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INTERACTION AND TOXICITY EVALUATION OF NOVEL INSECTICIDES AND FUNGICIDES WITH ENTOMOPATHOGENIC FUNGI *PAECILOMYCES LILACINUS* FOR SUSTAINABLE PEST MANAGEMENT

Rudra Kumar Porte*, V. K. Nirmalkar and R. K. S. Tiwari
Department of Plant Pathology, B.T.C. CARS, Bilaspur, Chhattisgarh, India. 495001
*Corresponding author E-mail: rudrakumar2903@gmail.com
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ABSTRACT

Interaction of twelve novel insecticides and fungicides with *Paecilomyces lilacinus* was evaluated using the poison food technique. Among the insecticides tested with *P. lilacinus*, emamectin benzoate 5% SG exhibited the highest mycelial growth (81.11 mm) with minimum inhibition (9.88%) at 7th days after inoculation (DAI). Moreover, sporulation was recorded maximum by Emamectin benzoate 5% SG (3.16 × 10^7 CFU mL^{-1}) and Novaluron 5.25% + Indoxacarb 4.5% SL (1.55 × 10^7 CFU mL^{-1}), while later recorded the spore germination and the highest conidial germination (71.33%) found in Novaluron 5.25% + Indoxacarb 4.5% SL. Based on toxicity profiling, Emamectin benzoate (5% SG) was categorized as toxic (T), whereas Novaluron (5.25%) + Indoxacarb (4.5% SL) was classified as low toxic (LT), the remaining insecticides ranged from toxic to highly toxic. Regarding fungicidal interaction, Validamycin was the only fungicide that supported the growth of *P. lilacinus* (55.11 mm) with a partially compatible response. It also promoted the highest sporulation (2.47 × 10^7 CFU mL^{-1} in *P. lilacinus*) and the maximum conidial germination rates (55.67% in *P. lilacinus*). Toxicity assessment revealed that Validamycin exhibited moderate toxicity (MT) to *P. lilacinus*, whereas all other fungicides exhibited high toxicity (VT).

***Keywords*:** Compatibility, Entomopathogenic fungi, Fungicides, Insecticides, *Paecilomyces lilacinus* etc.

Introduction

Insecticides are an indispensable component of modern agriculture, playing a crucial role in protecting crops from insect pests and ensuring global food security. However, the overreliance on chemical insecticides has led to significant challenges, including insecticide resistance, pest resurgence, environmental contamination and residue accumulation. Integrating bio-pesticides with conventional insecticides and fungicides has emerged as a promising strategy to mitigate these issues while, maintaining pest control efficiency and promoting sustainable agricultural practices (Mazid *et al.,* 2014; Rajwade *et al.,* 2023).

Bio-pesticides, derived from living organisms or their metabolic products, provide an eco-friendly alternative to synthetic pesticides. They include entomopathogenic fungi (EPF), bacteria, viruses, and botanical extracts, which can effectively manage insect pests and plant pathogens (Usha *et al.*, 2014; Verma *et al*., 2023). Studies suggest that combining bio-pesticidal formulations with inorganic pesticides enhances their effectiveness, broadens the spectrum of pest control and reduces application costs. However, ensuring compatibility between bio-pesticides and chemical pesticides is critical, as physical or chemical interactions may reduce biological efficacy or induce phytotoxic effects. The ability to integrate EPF with insecticides and fungicides without compromising their virulence or stability is essential for their successful deployment in agricultural systems (Nirmalkar *et al*., 2020[a]).

Entomopathogenic fungi (EPF) are widely studied bio-insecticides known for their ability to infect and kill a broad range of arthropod pests. These fungi primarily infect hosts through direct contact, germinating on the insect cuticle, penetrating it, and proliferating within the host body, leading to mortality (Behie and Bidochka, 2014; Nirmalkar *et al*., 2020[b]). Genera such as *Beauveria*, *Metarhizium*, *Isaria*, and *Lecanicillium* have been effectively used against aphids, whiteflies, thrips, and storage pests like *Acanthoscelides obtectus* (Ondrackova, 2015; Bhaskar *et al*., 2023; Urkude *et al*., 2024). Compatibility studies have shown that certain EPF strains can be effectively integrated with chemical insecticides without compromising their efficacy, potentially enhancing pest mortality through additive or synergistic effects.

Apart from insect control, EPF have also demonstrated antagonistic activity against plant-pathogenic fungi, making them potential bio-fungicides. Notably, *Lecanicillium lecanii* (previously *Verticillium lecanii*) exhibits mycoparasitic properties against fungal pathogens such as *Rhizoctonia solani* and *Puccinia* spp., offering a dual function as both an entomopathogen and a bio fungicide (Hall, 1981; Spencer, 1981). Furthermore, *Paecilomyces lilacinus*, an EPF commonly found in soil, effectively parasitizes nematode eggs and developmental stages, contributing to biological nematode management (Rita *et al*., 2004).

The efficacy of EPF as both insecticides and fungicides depends on their compatibility with synthetic agrochemicals under diverse environmental conditions (Kumar *et al*., 2024). Temperature, humidity, formulation type, and the chemical nature of pesticides influence their survival, germination, and virulence. For instance, *Paecilomyces lilacinus* thrives within a temperature range of 15–30°C, with optimal growth occurring at 25–30°C. Understanding these factors is crucial for integrating EPF into conventional pest and disease management programs.

This study aims to evaluate the compatibility of entomopathogenic fungi with commonly used insecticides and fungicides, assessing their viability, efficacy and synergistic potential in pest and pathogen control. The findings will provide valuable insights into developing integrated pest management (IPM) strategies that optimize the benefits of both biological and chemical control agents while, minimizing environmental risks. The study further emphasizes the need for standardized compatibility protocols to ensure the practical application of EPF-based formulations in modern agriculture. The outcomes of this research will contribute to the scientific community's knowledge base and aid in the formulation of policies promoting sustainable crop protection strategies.

