Pest Management in Horticultural Ecosystems
Vol. 28, No.2 pp 39-47 (2022)
DOI Number: 10.5958/0974-4541.2022.00036.4

In-vitro compatibility of entomopathogenic fungus, *Lecanicillium lecanii* (Zimm.) Zare and Gams with insecticides and fungicides

TEJASWI. G. GOWDA* and O. P. REJI RANI

Department of Agricultural Entomology, College of Agriculture Kerala Agricultural University, Vellayani, Thriruvananthapuram, Kerala, India

***E-mail:** tejaswigowda93@gmail.com

ABSTRACT: The compatibility of *Lecanicillium lecanii* with insecticides and fungicides was tested to identify and incorporate the compatible chemicals in the IPM package for sucking pest management. Among the new generation insecticides tested, we found flubendiamide 39.35% SC, chlorantraniliprole 18.5% SC, imidacloprid 17.8% SL and thiamethoxam 25% WG were found to be compatible with *L. lecanii* at all the three doses. Thiamethoxam, 25 % WG, was the least inhibitive at recommended dose with the highest Biological index (BI) of 80. Of the old-generation insecticides, dimethoate 30 % EC was compatible, while malathion 50 % EC, quinalphos 25% EC and chlorpyrifos 20% EC were toxic to *L. lecanii.* Quinalphos, 25 % EC, was the highly inhibitive insecticide with a BI of 14-18, exhibiting a significant reduction in growth, sporulation, and germination of the fungus. Among the fungicides tested, copper oxychloride 50% WP and azoxystrobin 23% SC were moderately toxic. Other fungicide *viz*., tebuconazole 25% EC, hexaconazole 5% EC, carbendazim 50% WP and mancozeb 75% WP were found to be toxic to *L. lecanii.*

Keywords- *Lecanicillium lecanii*, compatibility, biological index, fungicides

INTRODUCTION

The development of entomopathogenic fungi as environmentally acceptable substitutes for chemical pesticides has advanced significantly, and some species have been commercialised. The most commonly used entomopathogenic fungi are *Beauveria bassiana* (Bals.) Vuill., *Lecanicillium lecanii*, *Metarhizium anisopliae* (Metschn.) Sorokin, *Metarhizium acridum* (Driver & Milner), and *Isaria fumosorosea* Wize. *Lecanicillium lecanii* is widely used for managing the sucking pests of several crops. In the greenhouse condition, it is an efficient biocontrol agent for managing *Trialeurodes vaporariorum* Westwood (Kim *et al.,* 2002). It is the most widely distributed species, capable of causing epizootics in tropical and subtropical regions with prevalent warm, humid conditions (Nunez *et al.,* 2008).

The compatibility of the biological control agents with other crop protection chemicals will be critical to their successful implementation. Their compatibility with chemical fungicides used to combat plant fungal infections is particularly significant to growers. It is crucial to understand how commercial fungicides and insecticides affect entomopathogenic fungi since they could affect the pathogen's effectiveness and persistence on plant surfaces and in agricultural soils. The use of selective insecticides and fungicides in combination with entomopathogens can improve pest control efficiency by reducing the quantity of pesticides used, the risk of environmental contamination and the expression of insecticide resistance in pests (Shah *et al.,* 2009). In light of this, the present study was conducted to determine the compatibility of *L. lecanii* with the insecticides and fungicides commonly used for pest management.

MATERIALS AND METHODS

Eight insecticides and six fungicides of different chemical groups, including new and old generations, commonly used in the agroecosystem, were tested for their compatibility using the poisoned food technique suggested by Moorhouse *et al.,* (1992). The assays were carried out under *in vitro* conditions. *Lecanicillium lecanii* (isolate no. V1 8) was originally sourced from the National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru and was revived by passing through eggplant mealybug, *Coccidohystrix insolitus* (Green). Compatibility was tested at three doses, the recommended, half the recommended, and double the recommended doses for insecticide (Table 1). For fungicides, the compatibility was tested only at the recommended dose (Table 3). Compatibility was assessed based on radial growth, sporulation and germination of the fungus in the poisoned medium.

