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Research Article

Compatibility of *Lecanicillium lecanii* with pesticides

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ABSTRACT: The present investigation on "Studies on compatibility of *Lecanicillium lecanii* with pesticides" was conducted at the Government College of Agriculture, Dhule, in the laboratory of Biocontrol at the Agricultural Entomology Section to investigate the compatibility of *L. lecanii* with pesticides. For the study, the pure culture of *L. lecanii* was obtained from the Government College of Agriculture, Dhule and was preserved on PDA slants for further research. For experimental studies, 20 treatments were conducted using the 'Poisoned Food Technique' to study the effect of pesticides on the development of *L. lecanii*. The results of the compatibility experiments clearly indicated that the insecticidal treatments with imidacloprid 17.8% SL, chlorantriniliprole 18.5% SC, flupyridifurone 17.09% SL, spiromesifen 22.9% SC and azadirachtin 3000 ppm are highly compatible with *L. lecanii.* Insecticidal treatments with acetamiprid 20% SP, diafenthiuron 50% WP, deltamethrin 2.8% EC, thiamethoxam 25% WG, fipronil 5% SC, flonicamid 50% WG, lambda cyhalothrin 5% EC, spinosad 45% SC, flubendamide 39.35% SC, and Emamectin benzoate 5% SG are moderately compatible with *L. lecanii.* While insecticidal treatment with triazophos 40% EC was partially compatible with *L. lecanii*, treatments that were incompatible with *L. lecanii* included fungicides such as carbendazim 50% WP, copper oxychloride 50% WP and propiconazole 25% EC.

KEYWORDS: Compatibility, growth inhibition, inoculation, *Lecanicillium lecanii,* pesticides, poisoned food technique

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INTRODUCTION

The extensive and long-term use of synthetic chemical pesticides has caused serious environmental, ecological, and public health concerns. Chemical pesticides often persist in soil and water, leading to environmental contamination, bioaccumulation, and harmful effects on non-target organisms, including pollinators, natural enemies, aquatic fauna, and humans. According to Kumar *et al.,* (2022), repeated pesticide applications significantly contribute to soil degradation, reduction of microbial biodiversity and disruption of ecosystem services. Furthermore, pesticide residues in food products pose long-term health risks, including cancer-causing and endocrine-disrupting effects (Sharma *et al*., 2023). Use of chemical pesticides leads to the buildup of pesticide residues in the food chain, posing health risks. According to Sparks and Nauen (2022), resistance has been observed in hundreds of pest species worldwide, raising production costs and requiring higher doses or more toxic alternatives.

With increasing environmental concerns and regulatory restrictions on synthetic pesticides, biological control has become a core strategy in sustainable agriculture and integrated pest management (IPM). Entomopathogenic fungi (EPF) are recognised as effective biological control agents because of their ability to infect and suppress populations of various insect pests while posing minimal risk to non-target organisms and ecosystems (Shree *et al.*, 2024). They pose less threat to the environment and human health (Suman and Dikshit, 2010). In contrast, biopesticides, including microbial agents such as entomopathogenic fungi, bacteria, viruses and botanical extracts, provide a safer and more

sustainable alternative. Biopesticides are generally target-specific, biodegradable and compatible with integrated pest management (IPM) programs. Mishra *et al.,* 2021), emphasised that microbial biopesticides decrease chemical residues, conserve beneficial organisms and enhance ecological balance. Additionally, their complex modes of action lower the risk of rapid resistance development compared to conventional chemicals (Isman, 2021). Another important reason to support these EPFs is that, so far, there have been no reports of resistance developing (Halder *et al.,* 2012). Entomopathogenic fungi (EPF) are biological agents that have insecticidal activity against a wide variety of insect pests in agriculture. (Sogan *et al*., 2023). These microorganisms exhibit unique modes of action during host infection. Unlike bacteria and viruses, EPF do not require ingestion and can penetrate their host directly through the cuticle (Vega *et al*., 2012). Many examples exist where the application of different selective chemical insecticides and fungi, when used in combination, provides satisfactory control against numerous agricultural insect pests. (Serebrove *et al*., 2005; Purwar and Sachen, 2006).

Biocontrol performance of *L. lecanii* also extends beyond agricultural pests. Sogan *et al.,* (2023), developed stable granule formulations of *L. lecanii* and demonstrated significant larvicidal effects against the malarial vector *Anopheles culicifacies*, indicating its potential role in vector control strategies and public health applications. These formulation innovations help address common challenges, including environmental stress and variability in field efficacy.

