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Release of *Ceranisus menes* as a Biological Control Agent Against *Thrips tabaci* on Tomato (*Solanum lycopersicum*) Under Net House Conditions

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A B S T R A C T

Onion thrips (*Thrips tabaci* Lindeman) are one of the main pests of tomatoes grown around the world. Adult and nymph life stages of this pest feed on tomato foliage by chewing through foliage to their vascular areas, causing silvering, chlorosis, foliar curling, and reduced photosynthesis, along with stunted plant growth. These injuries cause significant yield losses. *T. tabaci* also transmits many economically important tospoviruses, which makes its management very difficult on both open field and protected agricultural crops. The use of synthetic insecticides has resulted in insecticide resistance, environmental degradation, and the resurgence of insect pest populations, as well as negative effects on beneficial arthropods. Because of these problems, biologically-based environmentally sustainable control methods have become increasingly important components of integrated pest management programmes. The purpose of this study was to evaluate the potential of *Ceranisus menes*, a larval endoparasitoid, as a biological control agent against *T. tabaci* in protected agriculture. Four replicate tomato microplots were created with a total of 60 to 120 *T. tabaci* plot, and *C. menes* were released at densities of 15, 20, 25, and 30 adults at each release in sequential releases. *T. tabaci* populations were monitored prior to each *C. menes* release and again after to assess the percentage reduction of *T. tabaci* detected following each release. The data showed a clear density-dependent suppression of *T. tabaci*, with the highest parasitoid release density resulting in the greatest reduction of *T. tabaci* over time. The data from the cumulative release densities indicated a 60% level of suppression of *T. tabaci* populations within the high-density release treatment, and moderate levels of significant *T. tabaci* suppression occurred with the two lower release densities. The results of this study clearly demonstrate that the use of repeated releases of *C. menes* will substantially suppress *T. tabaci* populations and keep *T. tabaci* population densities below economic thresholds of damage in managed agriculture. These results also indicate high potential for *C. menes* to be an effective replacement for synthetic chemical insecticides used in tomato production systems, which is a safe and environmentally friendly manner. The integration of *C. menes* into integrated pest management programmes will result in sustainable reductions in the dependence of herbicides on tomato production systems while conserving and improving the populations of beneficial insects and enhancing the ecological sustainability of tomato production systems.

Introduction

Tomatoes are one of the most significant crops produced worldwide, contributing to food security, agricultural revenues, and food processing industries. Tomatoes are grown worldwide due to their adaptability, seasonal availability, strong market demand, and high nutritional value. Tomatoes also contain a lot of vitamins A and C, lycopene, carotenoids, flavonoids, dietary fibre and other nutrients that reduce oxidative stress and lower the risk of CVD and certain cancers. India has been a major tomato producer for decades. Polyhouses and net houses in India have expanded protected cultivation of numerous crops, improving tomato yields, fruit quality, and year-round tomato availability. However, excessive farming increases insect pest populations, which severely limit tomato yield. Over the last 30 years, onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), has become one of the most commercially important and harmful tomato arthropod pests in the world. *T. tabaci*, once a pest of onion, now infects over 300 species of cultivated and wild plants, including tomato, onion, garlic, chilli pepper, cabbages, cotton, potatoes, cucurbits, tobacco, and many ornamental plants. Onion thrips' remarkable host adaptability, rapid reproduction, short generation time, and ability to survive a wide range of environmental conditions in Asia, Europe, Africa, Australia, and North and South America explain its global distribution and prevalence.

