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Entomopathogenic fungi, *Metarhizium anisopliae* as a chemical substitute for termite pest management in sugarcane

D. Sudha Rani*, **K. Krishnamma and J. S. Rani**

Sugarcane Research Station (Acharya N G Ranga Agricultural University), Vuyyuru-521 165, India

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***Corresponding Author Email :** d.sudharani@angrau.ac.in ***ORCiD:** https://orcid.org/0000-0002-8705-8621

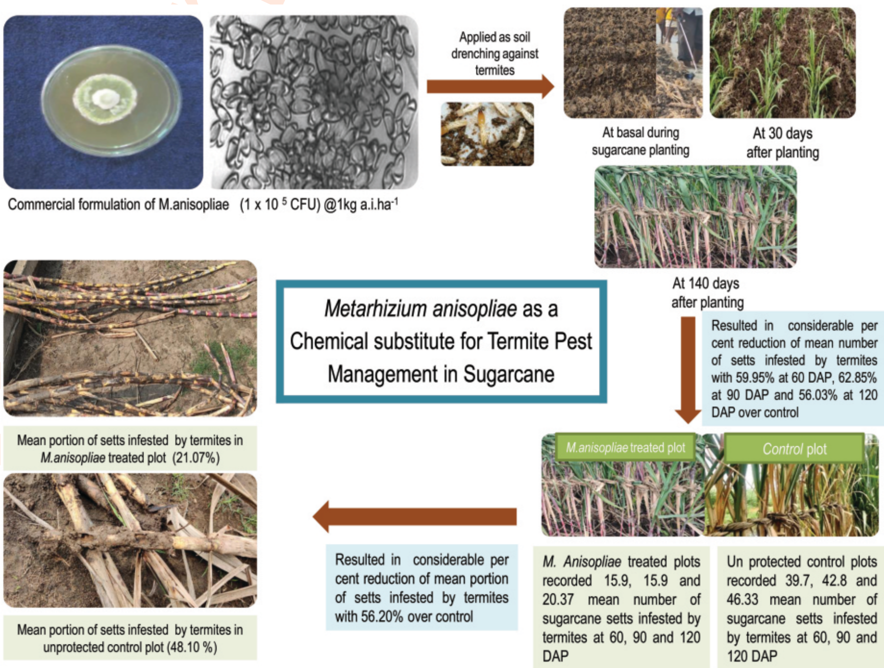
Abstract

Aim: The present research study was undertaken to assess the efficacy of microbial and natural origin bio-pesticides in comparison to chemical control against termites infesting sugarcane.

Methodology: Field trials were executed for a period of three successive seasons *i.e.,* 2019-20, 2020-21 and 2021-22 at Sugarcane Research Station, Vuyyuru, Krishna district, Andhra Pradesh. The experiment was laid out in randomized block design with seven treatments replicated thrice and imposed the treatments as per protocol. A set of four bio-pesticides (*Beauveria bassiana*, *Metarhizium anisopliae*, *Bacillus thuringiensis* and Azadirachtin) and two insecticides (Imidacloprid and Bifenthrin) were evaluated for their efficacy against termite infestation in terms of both mean number of sugarcane setts infested and mean portion of setts infested by termites.

Results: The chemicals imidacloprid and bifenthrin had registered highest per cent reduction of termite infestation over control. However, the biopesticides, *Metarhizium anisopliae* had registered least per cent reduction of mean number of setts infested with 59.95 at 60 DAP, 62.85 at 90 DAP and 56.03 at 120 DAP and mean portion of setts infested with termite was 56.20 per cent. With respect to yield also the chemical treatments *viz.,* imidacloprid and bifenthrin had recorded higher yields with pooled mean of 77.33 and 76.78 t ha^{-1}, followed by *M. anisopliae* with 73.94 t ha^{-1}.

Interpretation: Even though the chemical based treatments were found superior in reducing termite infestation, entomopathogenic fungi, *M. anisopliae* as biopesticide also attributed better results with regard to suppression of termite infestation and can be suggested as alternative or substitution to chemical based management.



Key words: Chemical control, Entomopathogenic fungi, *Metarhizium*, Sugarcane, Termites

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Introduction

Sugarcane is the most important cash crop with vast global market for sugar besides, by products and derivatives. The crop has occupied premeditated position in the world because of its massive uses in the day-to-day life and also for industrial uses intended at nutritional and economic sustenance. It endows raw material to major agro-based industries of our country, *i.e.,* the sugar industry supports rural cottage industries to some extent (Sudha and Krishnamma, 2020). The average annual production of sugarcane is around 35.5 crore tonnes which is used to produce around 3 crore tonnes of sugar. In India sugarcane contributes about five per cent to the total value of agriculture output accounting 2.6 per cent of gross cropped area (Rama Rao, 2020). Sugarcane accounted for about 639 billion Indian rupees in the Indian economy during the financial year 2020 (Keelery, 2023). Sugarcane accounted for about 648 billion Indian rupees in the Indian economy during the financial year 2019-20 (Singh *et al*., 2022). In India sugarcane contributes 1.1 per cent to the national GDP, which is significant considering that the crop is grown only in 2.57 percent of the gross cropped area (Solomon, 2016). Andhra Pradesh state accounts nearly 8.4 per cent of total sugarcane production in our country, being cultivable in 85,994 ha with an out turn of 8,35,520 tonnes during the year 2020 (Sudha, 2022).