Mechanistically, *L. lecanii* infects target insects through direct contact: fungal conidia adhere to the insect cuticle, germinate and penetrate via a suite of degrading enzymes, ultimately leading to host mortality. Recent work by Parvathi M. (2024) and collaborators demonstrated effective suppression of the cowpea aphid *Aphis craccivora* using foliar biocapsule applications of *L. lecanii*, achieving high pest reduction while preserving beneficial natural enemies.

Beyond *L. lecanii* itself, recent taxonomic expansions within the genus by Tongyi Liu, Wei Chen, and others (2025) have identified new *Lecanicillium* species with virulence against pests such as *Galleria mellonella* and *Lipaphis erysimi*, broadening the genetic resources available for biocontrol agent development.

Despite these advances, field efficacy can still be affected by environmental factors such as temperature, humidity and ultraviolet exposure, which influence spore viability and infection success. *L. lecanii* represents a promising and evolving biological control agent against agricultural and public-health pests. Continued investigation into its mechanisms of action, host range and application strategies will further consolidate its role in sustainable pest management.

Use of incompatible pesticides with bioagents may cause adverse effects on the growth and development of bioagents, which makes it necessary to check the compatibility studies on priority. Several experiments have been conducted to assess the harmful effects of chemical insecticides on various developmental stages of fungi (Alizadeh *et al*., 2007). The results from such experimental work would guide farmers to select more compatible pesticide and the negative effects of the careless use of insecticides can be reduced (Butt *et al*., 2001 and Inglis *et al*., 2001). After screening, it was observed that studies on the compatibility of *L. lecanii* with pesticides are very few. Therefore, the current work was carried out to analyse pesticides compatible with *L. lecanii* to assess their compatibility with these biological control agents, aiming to reduce pesticide use and promote long-term agricultural productivity, environmental conservation, and human health protection.

MATERIALS AND METHODS

The present research was conducted at the Government College of Agriculture in the Biocontrol Laboratory of the Entomology Section. The study used a completely randomised design with three replications for each treatment. A pure culture of *L. lecanii* was obtained from the Government College of Agriculture, Dhule and was preserved on PDA slants for further research. The fungus was cultured on Potato Dextrose Agar medium and poured into sterilised petri plates. A total of 20 treatments with three replications were maintained. Out of these, 16 treatments were insecticides and 03 treatments were fungicides. The research was conducted using the 'Poisoned Food Technique'. Observations were recorded after 3, 6, 9 and 12 days of inoculation on the mycelium growth of *L. lecanii*. Data obtained from the research were analysed using a Completely Randomised Design (CRD) with arcsine transformation.

RESULTS AND DISCUSSION

Compatibility of *Lecanicillium lecanii* with pesticides

On the third day after inoculation

After 3 days of inoculation, the growth of *L. lecanii* was recorded and presented in Table 1, revealing that the highest (17.33 mm) mycelial growth was observed in the control treatment and is significantly superior to all treatments. Among the insecticides tested, the maximum mycelial growth (14 mm) was observed in the treatment spiromesifen 22.9% SC and was comparable to imidacloprid 17.8% SL (13 mm), fipronil 5% SC (13 mm) and deltamethrin 2.8% EC (13 mm). These results indicate better compatibility with *L. lecanii*. The next most compatible treatments were flonicamid 50% WG (12.33 mm) and flupyridifurone 17.09% SL (12.33 mm). Among treatments with fungicides, all three fungicides showed incompatibility as no growth of *L. lecanii* was observed.

The minimum (18.97%) growth inhibition of *L. lecanii* was observed with the insecticidal treatment spiromesifen 22.9% SC and was significantly superior over the rest of the pesticides except imidacioprid 17.8% SL (24.99%), fipronil 5% SC (24.99%), deltamethrin 2.8% EC (24.99%), flonicamid 50% WG (26.13%) and flupyridifurone 17.09% SL (28.47%), which indicates their better compatibility with *L. lecanii*.

