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In vitro compatibility of the entomopathogenic fungus Metarhizium anisopliae (Metschnikoff) Sorokin (Hypocreales: Clavicipitaceae) with insecticides used against termites in wheat, at sub-recommended, recommended and supra-recommended concentrations

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Abstract

Background

Subterranean termites, chiefly *Odontotermes obesus* (Rambur) and *Microtermes obesi* Holmgren, are major pests of wheat in north Gujarat, India. Their management relies on chlorpyriphos, imidacloprid and fipronil. Integrating the entomopathogenic fungus *Metarhizium anisopliae* with these chemicals requires knowing which insecticides the fungus tolerates. Seven insecticides were therefore tested in vitro against *M. anisopliae* by the poisoned food technique. Each was tested at 25% below, at, and 25% above its recommended concentration. Radial growth was recorded daily for 10 days and conidial yield on day 10. Compatibility was classified with the toxicity index (T) of Alves et al. (1998).

Results

All insecticides reduced fungal growth and sporulation, and inhibition increased with concentration. Chlorantraniliprole 18.5 SC was the most compatible at every concentration. Its T values were 76.73, 74.10 and 66.47, with 31.20, 31.50 and 29.50 mm radial growth and 3.60, 3.40 and 3.00 × 10^4 conidia/ml. Thiamethoxam 30 FS was also compatible (T = 60.85, 62.94 and 60.34). Fipronil 5 SC was moderately toxic at the lower and recommended concentrations (T = 55.80, 49.46) and toxic at the higher one (T = 41.50). Bifenthrin 10 EC changed from moderately toxic (T = 47.60) to toxic (T = 41.66, 35.10). Chlorpyriphos 20 EC (T = 11.57–20.03) and imidacloprid 600 FS (T = 7.42–13.10) were highly toxic at all concentrations. Imidacloprid 600 FS inhibited growth by 67.83–79.73% and sporulation by 91.67–95.79%. The ready mix of imidacloprid 17.8 SL + fipronil 5 SC was toxic at the lower concentration and highly toxic at the recommended and higher ones.

Conclusions

Chlorantraniliprole 18.5 SC and thiamethoxam 30 FS can be combined or rotated with *M. anisopliae* in termite management in wheat, even at 25% above the field rate. Chlorpyriphos 20 EC and imidacloprid 600 FS should be separated from the fungus in time or space. Their field compatibility should be confirmed in soil before the combinations are recommended.

Background

Wheat (*Triticum aestivum* L.) is the main *rabi* cereal of north Gujarat. In the region's light, sandy soils it is regularly damaged by subterranean termites (Isoptera: Termitidae), chiefly *Odontotermes obesus* (Rambur) and *Microtermes obesi* Holmgren (Rajagopal 2002). Termites cut the roots and hollow the stems of seedlings and tillers, and the damaged plants dry out in patches.

After the organochlorines were banned, termite control in wheat came to rely on a few insecticides used as seed or soil treatments. These are chlorpyriphos, imidacloprid, fipronil and, more recently, thiamethoxam and chlorantraniliprole. Repeated use of these chemicals raises concern over residues, effects on non-target soil fauna, and the risk of resistance. Entomopathogenic fungi offer a complementary option. *Metarhizium anisopliae* (Metschnikoff) Sorokin is a soil-dwelling hypocrealean fungus that infects termites by direct penetration of the cuticle. It is widely used against soil insect pests (Zimmermann 2007; Patel et al. 2022).

Used alone, fungal biopesticides act slowly and their efficacy varies with the weather. Combining them with a compatible insecticide can speed up kill and lower the chemical dose needed. Sub-lethal insecticide stress can also make insects more susceptible to infection (Hokkanen and Kotiluoto 1992; Neves et al. 2001). Fipronil applied with *M. anisopliae*, for example, killed the subterranean termite *Coptotermes curvignathus* Holmgren faster than either agent alone (Yii et al. 2016). Thiamethoxam combined with *M. anisopliae* likewise shortened the lethal time for rice planthoppers (Tang et al. 2019).

An insecticide can, however, also inhibit the fungus's germination, mycelial growth or conidiation. The effect depends on the active ingredient, the formulation and the concentration (Anderson and Roberts 1983; Schumacher and Poehling 2012). Published results are inconsistent. Imidacloprid, for instance, has been reported as compatible (Batista Filho et al. 2001; Niassy et al. 2012) and as moderately to highly toxic (Akbar et al. 2012; Amutha and Banu 2012), depending on formulation and dose. Compatibility therefore has to be tested for the formulations actually used in the target crop, at and around their field rates.