The effect of insecticides and fungicides on colony growth was assessed in a poisoned medium prepared using double strength PDA. The required quantity of chemicals was dissolved in sterile double distilled water and added to an equal amount of molten double strength PDA. The poisoned PDA was immediately poured into Petri plates for solidification. The plates were then

Table 1. Radial growth of *L. lecanii* on PDA poisoned with insecticides

Insecticide	Concentrations (%)	Dose	Mean colony diameter (cm)		Growth inhibition (%) on 21 DAI
			10 DAI	21 DAI	
Flubendiamide 39.35 % SC	0.0025	0.5x	2.23 (1.49)^{bc}	3.90 (1.98)^{d}	12.75
	0.005	x	2.13 (1.46)^{c}	3.70 (1.92)^{e}	17.23
	0.01	2x	2.10 (1.45)^{c}	3.40 (1.84)^{f}	23.94
Chlorantraniliprole 18.5 % SC	0.003	0.5x	2.10 (1.45)^{c}	4.20(2.05)^{cd}	6.04
	0.006	x	2.07 (1.44)^{c}	4.10(2.03)^{bc}	8.28
	0.012	2x	1.87 (1.37)^{d}	3.90 (1.98)^{d}	12.75
Imidacloprid 17.8 % SL	0.003	0.5x	2.33 (1.53)^{ab}	4.40(2.10)^{ab}	1.57
	0.006	x	2.17 (1.47)^{bc}	4.30(2.07)^{abc}	3.80
	0.012	2x	2.13 (1.46)^{c}	4.10 (2.03)^{cd}	8.28
Thiamethoxam 25 % WG	0.0025	0.5x	2.13 (1.46)^{c}	4.40 (2.10)^{ab}	1.57
	0.005	x	2.2 (1.48)^{bc}	4.20 (2.05)^{bc}	6.04
	0.01	2x	2.13 (1.46)^{c}	4.10 (2.02)^{cd}	8.28
Malathion 50 % EC	0.05	0.5x	1.4 (1.18)^{gh}	2.47 (1.57)^{i}	44.74
	0.1	x	1.47 (1.21)^{g}	2.30 (1.52)^{j}	48.55
	0.2	2x	1.30 (1.14)^{h}	2.20 (1.48)^{j}	50.78
Quinalphos 25 % EC	0.025	0.5x	0.80 (0.89)^{i}	1.10 (1.05)^{k}	75.39
	0.05	x	0.80 (0.89)^{i}	1.10 (1.05)^{k}	75.39
	0.1	2x	0.77 (0.87)^{i}	1.00 (1.00)^{k}	77.63
Dimethoate 30 % EC	0.02	0.5x	1.73 (1.32)^{de}	3.63 (1.91)^{e}	18.79
	0.04	x	1.67 (1.29)^{ef}	3.60 (1.90)^{e}	19.46
	0.08	2x	1.50 (1.22)^{g}	2.90 (1.7)^{g}	35.12
Chlorpyrifos 20 % EC	0.03	0.5x	1.53 (1.24)^{fg}	2.70 (1.64)^{h}	39.60
	0.06	x	1.47 (1.21)^{g}	2.50 (1.58)^{i}	44.07
	0.12	2x	1.27 (1.13)^{h}	2.27 (1.51)^{j}	49.22
Control			2.47 (1.57)^{a}	4.47 (2.11)^{a}	-
CD (0.05)			(0.063)	(0.051)	
S.E(m) ±			0.069	0.107	

DAI-Days after inoculation, x- recommended dose, Figures in the parentheses are square root transformed values. Values sharing same alphabets in superscript are statistically on par based on ANOVA

inoculated with a 5 mm disc of the seven-day-old actively growing culture of *L. lecanii*, using a flame-sterilized cork borer and incubated at room temperature. PDA without pesticides served as control. The experiment was laid out in a Completely Randomized Design (CRD), where each treatment was replicated thrice. Observations were recorded on the radial growth of fungus on the 10th and 21st Day after Inoculation (DAI).

Spore count was enumerated from 21-day-old cultures. Conidia of the fungus were dispersed in sterile water (10 mL) with 0.02 % tween 20 by scraping off the mycelia with a sterilized L rod. Ten µL each of the suspensions was transferred into a haemocytometer using a micropipette for counting the spores. For germination studies, spore suspension of the fungus was prepared from 21-day-old culture, and the spore count was adjusted to 105 conidia mL-1 by serial dilution method. A sterile glass slide was evenly coated with a drop of molten poisoned PDA and was allowed to dry in a laminar airflow chamber. After drying, 100 µL of the spore suspension was dropped onto a glass slide and spread uniformly. The slide was incubated in a Petri dish lined with moistened filter paper for 24 h at room temperature. After 24 h, the slides were observed under 40 × magnifications in a compound microscope to count 100 spores randomly, and the numbers of germinated spores were noted. Spores with germ tubes more than the diameter of the spores were considered germinated.