The maximum growth inhibition of 71.06% was recorded in all three fungicidal treatments - carbendazim 50% WP, Copper oxychloride 50% WP and propiconazole 25% EC, indicating that these fungicides are not compatible with *L. lecanii.*

On the sixth day after inoculation

After 6 days of inoculation, the growth of *L. lecanii* was recorded for mycelial growth and growth inhibition and presented in Table 1. It revealed that the highest (24.66 mm) mycelial growth was observed in the control treatment and is significantly superior to all other treatments. Among the insecticides tested, the maximum mycelial growth (21 mm) was observed in treatments with thiamethoxam 25% WG, spiromesifen 22.9% SC and chlorantraniliprole 18.5% SC, all measuring 21.00 mm. This was comparable to imidacloprid 17.8% SL and flupyridifurone 17.09% SL, both at 20.66 mm, as well as spinosad 45% SC at 20.33 mm, flonicamid 50% WG at 19.33 mm and azadirachtin 3000 ppm at 19.00 mm, indicating better compatibility with *L. lecanii* after 6 days of inoculation. Among treatments with fungicides, all three fungicides showed incompatibility as no growth of *L. lecanii* was recorded.

Table 1. Compatibility of *L.lecanii* with pesticides at 3rd, 6th, 9th and 12th day after inoculation

Sr. No.	Treatment	Dose (gm/ ml)/lit	Mycelial Growth (mm) Mean				Growth Inhibition(%) Mean			
			3rd day	6th day	9th day	12th day	3rd day	6th day	9th day	12th day
1	Acetamiprid 20% SP	0.20	10.66	18.00	23.66	35.66	38.42 (38.27)*	26.71 (30.92)*	35.15 (35.79)*	28.19 (31.91)*
2	Diafenthiuron 50% WP	1.20	10.33	18.33	24.33	34.66	40.27 (39.38)	25.49 (30.26)	32.36 (34.66)	30.19 (33.32)
3	Deltamethrin 2.8% EC	0.89	13.00	18.66	21.00	31.00	24.99 (29.97)	24.21 (29.45)	41.60 (40.15)	37.59 (37.92)
4	Thiamethoxam 25% WG	0.20	11.33	21.00	26.66	34.33	34.25 (35.69)	14.78 (22.35)	25.98 (30.41)	30.87 (33.73)
5	Imidacloprid 17.8% SL	0.23	13.00	20.66	30.00	45.33	24.99 (29.97)	16.36 (23.35)	16.51 (23.55)	8.70 (17.06)
6	Fipronil 5% SC	3.00	13.00	19.66	25.00	35.00	24.99 (29.97)	20.16 (25.96)	30.56 (33.56)	29.52 (32.91)

Table 1. Continued

7	Spiromesifen 22.9% SC	0.84	14.00	21.00	30.66	42.00	18.97 (25.53)	14.80 (22.61)	14.83 (22.64)	15.42 (23.09)
8	Triazophos 40 % EC	2.00	8.33	17.00	20.00	27.00	51.61 (45.92)	30.73 (33.52)	44.38 (41.76)	45.65 (42.50)
9	Flonicamid 50% WG	0.30	12.33	19.33	22.00	34.66	26.13 (30.19)	21.60 (27.68)	38.95 (38.60)	30.16 (33.25)
10	Lambda cyhalothrin 5 % EC	1.00	11.00	17.33	21.66	37.33	36.34 (37.01)	29.49 (32.77)	39.90 (39.15)	24.82 (29.88)
11	Flupyridifurone 17.09% SL	0.20	12.33	20.66	31.33	42.66	28.47 (32.06)	15.80 (22.43)	12.93 (21.06)	14.08 (21.82)
12	Chlorantraniliprole 18.5% SC	0.32	11.33	21.00	30.66	44.33	34.25 (35.71)	16.09 (23.58)	14.63 (21.74)	10.72 (19.11)
13	Spinosad 45 % SC	0.44	11.33	20.33	23.33	33.33	34.72 (36.09)	17.25 (24.13)	35.14 (36.33)	32.89 (34.98)
14	Flubendamide 39.35 % SC	0.30	10.66	18.66	22.66	31.66	38.19 (38.12)	24.26 (29.41)	36.99 (37.45)	36.23 (37.00)
15	Emamectin benzoate 5% SG	0.40	11.33	19.66	22.66	32.00	34.48 (35.94)	19.93 (26.14)	37.02 (37.47)	35.55 (36.59)
16	Azadirachtin 3000 ppm	4.00	11.00	19.00	27.00	41.00	36.10 (36.79)	22.65 (28.12)	24.98 (29.96)	17.45 (24.68)
17	Carbendazim 50 % WP	0.20	5.00	5.00	5.00	5.00	71.06 (57.46)	79.67 (63.20)	86.10 (68.11)	89.93 (71.49)
18	Copper oxychloride 50 WP	2.50	5.00	5.00	5.00	5.00	71.06 (57.46)	79.67 (63.20)	86.10 (68.11)	89.93 (71.49)
19	Propiconazole 25% EC	1.00	5.00	5.00	5.00	5.00	71.06 (57.46)	79.67 (63.20)	86.10 (68.11)	89.93 (71.49)
20	Untreated control	-	17.33	24.66	36.00	46.33	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.0)
	S.E.±		0.48	0.75	0.87	1.19	2.32	2.88	1.79	1.31
	CD at 5%		1.36	2.14	2.48	3.40	6.64	8.22	5.10	3.75