T. tabaci feeds on tomato plants, causing severe and physiological harm. Both the adult and larvae of *Thrips tabaci*, the onion thrip, have asymmetrical, rasping-sucking mouthparts that penetrate plant epidermal cells to get their contents. Thrips eating continuously destroys chloroplast-rich mesophyll tissue. Silvery spots, chlorosis, bronzing, curling, and necrotic lesions on freshly produced leaves are typical infestation symptoms. High infestations (100 thrips per plant) limit photosynthesis, delay flowering, impair fruit development, and drastically reduce crop output and quality. Under ideal conditions, unchecked infestations can reduce yields by 40–60%. Due to controlled conditions in protected cultivation, *Thrips tabaci* populations increase rapidly (Reitz *et al*., 2020). *Thrips tabaci* not only causes feeding harm but also efficiently spreads economically significant plant viruses like Orthotospovirus. The transmission of Tomato Spotted Wilt Virus (TSWV), Iris Yellow Spot Virus (IYSV), and other tospoviruses causes chlorosis, necrosis, wilting, deformed fruits, and productivity loss, which increases crop losses. The propagation of viruses produced by thrips feeding injury causes much bigger economic losses than the injury itself. Thus, thrips are a major plant viral vector in vegetable production. Insect biology complicates *T. tabaci* management. Unlike many other insect pests, female *T. tabaci* lay solitary eggs into leaf tissue, protecting them from insecticides and rain, wind, etc. The two larval instars that hatch from the eggs are energetic feeders and grow quickly before entering the prepupal and pupal stages. Larvae develop in dirt, plant debris, or other protected/hidden plant structures during prepupal and pupal stages. Pupae quickly become adults and feed and reproduce. A complete life cycle can take two to three weeks at 25–30°C, resulting in numerous overlapping generations over the growing season. Traditionally, onion thrips were controlled by periodically spraying organophosphate, carbamate, pyrethroid, neonicotinoid, and spinosyn pesticides. Synthetic pesticides initially suppress pest populations quickly, but their widespread use has raised ecological and economic issues. The usage of these pesticides has led to thrips resistance in many tomato-producing areas, reducing pesticide efficacy and raising production costs. Through environmental contamination and food crop residues, agricultural pesticides harm pollinators, parasitoids, predatory insects, soil microbes, aquatic ecosystems, and human health (Gill & Garg, 2014). IPM is gaining popularity worldwide due to the drawbacks of synthetic insecticides. Biological, cultural, mechanical, behavioural, and chemical approaches are used in IPM to keep pest populations below economic thresholds and reduce environmental consequences. Since natural enemies can lower pest levels without disrupting the ecosystem, biological controls are one of the most environmentally friendly IPM methods. Conserving and promoting beneficial organisms reduces pesticide use and promotes sustainable agriculture. Predacious bugs (Orius), mites (Amblyseius), lacewings, lady beetles, entomopathogenic fungi, nematodes, and parasitic wasps naturally attack thrips. Scientists have focused on parasitic wasps from the family Eulophidae because of their host specificity and capacity to parasitise thrips larvae. Ceranisus species may be promising biological control agents for onion and western flower thrips.

Ceranisus menes Walker (Hymenoptera: Eulophidae), a solitary endoparasitoid that develops inside thrips, is found throughout Asia, Europe, Africa, and Oceania. The female parasitoid aggressively searches for larval thrips (under five days old) and lays one parasite egg in each host larva using a long and slender ovipositor. Parasite larvae feed on host tissues to develop inside, keeping the host larva alive for most of their development. After developing, the parasitoid kills its host larva and pupates in the host remnants. Once grown, the parasitoid can attack more hosts. Thrips numbers can be reduced without harming the host plant due to the parasitoid's life history. Many lab and field experiments have shown that *C. menes* kills commercially important thrips species. The creation of significant *C. menes* populations has reduced thrips populations in greenhouses, vegetable crops, ornamental crops, and protected agricultural production systems. *C. menes* parasitism efficacy varies on host density, temperature, relative humidity, and release interval, according to previous studies. Repeated augmentative releases induce more thrips suppression than one introduction because they sync parasitoid populations with host availability.

Because *C. menes* are usually kept in a controlled environment, the net house culture approach is ideal for testing their performance before commercial usage. Many researchers have identified *C. menes* as a promising biological control agent for thrips worldwide, but little is known about its release tactics and efficiency against tomato in net houses in India. Most *C. menes* biology and thrips research has been done in labs or greenhouses outside of India. Few studies have quantified consecutive parasitoid releases in protected tomato production systems. To integrate *C. menes* into environmentally sustainable pest control approaches, more research is needed to determine the best density and release strategy and assess its ability to support thrips management.