Inhibition of the fungal growth parameter in the poisoned medium was calculated using the following formula

$$\text{Per cent inhibition} = [(C - T) / C] \times 100$$

C= colony growth or germination per cent or

Table 2. Spore count and germination of *L. lecanii* on PDA poisoned with insecticides

Insecticide	Concentration (%)	Dose	Spore count (10^7 spores mL^{-1})	Sporulation Inhibition (%)*	Germination (%)	Germination Inhibition (%)**
Flubendiamide 39.35 % SC	0.0025	0.5x	2.96 (1.72)^{cd}	27.98	93.00 (74.74)^{b}	7.00
	0.005	x	2.48 (1.57)^{cde}	39.66	92.67 (74.34)^{bc}	7.33
	0.01	2x	2.36 (1.54)^{def}	42.58	87.33(69.36) ^{defghi}	12.67
Chlorantraniliprole 18.5 % SC	0.003	0.5x	3.09 (1.76)^{bc}	24.82	89.67(71.25)^{cdefg}	10.33
	0.006	x	2.27 (1.51)^{ef}	44.77	87.00 (68.99) ^{efghi}	13.00
	0.012	2x	1.98 (1.41)^{ef}	51.82	85.33 (67.59)^{hi}	14.67
Imidacloprid 17.8 % SL	0.003	0.5x	3.01 (1.72)^{bcd}	26.76	90.33 (71.92)^{bcde}	9.67
	0.006	x	2.21 (1.49)^{ef}	46.23	86.33 (68.36)^{fghi}	13.67
	0.012	2x	1.80 (1.34)^{fg}	56.20	85.00 (67.32)^{i}	15.00
Thiamethoxam 25 % WG	0.0025	0.5x	3.73 (1.93)^{ab}	9.25	91.00 (72.56)^{bcd}	9.00
	0.005	x	2.46 (1.55)^{cde}	40.15	89.67 (71.38)^{cdef}	10.33
	0.01	2x	2.45 (1.56)^{cde}	40.39	86.00 (68.05)^{ghi}	14.00
Malathion 50 % EC	0.05	0.5x	0.38 (0.59)^{hi}	90.75	74.67 (59.82)^{j}	25.33
	0.1	x	0.31 (0.53)^{i}	92.46	71.67 (57.89)^{jk}	28.33
	0.2	2x	0.05 (0.22)^{j}	98.78	70.33 (57.02)^{jk}	29.67
Quinalphos 25 % EC	0.025	0.5x	0.06 (0.25)^{j}	98.54	52.33 (46.34)^{mn}	47.67
	0.05	x	0.04 (0.18)^{j}	99.03	47.00 (43.28)^{n}	53.00
	0.01	2x	0.03 (0.16)^{j}	99.27	32.67 (34.85)^{op}	67.33
Dimethoate 30 % EC	0.02	0.5x	2.18 (1.48)^{ef}	46.96	90.33 (71.92)^{bcde}	9.67
	0.04	x	2.00 (1.41)^{ef}	51.34	89.00(70.64)^{defgh}	11.00
	0.08	2x	1.34 (1.16)^{g}	67.40	87.67(69.46) ^{defghi}	12.33
Chlorpyrifos 20 % EC	0.03	0.5x	0.58 (0.76)^{h}	85.89	68.33 (55.76)^{kl}	31.67
	0.06	x	0.48 (0.69)^{hi}	88.32	63.33 (52.74)^{l}	36.67
	0.12	2x	0.36 (0.6)^{hi}	91.24	53.33 (46.91)^{m}	46.67
Control			4.11 (2.03)^{a}		100 (89.71)^{a}	
CD (0.05)			(0.207)		(3.244)	
S.E(m) ±			0.251		3.411	

DAI-Days after inoculation, x- recommended dose
* Values in parentheses are square root transformed ** Values in parentheses are arc sine transformed.

spore count in control

T= colony growth or germination per cent or spore count in treatment

Compatibility status was finally confirmed by calculating Biological Index (BI) as proposed by Rossie-Zalaf (2008)

BI = [47 x VG + 43 x SP + 10 x GER] / 100 where,

VG - Vegetative growth of the fungal colony (%) in relation to control; SP - Sporulation (%) in relation to control; GER - Conidial germination (%) in relation to control

BI values were grouped into three categories of toxicological classification *viz.,* 0 to 41 = toxic;

42 to 66 = moderately toxic; >66 = compatible.

The data were subjected to analysis of variance (ANOVA) using WASP 2 software and treatment variations were related.