Material and Methods

Procedure for PDA

Compatibility and other growth factors of fungi under *in vitro* conditions were performed on potato dextrose agar medium. Fresh peeled potatoes 200g were cut into small pieces and boiled in 1000 ml of water in pan for 30 min. The extract was strained through strainer and quantity was measured and adjusted volume one litter adding distilled water if required then add 20g agar-agar and 20g dextrose were dissolved by heating. The medium was poured into the conical flask then plugged with cotton and autoclave at 121.6 ˚C for 15-20 min.

Procedure of PDA inoculation

All *in-vitro* experiments were conducted in three replications. In general, 30-32ml of sterilized melted and cooled potato dextrose agar (PDA) medium was poured into petri dishes. Prior to the pouring, media was treated with streptomycin to avoid the bacterial contamination. When the radial growth was carried out, a 5-mm disc of actively growing entomopathogenic fungi was inoculated in the centre of petri dishes. The inoculated plates were incubated for 7 days at 25˚C in a BOD incubator. The growth and sporulation of the *Paecilomyces lilacinus* were observed. *In- vitro* studies were carried out on the growth and sporulation of *Paecilomyces lilacinus.* 7 and 15 days after inoculation, respectively (Kumar *et al*., 2024).

In – vitro compatibility study of entomopathogenic fungi with different novel agrochemicals

Three different concentrations are taken for study 1000, 1500 and 2000ppm. After cooling of sterilized medium, the agrochemicals will be added in given concentrations. The media was poured into petri plates and will be allowed for solidification, after solidification the plates were inoculated with the pure culture of *Paecilomyces lilacinus* and control plate (without agrochemicals) was also maintained for comparison. Three replications were maintained in a complete randomized design (CRD). Different agrochemical *i.e.,* insecticides, fungicides used for compatibility (Nene and Thapliyal, 1979).

Bio-insecticides

Fresh cultures of *Paecilomyces lilacinus* were procured from State Bio Control Laboratory (SBCL) BTC, College of Agriculture and Research Station,

IGKV, Bilaspur (C.G.) was used under the present investigation.

Mycelial growth and Percent inhibition (Vincent, 1927) was calculated at 7th DAI, while sporulation was recorded at 15th DAI by following formula.

$$\text{Mycelial growth} = \frac{\text{Length} + \text{Width}}{2}$$

$$\text{Percent inhibition (I)} = \frac{C - T}{C} \times 100$$

Where, I = Percent inhibition (%), C = Growth of entomopathogenic fungi isolate in control (mm), T = Growth of entomopathogenic fungi in treatment (mm)

Sporulation will be recorded by given formula (Nirmalkar *et al.*, 2020[c])

Sporulation = No. of conidia ml- ¹ or cm²= Average no. of spores × Dilution factor × 4000 ×1000

Spore germination

Spore suspension was prepared by serial dilution technique for that 9 ml sterile distilled water and 05mm disc of 15-day old *Paecilomyces lilacinus* colonies grown on poisoned media were used (Insecticides and fungicides) PDA and dissolved on it. The stock spore suspension was diluted up to 10^7 and vortexed for evenly distribute the spores throughout the medium. Subsequently, 200 microliter (one drop) of suspension were transferred to the cavity slides and incubated in temperature of 25±2˚C for 24hrs the observations were recorded by counting the number of spores that germinated in each microscopic field (10 X magnification), with a total of four microscopic fields measured. It was determined that the spores had germinated when they produced a germ tube. Spore germination was calculated by following formula (Nirmalkar *et al.*, 2020[c])

$$G = \frac{N}{T} \times 100$$

Where: G = Percentage germination, N = Total number of spores germinated, T= Total number of spores observed.

Compatibility Scaling

Compatibility scaling was determined based on the mycelia growth of fungi at 7th DAI, for *P. lilacinus* by poison food technique against the pesticides and the sporulation (10^7) at 15th DAI in relation to the control.

According to the scale proposed by Alves *et al.* (1998) the toxic impact of chemical substances on the development of fungi was determined with the following equation

T=20(VG)+80(SP)/100

Where: - VG-mycelium growth, SP- Sporification

The following scale was devised 0-30 % very toxic, 31-45 % toxic, 46-60 % moderate toxicity, above 60% low toxicity

Compatibility ratings

Compatibility ratings for test pesticides were classified in evaluation categories of 1 - 4 scoring index according to Jayasing's classification.

Sl. No	The average reduction in growth over an untreated control	Compatibility status
1.	< 20 % reduction in growth	Highly compatible
2.	20 - 50 % reduction in growth	Compatible
3.	50 - 80 % reduction in growth	Partially compatible
4.	> 80 % reduction in growth	Incompatible

Statistical analysis

To compare different numerical observation, data was statistically analysed using appropriate design *i.e.,* factorial CRD with desired transformation as applicable.

Results

Compatibility of novel insecticides on mycelial growth and sporulation of *P. lilacinus* at 7th DAI

Mycelial growth at 7th DAI at three different concentration (1000,1500 and 2000ppm) of novel insecticides was done and the data revealed from table 1 that the mean mycelial growth was recorded maximum in T_8- Emamectin benzoate 5% SG (81.11mm) followed by T_{12} – Novaluron 5.25% + Indoxacarb 4.5% SL (74.50 mm) and T_5- Spiromesifen 22.9% SC (70.89 mm) while, least mycelial growth was recorded in T_4 – Fipronil 5% SC (14.44mm) followed by T_7 – Profenofhos 40% + Cypermethrin 4% EC (14.72 mm), T_9- Propargite 57% EC (18.00mm). Treatment T_4 and T_7 showed at par with each other means showed almost equal effect on *P. lilacinus* mycelial growth. In all three concentration maximum mean mycelial growth was found in 1000ppm (56.31mm) followed by 1500ppm (49.42mm) and minimum mycelial growth was recorded in 2000ppm (43.27mm) and all three showed significant difference with each other.

The least percent inhibition of all three concentration (1000,1500 and 2000ppm) at 7th DAI was found in T_8- Emamectin benzoate 5% SG (9.88%) followed by T_{12}- Novaluron 5.25% + Indoxacarb 4.5% SL (17.22%) and T_5–Spiromesifen 22.9% SC (21.23%)

while, maximum percent inhibition was recorded in T_4- Fipronil 5% SC (83.95%) over control followed by T_7- Profenofhos 40% + Cypermethrin 4% EC (83.64%) and T_9- Propargite 57% EC (80.00%), T_4 and T_7 showed non-significant difference with each other for the inhibition of mycelial growth. In all three concentration maximum mean percent inhibition was found in 2000ppm (51.92%) followed by 1500ppm (45.09%) and minimum mean percent inhibition was recorded in 1000ppm (37.44%). The all three concentration exhibited significant difference with each other means have different effect while, using in differ concentration.

