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# Field evaluation of the entomopathogenic fungi enriched with organic amendments against *Holotrichia consanguinea* Blanchard (Coleoptera: Scarabaeidae) infesting groundnut crop

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## Abstract

**Background:** White grubs are highly polyphagous and most destructive soil pests inflicting damage to a groundnut crop that causes economic yield losses in commercial groundnut production in India. In this study, potential of the two entomopathogenic fungi (EPF) viz., *Metarhizium anisopliae* (Metchnikoff) Sorokin and *Beauveria bassiana* (Balsamo) Vuillemin enriched with organic amendments like neem cake, castor cake, vermicompost and poultry manure was evaluated to manage buildup of white grub population in groundnut crop.

**Results:** Results showed that the plot treated with soil application of vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha showed the least amount of plant mortality due to white grub which was at par with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha which showed only 1.74, 2.00 and 2.24% plant damage, respectively. Plots treated with vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha had the fewest (0.19) white grubs per one meter row length. Based on highest pod yield, net realization and net gain, the treatment with soil application of vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha was found most effective treatments for the management of white grub in groundnut.

**Conclusions:** Results indicated that *M. anisopliae* supplemented with various organic amendments, such as vermicompost, castor cake, and neem cake can be commercialized as a healthy alternative to minimize the use of synthetic pesticides in groundnut crops for white grub management.

**Keywords:** Entomopathogenic fungi, *Metarhizium anisopliae*, *Beauveria bassiana*, Vermicompost, Neem cake, White grub, Soil application

## Background

Groundnut or peanut (*Arachis hypogaea* L.) is known as “King of oilseed crops” and considered one of the most important oil seed crop in India, as well as it occupied

the fourth rank among important edible oil sources in the world. It originated in South America and contains 48–50% oil and 26–28% protein (Janila et al. 2013). In India, Gujarat is the largest producer contributing 25% of the total production, followed by Tamil Nadu (22.48%). It is valued as the fourth most important source of edible oil and the third most important source of vegetable protein (Deepthi 2014). The crop can be grown successfully

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in areas receiving rainfall from 600 to 1250 mm. Groundnut crop prefers sandy loam, loamy and medium black. The crop is grown as monoculture in Banas kantha region of Gujarat.

The plant suffers from the ravages of insect-pests and a loss in production both in terms of quality and quantity. As many as 52 species of insect-pests and 2 species of mites have been recorded infesting the groundnut crop in India (Singh et al. 1990). In India, the grubs of *Holotrichia consanguinea* Blanch (Coleoptera: Scarabaeidae) are of major economic importance attacking groundnut in Gujarat, Rajasthan, Bihar, Uttar Pradesh, Haryana and Punjab (Chandel et al. 2015). White grubs are polyphagous and they can feed on any root or underground stem (Veeresh 1988). The first instar larvae feed in part on organic matter in the soil, while the second and third instar grubs feed largely on roots or underground stems. The economic importance of chafers is primarily due to the feeding activity of the third instar grubs (Chandel et al. 2015).

The current method for the control of white grubs is through the use of chemical pesticides. However, concern about safety, environmental contamination and poor efficacy of recommended insecticides has increased the need to develop integrated pest management (IPM) approaches for these pests (Kumawat 2001). The emphasis has shifted from the dominant chemical pesticides to IPM, where the focus is on biological control and other natural resources with reduced reliance on chemicals. Yadava and Sharma (1995) have reported that several EPF such as *Metarhizium anisopliae* (Metchnikoff) Sorokin, *Beauveria bassiana* (Balsamo) Vuillemin, *B. brongniartii* (Saccardo) are pathogenic to white grubs and are effective in suppressing their population under field conditions.

Therefore, the present study aimed to evaluate the potential of EPF enriched with organic amendments against the white grub, *H. consanguinea* under field conditions.

## Methods

### Experimental site

Field trials were conducted at Agronomy Instructional Farm, C. P. College of Agriculture, SDAU, Sardarkrushinagar. This site is situated at longitude 24.3217°N, latitude 72.3177°E and with elevation 172 m/564 ft ASL. Area represents the typical climatic conditions of semi-arid regions having low rainfall with a wide chasm between diurnal and nocturnal temperatures. The soils are deep loamy sand to sandy loam. The general topography of the swathe is rugged plain.