This study examined *C. menes* biological control of *T. tabaci* in net-house tomato plants. The study compared different release rates of *C. menes* for suppressing *T. tabaci*, compared the reduction of *T. tabaci* populations after sequential releases, and evaluated the potential of *C. menes* as a component of integrated pest management approaches for sustainable tomato production. The project will help researchers, extension professionals, and vegetable producers find environmentally friendly alternatives to synthetic chemical insecticides.

Materials and Methods

Experimental Site-This study was conducted at D. S. College's Zoology Department Research Laboratory in Aligarh, Uttar Pradesh, India. The study used shielded net houses during the tomato growing season in favourable conditions. The net house was made of UV-stabilized nylon mesh to reduce insect pest entry and maximise airflow and natural light. For optimal growth of the tomato plants and parasitoids employed in the study, the net house temperature and relative humidity were monitored throughout the experiment. The study found that the average temperature was 24–31 degree Celsius and the relative humidity was 60–78%, which was suitable for the development of thrips (*Thrips tabaci*) and wasp (Ceratitis menes) spices and tomato plant and parasitoid growth.

Host Plant- The experiment used tomato (*Solanum lycopersicum* L.), a thrips (*Thrips tabaci*) favourite host plant. Once plots were ready, healthy, disease-free tomato seedlings from common kinds were transplanted into the net house.

The crop was grown according to standards. In accordance with lettuce culture, irrigation was scheduled and intercultural operations including weeding, trimming, staking, and fertilising were evenly distributed among all experimental plots.

No synthetic insecticides were employed during the trial to avoid interfering with the first and often second type of parasitoids.

Experimental Design- The experiment consisted of four independent nylon-net microplots, each measuring 3 × 10 m (30 m²).

Each microplot represented one parasitoid release treatment.

Treatment	Parasitoid Release Density
T1	15 *Ceranisus menes*
T2	20 *Ceranisus menes*
T3	25 *Ceranisus menes*
T4	30 *Ceranisus menes*

Each treatment was kept apart so That there would be no movement of parasitoids between the microplots. Tomato plants in each microplot had the opportunity to be infested by the naturally occurring populations of the thrip *Thrips tabaci*. Before the parasitoids were released, the average numbers of thrips per plant were counted, and that was used as the baseline number of thrips per plant prior to parasitoid release.

Maintenance of Thrips Population- Before the parasitoid was introduced, tomato plants with *Thrips tabaci* naturally developed.

Thrips were visually scanned weekly on a random sample of volunteer plants in each microplot. A 10× hand lens was used to accurately count larvae and adult thrips on young leaves, flowers, and sensitive shoots of the sample plants.

The Economic Threshold Level (ETL) utilised to assess biological control success in this experiment.

Collection and Maintenance of Parasitoids- The laboratory maintains parasitised natural thrips populations (T.H.) that produced mature *C. menes* (adults).

Most healthy and vigorous were released onto the field.

Before release, these codes were raised in laboratory insect rearing cages under controlled ventilation settings about cage size and room temperature:

Temperature : 25 ± 2°C

Relative Humidity : 70 ± 5%

Photoperiod : 14L : 10D

Only freshly emerged adult parasitoids were used in the experiment to ensure maximum searching ability and parasitization efficiency.

Parasitoid Release- Increased *Ceranisus menes* emissions in the morning reduced heat stress and improved parasitoid establishment.

On tomato leaf with actively feeding thrips larvae, parasitoids were discharged.

Three one-week breaks were given to each treatment.

The release densities were

Treatment 1 : 15 parasitoids
Treatment 2 : 20 parasitoids
Treatment 3 : 25 parasitoids
Treatment 4 : 30 parasitoids

The release schedule was maintained uniformly throughout the experiment.

Observation Recording- Parasitoid releases were assessed through observations made prior to each release and then again one week following each release.

The parameters noted for all observations included:

•The average amount of thrips that were alive per plant.
•The calculated percent decrease in thrips population.
•The amount of suppression (in terms of size) that occurred following each parasitoid release.
•Overall biological control effectiveness.

During each of the sampling intervals, ten randomly selected tomato plants from each experimental microplot were recorded upon.

