	Intercropped chili pepper + bunching onion (IRC)	10.03^{b}	32.32	2.50^{b}	38.57
F	Intercropped chili pepper + bunching onion (IPC)	9.47^{bc}	36.1	2.25^{b}	44.72
G	Sole chili pepper	14.82^{a}	-	4.07^{a}	
	CV (%)	21.30		11.50	

*The means in each row of a parameter followed by different letters are significantly difference ($P < 0.05$) according to the honestly significant difference (HSD) test.

Additionally, according to Sandhu & Arora (2014), the IPM model, which included coriander as a plant repellent, reduced the number of *H. armigera* eggs and larvae and consequently increased productivity. Our research showed that coriander may effectively reduce *T. parvispinus, B. dorsalis*, and *H. armigera* on chili peppers in the field, suggesting that it might be a useful plant to use as an intercrop repellant. All of these results showed that IRP intercrops reduce the need for insecticidal treatments by having a variety of effects on insect pests, including direct repellence or deterrence, infestation delay, and indirect control and regulation through the recruitment of natural enemies.

Plant growth and yield of chili plants due to different treatments are presented in Table 3 and 4. At 93 DAT, the maximum plant height and canopy width in sole chili showed better performance over different intercropping combinations. However, there were no significant differences due to the effects of treatments. This was probably because intercropping with certain species of IRPs can improve soil quality by increasing soil organic nitrogen, soil water content, pH values, and available nitrogen contents (Kaci et al., 2022). The coriander was growing more, but the chili pepper was unshadow. Thus, by favoring natural enemies, the intercropping strategy suggested by IRPs can lower insect incidence while raising chili pepper yields.

The fruit length and diameter of chili pepper fruits in different treatments varied from 11.43 to 12.20 cm and 1.68 to 2.03 cm, respectively, with maximum fruit weight (18.00 cm) and fruit diameter of 2.03 cm were found in intercropping chili pepper + bunching onion (IPC), whereas the minimum fruit weight (11.43 cm) and fruit diameter (1.74 cm) were found in Intercropped chili pepper + celery (IPC). Significantly, the highest number of fruits per plant was observed in chili pepper + coriander (230.90), and the lowest was in sole chili pepper (140.50). This might be associated with the number of pests attacked. The chili pepper + coriander (IRC) system recorded the highest chili pepper yield (12.35 t ha^{-1}) followed by chili pepper + celery (IPC) (11.61 t ha^{-1}) and chili pepper + bunching onion (11.31 t ha^{-1}) compared to sole chili in the other intercropping system. The increase in yield over sole chili pepper was 43.27%, 4.29%, and 31.21%, respectively (Table 3).

Table 3. Effect of different treatments on growth and yield of chili pepper

No.	Treatments	Plant height at 93 DAT (cm)	Canopy width at 93 DAT (cm)	Yield t ha^{-1}	Yield % Increasing yield
A.	Intercropped chili pepper + coliander (IRC)	72.30	46.51	12.35^{a}	43.27
B.	Intercropped chili pepper + coliander (IPC)	80.60	45.03	11.30^{a}	31.09
C.	Intercropped chili pepper + celery (IRC)	71.60	50.11	11.98^{a}	31.09
D.	Intercropped chili pepper + celery (IPC)	80.23	50.14	11.61^{a}	34.39
E.	Intercropped chili pepper + bunching onion (IRC)	63.43	49.29	11.28^{a}	30.85
F.	Intercropped chili pepper + bunching onion (IPC)	75.93	49.41	11.31^{a}	31.21
G.	Sole chili pepper	74.93 ns	50.00 ns	8.62^{b}	-
	CV (%)	7.18	8.29	7.54	

*The means in each row of a parameter followed by different letters are significantly difference ($P < 0.05$) according to the honestly significant difference (HSD) test.