RESULTS AND DISCUSSION

Compatibility with insecticides

In general, the new generation insecticides chlorantraniliprole 18.5 % SC, imidacloprid 17.8 % SL, flubendiamide 39.35 % SC and thiamethoxam 25 %

Table 3. Compatibility status of *L. lecanii* with insecticides based on biological index

Insecticide	Dose	VR	SP	GER	BI	Compatibility status
Flubendiamide 39.35% SC	0.0025	88.64	71.90	93	82	COMPATIBLE
	0.005	84.09	60.22	92.667	75	COMPATIBLE
	0.01	77.27	57.49	87.333	70	COMPATIBLE
Chlorantraniliprole 18.5% SC	0.003	93.18	75.18	89.667	85	COMPATIBLE
	0.006	95.45	55.18	87	77	COMPATIBLE
	0.012	88.64	48.15	85.333	71	COMPATIBLE
Imidacloprid 17.8% SL	0.003	100.00	73.24	90.333	88	COMPATIBLE
	0.006	97.73	53.84	86.333	78	COMPATIBLE
	0.012	93.18	43.77	85	71	COMPATIBLE
Thiamethoxam |25% WG	0.0025	100.00	90.85	91	95	COMPATIBLE
	0.005	95.45	59.95	89.667	80	COMPATIBLE
	0.01	93.18	59.49	86	78	COMPATIBLE
Malathion 50% EC	0.05	56.06	9.34	74.667	38	TOXIC
	0.1	52.27	7.64	71.667	35	TOXIC
	0.2	50.00	1.12	70.333	31	TOXIC
Quinalphos 25% EC	0.025	25.00	1.48	52.333	18	TOXIC
	0.05	25.00	0.80	47	17	TOXIC
	0.01	22.73	0.63	32.667	14	TOXIC
Dimethoate 30% EC	0.02	81.82	52.97	90.333	70	COMPATIBLE
	0.04	82.58	48.71	89	69	COMPATIBLE
	0.08	65.91	32.60	87.667	54	MODERATLY TOXIC
Chlorpyrifos 20% EC	0.03	61.36	14.18	68.333	42	TOXIC
	0.06	56.82	11.65	63.333	38	TOXIC
	0.12	51.52	8.76	53.333	33	TOXIC

BI values were grouped into three categories of toxicological classification *viz.,* 0 to 41 = toxic; 42 to 66 = moderately toxic; >66 = compatible.

WG, were the least inhibitory on growth, sporulation and germination of *L. lecanii* at all the three test doses (Table 1). In terms of growth, the recommended dose inhibition was below 17.23 per cent. Among these, imidacloprid 17.8% SL caused the least growth inhibition (3.80 per cent), followed by thiamethoxam 25 % WG (6.40 per cent). At half the recommended dose, these insecticides caused less than 12 per cent growth inhibition. At their double dose, less than 23.94 per cent inhibition was recorded. These insecticides significantly inhibited the sporulation of *L. lecanii* (table 4). All the new-generation insecticides caused nearly 40 to 46 per cent inhibition at the field dose. Germination was inhibited by less than 11 per cent at half doses and below 15 per cent at their recommended and double the recommended doses, which is minimal compared to old-generation insecticides. Non-inhibitive effect of chlorantraniliprole 18.5% SC in this experiment is in corroboration with the findings of Sitta *et al*. (2009) in *Metarhizium anisopliae* and Vijayasree (2013) in *L. lecanii.*

Imidacloprid and thiamethoxam were reported to exhibit less growth inhibition in *L. lecanii* and *Beauveria bassiana*, as substantiated in the experiments by Filho *et al.* (2001) and Kakati *et al.* (2018). Both thiamethoxam and imidacloprid had no adverse impact on the germination of *L. lecanii*, as reported by Gurulingappa *et al.* (2011). Ummer and Kurien (2021) reported that imidacloprid 17.8% SL caused only 4.19 per cent inhibition in *L. lecanii*. The sporulation inhibition by these new-generation insecticides is supported by the findings of Oliveira *et al.* (2003), where thiamethoxam showed 21.39 per cent sporulation inhibition in *B. bassiana*, while Akbar *et al.* (2012) observed 49.48 per cent inhibition in sporulation of *M. anisopliae*.

Among the old-generation insecticides tested, dimethoate 30% EC was comparatively less inhibitive, with an 18 to 19 per cent reduction in growth at its recommended and half the recommended doses. Growth inhibition was maximum with quinalphos 25 %

Table 4. Effect of fungicides on growth, sporulation and germination of *L. lecanii*

Fungicide	Concentrations (%)	Mean colony diameter (cm)*		Growth inhibition (%)
		10 DAI	21 DAI	
Copper oxychloride 50% WP	0.2	1.5 (1.41)[b]	3.27 (1.94)[b]	35.88
Azoxystrobin 23% SC	0.1	1.33 (1.35)[c]	2.97 (1.86)[c]	41.76
Carbendazim 50%WP	0.2	0.00 (0.71)[d]	0.00 (0.71)[e]	100
Mancozeb 75% WP	0.3	1.27 (1.33)[c]	2.40 (1.7)[d]	52.94
Hexaconazole 5% EC	0.15	0.00 (0.71)[d]	0.00 (0.71)[e]	100
Tebuconazole 25%EC	0.2	0.00 (0.71)[d]	0.00 (0.71)[e]	100
Control		2.67 (1.78)[a]	5.10 (2.37)[a]	
CD (0.05)		(0.054)	(0.063)	
S.Em ±		0.384	0.761	