### Field evaluation

Groundnut was raised in Kharif for 3 consecutive seasons viz., 2018, 2019 and 2020 by following standard agronomical practices. The local variety GG-2 was sown at spacing of 45 cm × 10 cm with a seed rate of 100 kg/ha. The experimental methodology was randomized block design (RBD), which split the entire farmed area into 13 equal plots (4.00 m × 3.15 m). Each treatment was repeated 3 times, and each plot was individually treated with one of the tested 12 treatments at a specified concentration. As a control, one plot was left untreated. The plot for each treatment followed all the recommended package of practices except white grub management. The calculated amount EPF viz., *M. anisopliae* and *B. bassiana* was mixed with different organic amendments 20 days prior to land preparation (Table 1). The treatments were applied at the time of land preparation. Observation on germination was recorded after 15 days

**Table 1** Treatment details

Sr. no	Treatments
1	Neem cake @ 1 ton/ha
2	Neem cake @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha
3	Neem cake @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha
4	Poultry manure @ 1 ton/ha
5	Poultry manure @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha
6	Poultry manure @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha
7	Vermicompost @ 1 ton/ha
8	Vermicompost @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha
9	Vermicompost @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha
10	Castor cake @ 1 ton/ha
11	Castor cake @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha
12	Castor cake @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha
13	Untreated control

of sowing from each net plot by recording total number of plants. Total number of plants and plants damaged by white grub were recorded at 20, 40, 60 and 80 days after germination (DAG) from net plot. The damaged plants were removed after each count. From these data, percent plant mortality due to white grub was computed. After harvesting, white grub population was recorded from 3 rows of one-meter area in each plot by digging soil. Yield was also recorded at harvest and economics of treatments was calculated.

**Statistical analysis**

Observed data of plant mortality and number of white grub/1 m row were analyzed on the pattern of a factorial randomized block design (FRBD). All obtained data were statistically subjected to analysis of variance (ANOVA) through the SPSS Computer program (IBM SPSS

Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.). Significance of differences between the treatment means was compared by Duncan’s multiple range tests (DNMRT) at  $P \leq 0.05$  (Gomez and Gomez 1984).

**Results**

**Effect of entomopathogenic fungi enriched with organic amendments on plant mortality (%)**

Results showed that there was non-significant difference on plant mortality (%) due to white grub infestation in all the treatments, 20 days after germination during seasons of 2018, 2019 and 2020 (Tables 2, 3 and 4). In the year 2018 (Table 2), at 40 days after germination the minimum plant mortality was observed in the treatment with vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha and it was at par with castor cake @ 1 ton/ha + *M. anisopliae*

**Table 2** Effect of entomopathogenic fungi enriched with organic amendments against white grub in groundnut (season of 2018)

