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Using Natural Enemies to Control Greenhouse Pests

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ABSTRACT

Biological pest control, often known as biological pest control or biocontrol, is a sustainable and ecologically friendly method of pest management in agriculture. It entails using living organisms, including predators, parasitoids, and diseases, to control pest populations and reduce agricultural loss. The study used the experimental method. The experiment was conducted in Al Batinah South Governorate from 2019-2021 to address crop loss and pesticide overuse in tomato and cucumber crops. Then, it was extended to Al Sharqiyah North, Ad Dakhiliyah, and Al Batinah North Governorates, using biological control methods like Green lacewing and Ladybird. The study used frequencies, percentages and standard deviations as statistical methods. The study employed the experimental method. In the current study, the researcher used certain natural enemies to test their effects on protecting tomato and cucumber crops in greenhouses from harmful pests in the Sultanate of Oman. The results revealed that Green lacewing and Ladybiboth both significantly eliminated whiteflies in tomato and cucumber crops by effectively controlling their populations. The study found that both the ladybird beetle and the green lacewing insect effectively reduced pest populations in tomato and cucumber plants over 10 days. The green lacewing insect led to an average reduction of 80% in pests, while the ladybird beetle was more effective, resulting in a 70% average reduction. Thus, the novelty of this research lies in its exploration of the use of natural enemies like the green lacewing and ladybird as a sustainable, eco-friendly alternative to chemical pesticides for controlling greenhouse pests, emphasizing the importance of sustainable pest management practices and integrating natural enemies with cultural practices and monitoring techniques.

INTRODUCTION

Oman's agricultural landscape faces challenges like water scarcity, high temperatures, soil salinity, pests, diseases, limited crop diversity, climate change, and inadequate infrastructure, requiring a comprehensive approach including water management, crop diversification, pest management, soil conservation, infrastructure investment, and climate-resilient practices.

In this sense, natural enemies, such as predatory insects, mites, parasitic wasps, pathogenic bacteria, fungi, and viruses, have been used as biological control agents against agricultural pests for various effectiveness levels (Riddick, 2022; Dreistadt *et al. et al.*, 2014). Biological pest control techniques are also crucial for preserving natural enemies and protecting human health and the environment in vegetable production (Türkten *et al.*, 2017). The reduction in pesticide use may be attributed to its potential to minimize environmental and human health risks (Yilmaz & Tanc, 2019).

Moreover, biological control in greenhouses is effective and inexpensive, compared to chemical control, and is more cost-effective than recent pesticides, despite limited research on greenhouse aspects (Parrella & Lewis, 2018). Effective biological pest management requires a comprehensive understanding of host plants, insects, biological control agents, and their deployment locations (Al-Kindi *et al.*, 2018).

On the other hand, crops grown in greenhouses are susceptible to pests and diseases (Pottorff & Panter, 2009). The surrounding environment of greenhouses provides homes, refuges, shelters, or food sources for insects, which poses the danger of crop colonisation by insect pests (Doehler *et al.*, 2023). Thus, biological control in greenhouse crops involves releasing natural enemies, such as predators or parasitoids, to maintain a necessary population for long-term control (Perdikis, Kapaxidi & Papadoulis, 2008).

Furthermore, natural enemies like ladybirds, Lacewings, and Trichogramma evanescens can reduce pests in greenhouses, proving beneficial for biological control in greenhouses (Leman, Vijverberg & Messelink, 2014; Snyder *et al.*, 2004). Trichogramma Evanescens can also be used in greenhouses for biological control (Keçeci & Öztop, 2017). Therefore, it is recommended to utilise ladybirds to assist in managing aphids in greenhouses (Riddick, 2017).

Based on the above mentioned, this study significantly contributes to previous studies by exploring the use of natural enemies like green lacewing and ladybird for controlling greenhouse pests in Oman, highlighting its benefits like sustainable management, reduced chemical dependency, improved crop quality, and cost-effectiveness, contributing to knowledge expansion in integrated pest management techniques.

Statement of the Problem

Greenhouse tomato production accounts for around

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2% - 5% of total Oman tomato production, whereas greenhouse cucumber production accounts for approximately 61% - 73% of total Oman cucumber production. Tomatoes are cultivated in greenhouses two to three times a year, while green-house cucumber is planted three to four times each year. There are several threats to the Sultanate's tomato and cucumber crops (Ishag & Al Rawahy, 2018). Infected tomatoes are common in various agricultural areas around the Sultanate of Oman (Al-Maawali *et al*., 2021). Cucumber agriculture in the Sultanate is also plagued by several pests (Mkook *et al*., 2020). Keeping in mind that chemical control initiatives in Oman have had minimal success as they provide only short-term solutions (Kwan *et al*., 2017; Al-Kindi *et al*., 2018), and taking into account that native and habitat-specific antagonistic microorganisms, which may be more adaptable to the prevailing local climatic conditions in Oman, may be suitable for use as biocontrol agents for the management of pre-and post-harvest diseases of vegetables (Al-Maawali *et al*., 2021), the researcher sees the statement of the problem to revolve around identifying the effectiveness of using natural enemies to control greenhouses pest in tomato and cucumber crops within the Sultanate of Oman.