DAI- Days after inoculation. * Values in parentheses are square root transformed values

EC (75.39 per cent), followed by malathion 50 % EC (48.55%) and chlorpyrifos 20 % EC (44.07 per cent). The same inhibitive trend was observed in sporulation, where all these insecticides caused more than 80 per cent inhibition. Quinalphos, 25 % EC, severely deterred the sporulation (>98 per cent) at all three test doses. Sporulation inhibition was high in malathion at 50 % EC (> 90 per cent) and in chlorpyrifos 20 % EC (> 80 %).

Germination inhibition was highest in quinalphos 25 % EC (47.67 to 67.33 per cent), followed by malathion 50 % EC and chlorpyrifos 20 % EC (25.33 to 29.67 per cent and 31.67 to 46.67 per cent, respectively). Dimethoate 30 % EC was comparatively less inhibitory (9.67 to 12.33 per cent).

The non-inhibitory nature of dimethoate 30 % EC in this study is supported by findings of Armarkar and Chikte (2008) and Kakati *et al.* (2018), where it was found to be compatible with *L. lecanii* causing only 19.63 and 21.25 per cent inhibition in growth. However, it was reported to have an adverse effect on the growth of *B. bassiana*, with 59.25 per cent inhibition (Dhanya *et al.,* 2019). The inhibitory nature of chlorpyrifos 20% EC and malathion 20% EC to entomopathogens such as *B. bassiana* was confirmed in the studies conducted by Rachappa *et al.* (2007), where there was a 58 per cent reduction in growth by malathion 50% EC and 69 per cent reduction by chlorpyrifos 20% EC.

Quinalphos 25% EC was highly inhibitive to the growth (75 to 77 per cent), sporulation (99 per cent) and germination (47 to 67 per cent). The inhibitory effect of quinalphos noted in this study is supported by the findings of various researchers. Rajanikanth *et al.* (2010) and Faraji *et al.* (2016) reported the non-compatibility of quinalphos 25% EC where there was a total inhibition in the conidial germination of *B. bassiana.*

The reason for inhibition noted with many of the old-generation insecticides, as opined in the study carried out by Rani, (2000) in the entomopathogenic fungus *Fusarium pallidoroseum* (Cooke) Sacc, might be due to the alteration in C: N ratio in the poisoned medium to non-ideal proportions. This may be why fungi respond differently in different media into which other chemicals are added. Only if the carbon and nitrogen source is available to the fungi to metabolise can it grow and sporulate well. The compatibility status calculated based on the Biological index (Table 5) reveals that malathion 50% EC, quinalphos 25% EC and chlorpyrifos 20% EC were "toxic' with BI ranging from 14 to 38. Only dimethoate 30% EC was found to be 'compatible' with the BI index of 69. The incompatibility of *L. lecanii* with chlorpyrifos is in agreement with studies conducted by Abidin *et al.,* (2017), where it was found to be toxic to *B. bassiana* and *M. anisopliae* based on the BI index (39.32 and 24.40 respectively). All four new-generation insecticides tested were highly compatible at all three test doses, with BI Indices ranging from 71 in chlorantraniliprole 18.5% SC to 95 in thiamethoxam 25% WG.

Table 5. Effect of fungicides on sporulation and germination of *L. lecanii*

Fungicide	Concentrations (%)	Spore count (10^7 spores mL^{-1})*	Sporulation Inhibition (%)	Germination (%)**	Germination Inhibition (%)
		21 DAI		24 h	
Copper oxychloride 50% WP	0.2	0.37 (0.93)^{c}	91.16	98.33 (83.87)^{ab}	0.67
Azoxystrobin 23% SC	0.1	0.60 (1.05)^{b}	85.68	95.67 (78.49)^{b}	3.36
Carbendazim 50%WP	0.2	0.00 (0.71)	100	0 (0.29)^{c}	100
Mancozeb 75% WP	0.3	0.04 (0.73)^{d}	99.045	0 (0.29)^{c}	100
Hexaconazole 5% EC	0.15	0.00 (0.71)	100	0 (0.29)^{c}	100
Tebuconazole 25%EC	0.2	0.00 (0.71)	100	0 (0.29)^{c}	100
Control		4.19 (2.17)^{a}	-	99.00 (86.48)^{a}	-
CD (0.05)		(0.066)		(5.79)	
S.Em ±		0.581		19.735	

DAI- Days after inoculation. * Values in parentheses are square root transformed values
** Values in parentheses are arc sine transformed.