1000 ppm

The highest mycelial growth and least percent inhibition was recorded in T_8- Emamectin benzoate 5% SG (88.00mm and 2.22%) followed by T_6 – Chlorantraniliprole 18.5% SC (87.67mm and 2.59%) and T_{12}- Novaluron 5.25% + Indoxacarb 4.5% SL (80.00mm and 11.11%).The least mycelial growth and highest percent inhibition was recorded in T_4-Fipronil 5% SC (16.83 mm and 81.30%) followed by T_7- Profenofhos 40% + Cypermethrin 4% EC (20.00mm and 77.78%) and T_9- Propargite 57% EC (22.83 mm and 74.63%). Treatment showed intermediate result by T_1-Chlorpyrifhos 20% EC (25.17 mm and 72.04%). Treatment T_9 and T_1 showed non-significant different with each other that means these insecticides showed similar result and rest of treatments showed significant different with each other.

1500 ppm

The highest mycelial growth and least percent inhibition was recorded in T_8- Emamectin benzoate 5% SG (80.33 mm and 10.74%) followed by T_{12}- Novaluron 5.25% + Indoxacarb 4.5% SL (76.33 mm and 15.19%) and T_5- Spiromesifen 22.9% SC (70.50 mm and 21.67%). The least mycelial growth and highest percent inhibition was recorded in T_4-Fipronil 5% SC (14.00 mm and 84.44%) followed by T_7- Profenofhos 40% + Cypermethrin 4% EC (14.83 mm and 83.52%) and T_9- Propargite 57% EC (16.83 mm and 81.30%), while intermediate result showed by T_1- Chlorpyrifhos 20% EC (23.33mm and 74.07%). T_4, T_7 and T_9 showed non-significant different with each other that means these insecticides showed similar result and rest of treatments showed significant different with each other.

2000 ppm

The highest mycelial growth and least percent inhibition was recorded in T_8- Emamectin benzoate 5% SG (75.00 mm and 16.67%) followed by T_{12}- Novaluron 5.25% + Indoxacarb 4.5% SL (67.17 mm and 25.37%) and T_5- Spiromesifen 22.9% SC (66.33mm and 26.30%). The least mycelial growth and highest percent inhibition was recorded in T_7- Profenofos 40% + Cypermethrin 4% EC (9.33mm and 89.63%) followed by T_4- Fipronil 5%SC (12.50 mm and 86.11%) and T_9- Propargit 57% EC (14.33 mm and 84.07%). Treatment showed intermediate result by T_1- Chlorpyriphos 20% EC (17.67 mm and 80.37%). All treatments showed significant different with each other.

Sporulation (conidia^{-ml})

The average no. of conidia^{-ml} of *Pacelomyces lilacinus* at 15th DAI were recorded and found maximum sporulation in T_8- Emamectin benzozte 5% SG (3.16×10^7) followed by T_{12}- Novaluron 5.25% + Indoxacarb 4.5% SL (1.55×10^7) and T_5- Spiromesifen 22.9% SC (1.27×10^7) and least sporulation was recorded from T_4- Fipronil 5% SC (0.22×10^7) and T_7- Profenofos 40% + Cypermethrin 4% EC (0.68×10^7). All the other treatment showed intermediate sporulation between maximum and minimum.

Compatibility of novel fungicides on mycelial growth and sporulation of *P. lilacinus* at 7th DAI

Recorded the mycelial growth on culture plate at 7th DAI at three different concentration (1000,1500 and 2000ppm) of novel fungicides was done and the data revealed in table 2 that the mean mycelial growth was recorded maximum in T_7- Validamycin 3% L (55.11mm) followed by T_6 – Metiram 70% WG (20.33 mm) and the least mycelial growth was recorded in T_2 – Flupyram 17.7% + Tebuconazole 17.7% SC (1.89 mm) while, in T_4-Propiconazole 25% EC, T_5- Hexaconazole 4% + Carbendazim 16% SC, T_8- Iprobenfos 48% EC, T_9-Tebuconazole 50% + Trifloxystrobin 25% WG) no growth (0.00 mm) was recorded by *Paecilomyces lilacinus.* In all three-concentration maximum (21.12mm) mean mycelial growth was found in 1000ppm followed by 1500ppm (18.13 mm) and minimum (15.46 mm) mycelial growth was recorded in 2000ppm. Treatment T_1- Carbendazim 50% WP (16.28mm) and T_{11}-Zineb 75% WP (16.06mm) showed non-significant difference with each other and rest of treatment significant difference with each other.

The minimum mean percent inhibition of all three concentration (1000,1500 and 2000ppm) at 7th DAI was found in T_7- Validamycin 3% L (38.77%) followed by T_6 – Metiram 70% WG (77.41%) and the maximum mean percent inhibition was recorded in T_2 – Flupyram 17.7% + Tebuconazole 17.7% SC (97.90%) while, T_4-Propiconazole 25% EC, T_5- Hexaconazole 4% + Carbendazim 16% SC, T_8-

Iprobenfos 48% EC, T_9-Tebuconazole 50% + Trifloxystrobin 25% WG) showed 100% mean percent inhibition over control. In all three concentration maximum (82.82%) mean percent inhibition was found in 2000ppm followed by 1500ppm (79.86%) and minimum (76.54%) mean percent inhibition was recorded in 1000ppm.