Questions of the Study

The main question of the current study is: How natural enemies can contribute to controlling greenhouse pests? Many sub-questions can be derived as follows:

1. How does the use of biological control agents (Ladybirds) contribute to protecting tomato and cucumber crops?
2. How does the use of biological control agents (Green Lacewing) contribute to protecting tomato and cucumber crops?

Significance of the Study

Overuse of pesticides in suppressing damaging pests can lead to insecticide resistance and have many negative effects on the environment and human health. Biological control of insect pests has long been acknowledged as a natural pest control strategy. Pest control in greenhouses can be difficult, but natural enemies like Ladybirds, Lacewings, and Trichogramma Evanescens can help reduce pest numbers in greenhouse crops. The significance of the study stems from the fact that biological control by natural enemies can be more cost-effective than chemical control approaches. While synthetic pesticides require constant application, natural enemies can provide continual pest control once established in an agricultural region. Omani Farmers can save money in the long run by minimising the costs of acquiring and applying chemical pesticides. In addition, Omani Farmers can maintain a healthy ecology and reduce crop loss caused by pests by depending on natural enemies.

Limitations of the Study

The limitations of the current study can be reviewed as follows:

Objective Limitations

The current study is limited to discussing the role of natural enemies in controlling greenhouse pests.

Time Limitations

This study has been conducted for three seasons during the period from 2019 to 2021.

Place Limitations

This study has been conducted in the General Directorate of Agricultural and Animal Research in Al-Rumais, Sultanate of Oman.

LITERATURE REVIEW

The main economic movers in developing nations are their economies, and agriculture is their backbone. Human health, plant soils, and the environment are all at risk due to the growing use of chemical fertilizers and hazardous pesticides. Microbial insecticides have recently been used to preserve crops. As an alternative to managing pests and pathogens, biological agents for pest control have drawn increased attention in the last year. It helps to reduce the overuse of hazardous compounds and offers a sustainable method of managing plant health. The antagonistic bacteria are classified into six distinct phyla: Actinomycetota, Bacteroidota, Pseudomonadota, Bacillota, and Mucoromycota. Various techniques have been used to produce microbial pesticides, such as the extraction of pure cultures and efficacy bioassays conducted in both controlled and uncontrolled environments. It is widely acknowledged that the most advanced technology for ecologically friendly agriculture is biological control agents or BCAs. There have been reports of several beneficial BCAs for managing plant health, but standardizing bioformulation and gaining effective acceptance was necessary (Negi *et al*., 2023).

In this sense, because of the protected habitat that separates them from their range of natural enemies and pathogens, certain pests can become more problematic in greenhouses than they are outdoors (Veronesi, 2022). In addition, In greenhouse systems, the frequent mass introduction of natural enemies has been a common biological control technique when the resident population of natural enemies is not large enough to control the pests. An even more cost-effective and efficient approach would be to assist in the formation and population growth of beneficials. One of the most important factors in the success of biological control programs nowadays is the proactive development of parasitoids and predators before the advent of pests. In both conservation biological control (CBC) and inoculative biological control (IBC), the "predators and parasitoids-in-first" approach is employed (Pijnakker *et al*., 2020).

Moreover, insect pests that damage crops frequently represent a serious risk to farmers. The ecology in the area, chemical control methods, and biological control strategies that use living things must all be vividly coordinated for pest management to be implemented successfully. Once desired modifications have been made at the genome level, natural enemies can be incorporated into the pest management system. Therefore, molecular interventions are required for the efficient modulation of natural enemies (Remya & Nisha, 2020). Thus, By using biocontrol agents against pests, biological control aims to reduce the harmful effects of synthetic pesticides on the environment. Biological control is based on three fundamental concepts: importation, augmentation, and conservation. To achieve an effective outcome, biocontrol agents are imported through the process of importation (Dey, 2020).