Tr. no	Treatments	Dead plants (%)				
		1–20 DAG	21–40 DAG	41–60 DAG	61–80 DAG	Mean over period
1	Neem cake @ 1 ton/ha	5.25 <sup>ab</sup> (0.84)	9.25 <sup>de</sup> (2.60)	11.01 <sup>f</sup> (3.65)	13.56 <sup>e</sup> (5.55)	9.77 <sup>fg</sup> (2.88)
2	Neem cake @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	4.69 <sup>bc</sup> (0.67)	8.77 <sup>ef</sup> (2.34)	10.43 <sup>fg</sup> (3.33)	12.81 <sup>e</sup> (4.97)	9.17 <sup>g</sup> (2.54)
3	Neem cake @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	5.03 <sup>abc</sup> (0.77)	6.74 <sup>f</sup> (1.41)	8.62 <sup>gh</sup> (2.25)	10.25 <sup>f</sup> (3.40)	7.66 <sup>h</sup> (1.78)
4	Poultry manure @ 1 ton/ha	5.03 <sup>abc</sup> (0.77)	13.74 <sup>c</sup> (5.65)	17.05 <sup>de</sup> (8.62)	19.26 <sup>cd</sup> (10.88)	13.77 <sup>de</sup> (5.67)
5	Poultry manure @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	5.34 <sup>ab</sup> (0.87)	14.32 <sup>c</sup> (6.12)	15.41 <sup>e</sup> (7.11)	18.11 <sup>d</sup> (9.69)	13.29 <sup>e</sup> (5.28)
6	Poultry manure @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	5.25 <sup>ab</sup> (0.84)	11.22 <sup>d</sup> (3.83)	11.79 <sup>f</sup> (4.33)	14.97 <sup>e</sup> (6.68)	10.80 <sup>f</sup> (3.51)
7	Vermicompost @ 1 ton/ha	5.34 <sup>ab</sup> (0.87)	17.50 <sup>ab</sup> (9.06)	21.08 <sup>ab</sup> (12.95)	22.88 <sup>b</sup> (15.19)	16.70 <sup>b</sup> (8.26)
8	Vermicompost @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	3.70 <sup>de</sup> (0.42)	16.0 <sup>bc</sup> (7.63)	18.69 <sup>cd</sup> (10.28)	21.01 <sup>bc</sup> (12.96)	14.85 <sup>cd</sup> (6.57)
9	Vermicompost @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	1.12 <sup>f</sup> (0.04)	6.54 <sup>f</sup> (1.33)	7.79 <sup>h</sup> (1.93)	9.52 <sup>f</sup> (2.76)	6.24 <sup>i</sup> (1.18)
10	Castor cake @ 1 ton/ha	3.31 <sup>e</sup> (0.34)	17.21 <sup>ab</sup> (8.77)	19.41 <sup>bc</sup> (11.06)	21.46 <sup>bc</sup> (13.46)	15.34 <sup>c</sup> (7.00)
11	Castor cake @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	5.03 <sup>abc</sup> (0.77)	14.66 <sup>c</sup> (6.43)	16.12 <sup>e</sup> (7.73)	19.34 <sup>cd</sup> (11.04)	13.78 <sup>de</sup> (5.67)
12	Castor cake @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	4.18 <sup>cd</sup> (0.33)	6.59 <sup>f</sup> (1.45)	8.35 <sup>gh</sup> (2.13)	9.66 <sup>f</sup> (2.85)	6.94 <sup>hi</sup> (1.46)
13	Neem cake @ 1 ton/ha	5.72 <sup>a</sup> (0.66)	19.07 <sup>a</sup> (10.69)	21.66 <sup>a</sup> (13.66)	26.85 <sup>a</sup> (20.45)	18.32 <sup>a</sup> (9.88)
S.Em. ±	T	0.28	0.75	0.73	0.74	0.395
	P	–	–	–	–	0.219
	T × P	–	–	–	–	0.790
C. D. at 5%	T	NS	2.18	2.22	2.17	1.108
C.V. (%)		10.70	10.39	10.23	11.12	11.36

1. Figures in parentheses are retransformed values of arc sin transformation; DAG: Days after germination; 2. Treatment means with the letter(s) in common are not significant by DNMRT at 5% level of significance; 3. Significant parameters and their interactions: T, P, T × P

**Table 3** Effect of entomopathogenic fungi enriched with organic amendments against white grub in groundnut (season of 2019)