1000 ppm

The highest mycelial growth and least percent inhibition was recorded in T_7-Validamycin 3% L (67.83 mm and 24.63%) followed by T_1 – Carbendazim 50% WP (25.33 mm and 71.85%) and T_6- Metiram 70% WG (23.00 mm and 74.44%) while, least mycelial growth was recorded in T_2- Fluopyram 17.7% + Tebuconazole17.7% SC (5.67mm and 93.70%) and zero mycelial growth and highest precent inhibition (0.00 mm and 100%) was recorded in T_4- Propiconazole 25% EC, T_5- Hexaconazole 4% + Carbendazim 16% SC, T_8- Iprobenfos 48% EC, T_9 - Tebuconazole 50% + Trifloxystrobin 25% WG) over control. All treatment showed significantly differ with each other while, T_3- Hexaconazole (5% SC) (16.17mm and 82.04%), T_{12}- Propineb (70% WP) (16.50mm and 81.67%), non-significant differ with each other.

1500 ppm

The highest mycelial growth and least percent inhibition was recorded in T_7-Validamycin 3% L (59.17 mm and 34.26%) followed by T_6- Metiram 70% WG (20.00 mm and 77.78%) while, least mycelial growth was recorded in T_{10}- Hexaconazole 4% + Zineb 75% WP (9.67 mm and 89.26%) and zero mycelial growth and highest precent inhibition was recorded in T_2-Flupyram 17.7% + Tebuconazole 17.7% SC, T_4-Propiconazole 25% EC, T_5-Hexaconazole 4% + Carbendazim 16% SC, T_8-Iprobenfos 48% EC, T_9-Tebuconazole 50% + Trifloxystrobin 25% WG) (0.00 mm and 100%) over control. Treatment T_1, T_2 and T_{11}, T_{12} non-significant differ with each other and rest of treatment showed significantly differ from each other.

2000 ppm

The highest mycelial growth and least percent inhibition was recorded in T_7-Validamycin 3% L (38.33 mm and 57.41%) followed by T_6- Metiram 70% WG (18.00 mm and 80.00%) while, least mycelial growth was recorded in T_{10}- Hexaconazole 4% + Zineb 68% WP (8.17 mm and 90.93%) and zero mycelial growth and highest precent inhibition (0.00 mm and 100%) was recorded in T_2 -Flupyram 17.7% + Tebuconazole 17.7% SC, T_4 -Propiconazole 25% EC,T_5-Hexaconazole 4% + Carbendazim 16% SC, T_8-Iprobenfos 48% EC,T_9-Tebuconazole 50% + Trifloxystrobin 25% WG, T_{10}-Hexaconazole 4% + Zineb 75% WP) over control. All treatment showed significantly differ with each other except those havening zero growth and T_{10}, T_3 non-significant differ with each other.

Sporulation (conidia^{-ml})

The average no. of conidia^{-ml} of *Pacelomyces lilacinus* at 15th DAI were recorded and found maximum sporulation in T_7-Validamycin 3% L (2.47×10^7) followed by T_6- Metiram 70% WG (1.14×10^7) while, minimum sporulation was observed in T_{10}- Hexaconazole 4% + Zineb 68% WP (0.46×10^7) and zero sporulation and zero growth recorded in fungicides *i.e.* Flupyram 17.7% + Tebuconazole 17.7% SC, Propiconazole 25% EC, Hexaconazole 4% + Carbendazim 16% SC, Iprobenfos 48% EC, Tebuconazole 50% + Trifloxystrobin 25% WG, all the other treatment showed intermediate sporulation between maximum and minimum sporulation.

Compatibility classification in terms of toxicity (T value) of novel insecticides against *P. lilacinus*

T value and Compatibility

T value based on mycelial growth and sporulation were showed in the table 3 different level of toxicity was denoted as VT - very toxic, T - toxic, MT - moderately toxic and LT - low toxic. The T value range from 63.33 to 6.36. In *Paecilomyces spp* treatment T_1 -Chlorpyriphos 20% EC (16.66), T_2-Deltamethrin 11% EC (23.85), T_3-Spinosad 45% SC (28.90), T_4- Fipronil 5% SC (6.36), T_7- Profenofos 40% + Cypermethrin 4% EC (13.02), T_9- Propargite 57% EC (14.32), T_{10}- Fenpyrioximate 5% EC (21.20), and T_{11}-Carbosulfan 25% EC (27.58)) showed very toxic insecticides against *Paecilomyces spp*, while T_5-Spiromesifen 22.9% (32.36), T_6- Chlorantraniliprole 18.5% SC (38.78) and T_8- Emamectin Benzoate 5% SG (33.96) were found in toxic insecticides against *Paecilomyces spp.* and T_{12} – Novaluron 5.25% + Indoxacarb 4.5% SL (63.33) are found low toxic against *Paecilomyces spp* it means one insecticide are compatible with *Paecilomyces spp.*

Among twelve insecticides eight was found very toxic that means they showed very incompatible, while three was toxic showed incompatible and one showed compatible with *Paecilomyces spp.*

Effect of novel insecticides on spore germination of *P. lilacinus*

Spore germination

The spore germination of novel twelve insecticides against *Paecilomyces lilacinus* was

conducted *in- vitro* and data revealed in table 4 showed that the maximum spore germination was recorded in treatments T_{12} – Novaluron 5.25% + Indoxacarb 4.5% SL (71.33%) followed by T_6 – Chlorantraniliprole 18.5% SC (45.56 %) and minimum spore germination was recorded in T_4 – Fipronil 5% SC (12.22 %). Where the treatment T_1- Chlorpyriphos 20% EC (24.67%), T_2- Deltamethrin 11% EC (30.67%), T_7 -Profenofos 40% + Cypermethrin 4% EC (20.00%) and T_{10} - Fenpyroximate 5% EC (29.22%) showed significant differ with each other means the treatments showed different effect to inhibit the spore germination of *Paecilomyces spp*, while, in treatment T_2, T_{10} and T_5, T_8 and T_3, T_{11} at par with each other.