Natural Enemies

Under sheltered conditions, the natural enemies that manage pests outdoors are absent. These factors lead to the development of insect problems indoors more frequently and more severely than outdoors. Pests such as nematodes, mites, and insects cause enormous losses in greenhouse vegetable and flower harvests. Effective management of these pests is crucial in preventing crop losses and boosting yields in protected vegetable and flower farming. Growers that implement effective pest management technology should anticipate receiving higher and more compensation for producing high-quality horticultural crops grown under protected cultivation (Mani, 2022). In this context, preservation biological control refers to the process of improving the natural enemies that already reside within crops. This can be accomplished by planting cover crops, which serve as insectary plantings and give natural enemies food and shelter (such as pollen and nectar) (Veronesi, 2022). Additionally, The main places where natural enemies can find a home are the boundaries of fields where crops and edge vegetation converge. In addition to taking into account the ideal field sizes, number of edges, and management techniques at and around edges, conservation and improvement of natural enemies may involve modifying plant species and arrangement, particularly at these edges. Combining the advantages of windbreak and agricultural systems is a viable strategy for managing field edges that also provides extra benefits related to wind protection (Mani, 2022). There are several types of natural enemies as follows:

Green Lacewing

The green lacewing is a highly efficient and practical general pest hunter in many types of crops and greenhouses. This is because insecticides like lufenuron, novaluron, and lambda-cyhalothrin are widely used in commercial products (Alsendi *et al.*, 2023). A possible predator of the Neuropterean insect known as the Chrysopid (green lacewing) has been discovered.

It is commonly referred to as the "green eye bug." Growing interest in incorporating beneficial predators into integrated pest management plans for horticultural and field crops has been observed lately, as producers look for chemical substitutes for controlling insect pests (Timke, Shetgar & Khandare, 2020).

Ladybird

Exotic ladybirds have been widely employed to control economically significant herbivorous insects. Recent instances of commercially significant bugs introducing themselves biologically have highlighted the necessity to carefully assess whether the anticipated advantages of pest management outweigh any potential environmental hazards (Rondoni *et al.*, 2021). A valuable biological pest management agent in all terrestrial landscapes, including agroecosystems, is the ladybird beetle. These pest predators are declining because of agricultural intensification, primarily because of pesticide use, habitat loss, and decreased food availability (Hussain, Nazir & Malik, 2022).

Trichogramma Evanescens

Trichogramma species are tiny endoparasitoids of insect eggs that play a crucial role in controlling lepidopteran pests, making them one of nature's most effective foes. Trichogramma females' lifespan, capacity for searching, fertility, and capacity to locate their hosts are all influenced by their body size (Taha *et al.*, 2022).

Greenhouse Cultivation

In both natural and artificial environments, beneficial insects provide biological control and pollination. High-value fruits and vegetables, especially those cultivated in greenhouses, require these ecosystem services (ES) in particular. Since its adults pollinate crops and its larvae feed on aphid pests, the hoverfly Eupeodes corollae provides both ES. In this study, we examined the dual function of E. corollae in three greenhouse-grown horticultural crops-strawberry, melon, and tomato-that are pollinated by insects and impacted by aphids (Li *et al.*, 2023). In this sense, in greenhouses, many forms of biological control, which are characterized as using the population of one organism to lower the population of another organism, are employed. In nations where greenhouse structures are frequently partially open, such as the Mediterranean Basin, the tropics, and the semi-tropics, natural biological control, or NatBC, is observed. NatBC is the process by which natural enemies naturally residing in the environment lower pest populations. Enhancing natural biological control can be achieved by cultivating plants close to greenhouses that offer natural enemies shelter, pollen, or nectar, or by growing such plants inside the greenhouse. Conservation biological control is the result of human activities that safeguard and enhance the activity of naturally occurring natural enemies (Van Lenteren, Alomar, Ravensberg & Urbaneja, 2020).

Biological Pest Control

In agricultural settings, biocontrol agents are considered a more environmentally friendly substitute for pesticides. To adopt more environmentally friendly methods, farmers use natural enemies as a biocontrol to eradicate aphids from crops; the harlequin ladybird is not yet regarded as toxic. Aphid management in crops may be better achieved by employing an augmentative or conservation biological control technique that uses native coccinellid species found in the area rather than the invasive harlequin ladybird (Camacho-Cervantes, Mendoza-Arroyo, Arellano-Sánchez & Del-Val, 2021). In a related context, In field crops, orchards, and forests, biological control can be crucial in lowering the quantity of pests. Trichogramma spp. are true egg parasitoids that are regarded as the most commonly utilized natural enemies in the world. This is partly because they are easy to produce in large quantities and may target a wide range of major insect agricultural pests, particularly lepidopterous ones in their early stages (their eggs). It is quite helpful to store natural enemies so they are ready for use when needed (Shawer *et al.*, 2021). In addition, ecosystems have a significant role in flowers, and intentionally selecting plant species based on their floral architecture is one way to support ecosystem services, including pest management, and biodiversity in agricultural settings. The field of sustainable agriculture holds immense importance, and it emphasizes how important it is to integrate ecological interactions between natural predators, prey, and floral resources into pest-management strategies (Hyder *et al.*, 2023).