During this study, the same set of plants were followed in order to minimize sampling variation.

Calculation of Percentage Reduction

The effectiveness of parasitoid release was calculated using the following equation:

$$\text{Percentage Reduction} = \frac{\text{Initial Thrips Population} - \text{Final Thrips Population}}{\text{Initial Thrips Population}} \text{x}100$$

This formula was applied after every parasitoid release to determine cumulative suppression of *Thrips tabaci* populations.

Statistical Analysis-All experimental observations were subjected to statistical analysis using IBM SPSS Statistics Version 26.0.

Ethical and Environmental Considerations

The research conducted was done on naturally occurring insect populations and helpful parasite insects, using no chemical pesticides that could cause harm to the environment.

The biological control programme was developed in accordance with Integrated Pest Management (IPM) guidelines to minimise environmental impact and to promote long-term use of ecologically sound agricultural practices for crop protection.

Using *Ceranisus menes* is an environmentally friendly method of preserving diversity, reducing pesticide levels and improving the sustainability of tomato production systems.

Results and Discussion

Sequential releases of the parasitoid *Ceranisus menes* significantly reduced the density of the thrips pest *Thrips tabaci* on tomato plants grown under protective netting. There was a significant density-dependent relationship between the amount of parasitoids released and their effectiveness in suppressing thrips. Increasing the density of parasitoid releases increased the effect of biological control throughout the duration of the experiment.

All experimental treatments displayed similar initial infestation levels of approximately 60 thrips per tomato plant prior to any parasitoid release, which indicated that the experimental sites had similar levels of thrips damage prior to starting the experiment. After parasitoids were released, there was a drastic reduction in the density of thrips on all of the experimental plots after one week and that continued for all subsequent releases.

Table 1. Effect of different release densities of *Ceranisus menes* on the population of *Thrips tabaci*

Treatment	Parasitoids Released	Initial Thrips/Plant (Mean ± SD)	Thrips After 1st Release	Thrips After 2nd Release	Thrips After 3rd Release
T1	15	60.00 ± 1.32^{a}	54.42 ± 1.24^{a}	44.67 ± 1.18^{a}	39.86 ± 1.15^{a}
T2	20	60.00 ± 1.41^{a}	52.92 ± 1.16^{b}	41.97 ± 1.09^{b}	35.71 ± 1.03^{b}
T3	25	60.00 ± 1.38^{a}	48.18 ± 1.11^{c}	30.32 ± 0.96^{c}	23.54 ± 0.88^{c}
T4	30	60.00 ± 1.27^{a}	45.12 ± 1.05^{d}	26.90 ± 0.82^{d}	18.41 ± 0.76^{d}

ANOVA: F = 48.76; P < 0.001

Standard deviations and means are shown. Tukey's HSD test ($P < 0.05$) assessed statistical significance, with alphabetic superscripts denoting significant differences.

Initial thrips numbers were similar between treatments, hence the experimental design was not significantly different ($P > 0.05$). All treatments reduced thrips populations after the first parasitoids release, however Treatment T4 (30 parasitoids) exhibited the greatest reduction. After parasitoids were released, suppression increased, and the highest density treatment had the fewest thrips after the third release.

Percentage Reduction in Thrips Population

Repeated releases of *Ceranisus menes* substantially increased biological control efficiency. Population suppression increased progressively with each release, demonstrating cumulative parasitoid activity.

Table 2. Percentage reduction of *Thrips tabaci* after sequential parasitoid releases

Treatment	First Release (%)	Second Release (%)	Third Release (%)
T1	9.30 ± 0.54^{a}	17.90 ± 0.71^{a}	21.73 ± 0.82^{a}
T2	11.80 ± 0.63^{b}	20.70 ± 0.84^{b}	26.23 ± 0.93^{b}
T3	19.70 ± 0.82^{c}	37.30 ± 1.12^{c}	47.44 ± 1.31^{c}
T4	24.80 ± 0.94^{d}	40.40 ± 1.28^{d}	60.31 ± 1.46^{d}

ANOVA: F = 71.53; P < 0.001

Superscript letters indicated significant changes between treatments. The percentage reduction grew dramatically after growers successfully released parasitoids. The cumulative suppression of more than 60% after the third release was achieved with 30 parasitoids. Other release densities reduced thrips population levels but less effectively.