Compatibility chart of *P. lilacinus* against novel insecticides

Among the T_8 -Emamectin benzoate 5%SG were found highly compatible insecticides with 9.88% mycelial growth inhibition followed by T_{12} Novaluron 5.25% + Indoxacarb 4.5% SL with 17.22% inhibition against *P. lilacinus*. Were insecticides evaluated against the entomopathogenic fungi *i.e. P. lilacinus*, the toxicity of insecticides were detected based on mycelial growth and no. of conidia produced, similarly the compatibility chart were prepared based on average percent reduction in mycelial growth against the pesticides used.Fipronil 5% SC and Profenofos 40% + Cypermethrin 4% EC found incompatible for *P. lilacinus.*

Compatibility classification in terms of toxicity (T value) of novel fungicides against *P. lilacinus*

T value and compatibility

T value based on, mycelial growth and sporulation were showed in the table 3 that the toxicity is denoted as VT - very toxic, T - toxic, MT - moderately toxic and LT - low toxic and result was concluded that the T value range from 47.66 to 0.00. In *Paecilomyces spp.* eleven treatment showed very toxic (T_1 – Carbendazim (50% WP) (14.08), T_3 – Fluopyram (17.7%) + Tebuconazole (17.7% SC) (0.42), T_4 – Hexaconazole (5% SC) (11.73), T_5 – Propiconazole (25% EC) (0.00), T_6 - Hexaconazole (4%) + Carbendazim (16% SC) (0.00), T_7 - Metiram (70%WG) (20.86), T_9 – Iprobenfos (48% EC) (0.00),T_{10} – Tebuconazole (50%) + Trifloxystrobin (25% WG) (0.00),T_{11} – Hexaconazole (4%) + Zineb (68% WP) (8.79),T_{12} - Zineb (75% WP) (13.60) and T_{13} - Propineb (70% WP) (13.03) except T_8 – Validamycin 3% L (47.66) are found in moderately toxic against of *Paecilomyces spp.*

Effect of novel fungicides on spore germination of *P. liacinus*

Spore germination

Fourteen different novel fungicides was evaluated against spore germination of *Paecilomyces spp.* under *in- vitro* condition at 15th DAI and data revealed from table 4 that maximum spore germination (55.67%) was recorded in treatments T_8 - Validamycin (3% L) followed by T_7 - Metiram (70%WG) (28.22%) and minimum spore germination (4.56%) was observed in T_3 – Fluopyram (17.7%) + Tebuconazole (17.7% SC), Where no spore germination was (0.00%) recorded in T_5-Propiconazole (25% EC), T_6 -Hexaconazole (4%) + Carbendazim (16% SC), T_9 -Iprobenfos (48% EC), and T_{10} .Tebuconazole (50%) + Trifloxystrobin (25% WG) showed significant differ with each other. All treatment have spore germination.

Compatibility chart of *P. lilacinus* against novel fungicides

Fourteen different fungicides were evaluated against entomopathogenic fungi and observed that only one fungicide showed compatible with *P. lilacinus* was T_8- Validamycin (3%L) 38.77% inhibition of mycelial. Apart from that Metiram 70% WG showed Partially compatible while rest other fungicides showed incompatible with *P. lilacinus*.

Discussion

Compatibility against novel insecticides with *P. lilacinus* done by poisones food techniques, Chlorpyriphos EC 20%, Fipronil SC 5% are found toxic or non-compatible insecticides and Emamectine benzoate 5% SG, Novaluron 5.25% + Indoxacarb 4.5%, Chlorantraniliprole and Spinosad were found compatible as less toxic effect and also produced higher spore recorded by Joshi *et al.,* (2018), Tekam *et al.,* (2018), Amutha and banu (2012) and Akbar (2012). Where confirmed our findings. Many researchers agreed with our finding and concluded their research, Sumalatha *et al*., (2017) reported Novaluron, the highest radical growth (62.26 mm) and highest conidial growth (95.08%) and Kumar *et al.,* (2024) also found Chlorantraniliprole (44.56mm) were highly compatible followed by Emamectine benzoate 5% SG (32.67mm) in case of fungicides Tebuconazole (50%) + Trifloxystrobin (25% WG) and Carbendazim (50% WP) (0.00mm) was incompatible.

Joshi *et al.,* (2018) and Faraji *et al.,* (2016) found similar trends of result in fungicidal compatibility, Carbendazim 50% WP, Indoxacarb 15.8% EC and Hexaconazole 5% EC found toxic chemicals and not compatible similarly, Shafa *et al.,* (2012) found

Tebuconazole, Propiconazole, Difenoconazole and Hexaconazole were incompatible against the EPF. They also confined our findings.

Different responses of *P. lilacinus* against various fungicides and insecticides in the study, it might be due to their inherent resistance and their ability to degrade these chemicals. *P. lilacinus* show compatibility with some insecticides and fungicides as they are tolerant of fungicides and successfully used in IPM strategy. They have the capability of degrading few chemicals compound and can survive in environment with remnant of fungicide and insecticides molecules. the study also suggests cautious approach with highly incompatible agrochemicals like Profenofos (40%) + Cypermethrin (4% EC), Fipronil (5%SC), Chlorpyriphos (20% EC), Deltamethrin (11% EC), Propargite (57% EC), Carbendazim (50% WP). Hence, to ensure sustainability of entomopathogens in the agro-ecosystems it is vital to consider the results of this study for management of soil insects including nematodes in open fields and protected cultivation as well foliar insects.

Conclusion

Insecticides and fungicides harm to our food chain and polluting surrounding environment, to overcome the problem and cost of application, bioinsecticides should be used. *Paecilomyces lilacinus* was highly compatible with different agrochemicals *i.e.,* Emamectin benzoate, Novaluron + Indoxacarb, Validamycin and metiram and showed the maximum spore germination.