Little such information exists for the termiticides used in wheat, and none for the ready-mix and seed-treatment (FS) formulations now sold in Gujarat. This study tested seven insecticides used against termites in wheat for in vitro compatibility with *M. anisopliae*. Each was tested at 25% below, at, and 25% above its recommended concentration. Vegetative growth, conidial yield and the toxicity index of Alves et al. (1998) were measured to identify products that can be safely integrated with the fungus.

Methods

Study site and fungal culture

Insecticides and concentrations

Seven insecticides from different chemical groups, all used against termites in wheat, were tested (Table 1). Each was tested at three concentrations: 25% lower than recommended, recommended, and 25% higher than recommended. PDA without insecticide served as the control (T8).

Table 1
Insecticides and concentrations (% in PDA) tested for compatibility with M. anisopliae

Treatment	Insecticide (formulation)	Chemical group	25% lower	Recommended	25% higher
T1	Bifenthrin 10 EC	Pyrethroid	0.0075	0.010	0.0125
T2	Fipronil 5 SC	Phenylpyrazole	0.011	0.015	0.018
T3	Chlorantraniliprole 18.5 SC	Anthranilic diamide	0.015	0.020	0.025
T4	Chlorpyriphos 20 EC	Organophosphate	0.037	0.050	0.062
T5	Imidacloprid 600 FS	Neonicotinoid	0.021	0.028	0.036
T6	Thiamethoxam 30 FS	Neonicotinoid	0.00015	0.00020	0.00025
T7	Imidacloprid 17.8 SL + Fipronil 5 SC	Neonicotinoid + phenylpyrazole	0.065	0.08	0.10
T8	Control (no insecticide)	—	—	—	—

EC emulsifiable concentrate, SC suspension concentrate, FS flowable concentrate for seed treatment, SL soluble liquid

Poisoned food technique

Sensitivity of *M. anisopliae* to the insecticides was tested by the poisoned food technique (Grover and Moore 1962). The quantity of each formulation needed for the target concentration was added to 100 ml of molten, cooled PDA in an Erlenmeyer flask and mixed by gentle shaking. Twenty millilitres of the poisoned medium was poured into each sterile 90-mm Petri plate. After solidification, a 5-mm mycelial disc cut from the margin of an actively growing culture was placed at the centre of each plate. Plates were incubated at 26 ± 1°C in a BOD incubator. The experiment followed a completely randomized design with three replications per treatment at each concentration.

Observations

Vegetative growth

Radial colony growth (mm) was measured with a calliper every 24 h from day 1 to day 10 after inoculation. Per cent growth inhibition (PGI) over the control was calculated on day 10 following Vincent (1947)

$$PGI\ (\%) = [(D_C - D_T) / D_C] \times 100$$

where D_C and D_T are the mean colony growth (mm) in the control and treated plates.

Conidial yield

On day 10, five 10-mm discs were cut from each plate and placed in 20 ml of sterile 0.05% Tween 80. They were vortexed for 30 s to dislodge the conidia, which were counted in a Neubauer haemocytometer. Conidia/ml was calculated as the mean number of conidia per large square × 10^4. Per cent sporulation inhibition over the control was calculated with the same formula as PGI.

Compatibility classification

The toxicity index (T) of each insecticide was calculated with the model of Alves et al. (1998):

$$T = [20\ (VG) + 80\ (SP)] / 100$$

where VG and SP are the vegetative growth and sporulation in the treatment, as a percentage of the control. Insecticides were classified as highly toxic (T = 0–30), toxic (31–45), moderately toxic (46–60) or compatible (T > 60).

Statistical analysis

Radial growth at each observation day and conidial yield were analysed by one-way ANOVA for a completely randomized design, separately for each concentration. Means were separated by Duncan's new multiple range test (DNMRT) at P = 0.05. Standard error of the mean (SEm ±), critical difference (CD at 5%) and coefficient of variation (CV%) are reported with each table.

Results

All seven insecticides reduced the vegetative growth and conidial yield of *M. anisopliae* compared with the untreated control (P < 0.05). The degree of inhibition depended on the insecticide and rose with concentration. Chlorantraniliprole 18.5 SC and thiamethoxam 30 FS were compatible at all three concentrations. Chlorpyriphos 20 EC and imidacloprid 600 FS were highly toxic at all three (Tables 2 and 3; Figs. 1, 2, 3 and 4).

Vegetative growth

Treatment differences were significant from the first day after inoculation and persisted through day 10 (Table 2; Fig. 1). The day-10 ranking was the same at all three concentrations: control >

chlorantraniliprole > thiamethoxam > fipronil > bifenthrin > imidacloprid + fipronil > chlorpyriphos > imidacloprid 600 FS.