Note:* Figures in parentheses are arc-sin transformed values

The lowest (14.78%) per cent growth inhibition of *L. lecanii* was observed with thiamethoxam 25% WG and was significantly superior over all other treatments except flupyridifurone 17.09% SL (15.80 %), spiromesifen 22.9% SC (14.80%), imidacloprid 17.8% SL (16.36%), chlorantraniliprole 18.5% SC (16.09 %), spinosad 45% SC (17.25 %), fipronil 5% SC (20.16 %), emamectin benzoate 5% SG (19.93 %), flonicamid 50% WG (21.60

%), azadirachtin 3000 ppm (22.65 %), flubendamide 39.35% SC (24.26 %), deltamethrin 2.8% EC (24.21 %) and diafenthiuron 50% WP (25.49 %). These results indicate better compatibility with *L. lecanii.*

The maximum growth inhibition of 79.67% was observed in all three fungicidal treatments - carbendazim 50% WP, Copper oxychloride 50% WP and propiconazole 25% EC, indicating that these fungicides are not compatible with *L. lecanii.*

On the 9th day after inoculation

After 9 days of inoculation, the growth of *L. lecanii* was recorded for mycelial growth and growth inhibition and presented in Table 1. The results revealed that the highest mycelial growth, measuring 36.00 mm, was observed in the control treatment and was significantly superior to all other treatments. Among the insecticides tested, the maximum mycelial growth of 31.33 mm was recorded in the treatment with Flupyridifurone 17.09% SL, which was comparable to spiromesifen 22.9% SC (30.66 mm), chlorantraniliprole 18.5% SC (30.66 mm), and imidacloprid 17.8% SL (30.00 mm), indicating better compatibility with *L. lecanii* at 9 days after inoculation. The next most compatible treatments were azadirachtin 3000 ppm (27.00 mm), thiamethoxam 25% WG (26.66 mm), fipronil 5% SC (25.00 mm) and diafenthiuron 50% WP (24.33 mm). Among the treatments with fungicides, all three fungicides showed incompatibility as no growth of *L. lecanii* was recorded.

The minimum (12.93 %) growth inhibition of *L. lecanii* was observed in insecticidal treatment with flupyridifurone 17.09% SL and was significantly superior over the rest of the insecticides and at par with chlorantraniliprole 18.5% SC (14.63%), spiromesifen 22.9% SC (14.83%) and imidacloprid 17.8% SL (16.51%), which showed better compatibility with *L. lecanii.*

The maximum growth inhibition of 86.10% was observed in all three fungicidal treatments - carbendazim 50% WP, Copper oxychloride 50% WP and propiconazole 25% EC, indicating that these fungicides are incompatible with *L. lecanii.*

On the 12th day after inoculation

After 12 days of inoculation, the growth of *L. lecanii* was recorded for mycelial growth and growth inhibition, and the results are presented in Table 1, Fig 1 & Fig 2. The highest mycelial growth of 46.33 mm was observed in the control treatment and was significantly superior to all other treatments. Among the insecticides tested, the maximum mycelial growth of 45.33 mm was recorded in the treatment with imidacloprid 17.8% SL, followed by chlorantraniliprole 18.5% SC (44.33 mm), flupyridifurone 17.09% SL (42.66 mm) and spiromesifen 22.9% SC (42.00 mm), indicating better compatibility with *L. lecanii*. Among the treatments with fungicides, all three fungicides showed incompatibility, as no growth of *L. lecanii* was recorded.