Compatibility with fungicides

Among the fungicides studied for compatibility, azoxystrobin 23% SC was comparatively less inhibitive (Tables 4 and 5). The inhibition was 41.76 per cent and 95 per cent, respectively, in growth and sporulation. However, the reduction in germination was only 3.33 per cent. Silva *et al.* (2013) reported the least inhibition in the growth and sporulation of *M. anisopliae*. On the contrary, Zumaeta (2014) pointed out that azoxystrobin 300 ppm reduced germination by 81 per cent and growth by 51 per cent.

Copper oxychloride 50% WP caused 31 and 97.87 per cent reduction in growth and sporulation. In terms of germination, its inhibition was negligible (1 per cent). The inhibitory effect of copper oxychloride 50% WP on the growth and sporulation of entomopathogenic fungi noted in this study follows the report of Olan and Cortez (2003), who found that there was 79.24 per inhibition in *L. lecanii. B. bassiana* caused 45-55 per cent inhibition in sporulation (Rachappa *et al.,* 2007; Usha *et al.,* 2014). Mancozeb 75% WP was found to be highly poisonous. It caused 51 per cent growth inhibition, 99 per cent sporulation inhibition and 100 per cent germination inhibition. Mancozeb is known to affect cellular respiration, interrupting the Krebs cycle in multiple stages, thus it inhibitory the growth and as well as germination of fungi (Liñan, 1997). Gonzalez *et al. (*2012) found that mancozeb 75% WP @ 2000 mg kg-1 exhibited a spore load of 2.3 x 107 mg kg-1 in *L. lecanii*, while there was 34.3 per cent growth inhibition. It was also reported to cause complete inhibition in the germination of *Lecanicillium muscarium* by Ali *et al. (*2013) and *Isaria fumosorosea* Wize, by Bernal *et al.* (2014).

Carbendazim 50% WP, hexaconazole 5% EC and tebuconazole 25% EC caused 100% inhibition in all the growth parameters. This complete inhibition of *L. lecanii* by carbendazim is in concordance with the observation of Krishnamoorthy and Visalakshi (2007) and Ummer and Kurien (2021). Inhibitory properties of hexaconazole 5% EC were reported by Raj *et al.* (2011) in *B. bassiana*, Lavanya and Matti (2020) and Johnson *et al. (*2020) in *M. anisopliae*, where there was a total arrest.

Compatibility status, when assessed for fungicides, showed that azoxystrobin 23% SC and copper oxychloride

Table 6. Compatibility status of *L. lecanii* with fungicides based on biological index

Fungicides	Dose	VR	SP	GER	BI	Compatibility status
Copper oxychloride 50% WP	1x	64.05	8.78	99.32	44	Moderately toxic
Azoxystrobin 23% SC	1x	64.05	14.35	96.63	46	Moderately toxic
Mancozeb 75% WP	1x	47.05	0.93	0	23	Toxic
Carbendazim 50%WP	1x	0	0	0	0	Toxic
Hexaconazole 5% EC	1x	0	0	0	0	Toxic
Tebuconazole 25%EC	1x	0	0	0	0	Toxic

50% WP were moderately toxic to the fungus (Table 8). Other fungicides *viz*., carbendazim 50% WP, mancozeb 75% WP, hexaconazole 5% EC and tebuconazole 25% EC was "toxic" to the fungus.

Bartlett *et al.* (2002) suggested that the toxicity of tebuconazole and hexaconazole, the triazole fungicides, is due to ergosterol biosynthesis inhibition, consequently preventing the formation of the fungal cell membrane. Mancozeb which was found to be toxic in this study, was earlier reported to be moderately toxic to *L. lecanii* by Gonzalez *et al.* (2012). This variation may be attributed to the fact that in their study, only growth and sporulation were considered for computing compatibility index based on the scale of classification put forth by the International Organisation of Biological Control (IOBC).

It can be concluded that the new generation insecticides are very well compatible with *L lecanii*, and the old generation insecticide is toxic. Among fungicides, copper oxychloride 50% WP and azoxystrobin 23 % SC are moderately toxic, and other fungicides were classified as toxic to *L. lecanii*. Therefore, compatible insecticides can be used along with *L. lecanii* to suppress the non-targeted pests, while moderately toxic fungicides can be used sequentially to manage diseases.

ACKNOWLEDGEMENT

The authors are thankful to Kerala Agricultural University, Thrissur, Kerala, India for providing infrastructural facilities and research fund to carry out research work.

