“COMPATIBILITY STUDIES AMONG BIOCONTROL AGENTS AND CHEMICAL PESTICIDES (*IN VITRO*)”.

by

Mr. Shinde Tushar Bhagavat.
(Reg. No. K-19/261)

DIVISION OF PLANT PATHOLOGY
AND AGRICULTURAL MICROBIOLOGY

RAJARSHEE CHHATRAPATI SHAHU MAHARAJ
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RAHURI-413722, DIST-AHMEDNAGAR
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A Thesis submitted to the
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MAHARASHTRA, INDIA.

In partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

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APPROVED BY

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2021

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part
there of has not been submitted
by me or other person to any
other University or Institute
for a Degree or
Diploma

Place: Kolhapur

Date:

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CERTIFICATE

This is to certify that the thesis entitled, **"COMPATIBILITY STUDIES AMONG BIOCONTROL AGENTS AND CHEMICAL PESTICIDES (*IN VITRO*)"** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (Maharashtra) in partial fulfilment of the requirement for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **AGRICULTURAL MICROBIOLOGY**, embodies the result of a piece of bonafide research work carried out by **Mr. SHINDE TUSHAR BHAGAVAT,** under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

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Place: Kolhapur **(U. B. Hole)**

Date:

ABSTRACT

COMPATIBILITY STUDIES AMONG BIOCONTROL AGENTS AND CHEMICAL PESTICIDES (*IN VITRO*)

By

Mr. SHINDE TUSHAR BHAGAVAT

(Reg. No. K-19/261)

A candidate for the degree of

MASTER OF SCIENCE (AGRICULTURE)

In

AGRICULTURAL MICROBIOLOGY

Division of Plant Pathology and Agricultural Microbiology

Rajarshee Chhatrapati Shahu Maharaj

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2021

Research guide	:	Dr. S. B. Mahajan
Department	:	Plant Pathology and Agricultural Microbiology

An investigation entitled “Compatibility studies among biocontrol agents and chemical pesticides (*in vitro*)” was conducted at Plant Pathology and Agricultural Microbiology Section, Rajarshee Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur during, 2020-21. The experiment was laid out in Completely Randomized Design (CRD) with four replications and seven treatments of fungicides, seven treatments of herbicides and seven treatments of insecticides on each of six fungal biocontrol agents. Biocontrol agents are *Trichoderma viride, Trichoderma harzianum, Metarhizium anisopliae, Verticillium lecanii, Beauveria bassiana* and *Paecilomyces lilacinus*.

In case of *Trichoderma viride*, fungicide, ametoctradin + dimethomorph was found moderately toxic while, fungicides, captan, carbendazim + mancozeb, thiophenate methyl, copper oxychloride and azoxystrobin + tebuconazole, were incompatible. Among the herbicides, carfentrazone ethyl, fomesafen + flauzifop-p-butyl, oxyfluorofen and metribuzin were compatible and glyphosate is incompatible. Herbicide, sulfentrazone + clomazone was found incompatible. All of the insecticides like emamectin benzoate, spinosad, chlorantraniliprole, imidacloprid, acetamiprid and thimethoxam + lamda cyhalothrin were found compatible.

In case of *Trichoderma harzianum*, fungicide, ametoctradin + diamethomorph was found to be moderately toxic, while carbendazim + mancozeb, copper oxychloride, azoxystrobin + tebuconazole, captan and thiophenate methyl, proved toxic. Among the herbicides, carfentrazone ethyl was found compatible and glyphosate was proved slightly toxic. oxyfluorofen and metribuzin are moderately toxic. The herbicides, sulfentrazone + clomazone and fomesafen +

flauzifop-p-butyl, are incompatible. Insecticides, imidachloprid, acetamiprid, spinosad, imamectin benzoate and chlorantraniliprole, were found compatible, whereas thimethoxam + lambda cyhalothrin was found slightly toxic.

In case of *Metarhizium anisopliae,* all fungicides like carbendazim + mancozeb, copper oxychloride, azoxystrobin + tebuconazole, ametoctradin + diamethomorph, captan and thiophenate methyl, were incompatible. Among the herbicides, only one herbicide, metribuzin, proved moderately toxic while, sulfentrazone + clomazone, oxyfluorofen, glyphosate, fomesafen + flauzifop-p-butyl and carfentrazone ethyl, were found incompatible. Among the insecticides, acetamiprid, chlorantraniliprole and spinosad were compatible whereas imidachloprid, emamectin benzoate, were moderately toxic. Thimethoxam + lambda cyhalothrin, proved toxic.

In case of *Verticillium lecanii,* among the fungicides, copper oxychloride and ametoctradin + diamethomorph, were proved moderately toxic while, carbendazim + mancozeb, azoxystrobin + tebuconazole, thiophenate methyl and captan, were proved totally incompatible. Among the herbicides, only one herbicide, carfentrazone ethyl, was found compatible and fomesafen + flauzifop-p-butyl and metribuzin were found slightly toxic. Glyphosate and oxyfluorofen were proved moderately toxic and sulfentrazone + clomazone, was totally incompatible. Among the insecticides, chlorantraniliprole, spinosad and emamectin benzoate were found compatible and acetamiprid, imidachloprid and thiamethoxam + lambda cyhalothrin were found slightly toxic.

In case of *Beauveria bassiana,* among the fungicides, copper oxychloride proved moderately toxic and carbendazim + mancozeb, thiophenate methyl, azoxystrobin + tebuconazole, ametoctradin + diamethomorph and captan, were incompatible. The herbicide fomesafen + flauzifop-p-butyl was found slightly toxic and glyphosate and carfentrazone ethyl, proved moderately toxic. Sulfentrazone + clomazone, oxyfluorofen and metribuzin, were totally incompatible. Among the insecticides, spinosad and imidacloprid were found slightly toxic. Chlorantraniliprole, was found to be moderately toxic while acetamiprid, emamectin benzoate and thimethoxam + lambda cyhalothrin, were found toxic.

In case of *Paecilomyces lilacinus,* among the fungicides, ametoctradin + diamethomorph was compatible and copper oxychloride was found slightly toxic while, captan was found to be moderately toxic. Carbendazim + mancozeb, thiophenate methyl and azoxystrobin + tebuconazole, are totally incompatible. Among the herbicides, fomesafen + flauzifop-p-butyl and carfentrazone ethyl were found to be compatible whereas, metribuzin and glyphosate, were proved moderately toxic. Sulfentrazone + clomazone and oxyfluorofen, proved totally incompatible. Among the insecticides, spinosad was found fully compatible and chlorantraniliprole and acetamiprid were found slightly toxic while, emamectin benzoate and imidachloprid were found to be moderately toxic, thimethoxam + lambda cyhalothrin was proved toxic.

Some chemical pesticides do not affect the growth and development of biocontrol agents. The combination of such chemical pesticides with biocontrol agents can provide an additive or synergistic effect in the control of diseases and pests. These chemical pesticides and biocontrol agents can be used in an integrated pest management programme.

1. INTRODUCTION

Control of plant diseases and pests by chemicals can be spectacular but this is relatively short term measure and moreover, the accumulation of harmful chemical residues sometimes causes serious ecological problems. In recent years, the increasing use of potentially hazardous pesticides and fungicides in agriculture has been the result of growing concern of both environmentalists and public health authorities. Use of such chemicals entails a substantial cost to the nation and developing country like India cannot afford it. On the other hand biological methods can be economical, long lasting and free from residual side effects. The main purpose of biological control of plant disease and pests is to suppress the inoculum load of the target pathogen to a level which would not cause potential economic loss in the crop.

In agriculture, biocontrol agents are a safe and environmentally acceptable alternative to pesticides (Gampala and Pinnamaneni, 2010). Recommended doses of insecticides along with biocontrol agents show promising effects on the management of various plant pests than the chemicals alone (Vinit *et al.*, 2012). Combining a fungicide tolerant biocontrol agent with respective fungicides has improved the extent of disease control and reduced the quantity of fungicides required for effective management (Buck, 2004). Therefore the combine use of biocontrol agents and chemical pesticides has enticed much attention as a way to obtain synergistic or additive effects in the control of soil borne pathogens (Locke *et al.,* 1985). A lot of examples exist where application of different selective chemical insecticides and bioagents when used in combination provide satisfactory control against many agricultural insect pests (Quintela and McCoy, 1998).

Soil and seed borne diseases are one of the major constraints in crop production. It is essential to treat the seed with protectants for early control of seed-borne pathogens as these pathogens are carried externally and/or internally through seeds. This can be achieved through chemical and/or biological means. *Trichoderma viride* is a potential biocontrol agent for several soil and seed borne pathogens (Papavizas, 1983) widely used throughout the world. *Trichoderma harzianum* in the greenhouse industry widely used for disease control instead of chemical fungicides because it is safer to use for growers, its disease control effects last longer than those of synthetic chemical pesticides (Goes *et al.*, 2002). *Metarhizium anisopliae* (Metschn.) is a widespread fungus with a wide range of hosts. This fungus has been found to infect over 100 species of insects from various orders. (Udayababu *et al.,* 2012). Some other potential biocontrol agents including *Beauveria bassiana* (Bals.), *Verticillium lecanii* (Zimm.) and *Paecilomyces lilacinus* are also have lot of importance in disease and pest control. Some fungicides and insecticides are effectively used as seed dressing. It is necessary to study compatibility of these with the commonly used bio agents.

Quite often, the desired result from biocontrol agent treatment in certain fields is hardly achieved owing to various reasons which include an adverse impact of pesticides used either in the previous or the current crop. Under such circumstances, there are more chances to reduce population of biocontrol agents because of poisonous effect of chemicals in the soil. It has been reported that *T. harzianum* is highly sensitive to mancozeb, tebuconazole and thiram (McLean *et al.*, 2011). A number of fungicides which include chlorothalonil have been reported to suppress the soil respiration by 30-50 percent affecting total fungal population (Chen *et al.*, 2001). Carbendazim, thiram, quinalphos, monocrotophos and butachlor have been reported to reduce the nitrogenase activity in field conditions (Martinez-Toledo *et al.*, 1998; Niewiadomska, 2004 and Niewiadomska and Klama, 2005). Experimental findings shows that hexaconazole, carbendazim, propiconazole, azoxystrobin and tebuconazole are not compatible with *Trichoderma viride* so these fungicides cannot be applied with *Trichoderma viride,* while mancozeb was found to be most compatible with *Trichoderma viride* so can be applied for the Sclerotinia stem rot of lentil and other crops for integrated management of disease (Mishra *et al.*, 2019).

It is to be noted that, only about 0.1 percent of the pesticide reaches the target organisms and the remaining contaminates the surrounding environment (Carriger *et al.*, 2006). Due to xenobiotic characteristics, these pesticides adversely affect beneficial soil microorganisms, inactive nitrogen-fixing and phosphate-solubilizing microorganisms and inhibit biological nitrogen fixation (Munoz-Leoz *et al.*, 2011). They also affect the function of beneficial root-colonizing microbes by influencing their growth, colonization and metabolic activities *etc.* (Menendez *et al.*, 2010).

The compatibility studies undertaken indicated successful use of biocontrol agents in combination with chemical pesticides for better results in plant protection in various crops. In the compatibility studies undertaken by Bindu madhavi *et al.*, 2011 the pesticide imidacloprid was shown to be very compatible with *Trichoderma viride*; fungicides propineb, pencycuron, mancozeb and tebuconazole; herbicides *viz.*, imizathafir, 2,4-D sodium salt and oxyfluorofen while being totally incompatible with systemic fungicides like carbendazim, hexaconazole, tebuconazole and propiconazole.

The *Myrothecium verrucaria,* a potential bioherbicidal fungus can be combined with commercial preparations of herbicides *viz.*, aminopyralid and metsulfuron and the growth in the presence of herbicide indicates that *M. verrucaria* could be incorporated into an integrated weed management program for kudzu (*Pueraria montana*) (Weaver and Lyn, 2011).

The herbicides, insecticides and fungicides applied as foliar spray or soil drench ultimately reach the soil and affect beneficial non-target mycoflora. Hence, knowledge of compatibility of all these biocontrol agents with important pesticides may help opt for better plant protection measures. Tolerance to commonly-used pesticides enhances the efficacy and expands the scope of application of biocontrol agent. Integrating the use of *Trichoderma* spp., *Verticillium* spp., *Paecilomyces* spp., *Metarhizium* spp., and *Beauveria* spp. strains with various chemical pesticides has significant importance in the overall framework of integrated pest and disease management. Hence, an *in vitro* study will be conducted to assess compatibility of some commonly-used, commercially available fungicides, insecticides and herbicides on growth of various biocontrol agents with the following objectives.

1. To study the compatibility of biocontrol agents and fungicides.
2. To study the compatibility of biocontrol agents and insecticides.
3. To study the compatibility of biocontrol agents and herbicides.

2. REVIEW OF LITERATURE

Various workers in the past have studied the compatibility of different pesticides and biocontrol agents *in vitro* and *in vivo* majority of the pesticides were incompatible while few were compatible with fungal biocontrol agents including mycoherbicides. The review gives overview for the studies undertaken till date.

2.1 Compatibility of *Trichoderma viride* with chemical pesticides.

Gampala and Pinnamaneni (2010) reported that *Trichoderma viride* is a biocontrol agent which shows antagonistic activity toward a broad spectrum of phytopathogens. They also reported that it is more compatible with fertilizers and pesticides and can be safely used with chemical fertilizers that provide major nutrients for any crop.

In vitro compatibility study of *Trichoderma viride* with 25 pesticides was undertaken by Bindu madhavi *et al.* 2011 revealed that among six seed-treatment chemicals tested, *T. viride* had the best compatibility with the pesticide imidacloprid (7.6 cm mycelial growth), followed by mancozeb (6.3 cm) and tebuconazole (5.3 cm) (3.7 cm). Pencycuron and propineb, two contact fungicides, were shown to be completely compatible with *T. viride*. The fungus was extremely compatible with imizathafir (9.0 cm), 2, 4-D sodium salt (8.9 cm), and oxyfluorofen (6.5 cm) among the 10 herbicides were examined, but completely incompatible with systemic fungicides such as carbendazim, hexaconazole, tebuconazole, and propiconazole.

Ranganathswamy *et al*. (2012) investigated the compatibility of *Trichoderma viride, Trichoderma harzianum* and *Trichoderma virens* with eighteen selected fungicides. They reported that benomyl, carbendazim, hexaconazole, propiconazole, tridemorph, tricyclozole were incompatible with *Trichoderma* species. On the other hand, captan, thiram, dinocap, fosetyl-Al, metalaxyl and copper oxychloride showed the least compatibility. Mancozeb, azoxystrobin and bordeaux mixture which showed inhibition of mycelial growth of 20-45 per cent and was found to be moderately compatible. Fungicide, wettable sulphur was found totally compatible and showed inhibition 2.2 per cent.

Thiruchchelvan *et al*. (2013) reported that the majority of chemicals are compatible with *Trichoderma*. As a result, commercial farmers may utilise it to preserve the environment through integrated disease control.

Bhale and Rajkonda (2015) experimented with the compatibility of fungicides (captan and mancozeb) with *Trichoderma*s pp. *in vitro* at different concentrations. Lower concentrations of captan and mancozeb did not affect the radial growth of *Trichoderma* spp. However, concentration of captan and mancozeb above 500 µg/ml significantly reduced the radial growth of *Trichoderma* spp.