At 25% below the recommended concentration, the control colony reached 37.30 mm on day 10. Chlorantraniliprole 18.5 SC supported the most growth among the insecticides (31.20 mm), followed by thiamethoxam 30 FS (28.00 mm) and fipronil 5 SC (24.80 mm). Imidacloprid 600 FS (12.00 mm) and chlorpyriphos 20 EC (15.60 mm) were the most restrictive.

At the recommended concentration, growth on chlorantraniliprole (31.50 mm) and thiamethoxam (29.50 mm) remained close to the control (37.23 mm). Growth on chlorpyriphos and imidacloprid 600 FS was limited to 13.00 and 10.00 mm.

At 25% above the recommended concentration, chlorantraniliprole (29.50 mm) and thiamethoxam (27.50 mm) still allowed vigorous growth. Imidacloprid 600 FS reduced colonies to 7.50 mm, against 37.00 mm in the control. The colonies' appearance on day 10 (Fig. 4) matches these measurements. Colonies on chlorantraniliprole and thiamethoxam were large, sporulating and lobed. Those on chlorpyriphos, imidacloprid 600 FS and the imidacloprid + fipronil mixture was small and compact.

Table 2
Radial growth (mm) and conidial yield of M. anisopliae on PDA amended with insecticides at three concentrations

Concentration	Treatment	2 DAI	4 DAI	6 DAI	8 DAI	10 DAI	Conidia (1× 10^4/ml)
25% lower than recommended	T1 Bifenthrin 10 EC	5.80^{e}	10.00^{e}	14.60^{e}	19.10^{e}	23.50^{e}	2.10
	T2 Fipronil 5 SC	6.80^{c}	11.10^{c}	15.70^{c}	20.20^{c}	24.80^{d}	2.55
	T3 Chlorantraniliprole 18.5 SC	10.90^{b}	15.60^{b}	20.90^{b}	26.20^{b}	31.20^{b}	3.60
	T4 Chlorpyriphos 20 EC	2.80^{g}	5.90^{g}	9.10^{g}	12.40^{g}	15.60^{g}	0.70
	T5 Imidacloprid 600 FS	2.00^{h}	4.40^{h}	6.90^{h}	9.40^{h}	12.00^{h}	0.40
	T6 Thiamethoxam 30 FS	6.30^{d}	10.70^{d}	15.20^{d}	19.80^{d}	28.00^{c}	2.75
	T7 Imidacloprid 17.8 SL + Fipronil 5 SC	4.10^{f}	8.00^{f}	11.90^{f}	15.90^{f}	19.80^{f}	1.50
	T8 Control	14.50^{a}	19.20^{a}	25.50^{a}	31.30^{a}	37.30^{a}	4.80
	SEm ±	0.07	0.10	0.13	0.13	0.16	0.07
	CD (P = 0.05)	0.21	0.29	0.38	0.39	0.48	0.20
	CV (%)	4.61	5.14	5.68	5.21	5.72	6.98
Recommended concentration	T1 Bifenthrin 10 EC	5.00^{e}	8.80^{d}	12.90^{d}	17.10^{d}	21.20^{e}	1.80
	T2 Fipronil 5 SC	5.90^{c}	10.00^{c}	14.40^{c}	18.80^{c}	23.20^{d}	2.20
	T3 Chlorantraniliprole 18.5 SC	10.50^{b}	14.90^{b}	20.50^{b}	26.00^{b}	31.50^{b}	3.40
	T4 Chlorpyriphos 20 EC	2.20^{g}	4.80^{f}	7.50^{f}	10.30^{f}	13.00^{g}	0.50
	T5 Imidacloprid 600 FS	1.50^{h}	3.40^{g}	5.50^{g}	7.80^{g}	10.00^{h}	0.30
	T6 Thiamethoxam 30 FS	5.60^{d}	9.90^{c}	14.30^{c}	18.80^{c}	29.50^{c}	2.80
	T7 Imidacloprid 17.8 SL + Fipronil 5 SC	3.40^{f}	6.90^{e}	10.40^{e}	14.00^{e}	17.50^{f}	1.20