Sugarcane crop is infested by more than 200 insect pests and is also bestowed with adequate natural enemy fauna (both the predators and parasitoids) because of its long duration, luxuriant vegetation and congenial micro climate for fast completion of life cycles for natural enemies (Sudha, 2022). Early shoot borer, internode borer and scale insect infestation in sugarcane are considered as endemic pests in Andhra Pradesh, India. However, sugarcane crop grown in loamy sand or sandy loam soils, termite attack is one of the deleterious damage to crop right from planting till harvest resulting in yield loss of 15-43 per cent (Sattar and Saliha, 2001). Termite is a perennial problem in most of the sugarcane growing areas due to the attack of *Odontotermes obesus* (Ramb.) and *Microtermes obesi* (Holgren) damaging the setts, shoots, cane and also stubbles. Termites attack the roots and stems of the plant and disrupts the translocaton of water and essential nutrients from the soil leading to death of the plant. Termite damage on sugarcane setts results in death of buds and young seedlings (Koto *et al.,* 2000). Termite may attack any part of sett, but in the hard rinded varieties, they prefer to attack the ends, eye buds and root bands (Choudhary *et al.,* 1986; Mill, 1996). Due to termite infestation the sett infestation may be up to 50 per cent and the infestation in standing crop may vary from 10-20 per cent (Bhattacharya *et al.,* 2014).

Studies of Wright *et al.* (2005) inferred that a single fungal isolate, C4-B, taxonomically identified as *Metarhizium anisopliae* (Metschnikoff), was found to cause rapid mortality of Formosan subterranean termite alates (first report of a biological control agent for termite alates). Field experiments by Maniania *et al.* (2002) stated that granular formulation of *M. anisopliae* is a useful option for the management of termites in maize ecosystem. Direct application of *M. anisopliae* fungi to termite nests had resulted in complete colony mortality, but studies where feeding sites or bait stations have been treated with fungus exhibited partial success rate in termite management (Andrew, 2000). Richard (2000) in his review paper clearly indicated, *Metarhizium* as a mycoinsecticide against termites. Nyam *et al.* (2021) inferred that to knock out the entire population of termites baits usage acts as smart missiles and among various bait matrixes, matrix made of dextrin, PVP K 90 and skim milk (DPS) was found effective. DPS bait impregnated with M. anisopliae resulted closed to 100% mortality of subterranean termite, *Coptotermes curvignathus* (Holmgren) in 19 days. Farmers rely simply on chemical insecticides and apply lethal or sub lethal doses and combinations for suppressing pest infestation that upshots adverse effects on the environment sourcing ecological imbalance besides health related tribulations. The studies on efficacy of bio-pesticides against the targeted pest are the need of the hour as they are risk-free, target oriented, economically feasible and effective. In view of the deleterious consequences of indiscriminate use of pesticides and the potential benefits of bio-pesticides, especially Metarhizium against termites, the present study was undertaken with an aim to evaluate the efficacy of various bio-pesticides in suppressing the termite infestation in sugarcane. In sugarcane, recommendation of bio based products against termites are meager, hence, field studies in termite infested plots for 2-3 consecutive seasons were undertaken to evaluate their efficacy.

Materials and Methods

Experimentation site, duration and objective: The field trial was executed at Sugarcane Research Station, Vuyyuru for a period of three successive seasons viz., 2019-20, 2020-21 and 2021-22 to evaluate the efficacy of pesticides of microbial and natural origin compared to chemical insecticides in suppressing the termite population and infestation in sugarcane crop. The popular sugarcane variety 2003V46 (Bharani) was used for experimentation with a plot of 6.0 m x 7.0 m (42 sq. m.) per replication and the spacing adopted was 80 cm x 30cm.

Design and experimental layout: The experiment was laid out in randomized block design with seven treatments *viz., Beauveria bassiana* (4.5 x 10^{11} CFU) @1kg a.i. ha^{-1}, Metarhizium anisopliae (1 x 10^{5} CFU) @1kg a.i. ha^{-1}, *Bacillus thuringiensis* (1 x 10^{9} CFU) @1kg a.i. ha^{-1}, Azadirachtin 10000 ppm @ 1000 ml ha^{-1}, Imidacloprid 17.8 SL @ 350 ml ha^{-1}, Bifenthrin 10% EC @1000 ml ha^{-1} and untreated control that were replicated thrice. The commercially available bio-pesticides were used for experimentation (Table 1). The treatments were imposed as soil drenching at basal, 30 and 140 days after plantings as per the standard recommendations.

Data recording: The data on termite incidence pertaining to mean number of setts infested in each plot were recorded at 60, 90 and 120 days after planting and mean portion of setts infested (at the time of harvest through destructive sampling) and per cent efficacy of bio-pesticides over control were recorded as per the formulae given below.

$$\text{Mean number of setts infested (\%)} = \frac{\text{Number of infested setts}}{\text{Total number of setts in each treatment}} \times 100$$

$$\text{Mean portion of setts infested (\%)} = \frac{\text{Length of infested setts}}{\text{Total length of setts in each treatment}} \times 100$$

$$\text{Per cent reduction over control} = \frac{\text{Termite infestation in untreated control} - \text{termite infestation in treatment}}{\text{Termite infestation in untreated control}} \times 100$$

Cane yield (t ha^{-1}): The plot wise yield of various treatments in three replications was recorded and the yield per plot was calculated and converted to tonnes per hectare. The quality parameters like per cent brix, sucrose and purity of sugarcane juice in each treatment was assessed through sucrolyzer.