Ghazanfar *et al.* (2018) investigated *Trichoderma spp.* showed that it has a parasitic nature on soil borne pathogens and many foliar plant pathogens. *Ttrichoderma spp.* show antagonistic activity involving antibiotics, mycoparasitism and competition for nutrients and also induces systemic resistance in plants.

Mishra *et al*. (2019) concluded that the fungus *Trichoderma viride* is the chief antagonist used for disease management in agriculture and is an effective and low cost biocontrol agent. They also reported that the fungicides thiophenate methyl, captan and iprodine exhibited intermediate inhibitory effect and were less compatible with *Trichoderma viride*, while hexaconazole, azoxystrobin, tebuconazole, carbendazim and propiconazole completely inhibited growth and were incompatible with *Trichoderma viride*.

Maheshwary *et al.* (2020) experimented that among contact fungicides, copper oxychloride, copper hydroxide and mancozeb were compatible with *Trichoderma spp.* and less compatible with captan. Among systemic fungicides, propiconazole, tebuconazole and carbendazim were incompatible and metalaxyl was compatible at all concentrations. Among the combination fungicides tested were not compatible with *Trichoderma spp*. but metalaxyl-m + mancozeb was found to be more compatible.

2.2 Compatibility of *Trichoderma harzianum* with chemical pesticides.

Desai and Kulkarni (2004) experimented with thirteen agrochemicals involving six herbicides, five fungicides and two insecticides at 500, 1000 and 2000 ppm dosages. Among these pesticides, carbendazim, alachlor, glyphosate, chloropyriphos, thiram and trifluralin were highly inhibitory to *T. harzianum*, while captan, atrazine, acephate and 2, 4-D sodium salt. Inhibitory effects increased with concentrations increased from 500 to 1000 ppm.

Sarkar *et al.* (2008) investigated the effect of insecticides, fungicides, and biopesticides on the mycelial growth of *T. harzianum* in *in vitro* conditions. Among the contact fungicides, copper oxychloride and copper hydroxide were highly compatible at lower concentrations and no inhibition was observed. Among insecticides, dicofol and quinalphos exhibited toxicity, even at a low concentration of 10 ppm. Propargite, fenpropathrin, and endosulfan were compatible with *T. harzianum*. Among the systematic fungicides, propiconazole and triflumizole were less toxic and hexaconazole was the most toxic. A per cent inhibition in the growth of fungus was observed as the concentration of fungicides increased.

Bhai and Thomas (2010) studied the compatibility of *Trichoderma harzianum* with agrochemicals. They reported that high inhibition of mycelial growth was recorded with treatment of Bordeaux mixture and quinalphos, which were 100 and 55.84 per cent respectively. Other chemicals, such as monocrotophos, chlorpyriphos, carbofuron, phorate, mancozeb, and copper oxychloride, had no inhibitory effect on *Trichoderma harzianum*.

Bagwan (2010) reported that among the fungicides tested, mancozeb (0.2%), copper oxychloride (0.2%) and thiram (0.2%) were found compatible with *Trichoderma harzianum* and *Trichoderma viride* as compared to other fungicides. *Trichoderma* was incompatible with the fungicides vitavax, tebuconazole, captan, propiconazole and chlorothalonil. But *Trichoderma* was tolerant to all the pesticides and herbicides tested.

McLean *et al*. (2011) investigated wether *Trichoderma harzianum* in furrow application would be effective with captan and/or benomyl. They also concluded that *T. harzianum* was most sensitive to thiram and tebuconazole and mancozeb and least sensitive to captan and procymidone.

Vinit *et al*. (2012) experimented that the *Trichoderma harzianuum* is compatible with decis (deltamethrin 2.8% EC), hilcron 36% SL (monocrotophos 36%), hilida (imidacloprid 17.8% SL) and rogar 30% EC and some insecticides are not compatible with the *Trichoderma harzianum* that is ekaulux 25% EC (quinolphos 25% EC), marshal 25% EC (carbosulphon 25% EC) and rocket 44% EC (profenofos40% + cypermethrin 4 %).

Vinit *et al*. (2012) concluded that integration of chemicals and biocontrol agents has been the subject of research during recent years. *Trichoderma spp* are also known as active biocontrol agents against soil borne pathogens of several important crops.

Saxena *et al.* (2014) experimented that among herbicides, alachlor, butachlor, 2, 4-D ethyl ester, pretilachlor, fluchloralin, anilifos and pendamethalin were found compatible with *T. harzianum* even at higher concentrations (250 µl a.i./ml). Among insecticides, profenofos, monocrotofos, triazophos and dichlorvos were found compatible up to 250 µl a.i./ml, while quinalphos, deltamethrin up to 100 µl a.i./ml. Among fungicides, thiram, captan, copper hydroxide and chlorothalonil were found compatible with *T. harzianum* up to 100 µg a.i./ml. However bayleton, ipridione, benomyl and thiophenate methyl were found incompatible with *T. harzianum* even at 25 µg a.i./ml, while mancozeb up to 250 µg a.i./ml was compatible with *T. harzianum.*

Borade and Bhosale (2015) experimented with the effect of four fungicides on *T. harzianum* under *in vitro* conditions. They showed that the toxicity of the systemic fungicides was higher than that of the contact fungicides, in which sulphur and copper oxychloride were completely incompatible at higher concentrations and no inhibition of growth was observed at lower concentrations. In the systemic fungicides, myclobutanil was found more toxic, followed by cymoxanil.

Radwan and Mohamed (2017) reported that pesticides iprodione, mancozeb, penconazole and fenarimol and high concentrations of imidacloprid, oxyfluorofen and glyphosate highly inhibit the growth of *T. harzianum* and it is incompatible with these pesticides.

2.3 Compatibility of *Metarhizium anisopliae* with chemical pesticides.

Rachappa *et al.* (2007) experimented that in the *Metarhizium anisopliae*, herbicides were also proved to be toxic, but the level of toxicity was low because the inhibition of fungal growth was from 10.26 percent to 26.07 percent. There was no significant difference between glyphosate, nitrofen, atrazin and pendamethalin (23.07%), but the toxicity was more than two times that of butachlor and 2, 4 - D inhibited 12.39% and 10.39 % respectively.

Udayababu *et al*. (2012) reported that the radial growth of *M. anisopliae* was not inhibited by tebuconazole, azoxystrobin and chlorothalonil treated medium. Total inhibition of radial growth was recorded in propiconazole treated medium. In tebuconazole and azoxystrobin treated medium, a significant reduction of *M. anisopliae* conidial concentration per cm was recorded.

Akbar *et al.* (2012) studied the compatibility of *Metarhizium anisopliae* with fungicides and insecticides. They found that spinosad and indoxacarb were proved compatible while match, metalaxyl + mancozeb, chlorpyrifos and profenofos found incompatible. Emamectin, cypermethrin, acetamiprid, imidacloprid and sinofos proved less toxic, respectively.

Silava *et al.* (2013) concluded that propiconazole, difenoconable, trifloxystrobin and azoxystrobin were incompatible with *M. anisopliae* at all biological stages and they should not be applied together with this fungus in tank mixing. The agrochemicals compatible with *M. anisopliae* were the insecticides thiamethoxam, lambda-cyhalothrin and methyl parathion and the herbicides bentazon, imazapic + imazapyr and glyphosate.

Abidin *et al.* (2017) concluded that the highest conidial germination of *Metarhizium anisopliae* was recorded with treatment of imidacloprid 0.5 × DF. Conidial production was obtained at its highest with treatment of imidacloprid. They showed that imidacloprid was found compatible with *Metarhizium anisopliae*.

Fiedler and Sosnowska (2017) studied the radial growth of *Metarhizium anisopliae* and *Acremonium spp.* is not inhibited by insecticides and fungicides and can be recommended for use in IPM.

Joshi *et al*. (2018) reported that insecticides like novaluron, indoxacarb, emamectin benzoate and lambda cyhalothrin were found compatible with *Metarhizium anisopliae*. Fungicides propiconazole, hexaconazole and carbendazim were found totally incompatible, whereas mancozeb was found compatible at a lower concentration.

Khun *et al.* (2020) showed that *Metarhizium anisopliae* was compatible with the chemical pesticides acephate, trichlorfon and indoxacarb. Fungicides pyraclostrobin and carbendazim are toxic to *Metarhizium anisopliae*.

2.4 Compatibility of *Verticillium lecanii* with chemical pesticides.

Hall (1981) reported that the separate application of *Verticillium lecanii* is advisable with cyhexatin, pyrazaphos, triforine, bupirimate, dioxathion and tetradifon, but the use of zineb should be avoided, as it is incompatible with *Verticillium lecanii*. The most toxic compounds with agar in this study were mancozeb, captan, maneb, thiram, chlorothalonil, dichlofluanid and quinomethionate proved to be incompatible with *V. lecanii* but fenarimol proved relatively harmless. On the basis of the results of this study, careful selection of pesticides and fungicide would permit the combined use of biocontrol agents and chemicals in integrated control programs.

Khalil *et al.* (1985) tested the compatibility of *Verticillium lecanii* with chemical pesticides. They showed that cypermethrin, benomyl, formothion, copper oxychloride, mevinphos, fenbutatin-oxide, cypermethrin, oxamyl, permethrin, thiophenate methyl, triademefon and primicarb were less affected to mycelial growth and spore germination at the sub lethal and recommended concentrations, whereas mancozeb, fenithrothion and methomyl found partially toxic. Pesticides bitertanol, dichlofluanid and metiram were found totally incompatible.

Krishnamoorthy *et al.* (2007) showed that pongamia oil exhibited a synergistic effect on the development of *Verticillium lecanii*. Chemical pesticides chlorothalonil, thiophenate methyl, carbendazim and iprodion + carbendazim inhibit the development of *Verticillium lecanii* and are highly toxic.

Alizadeh *et al.* (2007) reported that the pesticide flufenoxuron (at three concentrations), phozalone + teflubenzuron (at mc and twice the mc) induced levels of vegetative growth inhibition higher than 68%. Amitraz and imidachloprid (at half mc) did not affect the growth of *V. lecanii*, which indicated compatible formulations with *V. lecanii*.

Armarkar and Chikte (2008) tested the compatibility of nine chemical pesticides with *Verticillium lecanii*. Among these pesticides, streptocyclin gave maximum growth (61.60 mm) and a reduction in dry mycelial weight (9.51%) and was found to be the most compatible, followed by methyl dematon, thiometon and dimethoate. TMTD (thiram), mancozeb and monocrotophos are found incompatible with *Verticillium lecanii*.

Sword *et al.* (2011) studied the *in vitro* compatibility of *Lecanicillium lecanii* with insecticides and proved that hyphal growth and germination of conidia were totally inhibited by the insecticides endosulfan and thiodicarb, which were found completely incompatible with *Lecanicillium lecanii*. Acetamiprid and imidacloprid were found compatible and had no inhibitory effect on the mycelial growth of *Verticillium lecanii*.

Thiery *et al*. (2015) studied the biological control of pests and diseases. Fungi, parasitoids, predators and other beneficial organisms can be used. They also reported that biological control is alternatives to chemical pesticides. The fungus *Verticillium lecanii* is one of the biocontrol agents and the member of *Deuteromycetes*, and it can be used for controlling the pests.

Sumalatha *et al*. (2017) concluded that *Vericillium lecanii* has excellent compatibility with existing biological control measures and can be used in combination with several widely used pesticides, including fungicides.

Kakati *et al.* (2018) tested the compatibility of *Verticillium lecanii* with insecticides. Imidacloprid 17.8% SL had no inhibitory effect on *Verticillium lecanii* at 0.025% concentration while maximum inhibition of *Verticillium lecanii* was recorded with treatment of dimethoate 30 EC at 0.05% concentration.

2.5 Compatibility of *Beauveria bassiana* with chemical pesticides.

Oliveira *et al.* (2003) concluded that in comparison to the control, the insecticide formulations of thiamethoxam, cyfluthrinand, and alpha-cypermethrin caused reduced inhibition on conidia germination at the two lower doses. In terms of vegetative development, thiamethoxam at the two lower doses was shown to have no effect on radial growth. In terms of conidia formation, thiamethoxam had the least inhibitory effect. Because thiomethaxam and alpha-cypermethrin formulations are compatible with the entomopathogenic fungus *Beauveria bassiana*, they should be used in coffee IPM programmes for a B. basssiana inoculum conservation approach.

Puzari *et al.* (2006) reported that in *in vitro* compatibility of *Beauveria bassiana* with insecticides, deltamethrin at half of recommended dose was found compatible, which showed less inhibition, 14.06 per cent. More than 50 per cent inhibition of mycelial growth was recorded in alphamethrin, phosphamidon, deltamethrin and cypermethrin insecticides. Monocrotophos and dichlorvos were found compatible, which showed inhibition of 0.31 and 0.12 per cent respectively.

Khezri *et al.* (2007) experimented with three concentrations of pesticide (mean concentration-MC, half MC and twice MC) were tested on *B. bassiana*. The results indicated that flufenoxuron caused complete inhibition of its development and was not compatible with *B. bassiana*. Imidacloprid was compatible with *B. bassiana*. This formulation could be used in integrated pest management.

Ali *et al.* (2007) concluded that the chemical flufenoxuron is incompatible with *B. bassiana* which inhibits the growth and development of *B. bassiana*. They also reported that imidacloprid is compatible with *B. bassiana* and could be used with *B. bassiana* in integrated pest management (IPM).

Pandey and Kanaujia (2009) reported that the highest fungal growth of *Beauveria bassiana* was 6.67 mm was observed in the validamycin treated medium and hundred percent inhibition of growth was observed in the propiconazole treated medium at all higher and lower concentrations. They also studied that in all fungicide treated medium, no sporulation was recorded above 700 ppm concentrations and propiconazole completely inhibited sporulation at all the test concentrations.

Ambethgar *et al.* (2009) experimented with the effect of five herbicides on the mycelial growth of *Beauveria bassiana*. The herbicides classified into four categories based on percent reduction in mycelial growth: 1 = toxic (> 50%), 2 = moderately toxic (35-50%), 3 = slightly toxic (25-35%) and 4 = compatible (< 25% inhibition). They showed that *Beauveria bassiana* is sensitive to normal and higher field recommended dosages of herbicides. Among the herbicides tested, pendamethalin, butachlor and fluchloralin showed less reduction in mycelial growth and were compatible with *B. bassiana* in the field.

Amutha *et al.* (2010) tested the effect of chemical insecticides on the mycelial growth of *Beauveria bassiana* by using poisoned food technique. They showed that acetamiprid, imidacloprid, thiodicarb, endosulfan, quinalphos and econeem were proved slightly toxic. Triazophos was found to be moderately toxic. Indoxacarb, profenofos and methyldemeton were highly incompatible.

Vats *et al.* (2014) experimented with the compatibility in terms of biomass production and proved that acetamiprid and imidacloprid are compatible with *B. bassiana*. Since at 0.5 MC, MC, and 2 MC, acetamiprid exhibits only a 23%, 26%, and 32% reduction in biomass, respectively. At 0.5 MC, MC, and 2 MC, imidacloprid only exhibits a 25%, 26.7 percent, and 30% reduction in biomass, respectively. Profenofos is only compatible at 0.5 MC, but neemarin and endosulphan are incompatible at all concentrations.

Kos *et al.* (2016) concluded that *Beauveria bassiana* is highly affected by some herbicides and fungicides, even at very low rates. Flurochoridone, foramsulfuron, prosulfocarb and copper hydroxide stop sporulation. All tested pesticides, isoxaflutole, flauzifop-p-butyl and chlorothalonil, showed the least adverse effects and therefore, probably could be compatible with *B. bassiana* in the field.