Similar results of an increase in coriander and chili yield were reported by Dubey et al. (2023) who said that intercropping chili pepper and coriander with a ratio (85%: 15%) produced the highest yield. Intercropping of coriander and soybean showed much higher fresh weight per unit area than sole cropping (Weisany et al., 2021). The beneficial impact of coriander on carrot growth and yield formation was observed (Lepse & Zeipiņ, 2023).

Among both intercropping systems, interrow cropping (IRC) showed the best results in terms of reducing pest populations and damage compared to interplant cropping (IPC). The population density of IRPs is an important tool for increasing crop production. Talukder et al. (2015) reported that 100% onion + 20% coriander and 100% onion + 30% coriander rations gave a higher yield of onion. Our studies have shown that the presence of coriander, celery, and bunching onion on chili pepper plots significantly reduces the damage caused by *T. parvispinus*, *B. dorsalis,* and *H. armigera*.

Lopes et al. (2016) reported that higher yield was positively correlated with an increase in predator populations and predation rates, with a decline in rural laborers and an increase in farmer's revenue. The results of the experiment indicate that intercropping is a practical tactic for reducing the negatif impacts of agricultural intensification on beneficial arthropods. chili pepper + coriander might be a suitable combination for higher productivity, reducing pest populations and damage, and enhancing natural enemy populations (Table 4).

Table 4. Effect of different treatments on yield contributing characters

No	Treatments	Fruit weight (g)	Fruit length (cm)	Fruit diameeter (cm)	Fruit number/plant
A	Intercropped chili pepper + coriander (IRC)	16.82^{a}	12.20^{a}	1.68^{b}	230.90^{a}
B	Intercropped chili pepper + coriander (IPC)	14.16^{ab}	13.43^{a}	1.81^{ab}	184.75^{a}
C	Intercropped chili pepper + celery (IRC)	16.14^{ab}	13.23^{a}	1.83^{ab}	211.70^{a}
D	Intercropped chili pepper + celery (IPC)	11.43^{b}	11.89^{a}	1.74^{b}	161.17^{a}
E	Intercropped chili pepper + bunching onion (IRC)	18.00^{a}	12.02^{a}	2.03^{a}	173.17^{a}
F	Intercropped chili pepper + bunching onion (IPC)	15.73^{ab}	11.98^{a}	1.74^{b}	184.20^{a}
G	Sole chili pepper	11.50^{b}	12.00^{a}	1.74^{b}	140.50^{b}
	CV	5.22	ns2.83	2.62	12.50

*The means in each row of a parameter followed by different letters are significantly difference ($P < 0.05$) according to the honestly significant difference (HSD) test.

CONCLUSIONS

This study demonstrates that intercropping chili pepper with coriander, celery, and bunching onions significantly reduces plant damage compared to sole chili pepper cultivation. Among the various intercrop combinations, chili pepper + coriander was the most effective, reducing damage from three major pest species *T. parvispinus* (51.77%), *H. armigera* (47.67%), and *B. dorsalis* (40.35%). Additionally, this combination increased the population of predatory beetles, *Cheilomenses sexmaculatus* (Coleoptera: Coccinellidae), and enhanced chili yield by 43.27%. The effectiveness of intercropping in reducing pest damage can be attributed to the repellent properties of the intercrop plants. Coriander, celery, and bunching onions release volatile organic compounds (VOCs) that deter pests and attract beneficial predators. These natural repellents reduce the reliance on chemical insecticides, promoting a more sustainable and environmentally friendly approach to pest management.