Methodology Procedures

The experimental method was employed in this study. Kandilji (2018) described the experimental method as "the approach by which the researcher identifies various conditions and variables that appear in the investigation of information about a certain phenomenon, as well as controlling and manipulating such conditions and variables".

Study Variables

The study relied on several independent and dependent variables. The independent variables were represented by ladybirds and Green lacewing. The dependent variables were measures of tomato and cucumber crop protection (e.g., pest count, crop yield, crop quality).

Study Sample

The study sample included samples of tomato and cucumber crops. The samples were distributed into treatment and control groups. The application method of the biological agent was described for each group, including the quantity of the biological agent used and the duration of application.

Statistical Methods

Based on the nature of the study and the objectives the researcher aimed to achieve, the data were analyzed and results were extracted using the following statistical methods:

- Frequencies and percentages.
- Standard deviation.

The study seeks to answer the following main question: How does the use of biological control agents contribute to protecting tomato and cucumber crops? From there, the following sub-questions arise:

1. How does the use of biological control agents (ladybirds) contribute to protecting tomato and cucumber crops?
2. How does the use of biological control agents (Green lacewing) contribute to protecting tomato and cucumber crops?

The Experiment

The experiment was conducted in the Al Batinah South Governorate in Barka in a period extended for three seasons from 2019 to 2021, on tomato and cucumber crops. The researcher noticed that many farmers were complaining about crop loss and excessive spraying of pesticides, so the researcher conducted the study before transferring it to the farmers. After the first season, the experiment was extended to be applied to Al Sharqiyah North Governorate. In the second season, the Ad Dakhiliyah Governorate was included. In the third season, Al Batinah North Governorate was included. The current experiment was conducted on two crops, cucumber and tomatoes. The crops were treated against the following insects (thrips, whiteflies, mites). Biological control was implemented using Green lacewing and Ladybird. The study's results are presented in the following table:

Green Lacewing

Table 1: Illustrates the effect of Green lacewing on plant-damaging insects in (R1)

	Number of whiteflies	Number of thrips	Number of mites
R1	186	28	23
3 days	160	27	21
6 days	147	23	19
10 days	17	6	3

As shown in the previous table, it is evident that there is a positive effect of Green lacewing. Green lacewing insects play a crucial role in controlling agricultural pests, as the percentage of thrips decreased after (10) days of using Green lacewing. Additionally, mites were significantly affected, with their count reaching (3) on the day (10).

Table 2: Illustrates the impact of Green lacewing on pests causing plant damage in (R2)

	Number of whiteflies	Number of thrips	Number of mites
R2	181	20	17
3 days	155	15	14
6 days	89	6	3
10 days	0	2	1

As shown in the previous table, there is an effect of Green lacewing in reducing the number of harmful insects, including whiteflies, thrips, and mites. Whitefly was eliminated on the tenth day, while the count of thrips decreased to 2 and mites decreased to 1. This can be attributed to the role of Green lacewing in controlling and eliminating whiteflies, especially in the early stage of their life cycle, without causing any harmful side effects on plants.

Table 3: Illustrates the impact of Green lacewing on pests causing plant damage in (R3)

	Number of whiteflies	Number of thrips	Number of mites
R3	159	22	19
3 days	139	17	16
6 days	88	8	5
10 days	10	0	0

From the previous table, it is evident that there was an effect of Green lacewing on day 10, as both mites and thrips were eliminated. This can be attributed to the reliance on Green lacewing, which is an essential part of the pest control program, as thrips cause plant damage and weaken them.

Table 4: Demonstrates the impact of Green lacewing on pests causing plant damage in (R4)

	Number of whiteflies	Number of thrips	Number of mites
R4	188	30	14
3 days	169	26	11
6 days	60	12	9
10 days	8	2	0

From the previous table, it is evident that mites were eliminated on the tenth day, in addition to a decrease in the number of thrips to 2 and a decrease in whiteflies to 8. This can be attributed to the effect of Green lacewing, which helped reduce the number of harmful insects. Whiteflies cause a significant decrease in tomato yields, so relying on Green lacewing and other active predatory insects, including Ladybirds, is crucial as they feed on other small insects, including whiteflies, thrips, mites, and aphids.