Abidin *et al*. (2017) concluded that the imidacloprid was found compatible with *Beauveria bassiana*. Conidial production was obtained at its highest with treatment of imidacloprid. Conidial germination of *Beauveria bassiana* was recorded with treatment of deltamethrin 0.5 × DF.

Fiedler and Sosnowska (2017) reported that the fungus *B. bassiana* can be used together with insecticides, but not with fungicides as a biocontrol agent.

Kakati *et al.* (2018) tested the compatibility of *Beauveria bassiana* with insecticides. Imidacloprid inhibit mycelial growth of *Beauveria bassiana* by 9.81 per cent. Treatment of dimethoate 30 EC at 0.05 percent concentration showed 27.81 per cent growth inhibition in *Beauveria bassiana*.

Joshi *et al.* (2018) reported that profenophos was incompatible with *Beauveria bassiana* while chlorantraniliprole was compatible. Insecticides like novaluron, indoxacarb, emamectin benzoate and lambda cyhalothrin were found compatible with *Beauveria bassiana*. Fungicides propiconazole, hexaconazole and carbendazim were found totally incompatible, whereas mancozeb was found compatible at a lower concentration.

Ondrackova *et al.* (2019) studied the effect of seventeen pesticides on *Beauveria bassiana* under *in vitro* condition. Among fungicides mancozeb, metalaxyl-M, fludioxonil, thiram, carboxin, mancozeb and metalaxyl-M, dimethomorph + mancozeb, boscalid + pyraclostrobin and among herbicides chlorotoluron, pethoxamid, pendamethalin + imazamox and pendamethalin significantly inhibited the mycelial growth of *Beauveria bassiana* (20.4 - 100% and 14.9 - 100% respectively). Among insecticides acetamiprid, primicarb and fluvalinate inhibited mycelial growth of *Beauveria* strains (22.6 - 30% inhibition).

Khun *et al*. (2020) showed that *Beauveria bassiana* was compatible with acephate, sulfoxaflor, spinetoram, trichlorfon and indoxacarb. Fungicides pyraclostrobin and carbendazim are toxic to *Beauveria bassiana*.

2.6 Compatibility of *Paecilomyces lilacinus* with chemical pesticides.

Jacobs *et al.* (2003) reported that when the ability to develop and hinder the growth of an opposing colony at 10 and 20 degrees Celsius was assessed, *Paecilomyces lilacinus* emerged as the most successful competitor. *In vitro*, *Paecilomyces lilacinus* released a deffusable material that hindered *Rhizoctonia solani*'s growth and induced morphological defects in its hyphae, indicating that it may be employed to control the soil-borne fungal pathogen.

Mehmet and Ayhan (2004) studied whether fungicides have the potential to interfere with the growth of *Paecilomyces fumosoroseus* if they are to be applied together. The lower concentrations of cypermethrin and deltamethrin and the recommended concentration rate of primicarb and pymetrozine were less hazardous than carbaryl and malathion.

Sundararaju and Kiruthika (2009) studied that in banana crop, *Paecilomyces lilacinus* and neem cake are effective for management of root-knot nematode. They also reported that single use of biocontrol agents or botanicals cannot be very effective in the management of diseases induced by nematodes.

Dong *et al.* (2010) experimented with the compatibility of *Paecilomyces lilacinus* with two fungicides, one herbicide and one insecticide. They reported that the *Paecilomyces lilacinus* strain E7 was compatible with glyphosate and copper oxychloride and incompatible with the fungicide benomyl.

Gopalan and Venkatachalam (2014) tested the compatibility of entomopathogenic fungi *Paecilomyces lilacinus* with agrochemicals. Compatibility is tested through the serial dilution method, optical density values, and radial growth technique. Fungicides difenconazole (0.07%), blue copper (0.3%), propiconazole (0.05%) and herbicide gramoxone (0.5%) found complete growth inhibition. They also showed that fungicides are more toxic than herbicides to the entomopathogenic fungi *Paecilomyces lilacinus*.

Mathew and Louis (2018) reported that the *Paecilomyces lilacinus* was not compatible with the insecticides quinalphos and chloropyrifos; fipronil, cartap and dimethoate hydrochloride as the least compatible; imidachloprid as compatible and acephate, chlorantraniliprole, and flubendimide as moderately compatible. The *Paecilomyces lilacinus* is compatible with the insecticide imidachloprid and can be used in banana in IPM programs for controlling nematodes and other insect pests of banana.

2.7 Compatibility of other biocontrol agents with chemical pesticides.

Locke *et al*. (1985) reported that the combined use of biocontrol agents and chemical pesticides has enticed much attention as a way to obtain additive effects in the control of soil-borne pathogens.

Martinez-Toledo *et al.* (1998) studied the presence of captan enhanced denitrifying and total culturable bacteria, showing that some microbial groups can tolerate high doses of this fungicide.

Buck (2004) concluded that all combinations of *Rhodotorula glutinis* PM4 with azoxystrobin, trifloxystrobin or vinclozolin provided highly effective and consistent disease control not observed in treatments with the fungicides alone or the yeast alone.

Menendez *et al*. (2010) concluded that the application of dimethoate at the recommended concentration decreased the percentage of colonization of soybean by the indigenous AM population, but this effect was not observed on the colonization of soybean which was inoculated with *Glomus mosseae*.

Dhanya *et al*. (2016) reported that for integrated pest management in small cardamom farming, chemicals along with antagonists are recommended so as to reduce the environmental risk due to toxic pesticides.

Maina *et al*. (2018) reported that in the integrated pest management programme (IPM), mycoinsecticides have the potential to play a key role in effective and relatively safe insect pest management in field crops.

Ondrackova *et al.* (2019) studied the effect of seventeen pesticides on *Cordyceps fumosorosea, Akanthomyses muscarius* and *Purpureocillium lilacinus* under *in vitro* condition. Among fungicides mancozeb, metalaxyl-M, fludioxonil, thiram, carboxin, mancozeb and metalaxyl-M, dimethomorph + mancozeb, boscalid + pyraclostrobin and among herbicides chlorotoluron, pethoxamid, pendamethalin + imazamox and pendamethalin significantly inhibited the mycelial growth of all fungal biocontrol agent (20.4 - 100% and 14.9 - 100% respectively). In case of *Akanthomoces* and *Purpureocillium* insecticides did not significantly inhibited the mycelial growth. The mycelial growth of *Cordyceps fumosorosea* strains was faster in the presence of insecticides than in control.

1. MATERIAL AND METHODS

The present study was conducted at the section of "Plant Pathology and Agricultural Microbiology" in Rajarshee Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur, during the year 2020-21. All over laboratory work that is maintaining fungal cultures, sterilization of glassware's and culture medium, culture incubating and experimental method (poisoned food technique) were conducted in the laboratories of section.

3.1 Material

3.1.1 Glasswares

The common glassware's of BOROSIL brand, were used for the present study *viz*., petri plates, conical flasks, beakers, test tubes, measuring cylinder, glass slides, cover slips and glass rod etc.

3.1.2 Equipments and other appliances

Common laboratory equipments which is accurate and in good working condition is used, like weighing balances, hot air ovens, autoclaves, laminar air flow, BOD incubators, electronic microscopes and refrigerators etc.

3.1.3 Miscellaneous material

Miscellaneous material, like Cutting knife, rubbers, permanent marker, spirit lamp, forceps, inoculating needle, corkborer, measuring scale were used for marking, cutting, taking observations, inoculating the cultures and other purposes.

3.1.4 Chemicals

For preparation of potato dextrose agar medium 20 gm of dextrose and 15 gm of agar agar were used to making one litre of (PDA) potato dextrose agar medium.

3.1.5 Biocontrol agents

In the present investigation, for testing the compatibility of biocontrol agents with fungicides, hercicides and insecticides following biocontrol agents are selected.

1. *Trichoderma viride*
2. *Trichoderma harzianum*
3. *Metarhizium anisopliae*
4. *Beauveria bassiana*
5. *Verticillium lecanii*
6. *Paecilomyces lilacinus*

All the biocontrol agents are fungal biocontrol agents. In these biocontrol agents *Trichoderma viride and Trichoderma harzianum* are potential biocontrol agents to soil and seed borne pathogens whereas *Metarhizium anisopliae*, *Beauveria bassiana* and *Verticillium lecanii* are entomopathogenic in nature. Biocontrol agent *Paecilomyces lilacinus* is nematopathogenic in nature.

3.1.6 Chemical pesticides

In the present study six fungicides, six herbicides and six insecticides were selected for testing the compatibility with fungal biocontrol agents. Pesticides were selected which is easily available in market and commonly used by farmers for various diseases and pests management in the different crops.

Table 1. Fungicides

Sr. No.	Name of fungicide	Trade name
1	Captan 50% WP	Captaf
2	Carbendazim 12% + Mancozeb 63% WP	Starlet
3	Thiophenate Methyl 70% WP	Roko
4	Copper oxychloride 50% WP	Blitox
5	Azoxystrobin 11% + Tebuconazole 18.3% W/W SC	Custodia
6	Ametoctradin 22% + Dimethomorph 20% EC	Zampro

Table 2. Herbicides

Sr. No.	Name of herbicide	Trade name
1	Fomesafen 11.1% W/W + Flauzifop-p-Butyl 11.1%W/W SL	Fusiflex
2	Metribuzin 70% WP	Adrino
3	Sulfentrazone 28% + Clomazone 30% WP	Authority
4	Glyphosate 41% SL	Touchdown
5	Oxyfluorofen 23.5% EC	Goal
6	Carfentrazone ethyl 40% DF	Affinity

Table 3. Insecticides

Sr. No.	Name of insecticide	Trade name
1	Chlorantraniliprole 18.5% SC	Coragen
2	Imidachloprid 48% SL	Gaucho
3	Emamectin benzoate 5% WP	Rilon
4	Spinosad	Tracer
5	Thimethoxam 12.6% + Lambda cyhalothrin 9.5% ZC	Alika
6	Acetamiprid 20% SP	Manik

3.1.7 Culture medium

Potato Dextrose Agar (PDA) medium was used in poisoned food technique, as growth medium for biocontrol agents and also used for multiplication of cultures.

Table 4. Composition of PDA medium

Sr. No.	Content	Quantity
1	Peeled potato	200 g
2	Dextrose	20 g
3	Agaragar	15 g
4	Distilled water	1000 ml

3.2 Methods

3.2.1 Multiplication of cultures

The fresh cultures of biocontrol agents are available at Mahatma Phule Krishi Vidyapeeth, Rahuri and Rajarshee Chattrapati Shahu Maharaj College of Agriculture, Kolhapur.

All six fungal biocontrol agents are maintained on the potato dextrose agar (PDA) medium, which is autoclaved for 20 minutes at 121°C. PDA medium was sanitised and put into sterile Petri dishes. These Petri plates were injected with new biocontrol agent cultures using a sterile inoculation needle after the medium had solidified. For 5-7 days, these plates were incubated at 28 ± 2 °C.

3.2.2 Preparation of PDA medium

For the preparation of PDA medium fresh potatoes were used. Firstly potatoes were washed thoroughly with tap water and peeled by using hand peeler. After peeling small pieces were made by cutting and boiled in the proportion of 200 gm of potato pieces in 1000 ml double distilled water. After cooling potato extract was strained through strainer in beaker and maintained volume one litre by adding double distilled water. For one litre potato extract, 20 gm dextrose and 15 gm agar agar was added.

3.2.3 Preparation of containers

Required quantity of medium was prepared by pouring 100 ml of PDA medium in each conical flask (250 ml) by using measuring cylinder. Prepared flasks plugged tightly by sterilized cotton and mouth of flask wrapped with paper and rubber.

3.2.4 Sterilization of PDA medium and glassware's

Conical flasks containing PDA medium was sterilized in autoclave at 121 ºC temperature and 15 psi pressure for 15 minutes. Glassware's like, Petriplates, beakers and test tubes were sterilized in hot air oven at 180 ºC temperature for 15 minutes.

3.2.5 Preparation of medium with pesticides

After sterilization, allowed medium to cool at near the 40 ºC and precisely measured doses of chemical pesticides are added into the medium into each conical flask respectively. About 20 ml of PDA medium amended with various chemical pesticides is poured into each 9 cm sterilized Petri plate. Without pesticide amended medium served as control. A micro-pipette was used for measuring the quantity of liquid pesticides. All the Petri plates allowed to solidifying. Each treatment was performed in four replications.

3.2.6 Chemical pesticides and their concentrations

The *in vitro* bio-efficacy of pesticides was determined by the poisoned food technique (Nene and Thapliyal, 1993). Six different fungicides, six herbicides and six insecticides were selected for this study. All about eighteen chemical pesticides were used according to the recommended application rate for field crops.

Table 5. Concentration of fungicides

Sr. no.	Treatment	Chemical name	Trade name	Application rate/100 ml
1	T_1	Captan 50% WP	Caftaf	0.3 g
2	T_2	Carbendazim 12% + Mancozeb 63% WP	Starlet	0.3 g
3	T_3	Thiophenate methyl 70% WP	Roko	0.05 g
4	T_4	Copper oxychloride 50% WP	Blitox	0.3 g
5	T_5	Azoxystrobin 11% + Tebuconazole 18.3% W/W SC	Custodia	0.1 ml
6	T_6	Ametoctradin 22% + Dimethomorph 20% EC	Zampro	0.2 ml
7	T_7	Control	-	-

Table 6. Concentration of herbicides

Sr. no.	Treatment	Chemical name	Trade name	Application rate/100 ml
1	T_1	Fomesafen11.1% W/W + flauzifop-p-butyl 11.1% W/W SL	Fusiflex	0.3 ml
2	T_2	Metribuzin 70% WP	Adrino	0.05 g
3	T_3	Sulfentrazone 28% + Clomazone 30% WP	Authority	0.4 g
4	T_4	Glyphosate 41% SL	Touchdown	0.8 ml
5	T_5	Oxyfluorofen 23.5% EC	Goal	0.2 ml
6	T_6	Carfentrazone ethyl 40% DF	Affinity	0.01 g
7	T_7	Control	-	-

Table 7. Concentration of insecticides

Sr. no.	Treatment	Chemical name	Trade name	Application rate/100 ml
1	T_1	Chlorantraniliprole 18.5% SC	Coragen	0.03 ml
2	T_2	Imidachloprid 48% SL	Gaucho	0.03ml
3	T_3	Emamectin benzoate 5% WP	Rilon	0.04 g
4	T_4	Spinosad	Tracer	0.03 ml
5	T_5	Thimethoxam 12.6% + lambda cyhalothrin 9.5% ZC	Alika	0.1 ml
6	T_6	Acetamiprid 20% SP	Manik	0.05 g
7	T_7	Control	-	-

3.2.7 Inoculation of the medium with mycelial mat

After the medium has solidified, biocontrol agents are injected aseptically by transferring a circular 5 mm diameter disc produced from sterilised cork-borer from an actively developing 7 day old culture of the fungal biocontrol agent to the middle of the Petri dish. At 28±2 ºC, inoculated Petri plates are incubated. (Kos and Celar, 2016)

3.2.8 Estimation of daily fungal colony growth

Observations of the mycelial growth of biocontrol agents were recorded by measuring the diameter (mm) of radial growth by using the measuring scale. Observations of four replications are recorded every 24 hours till 7 days are completed. The growth inhibition of biocontrol agents was estimated by using the following formula given by Vincent (1947) and per cent inhibition of mycelial growth was obtained.

$$I = \frac{C - T}{C} \times 100$$

Where,

I = Percent growth inhibition.