REFERENCES

Abidin, A. F., Ekowati, N. and Ratnaningtyas, N. I. 2017. Compatibility of insecticides with entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae*. *Scripta Biologica,* **4**(4): 273-279.

Akbar, S., Shoaib, F., Asifa, H., Hafiza, T. G., Muhammad, A., Muhammad, N. M., Muhammad, N. and Muhammad, B. K. 2012. Compatibility of *Metarhizium anisopliae* with different insecticides and fungicides. *African Journal of Microbiology Research,* **6**(17): 3956-3962.

Ali, S., Huang, Z. and Ren, S. 2013. Effect of fungicides on growth, germination and cuticle degrading enzyme production by *Lecanicillium muscarium*. *Biocontrol Science and Technology,* **23**(6): 711-723.

Armarkar, S. V. and Chikte, P. B. 2008. Compatibility of *Verticillium lecanii* with different chemical pesticides. *Journal of Plant Diseases and Protection,* **3**(1): 43-45.

Bartlett, D. W., Clough, J. M., Godwin, J. R., Hall, A. A., Hamer, M. and Parr-Dobrzanski, B. 2002. The strobilurin fungicides. *Pest Management Science,* **58**: 649–662.

Bernal, E.P.G, Gomez Alvarez, M. I. and Zuluaga Mogollon, M. V. 2014. *In vitro* compatibility *Isaria fumosorosea* (Wize.) Brown y Smith (Hypocreales: Clavicipitaceae) with commercial plaguicides. *Acta Agronomica*, **63**(1): 48-54.

Dhanya, M. K., Sathyan, T., Murugan, M., Ashokkumar, K. and Surya, R. 2019. *In-vitro* compatibility of entomopathogenic fungi with synthetic insecticides and neem oil. *Pesticide Research Journal,* **31**(2): 275-281.

Faraji, S., Shadmehri, A. and Mehrvar, A. 2016. Compatibility of entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* with some pesticides. *Journal of Entomological Society of Iran,* **36** (2): 137-146.

Filho, A. B., Almeida, J. E. and Lamas, C. 2001. Effect of thiamethoxam on entomopathogenic microorganisms. *Neotropical Entomology,* **30** (3): 437-447.

Gonzalez, L. C., Nicao, M. E. L., Muino, B. L., Perez, R. H., Sanchez, D. G. and Martínez, V.L. 2012. Effect of six fungicides on *Lecanicillium (Verticillium) lecanii* (Zimm.) Zare and Gams. *Journal of Food, Agriculture and Environment,* **10** (2): 1142-1145.

Gurulingappa, P., Mc Gee, P. and Sword, G. A. 2011. *In vitro* and *in planta* compatibility of insecticides and the endophytic entomopathogen, *Lecanicillium lecanii*. *Mycopathologia,* **172** (2): 161-168.

Johnson, J.M., Deepthy, K.B. and Chellappan, M. 2020. Tolerance of *Metarhizium anisopliae* Sorokin isolates to selected insecticides and fungicides. *Entomon,* **45** (2): 143-148.

Kakati, N., Dutta, P., Das, P. and Nath, P.D., 2018. Compatibility of entomopathogenous fungi with commonly used insecticides for management of banana aphid transmitting banana bunchy top virus (BBTV) in Assam banana production system. *International Journal of Current Microbiology and Applied Sciences,* **7**(11): 2507-2513.

Kim, H. K., Hoe, H. S., Suh, D. S., Kang, S. C., Hwang, C. and Kwon, S. T. 2002. Gene structure and expression of the gene from *Beauveria bassiana* encoding bassiasin I, an insect cuticle-degrading serine protease, *Biotechnology Letters,* **21**: 777-783.

Krishnamoorthy, A. and Visalakshi, P. G. 2007. Influence of some pesticides on entomopathogenic fungus *Lecanicillium (Verticillium) lecanii* (Zimm.) Zare and Gams. *Journal of Horticultural Sciences,* **2**(1): 53-57.

Lavanya, D.S. and Matti, P., 2020. Compatibility of Entomopathogenic Fungi, *Metarhizium anisopliae* with Pesticides. *International Journal of Current Microbiology and Applied Sciences,* **9**(2): 714-721.

Liñan, C. 1997. Farmacología vegetal. España. p. 108.

Moorhouse, E. R., Gillsepie, A.T., Sellers, E.K and Charnley, A.K., 1992. Influence of fungicides and insecticides on the entomogenous fungus, *Metarhizium anisopliae*, a pathogen of the vine weevil, *Otiorhynchus sulcatus*. *Biocontrol Science and Technology*, **82**: 404 – 407.

Nunez. E. J., Iannacone and Omez H. G. 2008. Effect of two entomopathogenic fungi in controlling *Aleurodicus cocois* (Hemiptera: Aleyrodidae). *Chilean Journal of Agricultural Research,* **68**: 21-30.