Ladybird

Table 5: Illustrates the impact of Ladybirds on pests causing plant damage in R1

	Number of whiteflies	Number of thrips	Number of mites
R1	177	27	19
3 days	155	20	23
6 days	21	8	4
10 days	2	3	2

From the previous table, a decrease in the number of pests (mites, whitefly) to 2, and a decrease in thrips to 3 on the tenth day is evident. This can be attributed to the effect of Ladybird on crops, as Ladybird is an active predator that feeds on small insects, thus protecting plants from harmful pests.

Table 6: Illustrates the impact of Ladybirds on pests causing plant damage in (R2)

	Number of whiteflies	Number of thrips	Number of mites
R2	191	29	20
3 days	155	31	22
6 days	11	13	14
10 days	0	3	6

It is evident from the previous table that Ladybird was able to eliminate whitefly on the tenth day. This can be attributed to its ability to protect plants from agricultural pests and harmful insects.

Table 7: Illustrates the impact of Ladybird on pests causing plant damage in (R3)

	Number of whiteflies	Number of thrips	Number of mites
R3	149	28	25
3 days	161	23	9
6 days	40	15	4
10 days	4	5	0

The previous table demonstrates the impact of ladybirds on harmful pests, as mites were eliminated on the tenth day. This can be attributed to the effectiveness of ladybirds in controlling agricultural pests. They are safe to use and do not produce any harmful side effects on plants.

Table 8: Illustrates the impact of ladybirds on pests causing plant damage in (R4)

	Number of whiteflies	Number of thrips	Number of mites
R4	188	30	14
3 days	144	21	5
6 days	50	11	2
10 days	10	4	0

It is evident from the previous table that mites were eliminated on the tenth day. This can be attributed to the important role played by ladybirds in maintaining ecological balance. They help control the population of harmful insects, protecting plants and preventing significant damage.

Table 9: Green lacewing

	Efficiency of whitefly				Efficiency of thrips				Efficiency of mite			
	R1	**R2**	**R3**	**R4**	**R1**	**R2**	**R3**	**R4**	**R1**	**R2**	**R3**	**R4**
3 days	14	14.36	12.58	10.11	3.57	25	22.7	13.3	8.7	17.65	15.79	21.43
6 days	21	50.83	44.65	68.09	17.86	70	63.6	60	17.4	82.35	73.68	35.71
10 days	90.9	100	93.71	95.74	78.57	90	100	93.3	87	94.12	100	100

Table 10: Ladybird

	Efficiency of whitefly				Efficiency of thrips				Efficiency of mite			
	R1	**R2**	**R3**	**R4**	**R1**	**R2**	**R3**	**R4**	**R1**	**R2**	**R3**	**R4**
3 days	12.4	18.85	-8.05	23.4	25.93	-7	17.9	30	-21.1	-10	64	64.29
6 days	88.1	92.9	75.2	56.3	60	58.1	34.8	47.6	82.6	36.36	55.56	60
10 days	98.7	100	90	80	62.5	76.9	66.7	63.6	50	57.15	100	100

It is evident from Tables (9) and (10) that both Green lacewing and ladybirds were highly efficient in eliminating harmful pests such as mites, thrips, and whiteflies. However, Green lacewing had a greater impact in eliminating mites, thrips, and whiteflies on the tenth day. This can be attributed to the ability of Green lacewing to target and eliminate harmful insects that cause significant crop damage. Additionally, Green lacewing is larger compared to ladybirds, allowing them to consume a greater number of harmful insects in a day. They are also more aggressive than ladybirds, making them more effective in eliminating and controlling harmful pests.

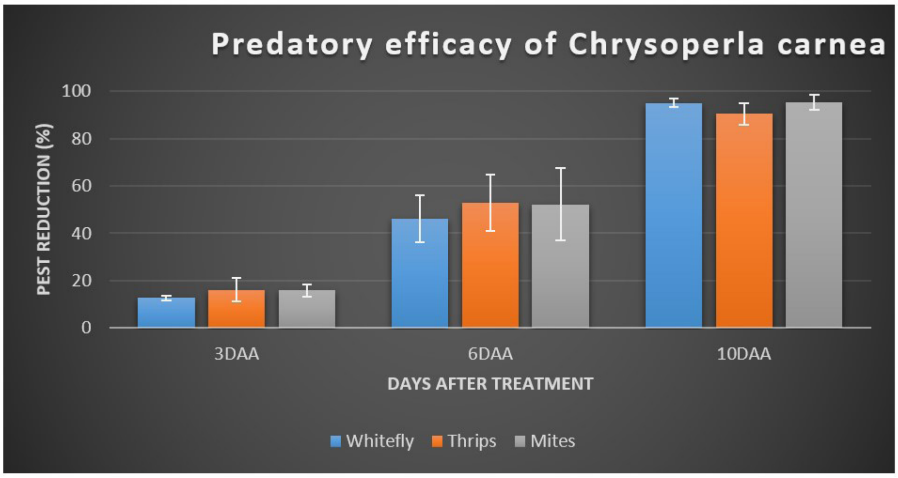

Figure 1: Illustrates the predatory efficacy of Chrysoperla carnea, which is a type of green lacewing