Tr. no	Treatments	Dead plants (%)				
		1–20 DAG	21–40 DAG	41–60 DAG	61–80 DAG	Mean over period
1	Neem cake @ 1 ton/ha	5.03 <sup>ab</sup> (0.77)	14.21 <sup>b</sup> (6.03)	16.84 <sup>cde</sup> (8.42)	21.16 <sup>b</sup> (13.05)	14.30 <sup>c</sup> (6.10)
2	Neem cake @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	4.95 <sup>ab</sup> (0.75)	13.02 <sup>b</sup> (5.08)	14.05 <sup>ef</sup> (5.92)	17.44 <sup>c</sup> (9.00)	12.36 <sup>d</sup> (4.58)
3	Neem cake @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	4.90 <sup>ab</sup> (0.73)	9.13 <sup>c</sup> (2.53)	9.87 <sup>g</sup> (3.00)	12.68 <sup>d</sup> (5.07)	9.14 <sup>e</sup> (2.52)
4	Poultry manure @ 1 ton/ha	5.03 <sup>ab</sup> (0.77)	13.70 <sup>b</sup> (5.62)	17.09 <sup>bcd</sup> (8.64)	21.46 <sup>b</sup> (13.39)	14.31 <sup>c</sup> (6.11)
5	Poultry manure @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	5.25 <sup>a</sup> (0.84)	14.04 <sup>b</sup> (5.89)	16.66 <sup>de</sup> (8.33)	21.00 <sup>b</sup> (12.89)	14.23 <sup>c</sup> (6.04)
6	Poultry manure @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	4.52 <sup>ab</sup> (0.63)	12.81 <sup>b</sup> (4.95)	13.63 <sup>f</sup> (5.67)	17.15 <sup>c</sup> (8.72)	12.02 <sup>d</sup> (4.34)
7	Vermicompost @ 1 ton/ha	5.35 <sup>a</sup> (0.87)	15.58 <sup>ab</sup> (7.25)	20.26 <sup>a</sup> (12.00)	24.23 <sup>ab</sup> (16.92)	16.35 <sup>b</sup> (7.92)
8	Vermicompost @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	4.51 <sup>ab</sup> (0.62)	14.88 <sup>ab</sup> (6.66)	19.59 <sup>abc</sup> (11.25)	23.91 <sup>ab</sup> (16.50)	15.72 <sup>b</sup> (7.34)
9	Vermicompost @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	4.03 <sup>b</sup> (0.50)	8.46 <sup>c</sup> (2.20)	9.14 <sup>g</sup> (2.53)	11.63 <sup>d</sup> (4.10)	8.31 <sup>e</sup> (2.09)
10	Castor cake @ 1 ton/ha	4.43 <sup>ab</sup> (0.63)	15.45 <sup>ab</sup> (7.17)	19.86 <sup>ab</sup> (11.55)	23.99 <sup>ab</sup> (16.67)	15.93 <sup>b</sup> (7.53)
11	Castor cake @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	5.15 <sup>a</sup> (0.81)	13.02 <sup>b</sup> (5.17)	14.49 <sup>def</sup> (6.33)	17.62 <sup>c</sup> (9.17)	12.56 <sup>d</sup> (4.73)
12	Castor cake @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	4.46 <sup>ab</sup> (0.61)	8.86 <sup>c</sup> (2.48)	9.44 <sup>g</sup> (2.77)	12.36 <sup>d</sup> (4.67)	8.78 <sup>e</sup> (2.33)
13	Neem cake @ 1 ton/ha	5.02 <sup>ab</sup> (0.77)	17.42 <sup>a</sup> (9.00)	22.14 <sup>a</sup> (14.22)	27.05 <sup>a</sup> (20.78)	17.90 <sup>a</sup> (9.45)
S.Em. ±	T	0.31	0.83	0.93	1.12	0.435
	P	–	–	–	–	0.241
	T × P	–	–	–	–	0.871
C. D. at 5%	T	NS	2.41	2.71	3.28	1.221
C.V. (%)		10.98	10.91	10.29	10.04	11.40

1. Figures in parentheses are retransformed values of arc sin transformation; DAG: Days after germination; 2. Treatment means with the letter(s) in common are not significant by DNMRT at 5% level of significance; 3. Significant parameters and their interactions: T, P, T × P

1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha, neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *B. bassiana* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha, whereas, at 60 and 80 DAG, minimum plant mortality was observed in the treatment with vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and it was at part with Castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha. Based on pooled results of season 2018, the most effective treatment was vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and it was at part with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha with minimum plant mortality 1.18 and 1.46%, respectively. In the season 2019 (Table 3), at 40, 60 and 80 days after germination

the minimum plant mortality was observed in the plot treated with soil application of vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and it was at part with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha, whereas, based on pooled results of season 2019, the most effective treatment was vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha (2.09%) and it was at part with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha (2.33%) and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha (2.52%). The results of season 2020 (Table 4), at 40, 60 and 80 days after germination showed that the minimum plant mortality was observed in the treatment of vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and it was at part with castor cake @ 1 ton/ha + *M.*

**Table 4** Effect of entomopathogenic fungi enriched with organic amendments against white grub in groundnut (season of 2020)