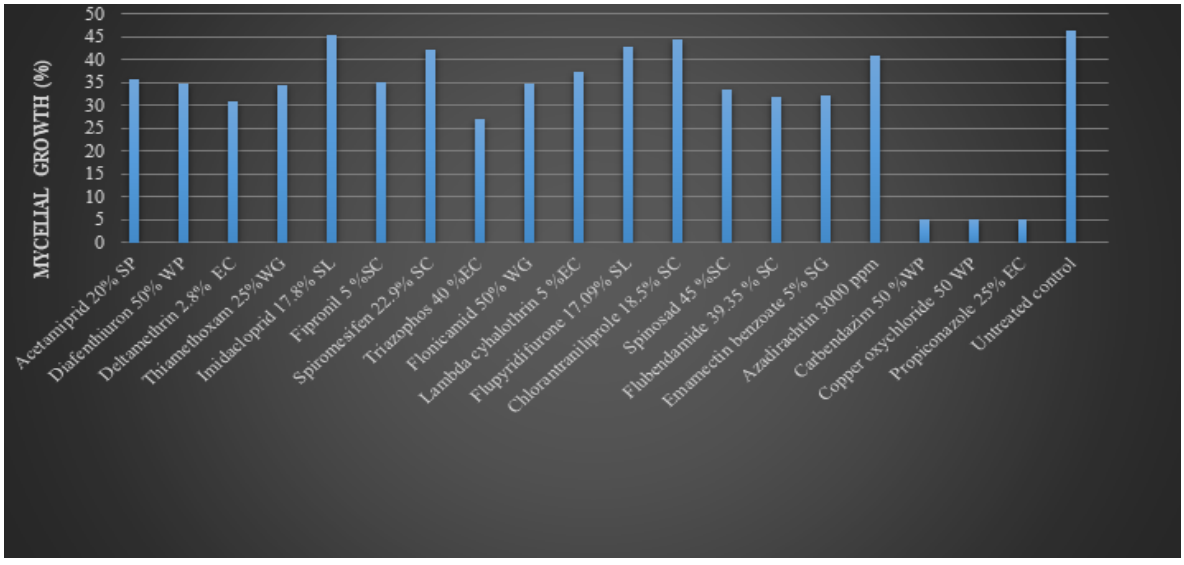


Figure 1. Compatibility of pesticides with *L. lecanii* at 12th day after inoculation.

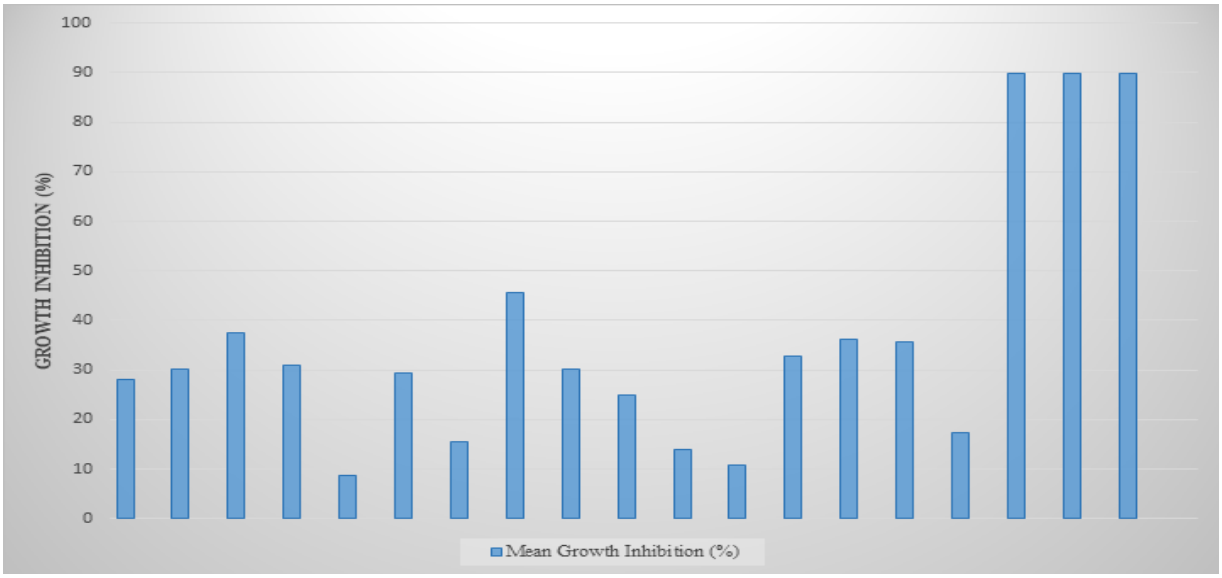


Figure 2. Compatibility of pesticides with *L. lecanii* at 12th day after Inoculation (% Growth inhibition).