C = Colony diameter in control (mm).

T = Colony diameter in treatment (mm).

3.2.9 Statistical analysis

All laboratory work was carried out in Completely Randomized Design, with four replications and seven treatments. Six treatments of chemical pesticide and seventh is control.

Data obtained which is in per cent format were transformed in arcsine format. Transformed data was subjected to analysis of variance.

4. RESULTS AND DISCUSSION

Laboratory studies were conducted to study the compatibility of biocontrol agents with fungicides, herbicides and insecticides. The results obtained in this study have been explained and discussed here. According to the reference of Ambethgar (2009), all the tested chemical pesticides were classified in four categories based on per cent inhibition in mycelial growth of fungal biocontrol agents: 1 = toxic (> 50%), 2 = moderately toxic (35-50%), 3 = slightly toxic (25-35%) and 4 = compatible (< 25% inhibition). The chemical pesticides were toxic or compatible is confirmed by inhibition per cent at 144 hrs.

4.1 Compatibility of *Trichoderma viride* with chemical pesticides.

In the present investigation compatibility of *Trichoderma viride* is tested with six fungicides, six herbicides and six insecticides.

4.1.1 Effect of fungicides on *Trichoderma viride*.

Among the six fungicides (Table 8), *Trichoderma viride* showed a high incompatibility with the fungicides carbendazim + mancozeb (0.0 mm mycelial growth) and azoxystrobin + tebuconazole (0.0 mm) in which 100 per cent inhibition of mycelial growth was observed, from 24 to 144 hours, in the case of both fungicides. Also, the fungicides, captan (27.37 mm), thiophenate methyl (36.75 mm), and copper oxychloride (37.75 mm), showed inhibition per cent of 67.12, 55.86, 54.65 respectively and found toxic. Ametoctradin + diamethomorph (51.75 mm) showed inhibition 37.84 per cent and proved moderately toxic. Inhibition per cent is decreased with days after inoculation is increased.

All the fungicides were found incompatible with *Trichoderma viride*. The result of the effect of fungicides on *Trichoderma viride* obtained in this study is in accordance with previous findings of Gampala and Pinnamaneni (2010) which proved that the *Trichoderma viride* was incompatible with the fungicides carbendazim and thiophenate methyl.

4.1.2 Effect of herbicides on *Trichoderma viride.*

Out of the the six herbicides (Table 9), carfentazone ethyl (78.15 mm mycelial growth) was found fully compatible with *Trichoderma viride*, which showed inhibition of 6.13 per cent at 144 hrs and 1.44 per cent at 72 hrs, followed by fomesafen + flauzifop-p-butyl (75.80 mm), oxyfluorofen (66.02 mm) and metribuzin (65.12 mm) which showed mycelial growth inhibition of 8.95, 20.69 and 21.77 per cent respectively and found completely compatible. Herbicide glyphosate (45.55 mm) was found moderately toxic showed inhibition of 45.29 per cent. 100 per cent mycelial growth inhibition was recorded at all 24 hrs to 144 hrs with treatment sulfentazone + clomazone (0.0 mm) and proved completely incompatible. In compatible herbicides inhibition per cent is constantly decreased with increasing days after inoculation.

Among the herbicides, the results obtained in this study are in agreement with earlier experiments (Bindhu Madhavi *et al.* 2011) which suggested that oxyfluorofen was compatible and glyphosate was moderately toxic to *Trichoderma viride.*

4.1.3 Effect of insecticides on *Trichoderma viride.*

Trichoderma viride was fully compatible with all insecticides (Table 10), Emamectin benzoate (82.65 mm) and spinosad (81.65 mm) had no effect on inhibition of mycelial growth, which showed 0.72 and 1.92 per cent inhibition respectively. *Trichoderma viride* is also completely compatible with chlorantraniliprole (77.57 mm), imidachloprid (77.57 mm), acetamiprid (68.87 mm) and thimethoxam + lambda cyhalothrin (67.42 mm), which showed inhibition of 6.82, 6.82, 17.27 and 19.01 per cent respectively. At 24 and 48 hrs, inhibition per cent is high and decreased at 72, 96, 120 and 144 hrs respectively.

Dhanya *et al.* (2016) studied and reported that insecticides spinosad, imidachloprid and chlorantraniliprole were 100 per cent compatible; whereas thimethoxam and acetamiprid showed 15.5 and 15.5 per cent inhibition of mycelial growth of *Trichoderma viride*, respectively. (Bindu madhavi *et al.* 2011) also reported that imidacloprid was highly compatible with *Trichoderma viride.* The results of this in vitro study also gave the same results as those of earlier reports.

Table 8. Effect of fungicides on the colony growth of *Trichoderma viride*.

Treatments	Average colony diameter of *Trichoderma viride* (mm)												Toxicity Level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Captan	0.50*	92.54 (74.14)**	8.50	60.56 (51.09)	10.75	80.03 (63.45)	19.65	72.21 (58.15)	24.65	68.79 (56.01)	27.37	67.12 (55.02)	Toxic
T_2 Carbendazim + Mancozeb	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_3 Thiophenate methyl	1.30	80.60 (63.86)	3.82	82.25 (65.08)	16.80	68.79 (56.04)	22.25	68.53 (55.86)	36.15	54.23 (47.39)	36.75	55.86 (48.36)	Toxic
T_4 Copper oxychloride	1.25	81.34 (64.41)	6.72	68.79 (56.03)	19.55	63.68 (52.94)	29.40	58.42 (49.82)	36.57	53.69 (47.07)	37.75	54.65 (47.67)	Toxic
T_5 Azoxystrobin+ Tebuconazole	0.00	100.00 (90.00)	0.00	100.00 (90)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_6 Ametoctradin+ Dimethomorph	0.87	86.94 (68.99)	3.50	83.76 (66.28)	16.50	69.35 (56.37)	28.75	59.34 (50.38)	46.25	41.44 (39.89)	51.75	37.84 (37.92)	Moderately Toxic
T_7 Control	6.70	0.00 (0.00)	21.55	0.00 (0.00)	53.82	0.00 (0.00)	70.70	0.00 (0.00)	78.97	0.00 (0.00)	83.25	0.00 (0.00)	
SEm±	0.04	0.66	0.17	0.52	0.35	0.40	0.69	0.57	0.98	0.84	0.97	0.73	
CD at 1%	0.14	1.94	0.50	1.54	1.05	1.19	2.04	1.68	2.90	2.48	2.86	2.14	

* Data is average of four replications

( )** = Figures in parenthesis are arcsine transformed value

Table 9. Effect of Herbicides on the colony growth of *Trichoderma viride*

Treatments	Average colony diameter of *Trichoderma viride* (mm)												Toxicity level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Fomesafen+ Flauzifop-p-butyl	1.50*	77.61 (61.91)**	9.75	54.76 (47.71)	25.75	52.16 (46.24)	41.50	41.30 (39.95)	64.90	17.82 (24.85)	75.80	8.95 (17.38)	Compatible
T_2 Metribuzin	2.00	70.15 (56.88)	11.15	48.26 (43.99)	27.32	49.23 (44.55)	40.97	42.04 (40.36)	60.20	23.77 (28.80)	65.12	21.77 (27.57)	Compatible
T_3 Sulfentrazone+ Clomazone	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_4 Glyphosate	1.82	72.76 (58.54)	9.57	55.57 (48.19)	29.97	44.31 (41.72)	36.05	49.01 (44.40)	42.30	46.44 (42.92)	45.55	45.29 (42.29)	Moderately Toxic
T_5 Oxyfluorofen	2.90	56.72 (48.86)	11.05	48.72 (44.24)	36.37	32.42 (34.67)	45.82	35.18 (36.33)	60.37	23.55 (28.80)	66.02	20.69 (26.82)	Compatible
T_6 Carfentrazone Ethyl	5.12	23.51 (28.98)	16.62	22.85 (28.52)	53.05	1.44 (6.25)	65.12	7.89 (16.11)	76.12	3.61 (8.73)	78.15	6.13 (14.01)	Compatible
T_7 Control	6.70	0.00 (0.00)	21.55	0.00 (0.00)	53.82	0.00 (0.00)	70.70	0.00 (0.00)	78.97	0.00 (0.00)	83.25	0.00 (0.00)	
SEm±	0.08	0.84	0.27	0.82	0.64	0.92	1.11	1.05	1.09	1.87	1.58	1.49	
CD at 1%	0.23	2.47	0.81	2.42	1.88	2.71	3.27	3.10	3.22	5.52	4.66	4.40	

* Data is average of four replications

( )** = Figures in parenthesis are arcsine transformed value

Table 10. Effect of Insecticides on the colony growth of *Trichoderma viride*

Treatments	Average colony diameter of *Trichoderma viride* (mm)												Toxicity level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Chlorantraniliprole	4.65*	30.60 (33.58)**	15.55	27.84 (31.73)	53.12	1.30 (6.38)	64.22	9.16 (17.34)	75.20	4.78 (11.32)	77.57	6.82 (14.17)	Compatible
T_2 Imidacloprid	4.82	27.99 (31.93)	15.62	27.49 (31.43)	53.05	1.44 (5.81)	63.97	9.51 (17.61)	74.72	5.38 (11.32)	77.57	6.82 (14.60)	Compatible
T_3 Emamectin benzoate	1.50	77.61 (61.76)	9.40	56.38 (48.62)	35.07	34.84 (36.07)	56.05	20.72 (26.83)	74.45	5.73 (13.83)	82.65	0.72 (4.10)	Compatible
T_4 Spinosad	1.75	73.88 (59.32)	15.75	26.91 (30.93)	53.00	1.53 (6.15)	54.90	22.35 (28.12)	77.62	1.71 (7.23)	81.65	1.92 (7.79)	Compatible
T_5 Thimethoxam+ Lambda cyhalothrin	1.75	73.88 (59.48)	6.30	70.77 (57.23)	37.65	30.05 (33.08)	49.70	29.70 (32.88)	64.15	18.77 (25.57)	67.42	19.01 (25.67)	Compatible
T_6 Acetamiprid	4.20	37.31 (37.65)	9.90	54.06 (47.29)	39.05	27.45 (31.39)	50.80	28.15 (31.89)	65.57	16.97 (24.33)	68.87	17.27 (24.47)	Compatible
T_7 Control	6.70	0.00 (0.00)	21.55	0.00 (0.00)	53.82	0.00 (0.00)	70.70	0.00 (0.00)	78.97	0.00 (0.00)	83.25	0.00 (0.00)	
SEm±	0.11	1.12	0.34	1.39	1.13	1.88	1.17	1.61	1.57	2.02	1.56	1.77	
CD at 1%	0.32	3.30	1.02	4.11	3.34	5.53	3.46	4.75	4.61	5.94	4.61	5.22	

* Data is average of four replications

( )** = Figures in parenthesis are arcsine transformed value

4.2 Compatibility of *Trichoderma harzianum* with chemical pesticides.

In the present investigation compatibility of *Trichoderma harzianum* is tested with six fungicides, six herbicides and six insecticides.

4.2.1 Effect of fungicides on *Trichoderma harzianum.*

Among the fungicides (Table 11), ametoctradin + diamethomorph (52 mm mycelial growth) inhibited growth by 37.87 per cent and was found to be moderately toxic. The biocontrol agent *Trichoderma harzianum* was completely incompatible with the fungicides carbendazim + mancozeb, copper oxychloride and azoxystrobin + tebuconazole, which showed 100 per cent growth inhibition and 0.0 mm average mycelial growth at 24 to 144 hrs. Captan (11.55 mm) and thiophenate methyl (12.80 mm) also proved toxic to the growth of *Trichoderma harzianum* which showed 86.20 and 84.71 per cent growth inhibition. In the exception of fungicide ametoctradin + diamethomorph, inhibition per cent in all fungicides is above 80 per cent at 24 to 144 hrs.

The fungicide ametoctradin + diamethomorph was found to be moderately toxic and the remaining all fungicides were incompatible with *Trichoderma harzianum*. Bhosale and Borade (2015) also suggested that copper oxychloride was highly incompatible with *Trichoderma harzianum*. Saxena *et al*. (2014) also reported that thiophenate methyl was found incompatible with *Trichoderma harzianum*. Bhale and Rajkonda (2015) showed that concentrations of mancozeb above 5000 µg/ml and captan above 500 µg/ml inhibited the mycelial growth of *Trichoderma* species.

4.2.2 Effect of herbicides on *Trichoderma harzianum.*

In the case of herbicides (Table 12), only carfentrazone ethyl was found compatible, which showed 75.82 mm mycelial growth and 9.41 per cent inhibition. Glyphosate (59.87 mm) inhibited mycelial growth by 28.46 per cent and proved slightly toxic. Oxyfluorofen (46.62 mm) was found moderately toxic and showed 44.30 per cent inhibition followed by metribuzin (51.02 mm) inhibited mycelial growth by 39.04 per cent. High mycelial growth inhibition was recorded 91.49 per cent, within the treatment sulfentrazone + clomazone (7.12 mm), followed by fomesafen + flauzifop-p-butyl (30.27 mm) which showed 63.83 per cent inhibition. In the treatment of sulfentrazone + clomazone, growth inhibition is high from 24 to 144 hrs.

Only one herbicide, carfentrazone ethyl, was found compatible with *Trichoderma harzianum,* while glyphosate was found slightly toxic. Oxyfluorofen and metribuzin proved moderately toxic. Mohamed and Radwan (2017) also reported that oxyfluorofen and glyphosate are moderately toxic.

4.2.3 Effect of Insecticides on *Trichoderma harzianum*.

Out of six insecticides (Table 13), imidachloprid (78.40 mm) was found highly compatible with *Trichoderma harzianum* which showed 6.33 per cent inhibition, followed by acetamiprid (77.82 mm), spinosad (74.80 mm), imamectin benzoate (67.87 mm) and chlorantraniliprole (66.05 mm) which showed inhibition of 7.02, 10.63, 18.91 and 21.09 per cent respectively. Thimethoxam + lambda cyhalothrin (58.22 mm) was slightly toxic and inhibited mycelial growth by 30.44 per cent. In the treatment of chlorantraniliprole and thimethoxam + lamda cyhalothrin at 24 hrs, inhibition was high *i.e.* 44.08 and 58.73 per cent respectively.