Concentration	Treatment	2 DAI	4 DAI	6 DAI	8 DAI	10 DAI	Conidia (1× 10^4/ml)
	T8 Control	14.44[a]	19.08[a]	25.31[a]	31.22[a]	37.23[a]	4.76
	SEm ±	0.06	0.09	0.12	0.13	0.15	0.06
	CD (P = 0.05)	0.19	0.28	0.36	0.38	0.47	0.19
	CV (%)	4.60	5.14	5.70	5.22	5.75	7.07
25% higher than recommended	T1 Bifenthrin 10 EC	4.20[d]	7.40[d]	11.00[d]	14.60[d]	18.20[e]	1.50
	T2 Fipronil 5 SC	4.90[c]	8.60[c]	12.50[c]	16.60[c]	20.70[d]	1.80
	T3 Chlorantraniliprole 18.5 SC	9.80[b]	13.80[b]	19.00[b]	24.20[b]	29.50[b]	3.00
	T4 Chlorpyriphos 20 EC	1.70[f]	3.80[f]	6.10[f]	8.30[f]	10.50[g]	0.35
	T5 Imidacloprid 600 FS	1.10[g]	2.50[g]	4.10[g]	5.80[g]	7.50[h]	0.20
	T6 Thiamethoxam 30 FS	4.80[c]	8.50[c]	12.70[c]	16.90[c]	27.50[c]	2.70
	T7 Imidacloprid 17.8 SL + Fipronil 5 SC	2.50[e]	5.20[e]	8.00[e]	10.80[e]	13.50[f]	0.90
	T8 Control	14.40[a]	19.00[a]	25.20[a]	31.00[a]	37.00[a]	4.75
	SEm ±	0.06	0.09	0.11	0.12	0.15	0.06
	CD (P = 0.05)	0.18	0.26	0.34	0.36	0.45	0.18
	CV (%)	4.65	5.18	5.72	5.24	5.78	6.87

DAI days after inoculation. Within a column and concentration, means followed by the same letter do not differ significantly (DNMRT, P = 0.05). Daily readings for days 1–10 are given in Fig. 1 *and Additional file 1: Tables S1–S3.*

Conidial yield

Conidial production was more sensitive to the insecticides than radial growth (Table 2; Fig. 2A). In the control, yield was 4.75–4.80 × 10^4 conidia/ml. Chlorantraniliprole 18.5 SC gave the highest yield among the insecticides at all concentrations: 3.60, 3.40 and 3.00 × 10^4 conidia/ml. Thiamethoxam 30 FS followed with 2.75, 2.80 and 2.70 × 10^4 conidia/ml; its yield stayed nearly constant across

concentrations. Imidacloprid 600 FS nearly suppressed conidiation (0.40, 0.30 and 0.20 × 10^4 conidia/ml). Chlorpyriphos 20 EC followed closely (0.70, 0.50 and 0.35 × 10^4 conidia/ml).

Growth inhibition, sporulation inhibition and compatibility class

Sporulation inhibition exceeded growth inhibition for every insecticide and concentration (Table 3; Fig. 3). With an 80% weight on sporulation in the Alves model, this gap determined each product's class.

- **Chlorantraniliprole 18.5 SC** caused the least inhibition: growth 15.39–20.27% and sporulation 25.00–36.84%. It was compatible at all concentrations (T = 76.73, 74.10 and 66.47).
- **Thiamethoxam 30 FS** was also compatible throughout (T = 60.85, 62.94 and 60.34). Its T value at the highest concentration lay close to the compatible/moderately toxic boundary.
- **Fipronil 5 SC** was moderately toxic at the lower and recommended concentrations (T = 55.80, 49.46) and became toxic at the higher one (T = 41.50).
- **Bifenthrin 10 EC** was moderately toxic at the lower concentration (T = 47.60) and toxic at the recommended and higher ones (T = 41.66, 35.10).
- **Imidacloprid 17.8 SL + fipronil 5 SC** was toxic at the lower concentration (T = 35.62) and highly toxic at the recommended and higher ones (T = 29.58, 22.46).
- **Chlorpyriphos 20 EC** (T = 11.57–20.03) and **imidacloprid 600 FS** (T = 7.42–13.10) were highly toxic at every concentration. Imidacloprid 600 FS inhibited sporulation by 91.67–95.79%.

Table 3
Growth inhibition, sporulation inhibition, toxicity index (T) and compatibility class of insecticides towards M. anisopliae on day 10