Statistical analysis: The recorded data was subjected to SPSS (Statistical Package for Social Sciences) based statistical analysis after suitable transformations and the significant differences in mean incidence of termite pest as influenced by various insecticides were separated using Duncan's Multiple Range Test (P= 0.05).

Results and Discussion

The data on mean portion of sugarcane setts infested by termites was recorded at 60, 90 and 120 DAP as influenced by various bio-pesticides compared to chemical control. Similarly mean portion of setts infested by sugarcane was also assessed through destructive sampling at the time of harvest in each treatment. The mean numbers of sugarcane setts infested by termites at 60 DAP ranged from 14.0 to 40.5 per cent. Among all the biopesticides evaluated, *M. anisopliae* registered low per cent infestation of 17.8, 16.5 and 13.5 mean number of setts infested during 2019-20, 2020-21 and 2021-22, respectively. However, the chemicals *viz.,* bifenthrin 10% EC @ 1000 ml ha^{-1} and imidacloprid 17.8 SL @ 350 ml ha^{-1} had recorded comparatively lower termite infestation with 14.8, 14.5 & 14.0 and 12.2, 13.8 and 11.5 during 2019-20, 2020-21 and 2021-22, respectively.

The other pesticides of microbial origin *viz., Beauveria* and *Bacillus* recorded less than 50 per cent control. The average mean number of setts infested by termites during study period indicated that, among all the treatments, bifenthrin 10.% EC recorded lowest infestation (12.50) followed by imidacloprid 17.8 SL (14.4), *M. anisopliae* (15.9), *B. thurungenesis* (23.6), *B. bassiana* (24.9), Azadirachtin 10000 ppm (26.7) as against highest in untreated control (39.7). The per cent reduction of termite infestation over control in descending order is as follows: bifenthrin (68.51) > imidacloprid (63.73) > *M. anisopliae* (59.95) > *B. thuringiensis* (40.55) > *B. bassiana* (37.28) > Azadirachtin (32.75) (Table 2). The mean number of sugarcane setts infested by termites at 90 DAP had ranged from 12.50 to 43.5 per cent. Similar trend was observed as in case at 60 DAP where in, *M. anisopliae* recorded least per cent infestation among all bio-pesticides evaluated with 20.7, 14.3 and 12.8 mean number of setts infested during 2019-20, 2020-21 and 2021-22, respectively with an average mean of 15.9 per cent. The highest per cent reduction over control was recorded in case with chemicals imidacloprid 17.8 SL and bifenthrin 10% EC which had recorded comparatively lower termite infestation with 13.8, 12.2 and 11.5 and 13.8, 14.0 and 14.8 during 2019-20, 2020-21 and 2021-22, respectively. The average mean number of setts infested by termites as influenced by other biopesticides during study period clearly depicted less than 40 per cent reduction over control with 30.5, 26.3 and 28.5 per cent infestation in *B. bassiana, B. thuringiensis* and Azadirachtin treated plots respectively recording only 28.74, 38.55 and 33.41 per cent reduction over control, respectively. The highest termite infestation was recorded in untreated control with 42.5, 43.5 and 42.5 mean number of setts infested by termites during 2019-20, 2020-21 and 2021-22, respectively, with an average mean of 42.8 per cent. The per cent reduction of termite infestation over control was highest in imidacloprid treated plots with 70.79 per cent, followed by bifenthrin (66.82)>*M. anisopliae* (62.85)>*B. thuringiensis* (38.55)> Azadirachtin (33.41)>*B. bassiana* (28.74) (Table 3).

Similar results were noticed at 120 DAP where in the chemical treatment with imidacloprid (16.8, 15.4 and 12.8) and

Table 1: Details of bio pesticides and insecticides evaluated against termites in sugarcane

Technical Name	Trade Name	Formulation	Dose ai ha^{-1}	Source of supply
Beauveria bassiana (Strain: IPL/BB/MI/01)	Daman	1.0% WP	4.5 x 10^{11} CFU	M/s International Panaacea Ltd, Gurgaon, New Delhi
Metarhizium anisopliae (Strain:IPL/KC/44)	Biomet	1.0% WP	1 x 10^{5} CFU	M/s Biotech international Ltd, New Delhi
Bacillus thuringiensis var. kurstaki (strain: Z-52, serotype H-3a, 3b)	Biolep	1.0% WP	1x10^{9} CFU	M/s Biotech international Ltd, New Delhi
Azadirachtin	Econeem	10000 ppm	1000 ml	M/s Margo Biocontrols Private, Limited, Bangalore
Imidacloprid	Media	17.8 SL	350 ml	M/s Dhanuka Agritech Ltd., Haryana
Bifenthrin	cofenrin	10% EC	1000 ml	M/s Rainbow Agro Sciences Pvt.Ltd, Ahmedabad