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REFERENCES

Adeleye, V.O., Seal, D.R., Liburd, O.E., McAuslane, H. & Alborn, H. 2022. Pepper weevil, Anthonomus eugenii (Coleoptera: Curculionidae) suppression on jalapeño pepper using non-host insect repellent plants. *Crop Protection* **154**, 105893. doi: 10.1016/j.cropro.2021.105893

Batista, M.C., Fonseca, M.C.M., Teodoro, A.V., Martins, E.F., Pallini, A. & Venzon, M. 2017. Basil (Ocimum basilicum L.) attracts and benefits the green lacewing Ceraeochrysa cubana Hagen. *Biological Control* **110**, 98–106. doi: 10.1016/j.biocontrol.2017.04.013

Breitenmoser, S., Steinger, T., Baux, A. & Hiltpold, I. 2022. Intercropping Winter Oilseed Rape (*Brassica napus* L.) Has the Potential to Lessen the Impact of the Insect Pest Complex. *Agronomy* **12**(3), 723. doi: 10.3390/agronomy12030723

Da Silva, L.R.R, Ferreira, O.O., Cruz, J.N., De Jesus, P.F.C., Anjos, T.O.D., Cascaes, M.M., Da Costa, W.A., De Aguiar, A.E.H. & De Oliveira, M.S. 2021. Lamiaceae essential oils, phytochemical profile, antioxidant, and biological activities. *Evidence-based Complementary and Alternative Medicine*, **1**, 1–18. doi: 10.1155/2021/6748052

Devi, S. 2018. Effect of Intercropping on Sucking Insect Pests and Natural Enemies of Cotton. *International Journal of Current Microbiology and Applied Sciences* **7**(04), 1101–1109. doi: 10.20546/ijcmas.2018.704.120

Dubey, S., Singh, D. & Wesley, C.J. 2023. Inter Cropping of Chilli with Coriander and Fenugreek in Prayagraj Agro-climatic Conditions. *International Journal of Environment and Climate Change* **13**(8), 1298–1304. doi: 10.9734/ijecc/2023/v13i82073

Gurlaz, K. & Sangha, K.S. 2016. Diversity of arthropod fauna associated with chili (*Capsicum annuum* L.) in Punjab. *J Entomol Zool Stud* **4**(5), 390–396.

Gurr, G.M., Wratten, S.D., Landis, D.A. & You, M. 2017. Habitat Management to Suppress Pest Populations: Progress and Prospects. *Annual Review of Entomology* **62**(1), 91–109. doi: 10.1146/annurev-ento-031616-035050

Huss, C.P., Holmes, K.D. & Blubaugh, C.K. 2022. Benefits and Risks of Intercropping for Crop Resilience and Pest Management. *Journal of Economic Entomology* **115**(5), 1350–1362. doi: 10.1093/jee/toac045

Isman, M.B. 2020. Bioinsecticides based on plant essential oils: a short overview. *Zeitschrift Für Naturforschung C*, **75**(7–8), 179–182. doi: 10.1515/znc-2020-0038

Järvinen, A., Hyvönen, T., Raiskio, S. & Himanen, S.J. 2023. Intercropping shifts the balance between generalist arthropod predators and oilseed pests towards natural pest control. *Agriculture Ecosystems & Environment* **348**, 108415. doi: 10.1016/j.agee.2023.108415

Kaci, G., Ouaret, W. & Rahmoune, B. 2022. Wheat-Faba bean intercrops improve plant nutrition, yield, and availability of nitrogen (N) and phosphorus (P) in soil. *Agronomy Research* **20**(3), 603–616. doi: https://doi.org/10.15159/AR.22.047

Lauren, D., Snyder, M., Gómez, I. & Alison, G. 2020. Power, crop varietal mixtures as a strategy to support insect pest control, yield, economic, and nutritional services. *Frontiers in Sustainable Food Systems* **4**(60), 1–14.

Lepse, L & Zeipiņ, S. 2023. Increasing the sustainability of vegetable crops production by using intercropping. *Agronomy Research* **21**(S2), 494–503. doi: 10.15159/AR.23.026

Li, X.W., Lu, X.X., Zhang, Z.J., Huang, J., Zhang, J.M., Wang, L.K., Hafeez, M., Fernández-Grandon, G.M. & Lu, Y.B. 2021. Intercropping Rosemary (Rosmarinus officinalis) with Sweet Pepper (*Capsicum annum*) Reduces Major Pest Population Densities without Impacting Natural Enemy Populations. *Insects* **12**(1), 74. doi: 10.3390/insects12010074