Treatment	Concentration	Growth inhibition (%)	Sporulation inhibition (%)	T	Class
T1 Bifenthrin 10 EC	25% lower	37.00	56.25	47.60	Moderately toxic
	Recommended	43.06	62.16	41.66	Toxic
	25% higher	50.81	68.42	35.10	Toxic
T2 Fipronil 5 SC	25% lower	33.51	46.88	55.80	Moderately toxic
	Recommended	37.68	53.75	49.46	Moderately toxic
	25% higher	44.05	62.11	41.50	Toxic
T3 Chlorantraniliprole 18.5 SC	25% lower	16.35	25.00	76.73	Compatible
	Recommended	15.39	28.52	74.10	Compatible
	25% higher	20.27	36.84	66.47	Compatible
T4 Chlorpyriphos 20 EC	25% lower	58.18	85.42	20.03	Highly toxic
	Recommended	65.08	89.49	15.39	Highly toxic
	25% higher	71.62	92.63	11.57	Highly toxic
T5 Imidacloprid 600 FS	25% lower	67.83	91.67	13.10	Highly toxic
	Recommended	73.14	93.69	10.42	Highly toxic
	25% higher	79.73	95.79	7.42	Highly toxic
T6 Thiamethoxam 30 FS	25% lower	24.93	42.71	60.85	Compatible
	Recommended	20.76	41.14	62.94	Compatible
	25% higher	25.68	43.16	60.34	Compatible
T7 Imidacloprid 17.8 SL + Fipronil 5 SC	25% lower	46.92	68.75	35.62	Toxic
	Recommended	52.99	74.77	29.58	Highly toxic
	25% higher	63.51	81.05	22.46	Highly toxic

*T = [20(VG) + 80(SP)]/100, with VG and SP as % of control (*Alves et al. 1998). *Classes: highly toxic (0–30), toxic (31–45), moderately toxic (46–60), compatible (> 60).*

Discussion

The seven termiticides differed widely in their effect on *M. anisopliae*. T values ranged from 7.42 for imidacloprid 600 FS to 76.73 for chlorantraniliprole 18.5 SC. Only chlorantraniliprole and thiamethoxam stayed compatible across a 1.67-fold concentration range. For every product, sporulation was inhibited more than radial growth, confirming that conidiation is the more sensitive trait (Silva et al. 2013; Schumacher and Poehling 2012). This matters in practice. Conidia are the infective units that spread the fungus within a termite colony through grooming and contact. A product that lets mycelium grow but suppresses conidiation can still disable the biocontrol agent. This is why the Alves et al. (1998) model gives sporulation 80% of the weight.

Chlorantraniliprole was the least harmful insecticide. Its target, the insect ryanodine receptor, has no counterpart in fungal cells, which may explain why mycelial growth was barely affected. Patil et al. (2025) likewise found chlorantraniliprole 18.5 SC to be the most compatible insecticide with *M. anisopliae*, at par with the fungus alone, and its combination with the fungus at half the field dose killed all *Spodoptera litura* larvae. However, insecticides can reduce *M. anisopliae* conidial germination even when colony growth is little affected (Schumacher and Poehling 2012). Germination was not measured here and should be included in follow-up work.

Thiamethoxam was compatible at all doses. This agrees with Batista Filho et al. (2001), Niassy et al. (2012) and Silva et al. (2013). Tang et al. (2019) found that thiamethoxam combined with *M. anisopliae* shortened the median lethal time of rice planthoppers and controlled them better in the field. This makes thiamethoxam seed treatment a strong candidate partner for soil application of the fungus in wheat. Its conidial yield also stayed almost constant across concentrations (2.70–2.80 × 10^4 conidia/ml). Normal field variation in dose is therefore unlikely to change its compatibility.

Imidacloprid gave contrasting results depending on formulation. Imidacloprid 600 FS was the most toxic product at all three concentrations, inhibiting sporulation by more than 91%. Imidacloprid 17.8 SL, the formulation most often tested, has been reported as compatible or only mildly toxic (Niassy et al. 2012; Nawaz et al. 2022). Two factors may explain the difference. First, the FS concentrations tested gave far more active ingredient per millilitre of medium than SL formulations at their spray rates. Second, FS products contain dispersants, binders, polymers and colourants that can be fungitoxic in their own right. Anderson and Roberts (1983) showed that the formulation can matter more to entomopathogen compatibility than the active ingredient. Batista Filho et al. (2001) and Akbar et al. (2012) also reported that imidacloprid strongly suppressed conidial production even when growth was little affected. The ready mix of imidacloprid 17.8 SL + fipronil 5 SC was toxic to highly toxic, consistent with additive effects of its two components.

Chlorpyriphos 20 EC was highly toxic at all three doses. Organophosphates and their emulsifiable concentrate formulations are consistently among the most fungitoxic insecticides tested against *M. anisopliae* (Asi et al. 2010; Akbar et al. 2012). The solvents and emulsifiers in EC formulations add to the effect of the active ingredient. The pyrethroid **bifenthrin 10 EC** was moderately toxic to toxic, also an EC.