Except for the insecticide thimethoxam + lambda cyhalothrin, all insecticides were compatible with *Trichoderma harzianum*. The results of the present investigation are similar to earlier studies (Thiruchchelvan *et al.* 2013) which showed that chlorantraniliprole, acetamiprid and imidacloprid were compatible with the biocontrol agent *Trichoderma harzianum.*

Table 11. Effect of fungicides on the colony growth of *Trichoderma harzianum*

Treatment	Average colony diameter of *Trichoderma harzianum* (mm)												Toxicity Level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Captan	1.20*	93.89 (75.68)**	3.52	86.64 (68.56)	6.90	86.88 (68.75)	7.40	88.01 (69.75)	9.30	88.24 (69.96)	11.55	86.20 (68.19)	Toxic
T_2 Carbendazim + Mancozeb	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_3 Thiophenate methyl	2.87	85.35 (67.49)	6.30	76.11 (60.73)	9.37	82.17 (65.01)	8.37	86.43 (68.40)	9.12	88.46 (70.19)	12.80	84.71 (67.02)	Toxic
T_4 Copper oxychloride	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_5 Azoxystrobin+ Tebuconazole	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_6 Ametoctradin+ Dimethomorph	2.62	86.62 (68.56)	6.50	75.36 (60.25)	24.50	53.40 (46.92)	33.75	45.32 (42.29)	45.25	42.76 (40.82)	52.00	37.87 (37.98)	Moderately Toxic
T_7 Control	19.62	(0.00)	26.37	0.00 (0.00)	52.57	0.00 (0.00)	61.72	0.00 (0.00)	79.05	0.00 (0.00)	83.70	0.00 (0.00)	
SEm±	0.11	0.16	0.18	0.29	0.33	0.39	0.46	0.46	0.54	0.54	0.70	0.47	
CD at 1%	0.32	0.47	0.54	0.87	0.98	1.15	1.37	1.37	1.60	1.59	2.07	1.40	

* Data is average of four replications

( )** = Figures in parenthesis are arcsine transformed value

Table 11. Effect of herbicides on the colony growth of *Trichoderma harzianum*

Treatments	Average colony diameter of Trichoderma harzianum (mm)												Toxicity level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Fomesafen+ Flauzifop-p-butyl	3.90*	80.13 (63.53)**	8.22	68.82 (56.00)	17.77	66.19 (54.42)	20.05	67.52 (55.29)	27.95	64.64 (53.52)	30.27	63.83 (53.03)	Toxic
T_2 Metribuzin	7.45	62.04 (51.93)	17.05	35.36 (36.28)	30.05	42.84 (40.81)	31.77	48.52 (44.12)	33.35	57.81 (49.49)	51.02	39.04 (38.66)	Moderately Toxic
T_3 Sulfentrazone+ Clomazone	1.12	94.27 (76.16)	3.80	85.59 (67.65)	4.90	90.68 (72.24)	5.22	91.54 (73.08)	6.87	91.30 (72.94)	7.12	91.49 (73.06)	Toxic
T_4 Glyphosate	12.80	34.78 (36.00)	20.77	21.23 (27.11)	31.80	39.51 (38.85)	40.22	34.83 (36.11)	53.87	31.85 (34.30)	59.87	28.46 (32.23)	Slightly Toxic
T_5 Oxyfluorofen	5.70	70.96 (57.37)	9.55	63.79 (52.85)	18.72	64.38 (53.32)	23.05	62.66 (52.33)	31.37	60.31 (50.97)	46.62	44.30 (41.67)	Moderately Toxic
T_6 Carfentrazone ethyl	12.55	36.05 (36.81)	19.12	27.49 (31.38)	35.80	31.91 (34.38)	47.20	23.53 (28.93)	55.12	30.27 (33.36)	75.82	9.41 (17.71)	Compatible
T_7 Control	19.62	0.00 (0.00)	26.37	0.00 (0.00)	52.57	0.00 (0.00)	61.72	0.00 (0.00)	79.05	0.00 (0.00)	83.70	0.00 (0.00)	
SEm±	0.24	0.92	0.45	1.28	0.63	0.87	1.00	1.06	1.21	1.01	1.55	1.17	
CD at 1%	0.72	2.72	1.35	3.78	1.86	2.56	2.96	3.12	3.58	2.97	4.57	3.45	

* Data is average of four replications

( )** = Figures in parenthesis are arcsine transformed value

Table 13. Effect of insecticides on the colony growth of *Trichoderma harzianum*

Treatments	Average colony diameter of *Trichoderma harzianum* (mm)												Toxicity Level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Chlorantra-niliprole	10.97*	44.08 (41.57)**	17.87	32.23 (34.42)	35.65	32.19 (34.47)	51.40	16.73 (23.34)	62.37	21.09 (26.98)	66.05	21.09 (27.14)	Compatible
T_2 Imidacloprid	16.22	17.32 (24.52)	23.45	11.09 (17.33)	38.87	26.06 (30.61)	49.12	20.41 (26.83)	59.12	25.21 (30.03)	78.40	6.33 (14.37)	Compatible
T_3 Emamectin benzoate	14.45	26.37 (30.79)	23.95	9.19 (15.18)	43.30	17.64 (24.26)	49.47	19.85 (26.35)	55.72	29.51 (32.85)	67.87	18.91 (24.75)	Compatible
T_4 Spinosad	13.87	29.30 (32.72)	22.30	15.45 (22.35)	49.87	5.14 (12.65)	54.30	12.03 (20.15)	66.37	16.03 (23.35)	74.80	10.63 (18.61)	Compatible
T_5 Thimethoxam+ Lambda cyhalothrin	8.10	58.73 (50.12)	13.87	47.39 (43.36)	29.87	43.18 (41.01)	35.90	41.84 (40.28)	47.65	39.72 (39.07)	58.22	30.44 (33.45)	Slightly Toxic
T_6 Acetamiprid	14.62	25.48 (30.26)	20.87	20.85 (26.99)	37.47	28.72 (32.32)	48.30	21.75 (27.65)	56.25	28.84 (32.46)	77.82	7.02 (15.15)	Compatible
T_7 Control	19.62	0.00 (0.00)	26.37	0.00 (0.00)	52.57	0.00 (0.00)	62.72	0.00 (0.00)	79.05	0.00 (0.00)	83.70	0.00 (0.00)	
SEm±	0.40	1.11	0.58	2.97	1.17	1.80	1.24	1.80	1.77	1.65	2.04	2.25	
CD at 1%	1.20	3.26	1.71	8.74	3.45	5.31	3.66	5.31	5.21	4.85	6.00	6.63	

* Data is average of four replications

( )** = Figures in parenthesis are arcsine transformed value

4.3 Compatibility of *Metarhizium anisopliae* with chemical pesticides.

In the present investigation compatibility of *Metarhizium anisopliae* is tested with six fungicides, six herbicides and six insecticides.

4.3.1 Effect of fungicides on *Metarhizium anisopliae*.

Among the fungicides (Table 14), carbendazim + mancozeb, copper oxychloride and azoxystrobin + tebuconazole inhibit the mycelial growth 100 per cent from 24 to 144 hrs and are totally incompatible with *Metarhizium anisopliae*. Also, fungicide ametoctradin + diamethomorph (3.0 mm) proved completely incompatible, which showed 95.96 per cent inhibition, followed by captan (13.62 mm) and thiophenate methyl (14.25 mm) which showed 81.64 and 80.80 per cent inhibition of mycelial growth respectively. In all fungicides at 24 to 144 hrs, inhibition of mycelial growth was found constant and above 80 per cent.

All fungicides were found to be fully incompatible with *Metarhizium anisopliae*, which completely inhibits the mycelial growth. Khun (2020) reported that carbendazim was incompatible with *Metarhizium anisopliae*.

4.3.2 Effect of herbicides on *Metarhizium anisopliae*.

Among the herbicides (Table 15), only one herbicide, metribuzin (18.95 mm), proved moderately toxic, inhibiting mycelial growth by 47.37 per cent. Herbicides, sulfentrazone + clomazone, at 24 to 144 hrs, inhibit mycelial growth 100 per cent and is totally incompatible with *Metarhizium anisopliae*. Oxyfluorofen (18.95 mm) was found incompatible with which showed inhibition 74.46 per cent, followed by glyphosate (24.30 mm), fomesafen + flauzifop-p-butyl (28.95 mm) and carfentrazone ethyl (32.15 mm) which showed respective inhibition of 67.25, 60.98 and 56.67 per cent. Only one herbicide, metribuzin (18.95 mm), proved moderately toxic, inhibiting mycelial growth by 47.37 per cent.

4.3.3 Effect of insecticides on *Metarhizium anisopliae*.

The experimental results indicated that (Table 16) acetamiprid (57.47 mm) inhibited 22.54 per cent of the mycelial growth of *Metarhizium anisopliae* and was found compatible, followed by chlorantraniliprole (56.55 mm) and spinosad (56.40 mm) which reduced the mycelial growth by 23.79 and 23.99 per cent respectively. Insecticides imidachloprid (46.27 mm) and emamectin benzoate (43.32 mm) reduced mycelial growth by 37.63 and 41.61 per cent and were found to be moderately toxic. Thimethoxam + lambda cyhalothrin (34.55 mm) proved toxic, which showed inhibition 53.44 per cent.

The insecticides acetamiprid, chlorantraniliprole and spinosad were found compatible with the biocontrol agent *Metarhizium anisopliae*. The obtained results are similar to earlier reports (Akbar *et al*. 2012) that showed that acetamiprid, chlorantraniliprole and spinosad were highly compatible with *Metarhizium anisopliae*. Joshi *et al.* (2018) also reported that chlorantraniliprole is compatible with *Metarhizium anisopliae*. Kakati *et al*. (2018) suggested that imidachloprid was compatible with *Metarhizium anisopliae*.

Table 14. Effect of fungicides on the colony growth of *Metarhizium anisopliae*

Treatments	Average colony diameter of *Metarhizium anisopliae* (mm)												Toxicity Level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Captan	0.00*	100.00 (90.00)**	0.00	100.00 (90.00)	2.05	95.34 (77.56)	7.10	86.36 (68.32)	10.72	83.12 (65.74)	13.62	81.64 (64.66)	Toxic
T_2 Carbendazim + Mancozeb	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_3 Thiophenate methyl	2.05	93.14 (74.82)	5.30	86.04 (68.10)	6.50	85.22 (67.38)	9.82	81.12 (64.25)	12.17	80.84 (64.04)	14.25	80.80 (64.01)	Toxic
T_4 Copper oxychloride	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_5 Azoxystrobin+ Tebuconazole	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_6 Ametoctradin+ Dimethomorph	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.75	98.29 (83.47)	1.50	97.12 (80.35)	2.25	96.46 (79.20)	3.00	95.96 (78.40)	Toxic
T_7 Control	29.87	0.00 (0.00)	37.97	0.00 (0.00)	43.97	0.00 (0.00)	52.05	0.00 (0.00)	63.55	0.00 (0.00)	74.20	0.00 (0.00)	
SEm±	0.13	0.09	0.20	0.34	0.29	0.84	0.28	0.40	0.37	0.36	0.42	0.40	
CD at 1%	0.41	0.27	0.59	1.00	0.87	2.48	0.84	1.20	1.08	1.06	1.25	1.20	

* Data is average of four replications

( )** = Figures in parenthesis are arcsine transformed value

Table 15. Effect of herbicides on the colony growth of *Metarhizium anisopliae*

Treatments	Average colony diameter of *Metarhizium anisopliae* (mm)												Toxicity Level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Fomesafen+ Flauzifop-p-butyl	1.00*	96.65 (79.45)**	1.35	96.45 (79.18)	5.85	86.70 (68.60)	14.15	72.81 (58.56)	23.07	63.69 (52.95)	28.95	60.98 (51.34)	Toxic
T_2 Metribuzin	11.85	60.33 (50.94)	17.95	52.73 (46.55)	23.42	46.73 (43.12)	27.15	47.84 (43.74)	31.95	49.72 (44.84)	39.05	47.37 (43.50)	Moderately Toxic
T_3 Sulfentrazone+ Clomazone	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_4 Glyphosate	2.52	91.55 (73.11)	6.40	83.15 (65.76)	8.15	81.47 (64.50)	17.82	65.75 (54.18)	21.40	66.33 (54.51)	24.30	67.25 (55.10)	Toxic
T_5 Oxyfluorofen	3.40	88.62 (70.28)	7.30	80.78 (64.01)	9.30	78.85 (62.63)	12.32	76.32 (60.94)	15.20	76.08 (60.72)	18.95	74.46 (59.66)	Toxic
T_6 Carfentrazone Ethyl	6.52	78.16 (62.21)	10.32	72.81 (58.59)	14.25	67.60 (55.33)	22.30	57.16 (49.09)	28.72	54.80 (47.79)	32.15	56.67 (48.83)	Toxic
T_7 Control	29.87	0.00 (0.00)	37.97	0.00 (0.00)	43.97	0.00 (0.00)	52.05	0.00 (0.00)	63.55	0.00 (0.00)	74.20	0.00 (0.00)	
SEm±	0.26	0.56	0.30	0.54	0.42	0.58	0.64	0.77	0.80	0.64	0.89	0.66	
CD at 1%	0.78	1.65	0.90	1.61	1.23	1.73	1.88	2.28	2.35	1.91	2.62	1.94	

* Data Average of four replications.

( )** = Figures in parenthesis are arcsine transformed value.

Table 16. Effect of insecticides on the colony growth of *Metarhizium anisopliae*

Treatments	Average colony diameter of *Metarhizium anisopliae* (mm)												Toxicity Level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Chlorantraniliprole	8.50*	71.55 (57.76)**	18.72	50.69 (45.39)	23.62	46.28 (42.85)	33.40	35.83 (36.76)	41.80	34.23 (35.79)	56.55	23.79 (29.17)	Compatible
T_2 Imidacloprid	6.05	79.75 (63.25)	13.10	65.50 (54.02)	19.50	55.66 (48.24)	34.37	33.96 (35.63)	40.97	35.52 (36.59)	46.27	37.63 (37.83)	Moderately Toxic
T_3 Emamectin benzoate	3.30	88.95 (70.58)	12.35	67.48 (55.24)	19.82	54.92 (47.81)	30.02	42.32 (40.57)	36.75	42.17 (40.41)	43.32	41.61 (40.16)	Moderately Toxic
T_4 Spinosad	13.62	54.39 (47.50)	23.05	39.30 (38.79)	26.80	39.06 (38.66)	39.47	24.16 (29.31)	48.20	24.15 (29.42)	56.40	23.99 (29.32)	Compatible
T_5 Thimethoxam+ Lambda cyhalothrin	5.20	82.59 (65.45)	9.52	74.92 (59.98)	15.05	65.78 (54.20)	20.20	61.19 (51.47)	23.82	62.51 (52.23)	34.55	53.44 (46.96)	Toxic
T_6 Acetamiprid	8.62	71.13 (57.49)	18.30	51.81 (46.03)	20.72	52.87 (46.64)	27.20	47.74 (43.68)	40.05	36.98 (37.40)	57.47	22.54 (28.32)	Compatible
T_7 Control	29.87	0.00 (0.00)	37.97	0.00 (0.00)	43.97	0.00 (0.00)	52.05	0.00 (0.00)	63.55	0.00 (0.00)	74.20	0.00 (0.00)	
SEm±	0.32	0.80	0.55	0.87	0.57	0.73	0.83	0.99	1.14	1.11	1.22	0.99	
CD at 1%	0.96	2.37	1.64	2.56	1.68	2.16	2.44	2.91	3.36	3.28	3.59	2.91	

* Data Average of four replications

( )** = Figures in parenthesis are arcsine transformed value

4.4 Compatibility of *Verticillium lecanii* with chemical pesticides.

In the present investigation compatibility of *Verticillium lecanii* is tested with six fungicides, six herbicides and six insecticides.

4.4.1 Effect of fungicides on *Verticillium lecanii*.

Out of six fungicides (Table 17), copper oxychloride proved moderately toxic (23.50 mm) which showed inhibition of 45.19 per cent, followed by ametoctradin + diamethomorph (27.50 mm) which inhibited mycelial growth by 35.86 per cent. Carbendazim + mancozeb, at 24 to 144 hrs, completely inhibited the growth of *Verticilllium lecanii* and proved totally incompatible, followed by azoxystrobin + tebuconazole (8.07 mm), thiophenate methyl (9.95 mm) and captan (10.25), which showed inhibition 81.17, 76.79 and 76.09 per cent respectively.