Table 11: Illustrates the standard deviations and standard errors of estimation for whiteflies, thrips, and mites

Days	Whitefly	SD	SE	Thrips	SD	SE	Mites	SD	SE
3DAA	12.76	1.92	0.962	16.16	9.8	4.9	15.89	5.34	2.67
6DAA	46.13	19.5	9.745	52.9	23.7	11.9	52.3	30.8	15.4
10DAA	95.08	3.84	1.92	90.47	8.96	4.48	95.27	6.19	3.095

It is evident from the previous table that the highest standard deviation at 3 days after application (3DAA) was 9.8, which corresponds to thrips. The highest standard deviation at 6 days after application (6DAA) was 30.8, which corresponds to mites. The highest standard deviation at 10 days after application (10DAA) was 8.96, which corresponds to thrips.

RESULTS

The study yielded the following results:

- The study showed that both the ladybird beetle and the green lacewing were effective in reducing the populations of targeted pests in tomato and cucumber plants (Table 1, Table 2). Over 10 days, the green lacewing insect led to an average reduction of 80% in the number of pests in both crops, compared to control groups (Figure 1). Additionally, the green lacewing insect demonstrated a significant impact on both thrips and mites, with their average numbers decreasing to 2 and 1, respectively, by the tenth day (Table 1). On the other hand, the ladybird beetle was more effective in significantly reducing the number of pests, resulting in a 70% average reduction.

- They are one of the most important factors in the success of biological control programs nowadays is the proactive development of parasitoids and predators before the advent of pests. In both conservation biological control (CBC) and inoculative biological control (IBC), the "predators and parasitoids-in-first" approach is employed (Pijnakker *et al.*, 2020).

- The results of this study are consistent with previous studies that have demonstrated the effectiveness of both the ladybird beetle and the green lacewing insect in pest control. The green lacewing is a highly efficient and practical general pest hunter in many types of crops and greenhouses. This is because insecticides like lufenuron, novaluron, and lambda-cyhalothrin are widely used in commercial products (Alsendi *et al.*, 2023).

- In addition, a valuable biological pest management agent in all terrestrial landscapes, including agroecosystems, is the ladybird beetle. These pest predators are declining because of agricultural intensification, primarily because of pesticide use, habitat loss, and decreased food availability (Hussain, Nazir & Malik, 2022).

- On the other hand, the ladybird beetle was more effective in significantly reducing the number of pests, resulting in a 70% average reduction in both crops (Table 2). The ladybird beetle also showed a notable impact on thrips, with their average numbers decreasing to 6 by the tenth day. However, its effect on mites was not as significant as the impact of the green lacewing insect.

- Green lacewing played a significant role in eliminating whiteflies in both tomato and cucumber crops by effectively controlling their populations. It also had an important role in eliminating both thrips and mites in both crops.

- Ladybirds also contributed to the elimination of a large number of whiteflies by consuming substantial amounts of them. It was capable of eliminating 50 whiteflies in a single day.

- Ladybirds also helped in reducing thrips populations significantly.

- Additionally, both Green lacewing and Ladybird safely and naturally eliminated mites.

CONCLUSION

Omani farmers rely on natural enemies to promote sustainable agriculture and pest management. Natural enemies control pest populations by preying on them or their eggs. They function as biological pesticides, minimizing the need for chemical pesticides, which contributes to the preservation of a balanced ecosystem. Omani farmers can lessen their reliance on chemical pesticides by relying on natural enemies for pest management. This provides several advantages, including economic savings, fewer chemical residues on crops, and a lower likelihood of pesticide resistance among target pests. This study shows that depending on natural enemies is a viable technique for sustainable agriculture and pest management. The work has helped us better understand the effectiveness of natural enemies in pest management. Furthermore, this study gives useful information for farmers looking to limit their usage of chemical pesticides. It is worth mentioning that the study followed all ethical requirements in scientific research to ensure thorough protection of all relevant parties participating in the research, to achieve advantages for all and safe outcomes. Future researchers can concentrate on investigating the effect of natural enemies on other crops or using other enemies rather than those employed in the current study to measure their effectiveness in protecting vegetables from harmful pests.