Tr. no	Treatments	Dead plants (%)				
		1–20 DAG	21–40 DAG	41–60 DAG	61–80 DAG	Mean over period
1	Neem cake @ 1 ton/ha	5.29 <sup>a</sup> (0.85)	14.30 <sup>b</sup> (6.10)	17.06 <sup>b</sup> (8.61)	21.30 <sup>bc</sup> (13.20)	14.48 <sup>c</sup> (6.25)
2	Neem cake @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	5.22 <sup>a</sup> (0.83)	13.02 <sup>b</sup> (5.08)	14.28 <sup>cd</sup> (6.08)	17.81 <sup>cd</sup> (9.36)	12.55 <sup>d</sup> (4.72)
3	Neem cake @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	5.09 <sup>a</sup> (0.79)	8.90 <sup>c</sup> (2.40)	9.65 <sup>e</sup> (2.81)	12.42 <sup>e</sup> (4.63)	9.01 <sup>e</sup> (2.45)
4	Poultry manure @ 1 ton/ha	5.10 <sup>a</sup> (0.79)	13.86 <sup>b</sup> (5.74)	17.20 <sup>b</sup> (8.74)	21.74 <sup>b</sup> (13.72)	14.47 <sup>c</sup> (6.24)
5	Poultry manure @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	5.10 <sup>a</sup> (0.79)	14.14 <sup>b</sup> (5.97)	16.92 <sup>bc</sup> (8.47)	21.11 <sup>bc</sup> (12.97)	14.31 <sup>c</sup> (6.11)
6	Poultry manure @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	4.83 <sup>ab</sup> (0.71)	12.98 <sup>b</sup> (5.05)	14.11 <sup>d</sup> (5.94)	17.33 <sup>d</sup> (8.87)	12.31 <sup>d</sup> (4.55)
7	Vermicompost @ 1 ton/ha	5.21 <sup>a</sup> (0.82)	15.41 <sup>ab</sup> (7.06)	20.32 <sup>a</sup> (12.06)	24.23 <sup>ab</sup> (16.85)	16.28 <sup>b</sup> (7.86)
8	Vermicompost @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	4.70 <sup>ab</sup> (0.67)	15.09 <sup>ab</sup> (6.78)	19.85 <sup>a</sup> (11.52)	24.02 <sup>ab</sup> (16.57)	15.91 <sup>b</sup> (7.51)
9	Vermicompost @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	4.25 <sup>b</sup> (0.55)	8.22 <sup>c</sup> (2.05)	8.71 <sup>e</sup> (2.29)	11.45 <sup>e</sup> (3.94)	8.15 <sup>e</sup> (2.01)
10	Castor cake @ 1 ton/ha	4.70 <sup>ab</sup> (0.67)	15.55 <sup>ab</sup> (7.19)	20.06 <sup>a</sup> (11.75)	24.23 <sup>ab</sup> (16.84)	16.13 <sup>b</sup> (7.72)
11	Castor cake @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	5.34 <sup>a</sup> (0.87)	13.06 <sup>b</sup> (5.11)	14.95 <sup>bcd</sup> (6.65)	17.95 <sup>cd</sup> (9.50)	12.82 <sup>d</sup> (4.92)
12	Castor cake @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	4.73 <sup>ab</sup> (0.68)	8.51 <sup>c</sup> (2.19)	9.14 <sup>e</sup> (2.53)	12.28 <sup>e</sup> (4.52)	8.66 <sup>e</sup> (2.27)
13	Neem cake @ 1 ton/ha	5.10 <sup>a</sup> (0.79)	17.53 <sup>a</sup> (9.07)	22.44 <sup>a</sup> (14.57)	27.30 <sup>a</sup> (21.03)	18.09 <sup>a</sup> (9.64)
S.Em. ±	T	0.25	0.80	0.86	1.14	0.427
	P	–	–	–	–	0.237
	T × P	–	–	–	–	0.854
C. D. at 5%	T	NS	2.34	2.50	3.34	1.198
C.V. (%)		8.67	10.59	9.42	10.18	11.10

1. Figures in parentheses are retransformed values of arc sin transformation; DAG: Days after germination; 2. treatment means with the letter(s) in common are not significant by DNMRT at 5% level of significance; 3. significant parameters and their interactions: T, P, T × P

*anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha. However, based on pooled results of season 2020, vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha was found most effective treatment which was at par with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha with minimum plant mortality 2.01, 2.27 and 2.45%, respectively.

The results presented in Table 5 revealed that during season 2018, the treatment vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha was found most effective against white grub and it was at par with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha, whereas, the results of seasons 2019 and 2020 showed that minimum plant

mortality was observed in the treatment of vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and it was at par with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha.

Looking to overall pooled results of the 3 consecutive seasons 2018, 2019 and 2020, it is clearly indicated that minimum plant mortality due to white grub was recorded in the plot treated with soil application of vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and it was at par with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha which show only 1.74, 2.00 and 2.24% plant damage, respectively (Table 5).