There is a positive correlation between parasitoid density and efficient biological control. The biological control efficiency of *T. tabaci* was progressively suppressed when the release density increased from 15 to 30 parasitoids over time. Augmentative releases of more parasitoids improve host-searching efficacy, increase rates of parasitism and reduce pest survival in a protected environment.

Table 3. Overall biological control efficiency of *Ceranisus menes*

Treatment	Overall Reduction (%)	Biological Efficiency
T1	21.73	Moderate
T2	26.23	Moderate
T3	47.44	High
T4	60.31	Very High

Overall, *C. menes* was shown to exhibit a consistent trend toward increased efficacy of biological control with increasing densities of parasitoids. Both the 25 and 30 parasitoid treatments had significantly greater suppression than the 15 and 20 parasitoid treatments.

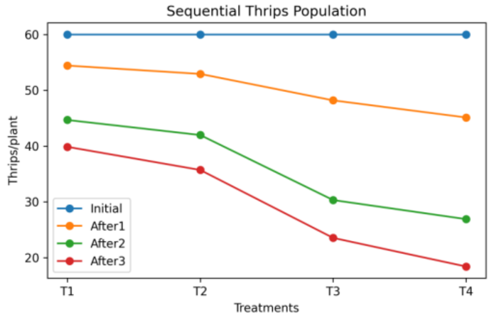

Figure 1. Sequential Changes in the Population of *Thrips tabaci* Following Repeated Releases of *Ceranisus menes*

Figure 1 shows that under net house settings, thrips population (*Thrips tabaci*) decreased over time for each of the three treatments releasing 15, 20, 25, and 30 adults of *Ceranisus menes* to reduce tomato plant thrips. Before parasitoid release, thrips populations were similar across treatments. Thrips numbers decreased significantly after each of the three releases (15, 20, 25, and 30 adults), with T4 (30 adults) having the biggest decrease and T1 (15 adults) having the lowest. These data show that repeated parasitoid releases considerably improved biological thrips control in protected crop production.

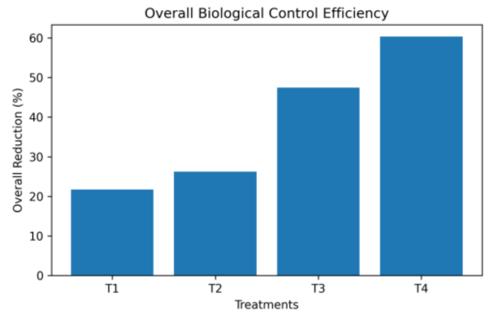

Figure 2. Overall Biological Control Efficiency of *Ceranisus menes*

Figure 2 shows the overall percentage reduction in thrips populations attributable to the different levels of parasitoid releases. The best biological control of thrips (60.3% reduction) was achieved with the highest number of releases (30 parasitic wasps), followed by 47.4% for 25 wasp releases. Both of the lower numbers of wasp releases (20 and 15) produced lesser reductions of thrips populations. These results demonstrate that the biological control of thrips was facilitated by increasing release numbers.

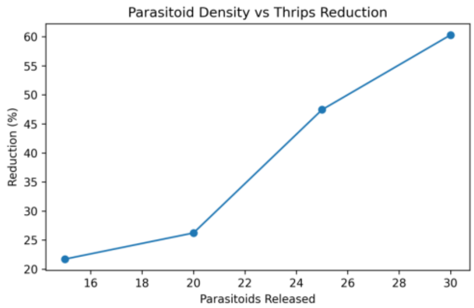

Figure 3. Relationship Between Parasitoid Release Density and Reduction in *Thrips tabaci* Population

Interpretation

In figure 3 the relationship between the density of parasitoids released and successful biological control is shown. The more released *Ceranisus menes*, the greater the impacts on reducing the number of thrips; in fact, the correlation appears to be almost linear which indicates that increasing density of parasitoids will lead to higher levels of efficiency in searching for hosts and parasitizing those hosts. Such a pattern supports using augmentative releases as part of an effective integrated pest management program.