Fipronil 5 SC was moderately toxic at and below the recommended rate, and toxic above it. This matches the dose-dependent inhibition reported by Rashid et al. (2010) and Schumacher and Poehling (2012). Fipronil at a sub-lethal dose has nevertheless acted synergistically with *M. anisopliae* against the subterranean termite *C. curvignathus* (Yii et al. 2016). Fipronil may therefore still be combined with the fungus at reduced rates, provided field efficacy is confirmed.

For every insecticide, compatibility fell as concentration rose, and the 25% lower dose was the least harmful. This supports reduced-dose combinations, in which a sub-lethal insecticide stresses the termites and the fungus completes the kill (Hokkanen and Kotiluoto 1992; Neves et al. 2001). Such combinations have improved control of lepidopteran pests compared with either agent alone (Dev et al. 2021; Atrchian and Mahdian 2022).

The poisoned food technique is a worst-case test. The fungus is in continuous, direct contact with the insecticide in a nutrient medium. In soil, adsorption, dilution, degradation and the physical separation of seed-applied insecticide from a fungus applied in a carrier all reduce exposure. Products classed as compatible in vitro are therefore very likely to be safe in the field. Those classed as toxic need field testing before they are ruled out (Alves et al. 1998). This study tested one isolate and did not assess conidial germination or virulence after exposure. Insecticide exposure can deform conidia and reduce their germination and cuticle penetration even when colonies grow (Sharma and Joshi 2022). Soil microcosm and termite bioassays of the most promising combinations are the next step.

In practice, these results suggest that wheat seed treated with thiamethoxam 30 FS or chlorantraniliprole can be combined with soil application of *M. anisopliae* enriched in organic carriers such as neem cake or vermicompost (Patel et al. 2022) to manage termites. Imidacloprid 600 FS and chlorpyriphos 20 EC should not be used in the same furrow or at the same time as the fungus.

Conclusions

Chlorantraniliprole 18.5 SC and thiamethoxam 30 FS were compatible with *M. anisopliae* at 25% below, at and 25% above their recommended concentrations. They are the preferred chemical partners for the fungus in termite management in wheat. Fipronil 5 SC and bifenthrin 10 EC were moderately toxic to toxic and may be used only at reduced rates or separated from the fungus in time. Chlorpyriphos 20 EC, imidacloprid 600 FS and the imidacloprid 17.8 SL + fipronil 5 SC ready mix were toxic to highly toxic. They should not be applied together with *M. anisopliae*. These in vitro rankings should next be validated in soil and in termite bioassays.

Abbreviations

ANOVA
analysis of variance
CD
critical difference

CV
coefficient of variation
DAI
days after inoculation
DNMRT
Duncan’s new multiple range test
EC
emulsifiable concentrate
FS
flowable concentrate for seed treatment
PDA
potato dextrose agar
PGI
per cent growth inhibition
SC
suspension concentrate
SEm
standard error of the mean
SL
soluble liquid
SP
sporulation
T
toxicity index
VG
vegetative growth

Declarations

Consent for publication: Not applicable.

Competing interests: The authors declare that they have no competing interests.

Author Contribution

RY conducted the experiments, analysed the data and drafted the manuscript. PSP conceived and supervised the study and revised the manuscript. NPP and RDD guided the mycological work. KS and PY contributed to the experimental design and revised the manuscript. All authors read and approved the final manuscript.