Table 2: Efficacy of bio-pesticides in comparison to chemical control in suppressing termite infestation in terms of mean number of setts infested at 60 DAP

Treatments	Per cent termite infestation				
	*Mean number of setts infested at 60 DAP			Mean	Reduction over control (%)
	2019-20	2020-21	2021-22		
T_1 : *Beauveria bassiana* (4.5 x 10^{11} CFU) @ 1kg a.i. ha^{-1}	23.5 (29.0)^{b}	24.5 (29.67)^{b}	26.7 (31.11)^{c}	24.9 (29.93)	37.28
T_2 : *Metarhizium anisopliae* (1 x 10^5 CFU) @ 1kg a.i. ha^{-1}	17.8 (24.95)^{a}	16.5 (23.97)^{a}	13.5 (21.56)^{a}	15.9 (23.50)	59.95
T_3 : *Bacillus thuringiensis* (1 x 10^9 CFU) @ 1kg a.i. ha^{-1}	20.8 (27.13)^{b}	25.5 (30.33)^{b}	24.5 (29.67)^{c}	23.6 (29.06)	40.55
T_4 : Azadirachtin 10000ppm @ 1000 ml ha^{-1}	22.5 (28.32)^{b}	28.2 (32.08)^{b}	29.5 (32.90)^{b}	26.7 (31.11)	32.75
T_5 : Imidacloprid 17.8 SL @ 350ml ha^{-1}	14.8 (22.63)^{a}	14.5 (22.38)^{a}	14.0 (21.97)^{ab}	14.4 (22.30)	63.73
T^6 : Bifenthrin 10% EC @ 1000 ml ha^{-1}	12.2 (20.44)^{a}	13.8 (21.81)^{a}	11.5 (19.82)^{a}	12.5 (20.70)	68.51
T^7 : Untreated control	38.5 (38.35)^{c}	40.5 (38.35)^{c}	40.0 (39.23)^{d}	39.7 (39.06)	-
CD(p=0.05)	2.14	2.35	2.57	2.4	-
CV	14.8	15.8	16.3	15.6	-

*Mean of three replications; Values in parentheses are arc sine transformations

Table 3: Efficacy of biopesticides in comparison to chemical control in suppressing termite infestation in terms of mean number of setts infested at 90 DAP

Treatments	Per cent termite infestation				
	*Mean number of setts infested at 90 DAP			Mean	Reduction over control (%)
	2019-20	2020-21	2021-22		
T_1 : *Beauveria bassiana* (4.5 x 10^{11} CFU) @ 1kg a.i. ha^{-1}	31.5 (34.14)^{d}	30.5 (33.52)^{c}	29.5 (32.90)^{b}	30.5 (33.52)	28.74
T_2 : *Metarhizium anisopliae* (1 x 10^5 CFU) @ 1kg a.i. ha^{-1}	20.7 (27.06)^{b}	14.3 (22.22)^{a}	12.8 (20.96)^{a}	15.9 (23.50)	62.85
T_3 : *Bacillus thuringiensis* (1 x 10^9 CFU) @ 1kg a.i. ha^{-1}	23.5 (29.00)^{b}	28.6 (32.33)^{b}	26.8 (31.18)^{b}	26.3 (30.85)	38.55
T_4 : Azadirachtin 10000ppm @ 1000 ml ha^{-1}	27.5 (31.63)^{cd}	28.0 (31.95)^{bc}	30.0 (33.21)^{b}	28.5 (32.27)	33.41
T_5 : Imidacloprid 17.8 SL @ 350ml ha^{-1}	13.8 (21.81)^{a}	12.2 (20.44)^{a}	11.5 (19.82)^{a}	12.5 (20.70)	70.79
T_6 : Bifenthrin 10% EC @ 1000 ml ha^{-1}	13.8 (21.81)^{a}	14.0 (21.97)^{a}	14.8 (22.63)^{a}	14.2 (22.14)	66.82
T_7 : Untreated control	42.5 (40.69)^{e}	43.5 (41.27)^{d}	42.5 (40.69)^{c}	42.8 (40.86)	
Sem	3.04	0.98	0.85		
CD(p=0.05)	3.04	2.97	3.08	3.0	
CV	13.5	21.6	18.9	18.0	

*Mean of three replications; Values in parentheses are arc sine transformations

bifenthrin (14.3, 11.5 and 18.1) recorded lowest termite infestation in relation to mean number of setts as against highest in untreated control (45.0, 47.2 and 46.8) during 2019-20, 2020-21 and 2021-22, respectively. Among the biopesticides, *M. anisopliae* had registered highest per cent reduction (56.03) of mean number of setts infested with termites over control recording 24.5, 20.1 and 16.5 per cent termite infestation during 2019-20, 2020-21 and 2021-22, respectively. The pooled

Table 4: Efficacy of biopesticides in comparison to chemical control in suppressing termite infestation in terms of mean number of setts infested at 120 DAP