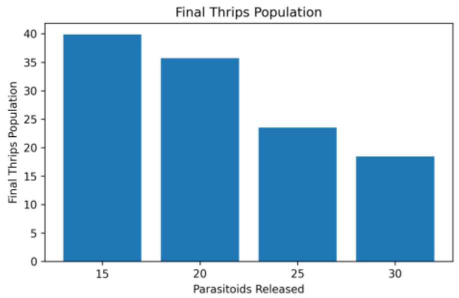

Figure 4. Final *Thrips tabaci* Population Remaining After Completion of Sequential Parasitoid Releases.

Interpretation Final Thrips populations, after completing an experiment; significantly impacted by thrips population decreases with higher densities of parasitoid releases. In treatment T4, the lowest populations were found and show that multiple releases of *Ceranisus menes* have been effective at reducing pest populations below their economic damage level.

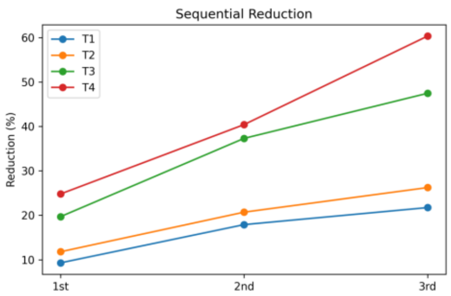

Figure 5. Sequential Percentage Reduction of *Thrips tabaci* Following Three Consecutive Releases of *Ceranisus menes*.

Interpretation

In Figure 5, biological control efficiency is cumulatively enhanced after several parasitoid introductions. All treatments experienced increasing levels of effectiveness with each introduction; however, the degree of effectiveness differed based on the numbers of parasitoids released. The treatments with the greatest density of introductions had the most significant reductions in pest numbers throughout the entire experiment. This finding highlights the need for repeated introductions of parasitoids for continuing pest control.

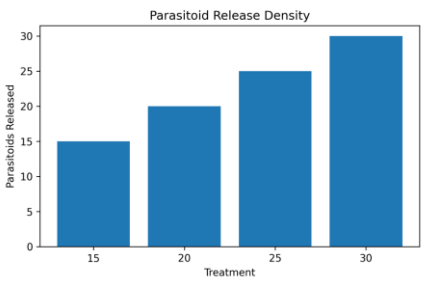

Figure 6. Comparison of Parasitoid Release Density Among Experimental Treatments.

Interpretation

Figure 6 shows the release densities of *Ceranisus menes* in the FIFO experiment for the four treatments. Increasing the number of parasitoids from 15-30 progressively improved the level of biological control of *Thrips tabaci*. This figure summarizes the experiment and emphasizes that an increase in the amount of parasitoids released is directly related to their performance as biological controls as determined during the study.

According to the one-way analysis of variance, there were significant treatment differences ($\alpha = 0.001$). Using Tukey's HSD comparisons revealed that the increases in the number of parasitoids utilized had a positive and statistically significant effect on the reduction of the number of thrips from treatments. The 30 parasitoid release treatment produced the most biological control efficiency of all treatments and was significantly different from all other treatments.

The results of the statistical analyses support the conclusion that the repeated augmentative releases of *Ceranisus menes* can successfully keep *T. tabaci* populations below economic threshold levels in the cultivation of tomatoes in a protected environment.

All treatments that enhanced parasitoids reduced thrips populations, according to this study. Each time parasitoids were discharged in increasing numbers, thrips populations decreased considerably.

Treatments with more parasitoids initially reduced more than those without (e.g., T4 reduced 60.31% and provided the best biological control). All treatments had significant effects ($P < 0.001$), demonstrating that *C. menes* effectively controls *T. tabaci*.

C. menes is an effective and environmentally safe natural enemy of thrips that can suppress *T. tabaci* populations in net house onion production and integrated pest management programs for tomatoes.