Olan, H. J. F. and Cortez, M. H. 2003. Effect of three fungicides on seven strains of the entomopathogen *Lecanicillium* (*Verticillium lecanii*). *Manejo Integrado de Plagas Y Agroecologia*, **69**: 21-26.

Oliveira, C. N. D., Neves, P. M. O. J. and Kawazoe, L. S. 2003. Compatibility between the entomopathogenic fungus *Beauveria bassiana* and insecticides used in coffee plantations. *Scientia Agricola,* **60**(4): 663-667.

Pillai, K.G. and Visalakshy, P.N. 2017. Entomopathogenic fungi for the management of whitefly, *Bemisia tabaci* (Hemiptera: Aleyrodidae) on gerbera (*Gerbera jamesonii*) in polyhouses. *Pest Management in Horticultural Ecosystems*, **23**(1): 31-36.

Rachappa, V., Lingappa, S. and Patil, R. K. 2007. Effect of agrochemicals on growth and sporulation of *Metarhizium anisopliae* (Metschnikoff) Sorokin. *Karnataka Journal of Agricultural Sciences,* **20**(2): 410-413.

Raj, G. A., Janarthanan, S., Samuel, S. D., Baskar, K. and Vincent, S. 2011. Compatibility of entomopathogenic fungus *Beauveria bassiana* (Balsamo) Vuillemin isolated from Pulney hills, Western Ghats of Tamil Nadu with insecticides and fungicides. *Elixir Agriculture,* **40**: 5563-5567.

Rajanikanth, P., Subbaratnam, G. V. and Rahaman, S. J. 2010. Compatibility of insecticides with *Beauveria bassiana* (Balsamo) Vuillemin for use against *Spodoptera litura* Fabricius. *Journal of Biological Control,* **24**(3): 238-243.

Rani, R. O. P. 2000. Production and evaluation of the fungus *Fusarium pallidoroseum* (Cooke) Sacc. as a biopesticide against pea aphid *Aphis craccivora* Koch. Ph. D thesis, Kerala Agricultural University, Thrissur, 137p.

Rossie-Zalaf, L. S., Alves, S. B., Lopes, R. B., Silveira, N. S. and Tanzini, M. R. 2008. Interaction of microorganisms with other pest and disease control agents. In: Alves, S. B. and Lopes, R. B., (eds), *Microbial Control of Pest in Latin America: Advances and Challenges*. Fealq, Piracicaba, Brazil. 270-302.

Shah, F. A., Ansari, M. A., Watkins, J., Phelps, Z., Cross, J. and Butt, T. M. 2009. Influence of commercial fungicides on the germination, growth and virulence of four species of entomopathogenic fungi. *Biocontrol Science and Technology,* **19**(7): 743-753.

Silva, R. A. D., Quintela, E. D., Mascarin, G. M., Barrigossi, J. A. F. and Liao, L. M. 2013. Compatibility of conventional agrochemicals used in rice crops with the entomopathogenic fungus *Metarhizium anisopliae*. *Scientia Agricola,* **70**(3): 152-160.

Sitta, R. B., Gouveia, L. and Sosa-Gomez, D. R. 2009. Compatibilidade de inseticidas com fungos entomopatogênicos. Jornada Acadêmica da Embrapa Soja, 4 (Embrapa Soja. Documento, 312). Londrina: Editado por Odilon Ferreira Saraiva, Pula Geron Saiz Melo. Retrieved from https://ainfo.cnptia.embrapa.br/digital/bitstream/item/72358/1/ID-29937pdf

Ummer, N. and Kurien, S., 2021. *In vitro* evaluation on compatibility of *Lecanicillium lecanii* with selected pesticides. *Pesticide Research Journal,* 33(1): 105-108.

Usha, J., Babu, N. M. and Padmaja, V. 2014. Detection of compatibilty of entomopathogenic fungus *Beauveria bassiana* (Bals.) Vuill. with pesticides, fungicides and botanicals. *International Journal of Plant, Animal and Environmental Sciences,* **4**(2):613-624.

Vijayasree, V. 2013. Efficacy and biosafety of new generation insecticides for the management of fruit borers of cowpea, brinjal and okra. Ph. D thesis, Kerala Agricultural University, Thrissur, 294 p.

Zumaeta, J. 2014. Efecto de diferentes concentraciones de Azoxystrobin sobre la germinación y crecimiento de Lecanicilium Jecanii y *Metarhizium anisopliae* en condiciones de laboratorio. Universidad Nacional de Trujillo. 65p.

MS Received: 22 August 2022
MS Accepted : 08 October 2022