The results on cumulative plant damage due to white grub during different seasons clearly showed that soil

**Table 5** Effect of entomopathogenic fungi enriched with organic amendments against white grub in groundnut (pooled over period and seasons)

Tr. no	Treatments	Dead plants (%)			Pooled over period and seasons
		2018	2019	2020	
1	Neem cake @ 1 ton/ha	9.77 <sup>fg</sup> (2.88)	14.30 <sup>c</sup> (6.10)	14.48 <sup>c</sup> (6.25)	12.85 <sup>def</sup> (4.95)
2	Neem cake @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	9.17 <sup>g</sup> (2.54)	12.36 <sup>d</sup> (4.58)	12.55 <sup>d</sup> (4.72)	11.36 <sup>f</sup> (3.88)
3	Neem cake @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	7.66 <sup>h</sup> (1.78)	9.14 <sup>e</sup> (2.52)	9.01 <sup>e</sup> (2.45)	8.60 <sup>g</sup> (2.24)
4	Poultry manure @ 1 ton/ha	13.77 <sup>de</sup> (5.67)	14.31 <sup>c</sup> (6.11)	14.47 <sup>c</sup> (6.24)	14.18 <sup>cd</sup> (6.00)
5	Poultry manure @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	13.29 <sup>e</sup> (5.28)	14.23 <sup>c</sup> (6.04)	14.31 <sup>c</sup> (6.11)	13.94 <sup>d</sup> (5.80)
6	Poultry manure @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	10.80 <sup>f</sup> (3.51)	12.02 <sup>d</sup> (4.34)	12.31 <sup>d</sup> (4.55)	11.71 <sup>ef</sup> (4.12)
7	Vermicompost @ 1 ton/ha	16.70 <sup>b</sup> (8.26)	16.35 <sup>b</sup> (7.92)	16.28 <sup>b</sup> (7.86)	16.44 <sup>b</sup> (8.01)
8	Vermicompost @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	14.85 <sup>cd</sup> (6.57)	15.72 <sup>b</sup> (7.34)	15.91 <sup>b</sup> (7.51)	15.49 <sup>bc</sup> (7.13)
9	Vermicompost @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	6.24 <sup>i</sup> (1.18)	8.31 <sup>e</sup> (2.09)	8.15 <sup>e</sup> (2.01)	7.57 <sup>g</sup> (1.74)
10	Castor cake @ 1 ton/ha	15.34 <sup>c</sup> (7.00)	15.93 <sup>b</sup> (7.53)	16.13 <sup>b</sup> (7.72)	15.80 <sup>b</sup> (7.41)
11	Castor cake @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	13.78 <sup>de</sup> (5.67)	12.56 <sup>d</sup> (4.73)	12.82 <sup>d</sup> (4.92)	13.06 <sup>de</sup> (5.11)
12	Castor cake @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	6.94 <sup>hi</sup> (1.46)	8.78 <sup>e</sup> (2.33)	8.66 <sup>e</sup> (2.27)	8.13 <sup>g</sup> (2.00)
13	Neem cake @ 1 ton/ha	18.32 <sup>a</sup> (9.88)	17.90 <sup>a</sup> (9.45)	18.09 <sup>a</sup> (9.64)	18.10 <sup>a</sup> (9.65)
S.Em. ±	T	0.395	0.435	0.427	0.510
	P	0.219	0.241	0.237	0.310
	Y	–	–	–	0.116
	T × P	0.790	0.871	0.854	0.484
	T × Y	–	–	–	0.419
	P × Y	–	–	–	0.233
	T × P × Y	–	–	–	0.839
C. D. at 5%	T	1.108	1.221	1.198	1.489
	T × P × Y	–	–	–	NS
C.V. (%)		11.36	11.40	11.10	11.30

1. Figures in parentheses are retransformed values of arc sin transformation; DAG: Days after germination; 2. Treatment means with the letter(s) in common are not significant by DNMRT at 5% level of significance; 3. Significant parameters and their interactions: T, P, Y, T × P, T × Y, P × Y

application of vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha was the most effective treatment and it was at par with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha (Table 6).