Lishchuk, A., Parfenyk, A., Furdychko, O., Boroday, V., Beznosko, I., Drebot, O. & Karachinska, N. 2024. Ecotoxicological Hazard of Pesticide Use in Traditional Agricultural Technologies. *Journal of Ecological Engineering* **25**(2), 274–289. doi: 10.12911/22998993/177275

Lopes, T., Hatt, S., Xu, Q., Chen, J., Liu, Y. & Francis, F. 2016. Wheat (Triticum aestivumL.)-based intercropping systems for biological pest control. *Pest Management Science* **72**(12), 2193–2202. doi: 10.1002/ps.4332

Mahfudz, M., Saleh, S., Antara, M., Anshary, A., Bachri, S., Made, U., Hasanah, U. & Rauf, R.A. 2019. Adoption and advantages of eco-friendly technology application at the shallot farming system in Indonesia. *Agronomy Research* **17**(4), 1679–1687. doi: 10.15159/ar.19.188

Martin-Guay, M.O., Paquette, A., Dupras, J. & Rivest, D. 2018. The new Green Revolution: Sustainable intensification of agriculture by intercropping. *The Science of the Total Environment* **615**, 767–772. doi: 10.1016/j.scitotenv.2017.10.024

Mir, M.S., Saxena, A., Kanth, R.H., Raja, W., Dar, K.A., Mahdi, S.S., Bhat, T.A., Naikoo, N.B., Nazir, A., Amin, Z., Mansoor, T., Myint, M.Z., Khan, M.R., Mohammad, I. & Mir, S.A. 2022. Role of Intercropping in Sustainable Insect-Pest Management: A Review. *International Journal of Environment and Climate Change*, 3390–3404. doi: 10.9734/ijecc/2022/v12i111390

Moekasan, T.K. & Prabaningrum, L. 2017. Penggunaan rumah kasa untuk mengatasi serangan organisme pengganggu tumbuhan utama pada budidaya cabai merah di dataran tinggi. *Jurnal Hortikultura* **24**, 179–188. Indonesian with English abstract.

Rahman, M.M., Joaty, J.Y. & Islam, M.M. 2020. Intercropping for insect pest management in sustainable agriculture: A review. *Bulletin of the Institute of Tropical Agriculture, Kyushu University* **43**, 11–22. doi: 10.11189/bita.43.11

Rakotomalala, A.A., Ficiciyan, A.M. & Tscharntke, T. 2023. Intercropping enhances beneficial arthropods and controls pests: A systematic review and meta-analysis. *Agriculture Ecosystems & Environment* **356**, 108617. doi: 10.1016/j.agee.2023.108617

Sandhu, S. & Arora, R. 2014. Evaluation of oviposition efficiency on trap crops of marigold and coriander for management of tomato fruit borer,Helicoverpa armigera(Hubner) (Noctuidae: Lepidoptera) on potted plants. *Indian Journal of Agricultural Research* **48**(5), 367. doi: 10.5958/0976-058x.2014.01316.x

Salamanca, J., Souza, B. & Rodriguez-Saona, C. 2018. Cascading effects of combining synthetic herbivore-induced plant volatiles with companion plants to manipulate natural enemies in an agro-ecosystem. *Pest Management Science* **74**(9), 2133–2145. doi:10.1002/ps.4910

Setiawati, W., Muharam, A., Hasyim, A., Prabaningrum, L., Moekasan, T.K., Murtiningsih, R., Lukman & Mejana, M.J. 2022. Growth, and yield characteristics as well as pests and disease susceptibility of chili pepper (*Capsicum annuum* L.) under different plant density and pruning levels. *Applied Ecology and Environmental Research* **20**(1), 543–553. doi: 10.15666/aeer/2001_543553

Shivalingaswamy, T.M., Udayakumar, A & Mani, M.2022. Pests and their management in chilies and bell pepper. *Trends in Hortic Entomol*, 971–982. doi:10.1007/978-981-19-0343-4_39

Sujay, M.H & Giraddi, R.S. 2015. Role of intercrops for the management of chili pests. *Journal Agriculture Sciences* **28**(1), 53–58.