This study showed that sequential releases of the larval endoparasitoid *C. menes* can decrease *T. tabaci* populations in protected tomato production. As parasitoids were released in greater numbers, *T. tabaci* populations were suppressed more; therefore, *C. menes* is an environmentally safe and effective alternative to insecticides. Repeat parasitoid releases were more successful than a single release, highlighting the need of maintaining appropriate parasitoid populations throughout the growth season.

The original thrips population size was similar across all treatments before the parasitoids were released, proving that all treatments were conducted under the same experimental conditions so that the parasitoids success could be accurately measured. After the first parasitoid release, all treatments showed a measurable decrease in thrips population density, but the initial decline was minor. As parasitoids were released, the degree of population suppression gradually increased. This cumulative impact suggests that parasitoids from previously parasitised hosts and new emergent adults increase host seeking and parasitisation efficiency. This steady suppression of *T. tabaci* is typical of successful augmentative biological control strategies that synchronise parasitoid and host populations.

The maximum density of parasitoids (30 per microplot) suppressed *T. tabaci* populations the most, resulting in >60% population decreases. This suggests that parasitoid release density is crucial to biological control. Greater parasitoid release numbers enhance host encounters, parasitism, and pest population recovery loss. In greenhouse vegetable crop systems, increasing *C. menes* density suppresses thrips populations.

In this study, *C. menes* efficacy matches its lifetime. A solitary larval endoparasitoid, *C. menes* attacks *T. tabaci*'s early instar larvae and completes its life cycle within its host, killing it. Unlike chemical pesticides, *C. menes* will look for hosts throughout its adult life and produce progeny that decrease host numbers. Thus, biological control systems regulate pest numbers self-sustainingly, while pesticides kill pest populations temporarily.

Loomans (2003) reviewed *C. menes* and various Ceranisus species that may parasitise commercially important thrips. *Ceranisus menes* parasitised *T. tabaci* and F. occidentalis better than several other parasitoids. This study found that parasitoid establishment depends on environmental conditions and repeated augmentative releases, similar to Loomans & Van Lenteren (2005), who found that repeated parasitoids can significantly reduce thrips populations in Indian net houses. The progressive increase in suppression levels throughout the experiment supports Loomans & Van Lenteren (2005).

It is congruent with Reitz, *et al*. (2011), who indicated that biological control should be one of several components of integrated pest management systems for thrips. They also found that parasitoids and predators regulate pest populations long-term without the ecological damage caused by insecticides. We found that frequent parasitoid releases keep thrips numbers below the economic threshold and reduce crop loss. Mouden *et al*. (2017) found that parasitoid releases, sanitation, resistant cultivars, monitoring programs, and targeted pesticide use work better together than separately. This study supports an integrated strategy to augmentative C releases.Cultural practices can use menes to control pests and safeguard beneficial arthropods.

One of the main benefits of biological controls is that this study found no environmental impacts. Conventional insecticides can leave residues, kill natural enemy insects that prey on target pests, contaminate soil and water, and cause insecticide resistance. Parasitoids protect insect diversity and ecological equilibrium by selectively targeting pests. Protected cultivation methods require this level of selectivity since frequent use of agricultural chemicals may expose workers and consumers to chemical residues.

Control efficacy increased with each parasitoid wasp release in this investigation. This shows that a single release may not be enough to reduce pest populations. The parasitoids are available through *T. tabaci* generations. To account for parasitoids' death owing to natural causes, dispersal, or host insect fluctuations, sequential release is recommended.

The net house environment may have affected parasite performance. Optimal development of hosts (*T. tabaci*) and parasitoids (*C. menes*) occurred at 24–36℃ and moderate relative humidity. The shielded greenhouse protected the parasitoid from strong rains, winds, and dispersal, helping it establish and find the host. Similar greenhouse experiments in Europe and Asia confirm that enclosed growth systems promote parasitoid biological control.

This finding has major implications for tomato production sustainability. Growers want safer pesticide alternatives because to public concerns about pesticide residues, environmental damage, and insecticide resistance. *C. menes* biological control has shown that parasitoids can control pests with less broad-spectrum synthetic insecticides while protecting crops. Tomato production in protected structures will likely become more ecologically sustainable and economically viable with biological control techniques.