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Figures

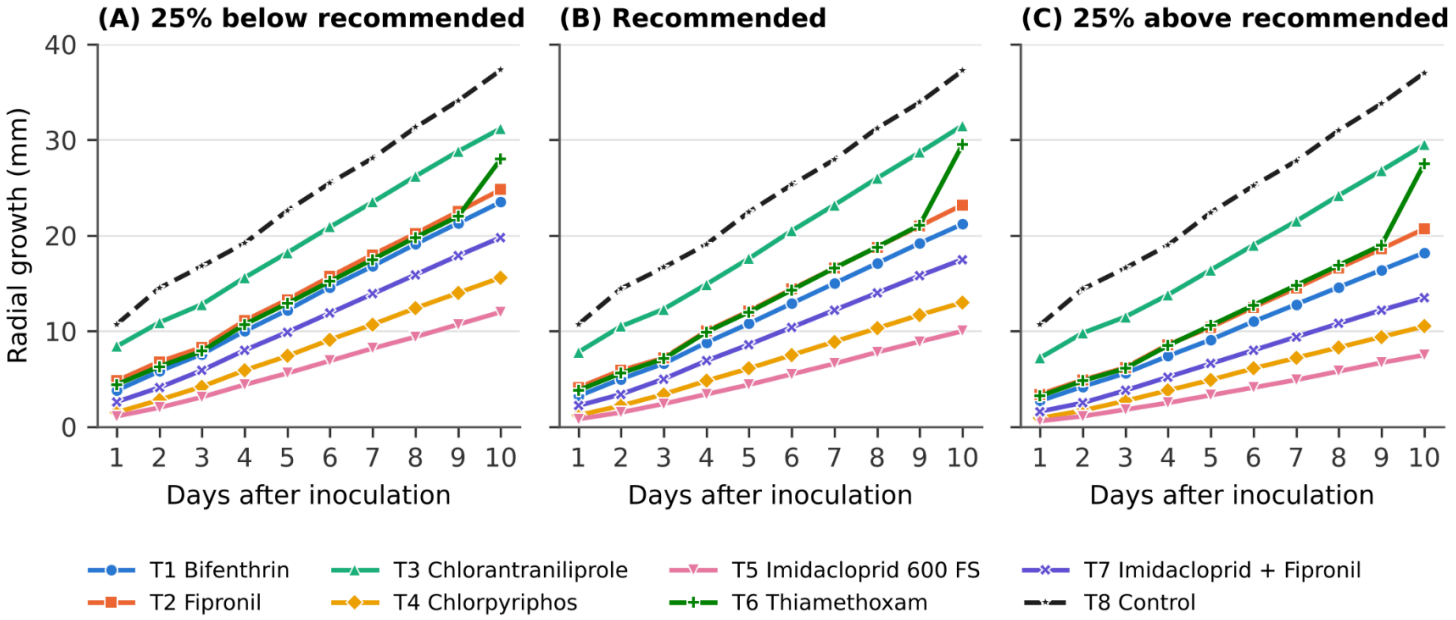

Figure 1

Radial growth (mm) of Metarhizium anisopliae on PDA amended with seven insecticides over 10 days after inoculation, at (A) 25% below, (B) at and (C) 25% above the recommended concentration. T8 = untreated control. Points are means of three replicates.