The growth response of *Verticillium lecanii* ranging from moderately toxic to toxic with the above fungicides observed in this experiment is in agreement with earlier findings by Hall (1981) who suggested that captan fungicide was toxic and by (Krishnamoorthy *et al.* 2007) who reported that thiophenate methyl and carbendazim totally inhibited the mycelial growth of *Verticilliumm lecanii* and proved incompatible with *Verticillium lecanii*.

4.4.2 Effect of herbicides on *Verticillium lecanii*.

In this experiment (Table 18), only one herbicide, carfentrazone ethyl (34.32 mm), was found compatible with *Verticillium lecanii*, which shows mycelial growth 34.32 mm and growth inhibition of 19.94 per cent. Fomesafen + flauzifop-p-butyl (28.15 mm) and metribuzin (28.05 mm) were found slightly toxic, which showed inhibition 34.34 and 34.58 per cent respectively. The herbicide glyphosate (22.05 mm) reduced the growth by 48.57 per cent and proved moderately toxic, followed by oxyfluorofen (24.40 mm) which reduced the mycelial growth by 43.09 per cent. From 24 hrs to 144 hrs, complete growth inhibition of *Verticillium lecanii* was recorded with the treatment of sulfentrazone + clomazone, which is totally incompatible.

According to these experimental findings, carfentrazone ethyl was compatible with *Verticillium lecanii* and fully incompatible with sulfentrazone + clomazone.

4.4.3 Effect of insecticides on *Verticillium lecanii*.

Among the insecticides (Table 19), chlorantraniliprole was found fully compatible, which shows mycelial growth of 37.40 mm and inhibition of 12.77 per cent, followed by spinosad (37.05 mm) and emamectin benzoate (35.85 mm) which reduce mycelial growth by 13.59 and 16.38 per cent respectively. At 72 hrs, inhibition of mycelial growth is very low, *i.e.* 8.57 per cent. Insecticide acetamiprid (31.02 mm), found slightly toxic, reduced the mycelial growth by 27.64 per cent, followed by imidachloprid (30.82 mm) and thiamethoxam + lambda cyhalothrin (30.25 mm), which reduced the growth by 28.10 and 29.45 per cent respectively.

The present investigation showed that insecticides chlorantraniliprole, spinosad and emamectin benzoate were found completely compatible with *Verticillium lecanii*. Parallel results are obtained as compared to previous reports by (Sword *et al*. 2011), (Pampapathy *et al.* 2011) and (Kakati *et al.*2018). Alizadeh (2007) also reported that imidacloprid had no effect on *Verticillium lecanii*.

Table 17. Effect of fungicides on the colony growth of *Verticillium lecanii*

Treatments	Average colony diameter of *Verticillium lecanii* (mm)												Toxicity level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Captan	1.52*	55.15 (47.91)**	2.30	74.86 (59.94)	3.15	79.97 (63.40)	6.85	81.84 (64.78)	8.10	79.72 (62.23)	10.25	76.09 (60.71)	Toxic
T_2 Carbendazim + Mancozeb	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_3 Thiophenate methyl	1.00	70.59 (57.18)	2.30	74.86 (59.90)	4.05	74.24 (59.52)	8.05	78.66 (62.47)	9.30	76.72 (61.15)	9.95	76.79 (61.19)	Toxic
T_4 Copper oxychloride	2.50	26.47 (30.87)	4.05	55.74 (48.28)	5.72	63.59 (52.87)	10.95	70.97 (57.38)	15.65	60.83 (51.25)	23.50	45.19 (42.21)	Moderately Toxic
T_5 Azoxystrobin+ Tebuconazole	0.00	100.00 (90.00)	2.20	75.96 (60.63)	2.95	81.24 (64.36)	4.95	86.88 (68.76)	6.52	83.67 (66.20)	8.07	81.17 (64.27)	Toxic
T_6 Ametoctradin+ Dimethomorph	2.00	41.18 (39.87)	4.50	50.82 (45.47)	8.75	44.36 (41.72)	13.00	65.54 (54.04)	20.00	49.94 (44.96)	27.50	35.86 (36.74)	Moderately Toxic
T_7 Control	3.40	0.00	9.15	0.00	15.725	0.00	37.72	0.00	39.95	0.00	42.87	0.00	
SEm±	0.02	0.56	0.10	0.59	0.14	0.56	0.32	0.45	0.38	0.61	0.36	0.52	
CD at 1%	0.08	1.65	0.29	1.75	0.42	1.66	0.95	1.33	1.12	1.81	1.07	1.53	

* Data is average of four replications

( )** = Figures in parenthesis are arcsine transformed value

Table 18. Effect of herbicides on the colony growth of *Verticillium lecanii*

Treatments	Average colony diameter of *Verticillium lecanii* (mm)												Toxicity level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Fomesafen+ Flauzifop-p-butyl	1.50*	55.88 (48.34)**	3.30	63.93 (53.06)	6.62	57.94 (49.54)	9.65	74.42 (59.59)	22.25	44.31 (41.72)	28.15	34.34 (35.70)	Slightly Toxic
T_2 Metribuzin	2.30	32.35 (34.52)	3.05	66.67 (54.69)	5.00	68.25 (55.72)	9.05	76.01 (60.65)	20.05	49.81 (44.91)	28.05	34.58 (35.83)	Slightly Toxic
T_3 Sulfentrazone+ Clomazone	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_4 Glyphosate	1.20	64.71 (53.50)	3.95	56.83 (48.88)	7.72	50.95 (45.53)	15.62	58.58 (49.91)	18.82	52.88 (46.64)	22.05	48.57 (44.06)	Moderately Toxic
T_5 Oxyfluorofen	2.10	38.24 (38.14)	3.75	59.02 (50.23)	6.72	57.30 (49.19)	9.40	75.08 (60.06)	19.37	51.50 (45.86)	24.40	43.09 (40.84)	Moderately Toxic
T_6 Carfentrazone ethyl	1.65	51.47 (45.78)	5.52	39.62 (38.99)	11.20	28.89 (32.45)	18.30	51.49 (45.83)	28.50	28.66 (32.34)	34.32	19.94 (26.15)	Compatible
T_7 Control	3.40	0.00	9.15	0.00	15.75	0.00	37.72	0.00	39.95	0.00	42.87	0.00	
SEm±	0.03	0.86	0.12	0.55	0.18	0.87	0.30	0.46	0.54	0.78	0.66	1.41	
CD at 1%	0.10	2.55	0.35	1.61	0.55	2.56	0.90	1.37	1.60	2.31	1.95	4.15	

* Data is average of four replications

( )** = Figures in parenthesis are arcsine transformed value

Table 17. Effect of insecticides on the colony growth of *Verticillium lecanii*

Treatments	Average colony diameter of *Verticillium lecanii* (mm)												Toxicity Level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Chlorantraniliprole	2.10*	38.24 (38.22)**	7.05	22.95 (28.37)	13.75	12.70 (19.32)	23.42	37.91 (38.01)	30.20	24.41 (29.60)	37.40	12.77 (19.97)	Compatible
T_2 Imidacloprid	2.30	32.35 (34.53)	4.85	46.99 (43.14)	8.35	46.98 (43.06)	17.67	53.15 (46.77)	28.10	29.66 (32.97)	30.82	28.10 (31.91)	Slightly Toxic
T_3 Emamectin benzoate	2.40	29.41 (32.65)	7.92	13.39 (18.44)	14.40	8.57 (15.86)	23.52	37.64 (37.77)	28.50	28.66 (32.36)	35.85	16.38 (21.78)	Compatible
T_4 Spinosad	1.92	43.38 (41.09)	6.52	28.69 (32.10)	12.30	21.90 (27.80)	23.05	38.90 (38.54)	31.15	22.03 (27.96)	37.05	13.59 (21.21)	Compatible
T_5 Thimethoxam+ Lambda cyhalothrin	2.27	33.09 (35.06)	7.87	13.93 (20.79)	13.05	17.14 (23.43)	17.62	53.28 (46.85)	21.37	46.50 (42.98)	30.25	29.45 (32.63)	Slightly Toxic
T_6 Acetamiprid	1.42	58.09 (49.65)	5.20	43.17 (40.93)	10.10	35.87 (36.67)	15.00	60.24 (50.88)	24.72	38.11 (38.01)	31.02	27.64 (31.59)	Slightly Toxic
T_7 Control	3.40	0.00	9.15	0.00	15.75	0.00	37.72	0.00	39.95	0.00	42.87	0.00 (0.00)	
SEm±	0.05	1.16	0.19	3.16	0.36	2.65	0.58	0.94	0.71	1.12	0.97	2.69	
CD at 1%	0.16	3.42	0.57	9.23	1.07	7.80	1.71	2.76	2.11	3.31	2.87	7.91	

* Data Average of four replications

( )** = Figures in parenthesis are arcsine transformed value

4.5 Compatibility of *Beauveria bassiana* with chemical pesticides.

In the present investigation compatibility of *Beauveria bassiana* is tested with six fungicides, six herbicides and six insecticides.

4.5.1 Effect of fungicides on *Beauveria bassiana*.

Out of the six fungicides (Table 20), copper oxychloride at 72 hrs showed inhibition of 18.75 per cent, but inhibition per cent increased at 96, 120 and 144 hrs respectively. At 144 hrs, average mycelial growth was 14.62 mm and inhibition was 44.07 per cent, which was found to be moderately toxic. Carbendazim + mancozeb, thiophenate methyl and azoxystrobin + tebuconazole were found totally incompatible which showed 100 per cent mycelial growth inhibition at 24 to 144 hrs. Fungicide ametoctradin + diamethomorph (2.0 mm) reduced the growth by 92.35 per cent, followed by captan (5.20 mm) which reduced the growth of *Beauveria bassiana* by 80.11 per cent.

4.5.2 Effect of herbicides on *Beauveria bassiana*.

The herbicide (Table 21) fomesafen + flauzifop-p-butyl (18.52 mm) showed a slightly toxic effect on the biocontrol agent *Beauveria bassiana*, which reduced mycelial growth by 29.16 per cent, followed by glyphosate (16.12 mm) and carfentrazone ethyl (13.30 mm) which showed inhibition per cent of 38.34 and 49.14 respectively. Oxyfluorofen (10.37 mm) and metribuzin (12.40 mm) were found toxic, which showed 60.33 and 52.58 per cent inhibition of mycelial growth of *Beauveria bassiana* respectively. Sulfentrazone + clomazone at 24 to 144 hrs, completely inhibited growth and proved totally incompatible.

4.5.3 Effect of insecticides on *Beauveria bassiana*.

Among the insecticides (Table 22), spinosad (18.52 mm) and imidacloprid (17.65 mm) had a slightly toxic effect on *Beauveria bassiana*, which showed inhibition 29.16 and 32.50 per cent respectively. The Growth response of *Beauveria bassiana* to the treatment of chlorantraniliprole (13.30 mm) was found to be moderately toxic, which inhibited mycelial growth by 49.14 per cent. Acetamiprid (7.72 mm) found toxic effect on *Beauveria bassiana* showed inhibition of 70.46 per cent, followed by emamectin benzoate (9.05 mm) and thimethoxam + lambda cyhalothrin (10.22 mm), which showed 65.39 and 60.90 per cent inhibition of mycelial growth respectively.

In the present study, spinosad was found to be compatible with *Beauveria bassiana*. The growth response of *Beauveria bassiana* with insecticides was compatible; moderately toxic to toxic which is similar to earlier findings by (Amutha *et al*. 2010) who reported that spinosad and imidacloprid were slightly toxic. Khezri *et al*. (2007) and Ali *et al*. (2007) suggested that imidacloprid was compatible with *Beauveria bassiana*.

Table 17. Effect of fungicides on the colony growth of *Beauveria bassiana*

Treatments	Average Colony diameter of *Beauveria bassiana* (mm)												Toxicity level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Captan	0.80*	84.16 (66.53)**	1.55	79.19 (62.86)	2.20	75.00 (59.99)	2.55	79.80 (63.29)	3.87	78.01 (62.04)	5.20	80.11 (63.51)	Toxic
T_2 Carbendazim + Mancozeb	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_3 Thiophenate methyl	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_4 Copper oxychloride	2.22	55.94 (48.38)	5.15	30.87 (33.73)	7.15	18.75 (25.63)	8.15	35.45 (36.51)	10.82	38.58 (38.40)	14.62	44.07 (41.55)	Moderately Toxic
T_5 Azoxystrobin+ Tebuconazole	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_6 Ametoctradin+ Dimethomorph	0.00	100.00 (90.00)	1.62	78.19 (62.18)	2.00	77.27 (61.52)	2.00	84.16 (66.54)	2.00	88.65 (70.31)	2.00	92.35 (73.94)	Toxic
T_7 Control	5.05	0.00	7.45	0.00	8.80	0.00	12.62	0.00	17.62	0.00	26.15	0.00	
SEm±	0.03	0.25	0.06	0.58	0.07	0.43	0.07	0.33	0.12	0.30	0.15	0.37	
CD at 1%	0.10	0.74	0.19	1.72	0.21	1.27	0.23	0.97	0.36	0.88	0.46	1.11	

* Data Average of four replications.

( )** = Figures in parenthesis are arcsine transformed value.

Table 17. Effect of herbicides on the colony growth of *Beauveria bassiana*

Treatments	Average colony diameter of *Beauveria bassiana* (mm)												Toxicity level
	24 hrs	% Innhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Fomesafen+ Flauzifop-p-butyl	3.30*	34.65 (36.04)**	6.20	16.78 (24.12)	8.37	4.83 (11.97)	10.65	15.64 (23.16)	14.55	17.45 (24.46)	18.52	29.16 (32.60)	Slightly Toxic
T_2 Metribuzin	3.12	38.12 (38.06)	4.80	35.57 (36.61)	7.37	16.19 (23.40)	8.65	31.49 (34.09)	10.45	40.71 (36.61)	12.40	52.58 (46.46)	Toxic
T_3 Sulfentrazone+ Clomazone	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_4 Glyphosate	3.30	34.65 (35.90)	4.52	39.26 (38.76)	7.62	13.35 (21.35)	9.47	24.95 (29.96)	11.97	32.06 (34.34)	16.12	38.34 (38.24)	Moderately Toxic
T_5 Oxyfluorofen	3.05	39.60 (38.92)	4.05	45.64 (42.48)	6.12	30.40 (33.44)	7.55	40.20 (39.35)	8.87	49.65 (44.77)	10.37	60.33 (50.97)	Toxic
T_6 Carfentrazone ethyl	2.55	49.50 (44.68)	3.95	46.98 (43.24)	6.05	31.25 (34.00)	7.05	44.16 (41.62)	10.30	41.56 (40.09)	13.30	49.14 (44.49)	Moderately Toxic
T_7 Control	5.05	0.00	7.45	0.00	8.80	0.00	12.62	0.00	17.62	0.00	26.15	0.00	
SEm±	0.08	1.18	0.13	1.07	0.18	1.32	0.21	0.87	0.31	1.27	0.36	0.91	
CD at 1%	0.26	3.48	0.38	3.17	0.53	3.88	0.62	2.56	0.92	3.75	1.07	2.67	

* Data Average of four replications.

( )** = Figures in parenthesis are arcsine transformed value.