The present investigation had interesting findings but also limitations. The study took place in a net house with little release densities. To completely understand parasitoids' performance in diverse temperatures, tomato varieties, and natural pest levels, more research is needed across multiple growing seasons and locations. The interactions of *C. menes*, predatory mites, predatory bugs, entomopathogenic fungi, and selective pesticides need further study to improve IPM.

This study found that *C. menes* effectively managed *T. tabaci* in protected tomato crops. The suppression was density-dependent and reduced pest populations due to recurrent parasitoid releases, suggesting its use in sustainable integrated pest management systems. Thus, our findings will help create ecologically friendly pest management methods and reduce pesticide use while still allowing growers to profit from tomato production.

Conclusion

It has been shown throughout the current investigation that the larval endoparasitoid, *Ceranisus menes*, has some potential as an effective biological control agent when used in the sustainable management of *Thrips tabaci* in tomatoes. Sequential augmentative releases of *C. menes* at various densities have significantly reduced the level of thrips populations in experimental plots, with the extent of suppression increasing as the density of parasitoid release was increased. Among the four different release treatments evaluated, the highest parasitoid release density (30 per microplot) was associated with the greatest level of thrips population reduction (more than 60% suppression at the third release). These findings indicate that repeated releases of *C. menes* at higher parasitoid densities provide superior biological control compared to lower parasitoid density releases. In addition, *C. menes* maintained thrips populations below the economic threshold level, thus eliminating the risk of severe damage to tomato crops. Further, unlike synthetic insecticides, *C. menes* provided continuous biological suppression without contaminating the environment and without affecting non-target beneficial organisms. This ecological benefit of *C. menes* makes it a suitable candidate for inclusion into environmentally sustainable crop protection methods. The results of the current experiment support the use of augmentative releases of *C. menes* as a critical element of Integrated Pest Management (IPM) in protected tomato production. The role of biological control can not only be to reduce reliance on chemical insecticides, but to help mitigate the development of large-scale insecticide resistance, to promote biodiversity, and to produce agricultural system with less risk than conventional agriculture. Although the current investigation was conducted under controlled conditions in a net house, the positive results of this investigation suggest that *C. menes* has great potential for routine use in the commercial production of tomatoes by using large-scale releases. Future studies should examine the performance of *C. menes* in various tomato cultivars, agro-climatic regions, and different seasons. Additionally, the incorporation of *C. menes* into biological control programs with predacious insects, entomopathogenic fungi, botanical pesticides, and selective insecticides may enhance both the efficacy and cost-effectiveness of biological control programs. Overall, the current work provides evidence that augmentative releases of *C. menes* represent an environmentally safe, economically feasible, and sustainable means of managing *Thrips tabaci*. The implementation of this method can result in reduced pesticide usage, while supporting long-term ecological stability and economic tomato production.

Practical Recommendations

Future use recommendations based on study results:

• *Ceranisus menes* should be included in IPM programs for growing tomatoes in protected settings.

When thrips populations are high, release parasitoids sequentially rather than all at once.

For effective thrips suppression, higher parasitoid release numbers (about 30 adults per microplot) should be used in areas with strong pest pressure.

• Regular monitoring of thrips populations is crucial for appropriate parasitoid release timing.

• Avoid broad-spectrum insecticides for one week before and after parasitoids release to minimise impact on beneficial insects.

• Include cultural techniques (e.g., weed removal, sanitation, agricultural residue management, and planting resistant cultivars) in biological pest control programs.

• Long-term monitoring programs can assess parasitoid establishment, persistence, and seasonal population dynamics in commercial production.

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Conflict of Interest

The authors claim no conflicts of interest in publishing this work.

Author Work

Pooja: Ideation, experimentation, data gathering, manuscript writing, and interpretation.

Virendra Kumar: Experimental design, supervision, statistical interpretation, article review, editing, and approval.

Statement of Data Availability

The corresponding author can provide the datasets used in this study upon reasonable request.

An Ethics Statement

In controlled experiments, only agricultural insect species and helpful parasitoids were studied. This study involved no vertebrates or humans. Experimental methods followed institutional agricultural and entomological research guidelines.

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