Table 1: Compatibility of novel insecticides on mycelial growth and sporulation of *P. lilacinus* at 7th DAI

Treatments	Mycelial growth (mm)			Mean	% Inhibition			Mean	Sporulation (conidia^{-ml}) (X×10^7)			
	1000 ppm	1500 ppm	2000 ppm		1000 ppm	1500 ppm	2000 ppm		1000 ppm	1500 ppm	2000 ppm	Mean
T_1 – Chlorpyriphos (20% EC)	25.17 (30.10)	23.33 (28.87)	17.67 (24.85)	**22.06**	72.04 (58.08)	74.07 (59.41)	80.37 (63.71)	**75.49**	1.12	0.94	0.41	**0.82**
T_2 – Deltamethrin (11% EC)	52.50 (46.44)	39.33 (38.84)	34.67 (36.06)	**42.17**	41.67 (40.19)	56.30 (48.62)	61.48 (51.65)	**53.15**	1.35	1.34	0.72	**1.01**
T_3 – Spinosad (45%SC)	65.00 (53.74)	58.67 (49.99)	45.83 (42.61)	**56.50**	27.78 (31.78)	34.81 (36.16)	49.07 (44.47)	**37.22**	1.35	1.34	0.72	**1.14**
T_4 – Fipronil (5%SC)	16.83 (24.21)	14.00 (21.89)	12.50 (20.69)	**14.44**	81.30 (64.39)	84.44 (66.86)	86.11 (68.14)	**83.95**	0.26	0.22	0.18	**0.22**
T_5 – Spiromesifen (22.9% SC)	75.83 (60.56)	70.50 (57.12)	66.33 (54.58)	**70.89**	15.74 (23.35)	27.67 (27.70)	26.30 (30.76)	**21.23**	1.33	1.28	1.20	**1.27**
T_6 – Chlorantraniliprole (18.5% SC)	87.67 (69.54)	62.50 (52.25)	58.33 (49.80)	**69.50**	2.59 (9.18)	30.56 (33.54)	35.19 (36.38)	**22.78**	3.00	0.28	0.25	**1.18**
T_7 – Profenofos (40%) + Cypermethrin (4% EC)	20.00 (26.55)	14.83 (22.61)	9.33 (17.78)	**14.72**	77.78 (61.89)	83.52 (66.09)	89.63 (71.22)	**83.64**	1.37	0.53	0.15	**0.68**
T_8 - Emamectin benzoate (5% SG)	88.00 (69.74)	80.33 (63.69)	75.00 (60.03)	**81.11**	2.22 (8.53)	10.74 (19.06)	16.67 (24.03)	**9.88**	3.57	3.50	2.42	**3.16**
T_9 – Propargite (57% EC)	22.83 (28.54)	16.83 (24.21)	14.33 (22.21)	**18.00**	74.63 (59.76)	81.30 (64.39)	84.07 (66.52)	**80.00**	1.03	0.86	0.28	**0.72**
T_{10} – Fenpyroximate (5% EC)	44.83 (42.03)	41.33 (40.00)	31.67 (34.24)	**39.28**	50.19 (45.11)	54.07 (47.35)	64.81 (53.63)	**56.36**	1.34	0.80	0.47	**0.87**
T_{11} - Carbosulfan (25 % EC)	63.33 (52.75)	54.50 (47.59)	39.67 (39.02)	**52.50**	29.63 (32.95)	39.44 (38.89)	55.93 (48.42)	**41.67**	1.36	1.06	0.90	**1.11**
T_{12} - Novaluron (5.25%) + Indoxacarb (4.5% SL)	80.00 (63.44)	76.33 (60.90)	67.17 (55.04)	**74.50**	11.11 (19.46)	15.19 (22.92)	25.37 (30.24)	**17.22**	2.23	1.33	1.08	**1.55**
T_{13} - Control	90.00 (71.57)	90.00 (71.57)	90.00 (71.57)	**90.00**	-	-	-	-	5.58	5.58	5.58	**5.58**
Mean	**56.31**	**49.42**	**43.27**		**37.44**	**45.09**	**51.92**		**1.91**	**1.44**	**1.10**	
	CD 5%		**SEm±**	**CV**		**CD 5%**	**SEm±**	**CV**				
Factor A (ppm)	0.73		3.65	3.58	**Factor A (ppm)**	0.84	4.20	4.59				
Factor B (Insecticides)	1.51		7.55		**Factor B (Insecticides)**	1.74	8.70					
Factor(A×B)	2.61		13.05		**Factor (A×B)**	3.02	15.01					

*Data given in parenthesis shows FCRD and arcsine percentage transformation.

Table 2 : Compatibility of novel fungicides on mycelial growth and sporulation of *P. lilacinus* at 7th DAI

Treatments	Mycelial growth (mm)			Mean	% Inhibition			Mean	Sporulation conidia^{-ml}) (X×10^7			
	1000 ppm	1500 ppm	2000 ppm		1000 ppm	1500 ppm	2000 ppm		1000 ppm	1500 ppm	2000 ppm	Mean
T_1 – Carbendazim (50% WP)	25.33 (30.21)	13.50 (21.55)	10.00 (18.42)	**16.28**	71.85 (57.98)	85.00 (67.22)	88.89 (70.55)	**81.91**	0.89	0.69	0.60	**0.73**
T_2 – Fluopyram (17.7%) + Tebuconazole (17.7% SC)	5.67 (13.69)	0.00 (0.27)	0.00 (0.27)	**1.89**	93.70 (75.94)	100.00 (89.74)	100.00 (89.74)	**97.90**	0.00	0.00	0.00	**0.00**
T_3 – Hexaconazole (5% SC)	16.17 (23.70)	13.00 (21.13)	9.17 (17.57)	**12.78**	82.04 (64.97)	85.56 (67.67)	89.81 (71.44)	**85.80**	1.00	0.57	0.28	**0.62**
T_4 – Propiconazole (25% EC)	0.00 (0.27)	0.00 (0.27)	0.00 (0.27)	**0.00**	100.00 (89.74)	100.00 (89.74)	100.00 (89.74)	**100.00**	0.00	0.00	0.00	**0.00**
T_5 - Hexaconazole (4%) + Carbendazim (16% SC)	0.00 (0.27)	0.00 (0.27)	0.00 (0.27)	**0.00**	100.00 (89.74)	100.00 (89.74)	100.00 (89.74)	**100.00**	0.00	0.00	0.00	**0.00**
T_6 - Metiram (70%WG)	23.00 (28.63)	20.00 (26.56)	18.00 (25.08)	**20.33**	74.44 (59.67)	77.78 (61.88)	80.00 (63.46)	**77.41**	1.60	1.09	0.74	**1.14**
T_7 - Validamycin (3% L)	67.83 (55.45)	59.17 (50.28)	38.33 (38.25)	**55.11**	24.63 (29.66)	34.26 (35.82)	57.41 (49.26)	**38.77**	2.65	2.52	2.25	**2.47**
T_8 – Iprobenfos (48% EC)	0.00 (0.27)	0.00 (0.27)	0.00 (0.27)	**0.00**	100.00 (89.74)	100.00 (89.74)	100.00 (89.74)	**100.00**	0.00	0.00	0.00	**0.00**
T_9 – Tebuconazole (50%) + Trifloxystrobin (25% WG)	0.00 (0.27)	0.00 (0.27)	0.00 (0.27)	**0.00**	100.00 (89.74)	100.00 (89.74)	100.00 (89.74)	**100.00**	0.00	0.00	0.00	**0.00**
T_{10} – Hexaconazole (4%) + Zineb (68% WP)	11.67 (20.05)	9.67 (18.08)	8.17 (16.59)	**9.87**	87.04 (68.85)	89.26 (70.91)	90.93 (72.48)	**89.03**	0.59	0.57	0.23	**0.46**
T_{11} - Zineb (75% WP)	18.33 (25.34)	15.50 (23.18)	14.33 (22.24)	**16.06**	79.63 (63.18)	82.78 (65.49)	84.07 (66.50)	**82.16**	1.10	0.66	0.35	**0.70**
T_{12} - Propineb (70% WP)	16.50 (23.95)	14.83 (22.63)	13.00 (21.13)	**14.78**	81.67 (64.66)	83.52 (66.07)	85.56 (67.67)	**83.58**	1.10	0.60	0.34	**0.68**
T_{13} - Control	90.00 (71.57)	90.00 (71.57)	90.00 (71.57)	**90.00**	-	-	-	**-**	5.58	5.58	5.58	**5.58**
Mean	**21.12**	**18.13**	**15.46**		**76.54**	**79.86**	**82.82**		**1.12**	**0.94**	**0.80**	
	CD 5%		**SEm±**	**CV**		**CD 5%**	**SEm±**	**CV**				
Factor A (ppm)	0.41		2.05	4.53	**Factor A**	0.64	3.20	2.08				
Factor B (fungicides)	0.85		4.25		**Factor B**	1.33	6.65					
Factor (A×B)	1.48		7.40		**Factor (A×B)**	2.30	11.50					