Treatments	Per cent termite infestation				
	*Mean number of setts infested at 120 DAP			Mean	Reduction over control (%)
	2019-20	2020-21	2021-22		
T_1 : *Beauveria bassiana*	35.5	32.4	31.8	33.23	28.28
(4.5×10^{11} CFU) @ 1kg a.i. ha^{-1}	(36.57)^{d}	(34.70)^{d}	(34.33)^{d}	(35.20)	
T_2 : *Metarhizium anisopliae*	24.5	20.1	16.5	20.37	56.03
(1×10^{5} CFU) @ 1kg a.i. ha^{-1}	(29.67)^{b}	(26.64)^{b}	(23.97)^{b}	(26.83)	
T_3 : *Bacillus thuringiensis*	29.5	31.0	32.0	30.83	33.46
(1×10^{9} CFU) @ 1kg a.i. ha^{-1}	(32.90)^{c}	(33.83)^{c}	(34.45)^{c}	(33.73)	
T_4 : Azadirachtin 10000ppm	29.5	32.5	34.5	32.17	30.56
@ 1000 ml ha^{-1}	(32.90)^{c}	(34.76)^{c}	(35.97)^{c}	(34.55)	
T_5 : Imidacloprid 17.8 SL	16.8	15.4	12.8	15.00	67.62
@ 350ml ha^{-1}	(24.20)^{a}	(23.11)^{a}	(20.96)^{a}	(22.79)	
T_6 : Bifenthrin 10% EC	14.3	11.5	18.1	14.78	68.10
@ 1000 ml ha^{-1}	(22.22)^{b}	(19.82)^{a}	(25.14)^{a}	(22.61)	
T_7 : Untreated control	45.0	47.2	46.8	46.33	-
	(42.13)^{e}	(43.39)^{e}	(43.17)^{e}	(42.90)	
Sem	1.85	2.14	1.18	1.72	
CD(p=0.05)	21.8	1.55	2.81	8.72	
CV	2.35	18.5	13.4	11.42	

*Mean of three replications; Values in parentheses are arc sine transformations

average mean number of setts infested by termites at 120 DAP in ascending order is as follows: bifenthrin (14.78) < imidacloprid (15.00) < *M. anisopliae* (20.37) < *B. thuringiensis* (30.83) < Azadirachtin (32.17) < *B. bassiana* (33.23) recording 68.10, 67.62, 56.03, 33.46, 30.56 and 28.28 per cent reduction over control, respectively (Table 4). The cumulative mean efficacy of bio-pesticides in comparison to chemical control in suppressing termite infestation in terms of mean number of setts clearly elucidated that *M. anisopliae* treated plots had registered per cent reduction of termite infestation ranging between 56.03 to 62.85 and the chemical treatments ranged between 63.73 to 70.79 and 66.82 to 68.51 with respect to imidacloprid and bifenthrin, respectively.

At the time of harvest destructive sampling was made and the per cent termite infestation as influenced by biopesticides and chemicals imposition in terms of mean portion of setts infested (Table 5). Among all the treatments, imidacloprid treated plots showed less infestation level, followed by bifenthrin chemical treated plots during 2019-20, 2020-21 and 2021-22 with an average mean of 16.77 and 18.70 per cent, respectively. *M. anisopliae* had registered more than 56.20 per cent reduction of termite infestation over control registering 19.2, 23.5 and 20.5 mean portion of setts infested during 2019-20, 2020-21 and 2021-22 with an average mean of 21.07 per cent. The highest infestation was noticed in case with untreated control with an average mean of 48.10 mean portions of setts infested. The pooled average mean portion of setts infested by termites was in the order: imidacloprid (16.77) < bifenthrin (18.70) < *M. anisopliae* (21.07) < *B. bassiana* (27.50) < *B. thuringiensis* (31.33) < Azadirachtin (33.63) recording 65.14, 61.12, 56.20, 42.83, 34.86 and 30.08 per cent reduction over control, respectively.

The influence of various treatments on sugarcane yield was recorded and the pooled mean yield data for three successive season's data is depicted in Table 6. All the treatments exhibited significant superiority over control and showed the following trend. Imidacloprid > bifenthrin > *M. anisopliae* > *B. bassiana* > *B. thuringiensis* > Azadirachtin > untreated control. The per cent sucrose data (pooled mean of three seasons) had varied among treatments, however, all were found on par to each other, except control. The highest per cent sucrose (20.27) was noticed in Azadirachtin treated plots, followed by imidacloprid (19.77) as against lowest in per cent untreated control (18.97).

The results clearly signified the bioefficacy of Metarhizium against sugarcane termites and are in accordance with the reports of Kimberly and Seow (2017) who reported *Metarhizium* as potential biocontrol control agents against agricultural pests, termites and biological vectors. Deka *et al.* (2021) inferred the potential of entomopathogenic fungi, *M. anisopliae* against termites infesting tea crop and found it to be effective in managing the pest, besides no phytotoxic effect on tea leaves, and with acceptable organoleptic attributes. Mishra *et al.* (2021) in their review on biological approaches for termite management clearly indicated *Metarhizium* as microbial based antagonist and termitoxicant. Similarly, Nichanun *et al.* (2018) confirmed that of the aqueous suspension *M. anisopliae* containing 10^{8} conidia ml^{-1} infected and killed the Sugarcane

Table 5: Efficacy of biopesticides in comparison to chemical control in suppressing termite infestation in terms of mean portion of setts infested