**Effect of entomopathogenic fungi enriched with organic amendments on number of white grub/meter row**

The perusal of data presented in Table 7 indicated that the plots treated with vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha registered the least (0.19) white grub population per one meter row length during pooled results of the different 3 seasons and it was at par with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP



**Table 6** Effect of entomopathogenic fungi enriched with organic amendments against white grub in groundnut (pooled over seasons)

Tr. no	Treatments	Cumulative dead plants (%)			Pooled over seasons
		2018	2019	2020	
1	Neem cake @ 1 ton/ha	20.81 <sup>ef</sup> (12.64)	32.10 <sup>c</sup> (28.25)	32.45 <sup>c</sup> (28.79)	28.44 <sup>cd</sup> (22.68)
2	Neem cake @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	19.64 <sup>f</sup> (11.31)	27.02 <sup>d</sup> (20.66)	27.55 <sup>d</sup> (21.39)	24.73 <sup>e</sup> (17.50)
3	Neem cake @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	16.17 <sup>g</sup> (7.83)	19.65 <sup>e</sup> (11.40)	19.22 <sup>e</sup> (10.84)	18.32 <sup>f</sup> (9.88)
4	Poultry manure @ 1 ton/ha	30.60 <sup>d</sup> (25.94)	32.18 <sup>c</sup> (28.38)	32.58 <sup>c</sup> (28.99)	31.78 <sup>c</sup> (27.74)
5	Poultry manure @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	29.18 <sup>d</sup> (23.79)	31.90 <sup>c</sup> (27.99)	32.11 <sup>c</sup> (28.26)	31.04 <sup>c</sup> (26.59)
6	Poultry manure @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	23.25 <sup>e</sup> (15.68)	26.59 <sup>d</sup> (20.04)	27.00 <sup>d</sup> (20.62)	25.59 <sup>de</sup> (18.66)
7	Vermicompost @ 1 ton/ha	38.09 <sup>b</sup> (38.07)	37.47 <sup>b</sup> (37.02)	37.40 <sup>b</sup> (36.89)	37.64 <sup>b</sup> (37.30)
8	Vermicompost @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	33.96 <sup>c</sup> (31.26)	36.25 <sup>b</sup> (35.01)	36.65 <sup>b</sup> (35.63)	35.61 <sup>b</sup> (33.90)
9	Vermicompost @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	14.20 <sup>g</sup> (6.05)	17.79 <sup>e</sup> (9.45)	17.38 <sup>e</sup> (8.93)	16.45 <sup>f</sup> (8.02)
10	Castor cake @ 1 ton/ha	35.44 <sup>bc</sup> (33.63)	36.77 <sup>b</sup> (35.96)	37.29 <sup>b</sup> (36.71)	36.50 <sup>b</sup> (35.38)
11	Castor cake @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	30.62 <sup>d</sup> (25.96)	27.52 <sup>d</sup> (21.39)	28.12 <sup>d</sup> (22.22)	28.75 <sup>cd</sup> (23.14)
12	Castor cake @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	15.05 <sup>g</sup> (6.76)	18.87 <sup>e</sup> (10.51)	18.53 <sup>e</sup> (10.10)	17.49 <sup>f</sup> (9.03)
13	Neem cake @ 1 ton/ha	42.58 <sup>a</sup> (45.80)	41.98 <sup>a</sup> (44.78)	42.47 <sup>a</sup> (45.60)	42.32 <sup>a</sup> (45.33)
S.Em. ±	T	1.00	1.17	1.15	1.206
	Y	–	–	–	0.308
	T × Y	–	–	–	1.111
C. D. at 5%	T	2.91	3.42	3.37	3.52
C.V. (%)		6.43	6.86	6.68	6.67

1. Figures in parentheses are retransformed values of arc sin transformation; DAG: Days after germination; 2. Treatment means with the letter(s) in common are not significant by DNMR at 5% level of significance; 3. Significant parameters and their interactions: T, T × Y

( $1 \times 10^8$  cfu/g) @ 2 kg/ha with 0.26 and 0.31 white grub population per one meter row length, respectively.

#### Effect of entomopathogenic fungi enriched with organic amendments on Pod yield (kg/ha)

Looking to overall pooled results of seasons 2018, 2019 and 2020, it was clearly indicated that maximum pod yield was observed in the plot treated with soil application of vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha (1669 kg/ha) and it was remained at par with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha (1649 kg/ha) and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha (1633 kg/ha) (Table 8).