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REFERENCES

Al-Kindi, K. M. *et al.* (2018). Predicting the potential geographical distribution of parasitic natural enemies of the Dubas bug (Ommatissus lybicus de Bergevin) using geographic information systems. *Ecology and Evolution, 8*(2019), 8297- 8310. https://doi.org/10.1002/ece3.4286.

Al-Maawali, S. S. *et al.* (2021). The potential of antagonistic yeasts and bacteria from tomato phyllosphere and fructoplane in the control of Alternaria fruit rot of tomato. *ALL LIFE, 14*(1), 34-48. https://doi.org/10.1080/26895293.2020.1858975.

Alsendi, A. *et al.* (2023). A Study on the Toxicity and Sublethal Concentrations of Three Insecticides on the Population Dynamics of Green Lacewing Chrysoperla carnea Stephens. *Arab Journal of Plant Protection, 41*(1), 28-36. https://doi.org/10.22268/AJPP-41.1.028036.

Camacho-Cervantes, M. *et al.* (2021). Exotic predators are not better biocontrol agents: the harlequin ladybird is not the most voracious in Mexico. *PeerJ, 9,* 1-13. 10.7717/peerj.12503.

Cortez Madrigal, H., & Gutiérrez Cárdenas, O. G. (2023). Enhancing biological control: conservation of alternative hosts of natural enemies. *Egyptian Journal of Biological Pest Control,* (2023), 1-13. https://doi.org/10.1186/s41938-023-00675-2.

Dey, S. (2020). Biological control of mite pest in greenhouse condition. *Agriculture & Food,* 69-70.

Doehler, M. *et al.* (2023). Effect of the Landscape on

Insect Pests and Associated Natural Enemies in Greenhouses Crops: The Strawberry Study Case. *Insects, 14*(302), 1-14. https://doi.org/10.3390/insects14030302.

Dreistadt, S. H. *et al.* (2014). Biological Control and Natural Enemies of Invertebrates - Integrated Pest Management for Home Gardeners and Landscape Professionals. *Pest Notes, 2014,* 1-6. https://ipm.ucanr.edu/legacy_assets/pdf/pestnotes/pnbiocontrol.pdf.

Hussain, M. *et al.* (2022). Community Structure of Ladybird Beetles (Coccinellidae: Coleoptera) Alongside the Chenab River at Wazirabad, Gujranwala, Punjab, Pakistan. *Pakistan J. Zool.,* 1-7. https://dx.doi.org/10.17582/journal.pjz/20180520120529.

Hyder, M. *et al.* (2023). Enhancing Coccinella Beetle Biological Pest Control via a Floral Approach in Cucumber Greenhouse. *Life, 13*(10), 1-12. https://doi.org/10.3390/life13102080.

Ishag, K. H. M., & Al Rawahy, M. S. S. (2018). Risk and Economic Analysis of Greenhouse Cucumber and Tomato Cropping Systems in Oman. *Sustainable Agriculture Research, 7*(4), 115-124. 10.5539/sar.v7n4p115.

Kandilji, Amer Ibrahim. (2018). Scientific research methodology. Amman: Dar Al-Yazouri Scientific Publishing and Distribution. https://shorturl.at/cgDKV

Keçeci, M., & Öztop, A. (2017). Possibilities for biological control of Tuta absoluta (Meyrick, 1917)(Lepidoptera: Gelechiidae) in the western Mediterranean Region of Turkey. *Turkish Journal of Entomology, 41*(2), 219-230. https://doi.org/10.16970/ted.25851.

Kwan, P. *et al.* (2017). Impact of environmental variables on Dubas bug infestation rate: A case study from the Sultanate of Oman. *PLoS ONE, 12*(5), 1-17. https://doi.org/10.1371/journal.pone.0178109.

Leman, A. *et al.* (2014). Optimizing biological control of mealybugs with lacewing larvae. *Integrated Control in Protected Crops, Temperate Climate IOBC-WPRS Bulletin, 102,* 127-131. https://www.researchgate.net/publication/269292205_Optimizing_biological_control_of_mealybugs_with_lacewing_larvae.

Li, H. *et al.* (2023). Hoverflies provide pollination and biological pest control in greenhouse-grown horticultural crops. *Frontiers in Plant Science, 14,* 1-11. https://doi.org/10.3389/fpls.2023.1118388.

Mani, M. (2022). Pest Management in Horticultural Crops Under Protected Cultivation. *Trends in Horticultural Entomology,* 387-417. https://link.springer.com/chapter/10.1007/978-981-19-0343-4_12.