Treatments	Per cent termite infestation				
	*Mean number of setts infested			Mean	Reduction over
	2019-20	2020-21	2021-22		
T_1 : *Beauveria bassiana* (4.5 x 10^{11} CFU) @ 1kg a.i. ha^{-1}	22.1 (28.04)^{c}	30.8 (33.71)^{c}	29.6 (32.96)^{c}	27.50 (31.63)	42.83
T_2 : *Metarhizium anisopliae* (1 x 10^{5} CFU) @ 1kg a.i. ha^{-1}	19.2 (26.71)^{b}	23.5 (29.00)^{b}	20.5 (26.92)^{b}	21.07 (27.32)	56.20
T_3 : *Bacillus thuringiensis* (1 x 10 9 CFU) @ 1kg a.i. ha^{-1}	25.4 (30.26)^{d}	33.7 (35.49)^{c}	34.9 (36.21)^{c}	31.33 (34.04)	34.86
T_4 : Azadirachtin 10000ppm @ 1000 ml ha^{-1}	28.5 (32.27)^{e}	35.6 (36.63)^{c}	36.8 (37.35)^{c}	33.63 (35.44)	30.08
T_5 : Imidacloprid 17.8 SL @ 350ml ha^{-1}	13.5 (21.56)^{a}	19.3 (26.06)^{a}	17.5 (24.73)^{a}	16.77 (24.17)	65.14
T_6 : Bifenthrin 10% EC @ 1000 ml ha^{-1}	18.7 (25.62)	18.5 (25.47)^{a}	18.9 (25.77)^{a}	18.70 (25.62)	61.12
T_7 : Untreated control	47.3 (43.45)^{f}	48.5 (44.14)^{c}	48.5 (44.14)^{c}	48.10 (43.91)	
Sem	0.94	0.84	2.05	1.28	
CD(p=0.05)	1.55	1.55	3.14	2.08	
CV	16.4	13.7	19.1	16.4	

*Mean of three replications; Values in parentheses are arc sine transformations

Table 6: Effect of various treatments on sugarcane yield and per cent sucrose

Treatments	Cane yield (t ha^{-1})			Mean	Sucrose (%)			Mean
	2019-20	2020-21	2021-22		2019-20	2020-21	2021-22	
T_1 : *Beauveria bassiana* (4.5 x 10^{11} CFU) @ 1kg a.i. ha^{-1}	64.18	65.69	61.07	63.65	19.2	19.5	18.9	19.20
T_2 : *Metarhizium anisopliae* (1 x 10^{5} CFU) @ 1kg a.i. ha^{-1}	73.55	72.39	75.87	73.94	19.4	19.6	18.9	19.30
T_3 : *Bacillus thuringiensis* (1 x 10^{9} CFU) @ 1kg a.i. ha^{-1}	62.10	63.60	60.48	62.06	19.8	19.6	19.6	19.67
T_4 : Azadirachtin 10000ppm @ 1000 ml ha^{-1}	60.74	60.43	63.71	61.63	20.0	20.4	20.4	20.27
T_5 : Imidacloprid 17.8 SL @ 350 ml ha^{-1}	76.14	77.29	78.55	77.33	19.8	19.7	19.8	19.77
T_6 : Bifenthrin 10% EC @ 1000 ml ha^{-1}	-	76.47	77.08	76.78	-	19.3	19.6	19.45
T_7 : Untreated control	53.58	56.65	54.58	54.94	18.9	18.5	19.5	18.97
SEm	0.98	0.84	1.21	1.01	0.41	0.58	0.68	0.56
CD(p=0.05)	2.74	2.35	2.08	2.39	0.18	0.21	0.22	0.20
CV	15.8	16.54	19.3	17.21	19.7	16.4	15.9	17.33

Longhorn Stem Borer Dorysthenes buqueti. Peter *et al.* (2001) developed Metarhizium-based biopesticides (isolate FI-1045) for use against sugarcane white grubs in Australia and was found effective. Mouneshwari *et al.* (2022) evaluated the performance of *M. anisopliae* @ 5 kg ac^{-1} and was found as the best technology compared to conventional method and also application of EPN (*H. indica*) for white grub control in sugarcane. Thirumurugan *et al.* (2020) stated that bio inoculants, *M. anisoplaie* (4 x 10^{9} cfu @ 5 kg ha^{-1}) applied at the time of earthing up was significantly effective in reducing white grub population (more than 80%) within 45th day of application and recorded highest cane yield of 81.05 t ha^{-1}. However, Jaipal and Chaudhary (2010) is of the opinion that Imidacloprid is an effective insecticide against termites infesting sugarcane crop. Bhagawati *et al.* (2017) also confirmed that setts treated with clothianidin registered the lowest infestation of termites (5.55 and 6.18%) and was on par with the combined application of acephate (50%) and imidacloprid (1.8 %) with 7.49 and 8.59 per cent number and portion infested respectively. The highest mean germination of eye buds was recorded in clothianidin treated setts (79.41%) followed by acephate + imidacloprid (72.49%) and imidacloprid (71.94%) treated setts. Mesquita *et al.* (2023) clearly discussed in their review paper stating the future implementation prospects of *Metarhizium* as a plant bioinoculant against many arthropod pests as a potential bioagent.