*Data given in parenthesis shows FCRD and arcsine percentage transformation.

Table 3 : Compatibility classification in terms of toxicity (T value) of novel insecticides and fungicides on *P. lilacinus*

Treatments (Insecticides)	*P. lilacinus*		Treatments (Fungicides)	*P. lilacinus*	
	"T" Value	Classification		"T" Value	Classification
T_1 – Chlorpyriphos (20% EC)	16.66	VT	T_1 – Carbendazim (50% WP)	**14.08**	VT
T_2 – Deltamethrin (11% EC)	23.85	VT	T_2 – Fluopyram (17.7%) + Tebuconazole (17.7% SC)	**0.42**	VT
T_3 – Spinosad (45%SC)	28.90	VT	T_3 – Hexaconazole (5% SC)	**11.73**	VT
T_4 – Fipronil (5%SC)	6.36	VT	T_4 – Propiconazole (25% EC)	**0.00**	VT
T_5 – Spiromesifen (22.9% SC)	32.36	T	T_5 - Hexaconazole (4%) + Carbendazim (16% SC)	**0.00**	VT
T_6 – Chlorantraniliprole (18.5% SC)	38.78	T	T_6 - Metiram (70%WG)	**20.86**	VT
T_7 – Profenofhos (40%) + Cypermethrin (4% EC)	13.02	VT	T_7 - Validamycin 3%	**47.66**	MT
T_8 - Emamectin benzoate (5% SG)	33.96	T	T_8 – Iprobenfos (48% EC)	**0.00**	VT
T_9 – Propargite (57% EC)	14.32	VT	T_9 – Tebuconazole (50%) + Trifloxystrobin (25% WG)	**0.00**	VT
T_{10} – Fenpyroximate (5% EC)	21.20	VT	T_{10} – Hexaconazole (4%) + Zineb (68% WP)	**8.79**	VT
T_{11} - Carbosulfan (25 % EC)	27.58	VT	T_{11} - Zineb (75% WP)	**13.60**	VT
T_{12} - Novaluron (5.25%) + Indoxacarb (4.5% SL)	63.33	LT	T_{12} - Propineb (70% WP)	**13.03**	VT
T_{13} - Control	100.00	-	T_{13} - Control	**100.00**	-

Table 4: Effect of novel insecticides and fungicides on spore germination of *P. lilacinus*

Treatment (Insecticides)	% spore germination of *P. lilacinus*	Treatment (Fungicides)	% spore germination of *P. lilacinus*
T_1 – Chlorpyriphos (20% EC)	24.67	T_1 – Carbendazim (50% WP)	21.17
T_2 – Deltamethrin (11% EC)	30.67	T_2 – Fluopyram (17.7%) + Tebuconazole (17.7% SC)	4.56
T_3 – Spinosad (45%SC)	35.67	T_3 – Hexaconazole (5% SC)	19.78
T_4 – Fipronil (5%SC)	12.22	T_4 – Propiconazole (25% EC)	0.00
T_5 – Spiromesifen (22.9% SC)	40.67	T_5 - Hexaconazole (4%) + Carbendazim (16% SC)	0.00
T_6 – Chlorantraniliprole (18.5% SC)	45.56	T_6 - Metiram (70%WG)	28.22
T_7 – Profenofos (40%) + Cypermethrin (4% EC)	20.00	T_7 - Validamycin 3%	55.67
T_8 - Emamectin benzoate (5% SG)	41.67	T_8 – Iprobenfos (48% EC)	0.00
T_9 – Propargite (57% EC)	22.22	T_9 – Tebuconazole (50%) + Trifloxystrobin (25% WG)	0.00
T_{10} – Fenpyroximate (5% EC)	29.22	T_{10} – Hexaconazole (4%) + Zineb (68% WP)	16.56
T_{11} - Carbosulfan (25 % EC)	34.56	T_{11} - Zineb (75% WP)	21.67
T_{12} - Novaluron (5.25%) + Indoxacarb (4.5% SL)	71.33	T_{12} - Propineb (70% WP)	21.22
T_{13} - Control	78.25	T_{13} - Control	78.67
CD 5%	**1.75**	**CD 5%**	**1.64**
SEm±	**8.75**	**SEm±**	**8.20**
CV	**2.79**	**CV**	**4.75**