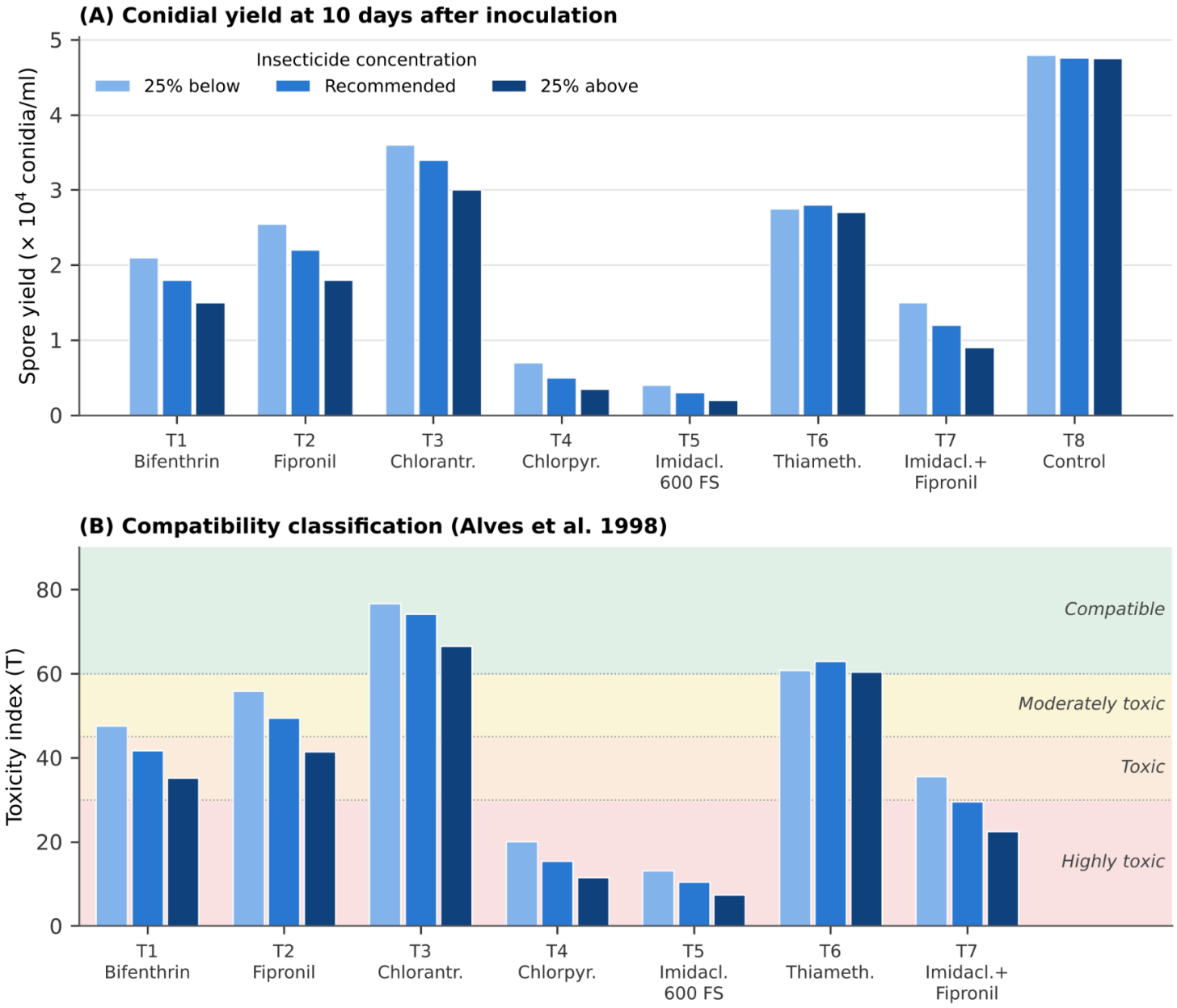

Figure 2

(A)*Conidial yield (× 10⁴ conidia/ml) of M. anisopliae on day 10, and* ***(B)****toxicity index (T) of each insecticide at three concentrations. Shaded bands mark the compatibility classes of Alves et al. (1998).*

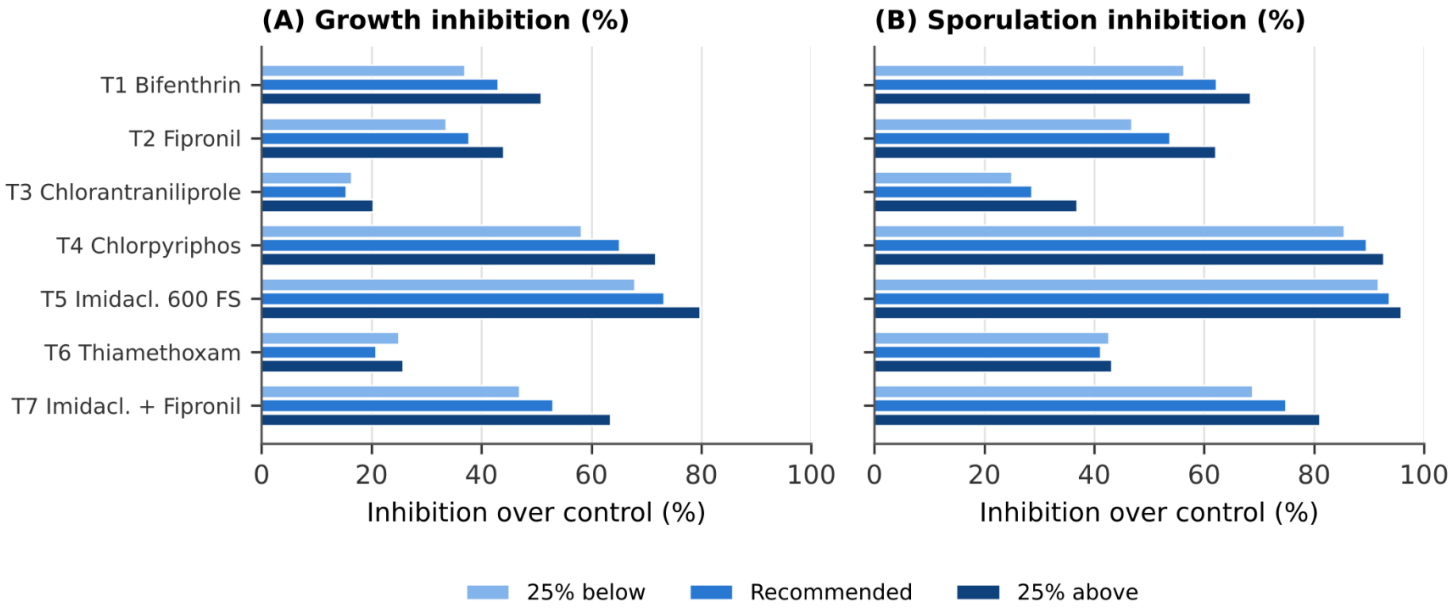

Figure 3

Per cent inhibition of (A) radial growth and (B) sporulation of M. anisopliae relative to the untreated control on day 10, at three insecticide concentrations.

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