The destruxins and proteases produced by *Metarhizium* after attacking termites (spore germination) may results in tetanic paralysis followed by flaccid paralysis in termite cells by inhibiting the synthesis of DNA, RNA, and proteins (Kershaw, 1999). Kim *et al.* (2020) studied the mechanisms of insecticidal action of *M. anisopliae* on adult Japanese pine beetles and inferred that muscle contraction and flaccid paralysis are likely the major mechanism underlying the insecticidal action of *M. anisopliae.* From various literatures it is proved that genetically modified bio-agents are found to be more successful to infect the targeted pest (Abbas, 2018; Van Aken *et al*., 2003). Chovenc *et al.* (2008) reported that *M. anisopliae* strains with the ability to form appressorium rapidly are more virulent and able to cause higher mortality. Zhang *et al.* (2014) inserted a gene from *Bacillus thuringiensis,* which encodes for the insect (*Spodoptera*) midgut-specific toxin Vip3Aal, into *M. anisopliae.* The genetically modified *M. anisopliae* wherein ingestion of fungal conidia process is rapid rather than penetration through cuticle was found successful in infecting the termites. Hence, advanced studies are needed on specific gene identification, which is toxic in the midgut of termite's acts as key for more virulent *M. anisopliae.*

The pooled mean for three seasons' *viz.,* 2019-20, 2020-21 and 2021-22 inferred that among all the biopesticides, *M. anisopliae* had registered highest per cent reduction of mean number of setts and mean portion of setts infested by termites in sugarcane with 56.03 and 56.20 per cent reduction over control, respectively. However, chemical treatment with imidacloprid (67.72 and 65.14) and bifenthrin (68.10 and 61.12) had recorded highest per cent reduction of termite infestation in relation to mean number of setts and mean portion of setts infested by termites in sugarcane. The pooled mean with regards to yield and quality parameters of sugarcane elucidated that the chemical based treatments *viz.,* imidacloprid and bifenthrin had registered highest yield with 77.33 and 76.78 t ha^{-1}, respectively. Next better treatment with respect to yield was observed in *M. anisopliae* based treatment as against lowest yield in control plots with 73.94 and 54.94, respectively. Hence, it can be concluded that, even though insecticides had exerted superiority in suppressing the termite infestation in sugarcane the biopesticide, *M. anisopliae* is also effective and can be recommended as an alternative to chemical based insecticides at least for one application as basal imposition at planting time. The results/ information from the present study may assist in further evaluation of native isolates of entomopathogens for effective termite management in sugarcane.

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References

Abbas, M.S.T.: Genetically engineered (modified) crops (*Bacillus thuringiensis* crops) and the world controversy on their safety. *Egypt J. Biol. Pest Control*., **28**, 52 (2018).

Andrew, C. Rath.: The use of entomopathogenic fungi for control of termites. *Biocon. Sci. Technol.,* **10**, 563-581 (2000).

Bhagawati, S., B. Badal, M. Himangshu and G. Dhanalakhi: Chemical management of termites (*Odontotermes obesus*) in preserved setts of sugarcane (*Saccharum officinarum*). *J. Entomol. Zool. Stud.,* **5**, 856-859 (2017).

Bhattacharya, B., H. Mishra, D. Gogoi and S. Bhagawati: Management of termite in preserved setts of sugarcane (*Saccharum officinarum*) with microbes. *Curr. Adv. Agric. Res. J.,* **6**, 176-179 (2014).

Chaudhary, J.P., S.P. Singh, K.K. Mrig, S.R. Yadav and S.C. Bhardawaj: Efficacy of some insecticidal granules, dusts and emulsions for the control of termites and shoot borers of sugarcane under Haryana conditions. *Indian Sug.,* **36**, 201-213 (1986).

Chouvenc, T., N.Y. Su and M.L. Elliott: Interaction between the subterranean termite *Reticulitermes flavipes* (Isoptera: Rhinotermitidae) and the entomopathogenic fungus *Metarhizium anisopliae* in foraging arenas. *J. Econ. Entomol.,* **101**, 885–893 (2008).

Deka, B., A. Babu, A.J. Peter, K.C. Kumhar, S. Sarkar, H. Rajbongshi, P. Dey, E.L.D.Amalraj and V.R. Talluri: Potential of the entomopathogenic fungus, *Metarhizium anisopliae S.l.* in controlling live-wood eating termite, *Microtermes obesi* (Holmgren) (Blattodea: Termitidae) infesting tea crop. *Egypt. J. Biol. Pest Control,* **31**, 132-135 (2021).

Jaipal, S. and O.P. Chaudhary: Imidacloprid as an effective insecticide against termites infesting sugarcane crop. *Ind. J. Sug. Tech.,* **25**, 54-57 (2010).

Kershaw, M.J., E.R. Moorhouse, R. Bateman, S.E. Reynolds, A.K. Charnley: The role of destruxins in the pathogenicity of *Metarhizium anisopliase* for three species of insect. *J. Invertebr. Pathol.,* **74**, 213– 223 (1999).