The lowest (8.70%) per cent radial growth reduction of *L. lecanii* was observed in the insecticidal treatment imidacloprid 17.8% SL and was significantly better than the rest of the pesticides, except chlorantraniliprole 18.5% SC (10.72%), which indicates better compatibility with *L. lecanii* 12 days after inoculation. The next best treatments in terms of compatibility with *L. lecanii* were flupyridifurone 17.09% SL (14.08%), spiromesifen 22.9% SC (15.42%)and azadirachtin 3000 ppm (17.45%).

The maximum growth inhibition of 89.93% was observed in all three fungicidal treatments - carbendazim 50% WP, copper oxychloride 50% WP and propiconazole 25% EC - indicating that these fungicides are incompatible with *L. lecanii.*

The results of the compatibility experiments on the 12th day after inoculation clearly indicate that the insecticidal treatments imidacloprid 17.8% SL, chlorantriniliprole 18.5% SC, flupyridifurone 17.09% SL, spiromesifen 22.9% SC and azadirachtin 3000 ppm are highly compatible with *L. lecanii.* The insecticidal treatments, acetamiprid 20% SP, diafenthiuron 50% WP, deltamethrin 2.8% EC, thiamethoxam 25% WG, fipronil 5% SC, flonicamid 50% WG, lambda cyhalothrin 5% EC, spinosad 45% SC, flubendamide 39.35% SC and emamectin benzoate 5% SG were compatible with *L. lecanii.* The insecticidal treatment triazophos 40% EC was partially compatible, while carbendazim 50% WP, copper oxychloride 50% WP, and propiconazole 25% EC were incompatible with *L. lecanii.*

J. Sumalatha *et al.,* (2017), showed that acetamiprid was less harmful to spore germination and mycelial growth of *L. lecanii,* and the results support the present findings. The current findings on the compatibility of *L. lecanii* align with those of Pampapathy *et al.,* (2011), who observed that there was a relatively lesser harmful effect when combined with insecticides such as diafenthiuron, thiamethoxam, imidacloprid, thiodicarb, primicarb and acetamiprid with *L. lecanii*. These findings also corroborate the results of Nikhade *et al.,* (2024), who observed the compatibility of diafenthiuron with *L. lecanii*. Additionally, the present findings on the compatibility of *L. lecanii* with insecticides agree with previous research by Kim *et al*., (2007), who found no impact on the mycelial growth of *L. attenuatum* when exposed to neonicotinoids like imidacloprid. Halder *et al.,* (2019), also noted the compatibility of *L. lecanii* with imidacloprid. Furthermore, the current study confirms that imidacloprid is compatible with *L. lecanii*, as suggested by Khezri *et al.,* (2007). In this study, spinosad was found to be compatible with *L. lecanii,* consistent with earlier findings by Amutha *et al*., (2010), who reported that spinosad and imidacloprid were only slightly toxic.

CONCLUSION

All the treatments included in the research showed variation in the growth of *L. lecanii.* Among all tested insecticides, imidacloprid recorded the maximum mycelial growth of *L. lecanii*, followed by chlorantraniliprole and flupyridifurone. Conversely, the insecticidal treatment with triazophos showed the least mycelial growth of *L. lecanii*.

Among the fungicides, carbendazim, copper oxychloride, and propiconazole showed no vegetative growth of *L. lecanii*, while all other insecticidal treatments demonstrated moderate compatibility with *L. lecanii*. Using such insecticides with *L. lecanii* can enhance control efficacy, reduce environmental pollution, and lower the risk of pest resistance development.

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AUTHOR CONTRIBUTION

Birappa Shejale - Conducted main research work, data collection, data analysis, chapter writing. Avinash Mahale - Guided outline of the research work, data collection and chapter writing. Nitin Parjane - Contribution in main research, data collection, analysis and chapter writing. All authors have read and agreed to the published version of the manuscript.