Table 23. Effect of insecticides on the colony growth of *Beauveria bassiana*

Treatment	Average colony diameter of *Beauveria bassiana* (mm)												Toxicity Level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Chlorantra niliprole	3.07*	39.11 (38.65)**	5.12	31.21 (33.93)	8.67	1.42 (4.78)	11.55	8.51 (16.83)	11.97	32.06 (34.50)	13.30	49.14 (44.50)	Moderately Toxic
T_2 Imidacloprid	3.57	29.21 (32.51)	4.97	33.22 (35.19)	7.97	9.38 (15.02)	9.55	24.36 (29.35)	13.62	22.70 (28.23)	17.65	32.50 (34.68)	Slightly Toxic
T_3 Emamectin benzoate	1.47	70.79 (57.29)	2.55	65.77 (54.19)	3.97	54.83 (47.67)	4.80	61.98 (51.94)	6.12	65.25 (53.87)	9.05	65.39 (53.95)	Toxic
T_4 Spinosad	2.65	47.52 (43.56)	4.37	41.28 (39.94)	6.22	29.26 (32.63)	7.40	41.39 (39.93)	13.30	24.54 (29.69)	18.52	29.16 (32.66)	Slightly Toxic
T_5 Thimethoxam+ Lambda cyhalothrin	1.97	60.89 (51.28)	3.25	56.38 (48.63)	5.40	38.64 (38.30)	5.52	56.24 (48.61)	6.62	62.41 (52.21)	10.22	60.90 (51.33)	Toxic
T_6 Acetamiprid	2.55	49.50 (44.68)	3.90	47.65 (43.65)	5.47	37.78 (37.70)	7.22	42.77 (40.81)	7.52	57.30 (49.17)	7.72	70.46 (57.06)	Toxic
T_7 Control	5.05	0.00	7.45	0.00	8.80	0.00	12.62	0.00	17.62	0.00	26.15	0.00	
SEm±	0.07	1.11	0.12	1.00	0.18	2.67	0.24	1.31	0.32	0.99	0.36	0.88	
CD at 1%	0.23	3.27	0.37	2.96	0.55	7.87	0.73	3.86	0.95	2.91	1.08	2.60	

* Data Average of four replications.

( )** = Figures in parenthesis are arcsine transformed value.

4.6 Compatibility of *Paecilomyces lilacinus* with chemical pesticides.

In the present investigation compatibility of *Paecilomyces lilacinus* is tested with six fungicides, six herbicides and six insecticides.

4.6.1 Effect of fungicides on *Paecilomyces lilacinus*.

In the present experiment (Table 23), the response of fungicide ametoctradin + diamethomorph (14.02 mm) to *Paecilomyces lilacinus* was compatible, which showed inhibition per cent of 13.96. Mycelial growth of *Paecilomyces lilacinus* was inhibited by copper oxychloride (12.20 mm) by 25.15 per cent and found slightly toxic. Fungicide captan (9.97 mm) was found to be moderately toxic, which shows inhibition of 38.80 per cent. The growth response of *Paecilomyces lilacinus* with treatments of carbendazim + mancozeb, thiophenate methyl and azoxystrobin + tebuconazole were completely incompatible and reduced 100 per cent of mycelial growth at 24 to 144 hrs.

In the present study, the fungicide ametoctradin + diamethomorph was proved compatible and the fungicide copper oxychloride was found slightly toxic. Dong *et al*. (2010) concluded that the fungicide copper oxychloride was compatible with *Paecilomyces lilacinus*.

4.6.2 Effect of herbicides on *Paecilomyces lilacinus*.

Among the herbicides (Table 24), the least inhibition of 1.07 per cent was recorded with treatment of fomesafen + flauzifop-p-butyl (16.12 mm) and found completely compatible. This was followed by carfentrazone ethyl (14.97 mm), which inhibited mycelial growth by 8.13 per cent, also found completely compatible. Metribuzin (10.37 mm) inhibited growth by 36.35 per cent, proved moderately toxic and was followed by glyphosate (8.37 mm) which showed inhibition of 48.62 per cent. Treatment of sulfentrazone + clomazone inhibited growth 100 per cent at 24 to 144 hrs, and proved totally incompatible with *Paecilomyces lilacinus*, followed by herbicide oxyfluorofen (5.45 mm) which showed inhibition of 66.56 per cent and was toxic.

In the present investigation, fomesafen + flauzifop-p-butyl and carfentrazone ethyl had no effect on the growth of *Paecilomyces lilacinus* and were found compatible.

4.6.3 Effect of insecticides on *Paecilomyces lilacinus*.

The experimental results of treatment of insecticides (Table 25) showed that spinosad had least effect on growth of *Paecilomyces lilacinus* which shows inhibition 1.99 per cent and found fully compatible. Insecticides chlorantraniliprole (11.47 mm) and acetamiprid (11.45 mm), showed inhibition 29.60 and 29.75 per cent respectively and found slightly toxic. Insecticides emamectin benzoate (9.30 mm) and imidachloprid (8.30 mm) inhibit the mycelial growth 42.94 and 49.08 per cent respectively and found moderately toxic. Thimethoxam + lambda cyhalothrin (5.05 mm) proved toxic which showed inhibition 69.02 per cent.

The results of the study of the compatibility of insecticides with *Paecilomyces lilacinus*, showed that spinosad, chlorantraniliprole, and acetamiprid were found to be compatible and have less effect on the mycelial growth of *Paecilomyces lilacinus*. Similar findings were reported in earlier reports by (Asi *et al.* 2010) who suggested that spinosad had a compatible and emamectin benzoate showed a moderately toxic effect on the growth of *Paecilomyces lilacinus.* Mathew and Louis (2018) revealed that insecticide imidachloprid is found compatible with *Paecilomyces lilacinus*.

Table 23. Effect of fungicides on the colony growth of *Paecilomyces lilacinus*

Treatments	Average colony diameter of *Paecilomyces lilacinus* (mm)												Toxicity level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Captan	0.55*	81.03 (64.20)**	3.07	22.64 (28.36)	4.15	41.75 (40.24)	6.07	43.22 (41.09)	8.02	34.36 (35.87)	9.97	38.80 (38.52)	Moderately Toxic
T_2 Carbendazim + Mancozeb	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_3 Thiophenate methyl	0.00	100.00 (90.00)	0.00	100 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_4 Copper oxychloride	1.00	65.52 (54.04)	2.70	32.08 (34.48)	6.62	7.02 (13.31)	8.47	20.79 (27.07)	10.02	18.00 (24.99)	12.20	25.15 (30.09)	Slightly Toxic
T_5 Azoxystrobin+ Tebuconazole	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	Toxic
T_6 Ametoctradin+ Dimethomorph	1.42	50.86 (45.49)	3.60	9.43 (17.68)	6.12	14.04 (21.88)	8.05	24.77 (29.80)	10.57	13.50 (20.84)	14.02	13.96 (21.80)	Compatible
T_7 Control	2.90	0.00 (0.00)	3.97	0.00 (0.00)	7.12	0.00 (0.00)	10.70	0.00 (0.00)	12.22	0.00 (0.00)	16.30	0.00 (0.00)	
SEm±	0.02	0.45	0.04	0.82	0.08	1.78	0.09	0.50	0.16	1.33	0.17	0.70	
CD at 1%	0.06	1.32	0.12	2.43	0.24	5.25	0.28	1.47	0.48	3.93	0.51	2.08	

* Data is average of four replications.

( )** = Figures in parenthesis are arcsine transformed value.

Table 24. Effect of herbicides on the colony growth of *Paecilomyces lilacinus*

Treatments	Average colony diameter of *Paecilomyces lilacinus* (mm)												Toxicity Level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Fomesafen+ Flauzifop-p-butyl	0.00*	100.0 (90.00)**	1.00	74.84 (59.89)	6.70	5.96 (37.91)	10.70	0.00 (26.06)	11.97	2.04 (5.74)	16.12	1.07 (5.00)	Compatible
T_2 Metribuzin	1.07	62.93 (52.48)	2.90	27.04 (31.24)	4.62	35.09 (36.30)	6.47	39.49 (38.83)	7.45	39.06 (38.69)	10.37	36.35 (37.06)	Moderately Toxic
T_3 Sulfentrazone+ Clomazone	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	Toxic
T_4 Glyphosate	1.00	65.52 (54.02)	1.55	61.01 (51.36)	4.70	34.04 (35.67)	5.47	48.83 (44.42)	6.52	46.63 (43.04)	8.37	48.62 (44.19)	Moderately Toxic
T_5 Oxyflourofen	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	0.00	100.0 (90.00)	3.40	72.19 (58.17)	5.45	66.56 (54.69)	Toxic
T_6 Carfentrazone ethyl	1.62	43.97 (41.51)	4.80	3.14 (7.20)	7.02	1.40 (4.62)	9.62	10.05 (17.31)	12.07	1.23 (4.46)	14.97	8.13 (15.81)	Compatible
T_7 Control	2.90	0.00 (0.00)	3.97	0.00 (0.00)	7.12	0.00 (0.00)	10.70	0.00 (0.00)	12.22	0.00 (0.00)	16.30	0.00 (0.00)	
SEm±	0.02	0.35	0.04	1.71	0.08	1.37	0.19	1.55	0.18	1.77	0.31	1.64	
CD at 1%	0.06	1.05	0.13	5.05	0.25	4.04	0.58	4.57	0.55	5.22	0.91	4.84	

* Data Average of four replications.

( )** = Figures in parenthesis are arcsine transformed value.

Table 25. Effect of insecticides on the colony growth of *Paecilomyces lilacinus*

Treatments	Average colony diameter of *Paecilomyces lilacinus* (mm)												Toxicity level
	24 hrs	% Inhibition	48 hrs	% Inhibition	72 hrs	% Inhibition	96 hrs	% Inhibition	120 hrs	% Inhibition	144 hrs	% Inhibition	
T_1 Chlorantra-niliprole	3.00*	5.17 (11.22)**	3.82	3.77 (9.57)	7.05	1.05 (5.06)	10.05	6.07 (11.63)	9.95	18.61 (25.52)	11.47	29.60 (32.95)	Slightly Toxic
T_2 Imidacloprid	2.70	6.90 (14.67)	3.80	4.40 (11.73)	6.62	7.02 (14.55)	10.57	1.17 (4.34)	6.95	43.15 (41.00)	8.30	49.08 (44.47)	Moderately Toxic
T_3 Emamectin benzoate	1.45	50.00 (44.92)	3.87	2.52 (7.82)	5.22	26.67 (30.87)	6.37	40.42 (39.43)	7.90	35.38 (36.50)	9.30	42.94 (40.94)	Moderately Toxic
T_4 Spinosad	1.05	52.59 (46.43)	2.97	25.16 (29.80)	6.97	2.11 (7.17)	10.05	6.07 (13.16)	11.97	2.04 (7.97)	15.97	1.99 (6.64)	Compatible
T_5 Thimethoxam+ Lambda cyhalothrin	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	0.00	100.00 (90.00)	3.12	74.44 (59.66)	5.05	69.02 (56.18)	Toxic
T_6 Acetamiprid	1.30	55.17 (47.87)	2.62	34.59 (35.82)	5.45	23.51 (28.97)	8.65	19.16 (25.32)	8.65	29.24 (32.68)	11.45	29.75 (33.05)	Slightly Toxic
T_7 Control	2.90	0.00 (0.00)	3.97	0.00 (0.00)	7.12	0.00 (0.00)	10.70	0.00 (0.00)	12.22	0.00 (0.00)	16.30	0.00 (0.00)	
SEm±	0.05	1.76	0.11	2.01	0.10	1.74	0.20	2.57	0.24	1.18	0.21	1.21	
CD	0.17	5.19	0.32	5.92	0.29	5.13	0.61	7.55	0.71	3.47	0.62	3.57	

* Data Average of four replications

( )** = Figures in parenthesis are arcsine transformed value

5. SUMMERY AND CONCLUSION

5.1 Summery

In the present investigation, biocontrol agents *Trichoderma viride, Trichoderma harzianum, Metarhizium anisopliae, Verticillium lecanii, Beauveria bassiana* and *Paecilomyces lilacinus* were compatible with some chemical pesticides and incompatible with others. The results of this study are summarized below.

5.1.1 Compatibility of *Trichoderma viride* with chemical pesticides.

Among the six fungicides, *Trichoderma viride* showed a high incompatibility with the fungicides carbendazim + mancozeb and azoxystrobin + tebuconazole, in which 100 per cent inhibition of mycelial growth was observed in the case of both fungicides. Also, the fungicides, captan, thiophenate methyl and copper oxychloride, showed inhibition of 67.12, 55.86 and 54.65 per cent respectively. Ametoctradin + diamethomorph showed inhibition of 37.84 per cent and proved moderately toxic.

Out of the the six herbicides, carfentazone ethyl was found fully compatible with *Trichoderma viride*, which showed inhibition of 6.13 per cent, followed by fomesafen + flauzifop-p-butyl, oxyfluorofen and metribuzin, which showed mycelial growth inhibition of 8.95, 20.69 and 21.77 per cent respectively and were found completely compatible. The herbicide glyphosate was found moderately toxic showed inhibition of 45.29 per cent. 100 per cent mycelial growth inhibition was recorded with the treatment of sulfentazone + clomazone, and proved completely incompatible.

Trichoderma viride was fully compatible with all insecticides. Emamectin benzoate and spinosad had no effect on inhibition of mycelial growth, which showed 0.72 and 1.92 per cent inhibition respectively. *Trichoderma* viride is also completely compatible with chlorantraniliprole, imidachloprid, acetamiprid and thimethoxam + lambda cyhalothrin, which showed inhibition of 6.82, 6.82, 17.27 and 19.01 per cent respectively.

5.1.2 Compatibility of *Trichoderma harzianum* with chemical pesticides.

Among the fungicides, ametoctradin + diamethomorph, inhibited growth by 37.87 per cent and was found to be moderately toxic. The biocontrol agent *Trichoderma harzianum* was completely incompatible with the fungicides carbendazim + mancozeb, copper oxychloride and azoxystrobin + tebuconazole, which showed 100 per cent growth inhibition. Captan and thiophenate methyl also proved toxic to the growth of *Trichoderma harzianum,* which showed 86.20 and 84.71 per cent growth inhibition.

In the case of herbicides, only carfentrazone ethyl was found compatible, which showed 9.41 per cent inhibition. Glyphosate inhibited mycelial growth by 28.46 per cent and proved slightly toxic. Oxyfluorofen was found moderately toxic and showed 44.30 per cent inhibition followed by metribuzin inhibited mycelial growth by 39.04 per cent. High mycelial growth inhibition was recorded 91.49 per cent within the treatment of sulfentrazone + clomazone, followed by fomesafen + flauzifop-p-butyl, which showed 63.83 per cent inhibition.

Out of six insecticides, imidachloprid was found highly compatible with *Trichoderma harzianum,* which showed 6.33 per cent inhibition, followed by acetamiprid, spinosad, imamectin benzoate and chlorantraniliprole which showed inhibition of 7.02, 10.63, 18.91 and 21.09 per cent respectively. Thimethoxam + lambda cyhalothrin was slightly toxic and inhibited mycelial growth by 30.44 per cent.

5.1.3 Compatibility of *Metarhizium anisopliae* with chemical pesticides.

Among the fungicides, carbendazim + mancozeb, copper oxychloride and azoxystrobin + tebuconazole inhibited mycelial growth 100 per cent from 24 to 144 hrs and are totally incompatible with *Metarhizium anisopliae*. Also, the fungicide ametoctradin + diamethomorph proved completely incompatible, which showed 95.96 per cent inhibition, followed by captan and thiophenate methyl, which showed 81.64 and 80.80 per cent inhibition of mycelial growth respectively.