Mkook, K. *et al.* (2020). Plant protection challenges in the Arab region - Vision 2050. Arab Society for Plant Protection.

Negi, R. *et al.* (2023). Microbial antagonists: diversity, formulation and applications for management of pest–pathogens. *Egyptian Journal of Biological Pest Control, 33*(1), 1-21. https://doi.org/10.1186/s41938-023-00748-2.

Parrella, M. P., & Lewis, E. (2018). Update on Biological Control and the Challenges Growers Face. *UCNFA News, 22*(2), 1-16. https://doi.org/10.1093/ae/tmx010.

Perdikis, D. *et al.* (2008). Biological control of insect and mite pests in greenhouse solanaceous crops. *The European Journal of Plant Science and Biotechnology, 2*(1), 125-144. https://www.researchgate.net/publication/258808727_Biological_control_of_insect_and_mite_pests_in_Greenhouse_solanaceous_crops.

Pijnakker, J. *et al.* (2020). Predators and parasitoids-in-first: From inundative releases to preventative biological control in greenhouse crops. *Frontiers in Sustainable Food Systems, 4,* 1-38. https://doi.org/10.3389/fsufs.2020.595630.

Pottorff, L. P., & Panter, K. L. (2009). Integrated Pest Management and Biological Control in High Tunnel Production. *HortTechnology, 19*(1), 61-65. https://doi.org/10.21273/HORTTECH.19.1.61.

Remya, S., & Nisha, M. S. (2020). Molecular approaches for the improvement of natural enemies. *J Entamol Zool Stud, 8,* 175-179. https://oa.mg/work/3017084930.

Riddick, E. W. (2017). Identification of Conditions for Successful Aphid Control by Ladybirds in Greenhouses. *Insects, 8*(38), 1-17. https://doi.org/10.3390/insects8020038.

Riddick, E. W. (2022). Topical Collection: Natural Enemies and Biological Control of Plant Pests. Insects, 13(2022), 1-3. 10.3390/insects13050421.

Rondoni, G. *et al.* (2021). Exotic ladybirds for biological control of herbivorous insects–a review. *Entomologia Experimentalis et Applicata, 169*(1), 6-27. https://doi.org/10.1111/eea.12963.

Shawer, M. B. *et al.* (2021). The impact of cold storage durations on Trichogramma evanescens (Westwood) (Hymenoptera: Trichogrammatidae) during their pupal stage. *Saudi Journal of Biological Sciences, 28*(12), 7202-7206. https://doi.org/10.1016/j.sjbs.2021.08.014.

Snyder, W. E. *et al.* (2004). Complementary biocontrol of aphids by the ladybird beetle Harmonia axyridis and the parasitoid Aphelinus asychis on greenhouse roses. *Biological Control, 30*(2004) 229–235. https://doi.org/10.1016/j.biocontrol.2004.01.012.

Taha, E. K. A. *et al.* (2022). Effect of emergence time on some biological aspects of Trichogramma evanescens (Westwood)(Hymenoptera: Trichogrammatidae). *Journal of King Saud University-Science, 34*(4), 1-6. https://doi.org/10.1016/j.jksus.2022.101981.

Timke, S. H. *et al.* (2020). Feeding potential of Chrysoperla carnea (Stephens) on Corcyra cephalonica (Stainton) at different temperature levels. *Journal of Entomology and Zoology Studies, 8*(6), 1322-1325. https://shorturl.at/hiwA8.

Türkten, H. *et al.* (2017). The Effects of Applying Biological Control Measures in Greenhouse Cultivation on the Production Efficiency in Kaş

District of Antalya Province, Turkey. *European Journal of Sustainable Development, 6*(2017), 1-10. https://doi.org/10.14207/ejsd.2017.v6n3p1.

Van Lenteren, J. C. *et al*. (2020). Biological control agents for control of pests in greenhouses. *Integrated pest and disease management in greenhouse crops,* 409-439. https://link.springer.com/chapter/10.1007/978-3-030-22304-5_14.

Veronesi, E. R. (2022). *Use of natural enemies to achieve biological control of the severe and persistent glasshouse pest, the potato-tomato psyllid: A thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy at Lincoln University*. Doctoral dissertation, Lincoln University, Missouri. https://hdl.handle.net/10182/15579.

Yilmaz, H., & Tanc, Z. A. (2019). Biological control in pest management in Turkey: Comparison of the attributes of participant and non-participant greenhouse farmers in government-subsidized biological control practices. *Future of Food: Journal on Food, Agriculture and Society, 105,* 1-8. https://www.thefutureoffoodjournal.com/index.php/FOFJ/article/view/2.