Kim, H.M., S.G. Jeong, I.S. Choi, J.E. Yang, K.H. Lee, J. Kim, J.C. Kim, J.S. Kim and H.W. Park: Mechanisms of insecticidal action of *Metarhizium anisopliae* on adult Japanese Pine Sawyer beetles (*Monochamus alternatus*). *ACS Omega.,* **5**, 25312–25318 (2020).

Kimberly, M.S.A. and M.H. Seow: Mode of infection of *Metarhizium* spp. fungus and their potential as biological control agents. *J. Fungi Basel.,* **3**, 30 pages (2017).

Koto, I.N., K.I. Nwasu and L.D. Busari: Control of termites in sugarcane using insecticides. *Sugar Tech.,* **2**,17-20 (2000).

Maniania, N.K., S. Ekesi and J.M. Songa: Managing termites in maize with the entomopathogenic fungus *Metarhizium anisopliae*. *Int. J. Trop. Insect Sci.,* **22**, 41-46 (2002).

Mesquita E., S. Hu, T.B. Lima, P.S. Golo and M.J. Bidochka: Utlization of *Metarhizium* as an insect biocontrol agnet and a plant bioincculant with special reference to Brazil. *Front. Fungal Biol*., **4,** 1276857 (2023).

Mill, A.: Termites as agricultural pests in Amazonas, Brazil. *Outlook Agric.,* **21**, 41-46 (1996).

Mishra, P., V.B. Monica, J. Saket, T. Arpita, P. Anand, D. Anupam and S. Satyawati: Biological approaches of termite management: A review. *Curr. Bot.,* **12**, 121-131 (2021).

Mouneshwari, R.K., A.R. Sulagitti and S. Sudha: Performance of biopesticides for management of white grub, *Holotrichia serrata* in sugarcane. *Pharm. Innov. J.,* **11**, 2152-2154 (2022).

Nichanun, K., U. Sopon and K. Naoto: Geographical distribution of sugarcane longhorn stem borer, *Dorysthenes Buqueti* Guerin (Coleoptera: Cerambycidae) and virulence bioassay of *Metarhizium anisopliae* (Metchnikoff) Sorokin isolates. *Adv. Biotech. Micro.,* **10**, 555782 (2018).

Nyam, V.T., J.B.C. Fah, O.K. Huat and P.K.J. Hung: Formulation of entomopathogen *Metarhizium anisopliae* var. anisopliae bait to control subterranean termite, *Coptotermes curvignathus* Holmgren (Blattodea: Rhinotermitidae). *Serangga*, **26**, 42-59 (2021).

Peter, S., R. Les, B. Peter, C. Robert, A. Horsfield, D. Logan, C. Kettle, B. Harris, P. Allsopp, N. McGill, R. Milner and G. Bullard: Development of Metarhizium-based biopesticides for use against sugarcane whitegrubs in Australia. Conference: *Proceedings of the Int. Soci. Sugar Cane Technol.,* **24**, 19 (2001).

Rama Rao, I.V.Y.: Economic analysis of sugarcane cultivation in Andhra Pradesh, India. *Int. J. Theoret. Appl. Sci*., **12**, 49-52 (2020).

Richard, J.M.: Current status of Metarhizium as a mycoinsecticide in Australia. *Biocontrol. News Inform.,* **21**, 247-250 (2000).

Sattar, A. and Z. Saliha: Detection and control of subterranean termites. In: Technologies for Sustainable. *Agriculture Proc. National Workshop NIAB. Fsd Pak.,* **24-26**, 195-198 (2001).

Singh, S.P., A.K. Srivastava and S. Sinha: Growth trend and instability in area, production and productivity of sugarcane in Uttar Pradesh: An overview. *Econ. Aff.,* **67**, 739-744 (2022).

Solomon, S.: Sugarcane production and development of sugar industry in India. *Sugar Tech.,* **18**, 1-15 (2016).

Sudha, R.D. and K. Krishnamma: Evaluation of bio-intensive integrated pest management strategies against sugarcane borer complex. *Andhra Agric. J.,* **67 Spl:** (IARD-2020), 75-80 (2020).

Sudha, R.D.: Impact of insecticides on parasitic potentiality of egg parasitoid, Tetrastichus pyrillae and ecto parasitoid, *Epiricania melanoleuca* against sugarcane leaf hopper, *Pyrilla perpusilla. Scientist,* **1**, 4635-4645 (2022).

Thirumurugan, V. Ravichandran and J. Jayakumar: Eco-friendly approach for management of white grub *Holotrichia serrata* (Blanch) in sugarcane. *Int. J. Curr. Microbiol. App. Sci.,* **9**, 1302-1307 (2020).

Van Aken, J. and E. Hammond: Genetic engineering and biological weapons. New technologies, desires and threats from biological research. *EMBO Rep.*, **4**, S57-S60 (2003).

Wright, M.S., A.K. Raina and A.R. Lax: A strain of the fungus *Metarhizium anisopliae* for controlling subterranean termites. *J. Econ. Entomol.,* **98**, 1451-1458 (2005).

Zhang, L., H.S. Ying and M.G. Feng: Assessment of oral virulence against *Spodoptera litura,* acquired by a previously non-pathogenic *Metarhizium anisopliae* isolate, following integration of a midgut-specific insecticidal toxin. *Biol. Control.,* **79**, 8–15 (2014).