Among the herbicides, sulfentrazone + clomazone inhibit mycelial growth 100 per cent and is totally incompatible with *Metarhizium anisopliae*. Oxyfluorofen was found incompatible with which showed inhibition of 74.46 per cent, followed by glyphosate, fomesafen + flauzifop-p-butyl and carfentrazone ethyl, which showed respective inhibition of 67.25, 60.98 and 56.67 per cent. Only one herbicide, metribuzin, proved moderately toxic, inhibiting mycelial growth by 47.37 per cent.

The experimental results indicated that, in insecticides, acetamiprid inhibited 22.54 per cent of the mycelial growth of *Metarhizium anisopliae* and was found compatible, followed by chlorantraniliprole and spinosad, which reduced the mycelial growth by 23.79 and 23.99 per cent respectively. Insecticides imidachloprid and emamectin benzoate reduced mycelial growth by 37.63 and 41.61 per cent and were found to be moderately toxic. Insecticide, Thimethoxam + lambda cyhalothrin, proved toxic, which showed inhibition of 53.44 per cent.

5.1.4 Compatibility of *Verticillium lecanii* with chemical pesticides.

Out of six fungicides, copper oxychloride proved moderately toxic, which showed an inhibition of 45.19 per cent, followed by ametoctradin + diamethomorph, which inhibited mycelial growth by 35.86 per cent. Fungicide carbendazim + mancozeb completely inhibited the growth of *Verticilllium lecanii* and proved totally incompatible, followed by azoxystrobin + tebuconazole, thiophenate methyl and captan, which showed inhibition of 81.17, 76.79 and 76.09 per cent respectively.

In this experiment, only one herbicide, carfentrazone ethyl, was found compatible with *Verticillium lecanii*, which showed mycelial growth of 34.32 mm and growth inhibition of 19.94 per cent. Fomesafen + flauzifop-p-butyl and metribuzin were found slightly toxic, which showed inhibition of 34.34 and 34.58 per cent respectively. The herbicide glyphosate reduced the growth by 48.57 per cent and proved moderately toxic, followed by oxyfluorofen, which reduced the mycelial growth by 43.09 per cent. Complete growth inhibition of *Verticillium lecanii* was recorded with the treatment of sulfentrazone + clomazone, which is totally incompatible.

Among the insecticides, chlorantraniliprole was found fully compatible with *Verticillium lecanii*, which shows mycelial growth inhibition of 12.17 per cent, followed by spinosad and emamectin benzoate, which reduce mycelial growth by 13.59 and 16.38 per cent respectively. Insecticide acetamiprid, found slightly toxic, reduced the mycelial growth by 27.64 per cent, followed by imidachloprid and thiamethoxam + lambda cyhalothrin, which reduced the growth by 28.10 and 29.45 per cent respectively.

5.1.5 Compatibility of *Beauveria bassiana* with chemical pesticides.

Out of the six fungicides, copper oxychloride inhibited 44.07 per cent mycelial growth, which was found to be moderately toxic. Carbendazim + mancozeb, thiophenate methyl and azoxystrobin + tebuconazole were found totally incompatible and showed 100 per cent mycelial growth inhibition. Fungicide ametoctradin + diamethomorph reduced the growth by 92.35 per cent, followed by captan, which reduced the growth of *Beauveria bassiana* by 80.11 per cent and was found incompatible with *Beauveria bassiana*.

The herbicide fomesafen + flauzifop-p-butyl showed a slightly toxic effect on the biocontrol agent *Beauveria bassiana*, which reduced mycelial growth by 29.16 per cent, followed by glyphosate and carfentrazone ethyl, which showed inhibition per cent of 38.34 and 49.14 respectively. Oxyfluorofen and metribuzin were found toxic, which showed 60.33 and 52.58 per cent inhibition of mycelial growth of *Beauveria bassiana* respectively. The herbicide, Sulfentrazone + clomazone, completely inhibited growth and proved totally incompatible.

Among the insecticides, spinosad and imidacloprid had a slightly toxic effect on *Beauveria bassiana*, which showed inhibition of 29.16 and 32.50 per cent respectively. The growth response of *Beauveria bassiana* to the treatment of chlorantraniliprole was found to be moderately toxic, which inhibited mycelial growth by 49.14 per cent. Acetamiprid found toxic effect on *Beauveria bassiana* showed inhibition of 70.46 per cent, followed by emamectin benzoate and thimethoxam + lambda cyhalothrin, which showed 65.39 and 60.90 per cent inhibition of mycelial growth respectively.

5.1.6 Compatibility of *Paecilomyces lilacinus* with chemical pesticides.

In the present experiment, the response of fungicide ametoctradin + diamethomorph to *Paecilomyces lilacinus* was compatible, which showed an inhibition per cent of 13.96. Mycelial growth of *Paecilomyces lilacinus* was inhibited by copper oxychloride by 25.15 per cent and found slightly toxic. The fungicide captan was found to be moderately toxic, which showed inhibition of 38.80 per cent. The growth response of *Paecilomyces lilacinus* to treatments of carbendazim + mancozeb, thiophenate methyl and azoxystrobin + tebuconazole were completely incompatible and reduced 100 per cent of mycelial growth.

Among the herbicides, the least inhibition of 1.07 per cent was recorded with treatment of fomesafen + flauzifop-p-butyl and was found to be completely compatible. This was followed by carfentrazone ethyl, which inhibited mycelial growth by 8.13 per cent, also found to be completely compatible. Herbicide metribuzin, inhibited growth by 36.35 per cent, proved moderately toxic and was followed by glyphosate, which showed inhibition of 48.62 per cent. The treatment of sulfentrazone + clomazone inhibited growth 100 per cent, and proved totally incompatible with *Paecilomyces lilacinus*, followed by herbicide oxyfluorofen, which showed inhibition of 66.56 per cent and was toxic.

The experimental results of treatment of insecticides showed that spinosad had the least effect on the growth of *Paecilomyces lilacinus*, which showed inhibition of 1.99 per cent and was found to be fully compatible. Insecticides chlorantraniliprole and acetamiprid showed inhibition of 29.60 and 29.75 per cent respectively and were found slightly toxic. Insecticides emamectin benzoate and imidachloprid inhibit mycelial growth by 42.94 and 49.08 per cent respectively and are found to be moderately toxic. The combination of thimethoxam + lambda cyhalothrin proved toxic, which showed inhibition of 69.02 per cent.

5.2 CONCLUSION

The results obtained in this study clearly showed that some chemical pesticides severely affected the growth and development of biocontrol agents. These pesticides can cause harmful effects on biocontrol agents when they are applied together or in an integrated pest management programme. The use of such chemicals with biocontrol agents cannot provide satisfactory control against deseases and pests and can cause economic loss to farmer.

Some chemical pesticides do not affect the growth and development of biocontrol agents. The combination of such chemical pesticides can provide an additive or synergistic effect in the control of diseases and pests. These chemical pesticides and biocontrol agents can be used in an integrated pest management programme.

The present study concluded that the fungicides, ametoctradin + dimethomorph had a moderately toxic effect on the growth of *Trichoderma viride*, so caution must be taken when applied with *Trichoderma viride*. Fungicides, captan, carbendazim + mancozeb, thiophenate methyl, copper oxychloride and azoxystrobin + tebuconazole, were incompatible with *Trichoderma viride*, so these pesticides cannot be applied with *Trichoderma viride*.

Among the herbicides, carfentrazone ethyl, fomesafen + flauzifop-p-butyl, oxyfluorofen and metribuzin were compatible with *Trichoderma viride*, so these herbicides can be safely incorporated with *Trichoderma viride*, into IPM. Herbicide glyphosate is incompatible, so caution must be taken when applied with *Trichoderma viride*. Sulfentrazone + clomazone is found incompatible, so cannot be applied with *Trichoderma viride*.

All of the insecticides like emamectin benzoate, spinosad, chlorantraniliprole, imidacloprid, acetamiprid and thimethoxam + lamda cyhalothrin were compatible with *Trichoderma viride*, so these insecticides can be applied with *Trichoderma viride*, in the IPM.

Among the fungicides, ametoctradin + diamethomorph was found to be moderately toxic, so caution must be taken when applied with *Trichoderma harzianum*. Fungicide carbendazim + mancozeb, copper oxychloride, azoxystrobin + tebuconazole, captan and thiophenate methyl, proved toxic, so they cannot be applied with *Trichoderma harzianum*.

In the case of herbicides, carfentrazone ethyl was found compatible and glyphosate was proved slightly toxic, so it can be applied safely in IPM. Herbicides like oxyfluorofen and metribuzin are moderately toxic, so caution must be taken, when applied with *Trichoderma harzianum*. The herbicides, sulfentrazone + clomazone and fomesafen + flauzifop-p-butyl, are incompatible, so they cannot be applied with *Trichoderma harzianum*.

Among the insecticides, imidachloprid, acetamiprid, spinosad, imamectin benzoate and chlorantraniliprole, were compatible with *Trichoderma harzianum*. Thimethoxam + lambda cyhalothrin was slightly toxic, so these insecticides were safe for an integrated pest management programme.

All fungicides like carbendazim + mancozeb, copper oxychloride, azoxystrobin + tebuconazole, ametoctradin + diamethomorph, captan and thiophenate methyl, were incompatible with *Metarhizium anisopliae*, so it is found to be harmful in IPM.

Among the herbicides, only one herbicide, metribuzin, proved moderately toxic, so caution must be taken when using it in an integrated disease and pest management programme. Sulfentrazone + clomazone, oxyfluorofen, glyphosate, fomesafen + flauzifop-p-butyl and carfentrazone ethyl, were incompatible, so application of these herbicides is better with *Metarhizium anisopliae*.

Among the insecticides, acetamiprid, chlorantraniliprole and spinosad were compatible with *Metarhizium anisopliae*, so these insecticides were safe for IPM. imidachloprid, emamectin benzoate, were moderately toxic, caution must be taken when using these herbicides with *Metarhizium anisopliae*. The herbicide, thimethoxam + lambda cyhalothrin, proved toxic and cannot be applied with *Metarhizium anisopliae*.

Among six fungicides, copper oxychloride and ametoctradin + diamethomorph, were proved moderately toxic, so caution must be taken when applied with *Verticillium lecanii.* Fungicides, carbendazim + mancozeb, azoxystrobin + tebuconazole, thiophenate methyl and captan, were proved totally incompatible, so cannot be applied these fungicides with *Verticillium lecanii*, in IPM.

Among the herbicides, only one herbicide, carfentrazone ethyl, was found compatible and fomesafen + flauzifop-p-butyl and metribuzin were found slightly toxic, so they can be applied safely in combination with *Verticillium lecanii*. The herbicide glyphosate and oxyfluorofen were proved moderately toxic and caution must be taken when applied in IPM with *Verticillium lecanii*. Herbicide, sulfentrazone + clomazone, was totally incompatible, so it cannot be used with *Verticillium lecanii*.

Among the insecticides, chlorantraniliprole, spinosad and emamectin benzoate were found compatible and insecticides, acetamiprid, imidachloprid and thiamethoxam + lambda cyhalothrin were found slightly toxic, so all the insecticides can be applied with *Verticillium lecanii,* in an integrated disease management programme.

Among the six fungicides, copper oxychloride proved moderately toxic, so caution must be taken when using it with *Beauveria bassiana.* Fungicides, carbendazim + mancozeb, thiophenate methyl, azoxystrobin + tebuconazole, ametoctradin + diamethomorph and captan, were incompatible with *Beauveria bassiana,* so they cannot be applied with *Beauveria bassiana* in integrated disease and pest management.

The herbicide fomesafen + flauzifop-p-butyl showed a slightly toxic effect on *Beauveria bassiana,* so it can be applied with *Beauveria bassiana*. Herbicides, glyphosate and carfentrazone ethyl, proved moderately toxic, so caution must be taken when applied with *Beauveria bassiana.* Herbicides, Sulfentrazone + clomazone, oxyfluorofen and metribuzin, are totally incompatible, so they cannot be applied with *Beauveria bassiana*.

Among the insecticides, spinosad and imidacloprid had a slightly toxic effect, so these insecticides can be applied with *Beauvria bassiana.* Insecticide, chlorantraniliprole, was found to be moderately toxic, so caution must be taken when applied with *Beauveria bassiana.* Insecticides, acetamiprid, emamectin benzoate and thimethoxam + lambda cyhalothrin, were found toxic, so they cannot be applied with *Beauveria bassiana.*

In the present experiment, the response of fungicide ametoctradin + diamethomorph was compatible and copper oxychloride was found slightly toxic, so it can be applied with

Paecilomyces lilacinus in IPM. Fungicide captan was found to be moderately toxic, so caution must be taken when applied with *Paecilomyces lilacinus.* Fungicides, carbendazim + mancozeb, thiophenate methyl and azoxystrobin + tebuconazole, are totally incompatible, so they cannot be applied with *Paecilomyces lilacinus* in IPM.

Among the herbicides, fomesafen + flauzifop-p-butyl and carfentrazone ethyl were found to be compatible, so they can be applied with *Paecilomyces lilacinus.* Herbicides, metribuzin and glyphosate, were proved moderately toxic, so caution must be taken when applied with *Paecilomyces lilacinus*. The herbicides, sulfentrazone + clomazone and oxyfluorofen, proved totally incompatible with *Paecilomyces lilacinus*, so they cannot be applied with *Paecilomyces lilacinus* in IPM.

Among the insecticides, spinosad was found fully compatible and the insecticides chlorantraniliprole and acetamiprid were found slightly toxic, so they can be applied with *Paecilomyces lilacinus.* Insecticides emamectin benzoate and imidachloprid were found to be moderately toxic, so caution must be taken when applied with *Paecilomyces lilacinus.* Thimethoxam + lambda cyhalothrin was proved toxic, so it cannot be applied with *Paecilomyces lilacinus* in integrated pest and disease management.

Other conclusions from the all-over study are that, among all pesticides, the fungicide ametoctradin + dimethomorph was found to be moderately toxic to the biocontrol agents, *Trichoderma viride, Trichoderma harzianum* and *Verticillium lecanii,* while compatible with *Paecilomyces lilacinus.* The fungicide, copper oxychloride, was proved moderately toxic to *Verticillium lecanii* and *Beauveria bassiana,* while slightly toxic to *Paecilomyces lilacinus*.

Among herbicides, metribuzin was found moderately toxic to the biocontrol agents, *Trichoderma harzianum, Metarhizium anisopliae, Verticillium lecanii* and *Paecilomyces lilacinus,* while compatible with *Trichoderma viride.* Herbicide carfentrazone ethyl, found compatible with *Trichoderma viride, Trichoderma harzianum, Verticillium lecanii* and *Paecilomyces lilacinus.* The herbicide sulfentrazone + clomazone, was found incompatible with all six biocontrol agents.

Among insecticides, thimethoxam + lambda cyhalothrin was found incompatible with biocontrol agents, *Metarhizium anisopliae, Beauveria bassiana* and *Paecilomyces lilacinus,* while slightly toxic to *Trichoderma harzianum* and *Verticillium lecanii* and compatible with *Trichoderma viride.*

In this all over study, one more important conclusion was obtained, *i.e.,* insecticides are more compatible with biocontrol agents than herbicides, whereas herbicides are more compatible with biocontrol agents than fungicides. In other words, fungicides are more toxic than herbicides and herbicides are more toxic than insecticides.

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8. VITAE

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IN

AGRICULTURAL MICROBIOLOGY

2021

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