Sujayanand, G., Sharma, R. & Shankarganesh, K. 2016. Impact of intercrops and border crops on pest incidence in okra. *Indian Journal of Horticulture* **73**(2), 219. doi:10.5958/0974-0112.2016.00051.7

Sumathi, E., Vishnupriya, R., Ramaraju, K. & Geetha, M. 2019. Biological Control of Phytophagous Mites: A Review. *International Journal of Current Microbiology and Applied Sciences* **8**(01), 2153–2160. doi: 10.20546/ijcmas.2019.801.225

Talgre, L., Eremeev, V., Mäeorg, E. & Luik, A. 2023. Diversified cropping systems for promoting the beneficial insects-ground beetles (Coleoptera: Carabidae). *Agronomy Research* **21**(2), 592–597. doi: 10.15159/ar.23.027

Talukder, A., Rahman, J., Rahman, M., Biswas, M. & Asaduzzaman, M. 2015. Optimum Ratio of Coriander Intercropping with Onion. *International Journal of Plant & Soil Science* **4**(4), 404–410. doi: 10.9734/ijpss/2015/12600

Togni, P.H., Venzon, M., Muniz, C.A., Martins, E.F., Pallini, A. & Sujii, E.R. 2016. Mechanisms underlying the innate attraction of an aphidophagous coccinellid to coriander plants: Implications for conservation biological control. *Biological Control* **92**, 77–84. doi: 10.1016/j.biocontrol.2015.10.002

Tu, H. & Qin, Y. 2017. Repellent Effects of Different Celery Varieties in Bemisia tabaci (Hemiptera: Aleyrodidae) Biotype Q. *Journal of Economic Entomology* **110**(3), 1307–1316. doi: 10.1093/jee/tox110

Udiarto, B.K., Murtiningsih, R., Muharam, A., Moekasan, T.K., Setiawati, W., Hasyim, A., Sulastrini, I., Gunaeni, N., Korlina, E., Gunadi, N., Udiati, T., Tursilarini, T.Y., Negara, A., Ardjanhar, A. & Manzila, I. 2023. Preferences and functional response of Coccinellidae to Bemisia tabaci (Hemiptera: Aleyrodidae). *Chilean Journal of Agricultural Research* **83**(6), 715–724. doi: 10.4067/s0718-58392023000600715

Wang, J., Li, S., Fang, Y., Zhang, F., Jin, Z., Desneux, N. & Wang, S. 2021. Enhanced and sustainable control of Myzus persicae by repellent plants in organic pepper and eggplant greenhouses. *Pest Management Science* **78**(2), 428–437. doi: 10.1002/ps.6681

Weisany, W., Tahir, N.A.R. & Schenk, P.M. 2021. Coriander/soybean intercropping and mycorrhizae application lead to overyielding and changes in essential oil profiles. *European Journal of Agronomy* **126**, 126283. doi: 10.1016/j.eja.2021.126283

Woldemelak, W.A. 2020. The major biological approaches in the integrated pest management of onion thrips (Thysanoptera: Thripidae). *J. Hortic. Res*., **28**, 13–20. doi: 10.2478/johr-2020-0002

Yousefi, M., Marja, R., Barmettler, E., Six, J., Dray, A. & Ghazoul, J. 2024. The effectiveness of intercropping and agri-environmental schemes on ecosystem service of biological pest control: a meta-analysis. *Agronomy for Sustainable Development* **44**(2). doi: 10.1007/s13593-024-00947-7

Zhang, W., Zhang, T.T., Machado, R.A.R. & Dai, C.-C. 2024. Correction to: Intercropping-induced leaf metabolic changes increase plant resistance to herbivory. *Plant and Soil*. doi: 10.1007/s11104-024-06505-0