Table 5: Compatibility chart of *P. lilacinus* against of novel insecticides and fungicides

Treatments (Insecticides)	*P. lilacinus*		Treatments (Fungicides)	*P. lilacinus*	
	% inhibition in mycelial growth	Compatibility status		% inhibition in mycelial growth	Compatibility status
T_1 – Chlorpyriphos (20% EC)	75.49	Partially compatible	T_1 – Carbendazim (50% WP)	81.91	Incompatible
T_2 – Deltamethrin (11% EC)	53.15	Partially compatible	T_2 – Fluopyram (17.7%) + Tebuconazole (17.7% SC)	97.90	Incompatible
T_3 – Spinosad (45%SC)	37.22	Compatible	T_3 – Hexaconazole (5% SC)	85.80	Incompatible
T_4 – Fipronil (5%SC)	83.95	Incompatible	T_4 – Propiconazole (25% EC)	100.00	Incompatible
T_5 – Spiromesifen (22.9% SC)	21.23	Compatible	T_5 - Hexaconazole (4%) + Carbendazim (16% SC)	100.00	Incompatible
T_6 – Chlorantraniliprole (18.5% SC)	22.78	Compatible	T_6 - Metiram (70%WG)	77.41	Partially compatible
T_7 – Profenofos (40%) + Cypermethrin (4% EC)	83.64	Incompatible	T_7 - Validamycin (3%L)	38.77	Compatible
T_8 - Emamectin benzoate (5% SG)	9.88	Highly compatible	T_8 – Iprobenfos (48% EC)	100.00	Incompatible
T_9 – Propargite (57% EC)	80.00	Partially compatible	T_9 – Tebuconazole (50%) + Trifloxystrobin (25% WG)	100.00	Incompatible
T_{10} – Fenpyroximate (5% EC)	56.36	Partially compatible	T_{10} – Hexaconazole (4%) + Zineb (68% WP)	89.03	Incompatible
T_{11} - Carbosulfan (25 % EC)	41.67	Compatible	T_{11} - Zineb (75% WP)	82.16	Incompatible
T_{12} - Novaluron (5.25%) + Indoxacarb (4.5% SL)	17.22	Highly compatible	T_{12} - Propineb (70% WP)	83.58	Incompatible
T_{13} - Control	0.00	-	T_{13} - Control	0.00	-

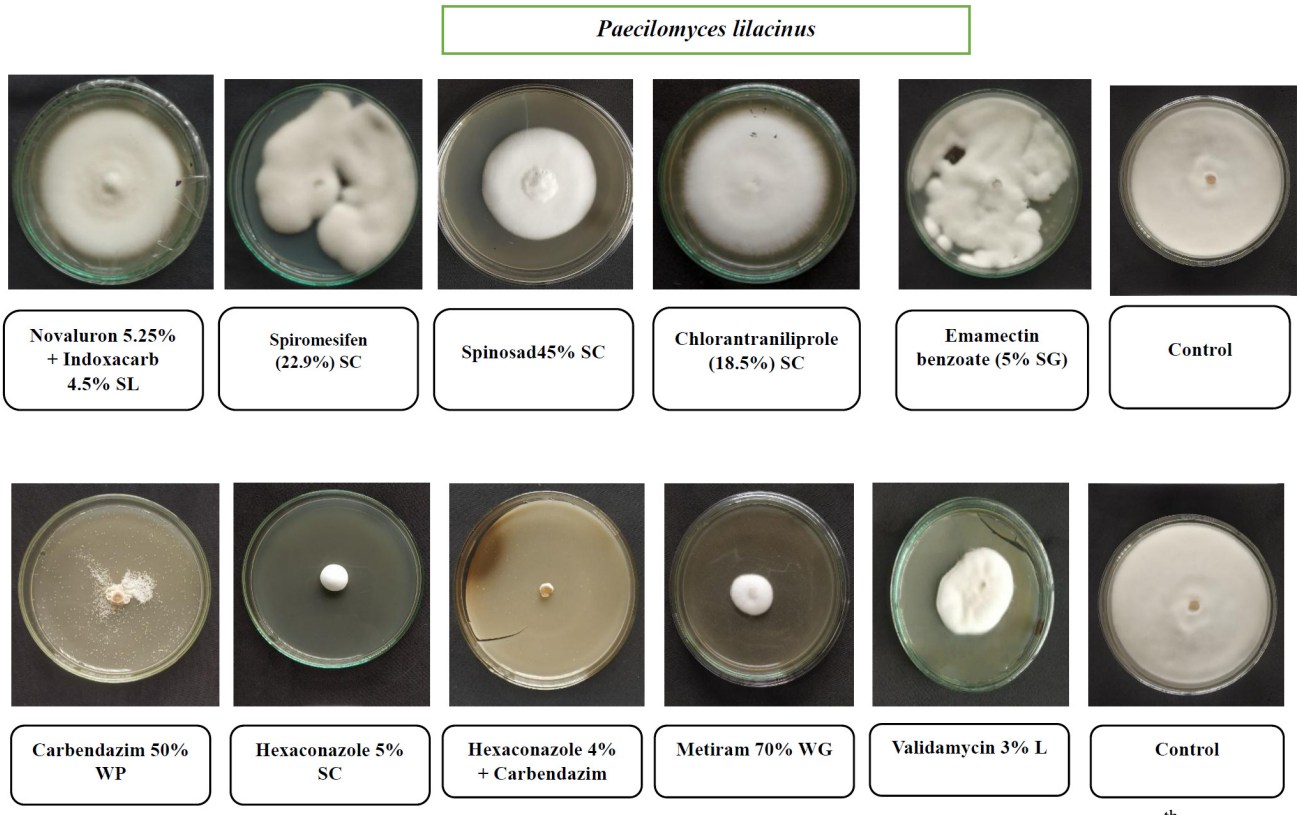

Fig. 1: Compatibility of novel insecticides and fungicides on mycelial growth of *P. lilacinus* at 7th DAI.

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