#### Economics

The data (Table 9) showed that maximum net realization and net gain was obtained in the treatment of vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha, followed by castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha. The highest ICBR was recorded in the treatment of castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha (1: 6.88).

#### Discussion

The majority of research on EPF has focused on developing them as inundative biological control agents for white grubs. The majority of commercially produced fungus is *Beauveria* or *Metarhizium* species, both of which are

**Table 7** Effect of entomopathogenic fungi enriched with organic amendments against white grub/1 m row in groundnut (pooled over seasons)

Tr. no	Treatments	White grub/1 m row			Pooled over seasons
		2018	2019	2020	
1	Neem cake @ 1 ton/ha	0.93 <sup>ef</sup> (0.36)	1.16 <sup>d</sup> (0.86)	1.13 <sup>c</sup> (0.77)	1.07 <sup>de</sup> (0.64)
2	Neem cake @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	0.91 <sup>ef</sup> (0.33)	1.05 <sup>de</sup> (0.60)	1.10 <sup>c</sup> (0.71)	1.01 <sup>e</sup> (0.52)
3	Neem cake @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	0.89 <sup>ef</sup> (0.29)	0.91 <sup>ef</sup> (0.33)	0.90 <sup>d</sup> (0.32)	0.90 <sup>f</sup> (0.31)
4	Poultry manure @ 1 ton/ha	1.20 <sup>bcd</sup> (0.94)	1.20 <sup>cd</sup> (0.94)	1.17 <sup>c</sup> (0.87)	1.18 <sup>c</sup> (0.89)
5	Poultry manure @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1.16 <sup>cd</sup> (0.85)	1.16 <sup>d</sup> (0.86)	1.12 <sup>c</sup> (0.76)	1.14 <sup>cd</sup> (0.80)
6	Poultry manure @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1.07 <sup>de</sup> (0.64)	1.05 <sup>de</sup> (0.60)	1.09 <sup>c</sup> (0.68)	1.06 <sup>de</sup> (0.62)
7	Vermicompost @ 1 ton/ha	1.39 <sup>b</sup> (1.43)	1.39 <sup>b</sup> (1.45)	1.42 <sup>b</sup> (1.50)	1.39 <sup>b</sup> (1.43)
8	Vermicompost @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1.36 <sup>bc</sup> (1.35)	1.35 <sup>bc</sup> (1.33)	1.38 <sup>b</sup> (1.40)	1.36 <sup>b</sup> (1.35)
9	Vermicompost @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	0.84 <sup>f</sup> (0.21)	0.85 <sup>f</sup> (0.22)	0.82 <sup>d</sup> (0.17)	0.83 <sup>f</sup> (0.19)
10	Castor cake @ 1 ton/ha	1.35 <sup>bc</sup> (1.32)	1.35 <sup>bc</sup> (1.36)	1.39 <sup>b</sup> (1.43)	1.36 <sup>b</sup> (1.35)
11	Castor cake @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1.29 <sup>bcd</sup> (1.16)	1.06 <sup>de</sup> (0.63)	1.12 <sup>c</sup> (0.75)	1.15 <sup>cd</sup> (0.82)
12	Castor cake @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	0.86 <sup>ef</sup> (0.24)	0.89 <sup>ef</sup> (0.30)	0.86 <sup>d</sup> (0.24)	0.87 <sup>f</sup> (0.26)
13	Neem cake @ 1 ton/ha	1.70 <sup>a</sup> (2.39)	1.63 <sup>a</sup> (2.18)	1.66 <sup>a</sup> (2.24)	1.66 <sup>a</sup> (2.26)
S.Em. ±	T	0.07	0.06	0.06	0.035
	Y	–	–	–	0.017
	T × Y	–	–	–	0.061
C. D. at 5%	T	0.19	0.18	0.16	0.10
	T × Y	–	–	–	NS
C.V. (%)		9.86	9.36	8.23	9.17

1. Figures in parentheses are retransformed values of  $\sqrt{x + 0.5}$  transformation; DAG: Days after germination; 2. Treatment means with the letter(s) in common are not significant by DNMRT at 5% level of significance

very easy to mass-produce. Production criteria include low cost, long-term stability, and, most significantly, consistent efficacy in the field. The development of a suitable formulation is mandatory in order to enhance spore application and successful utilization in soil (Chandel et al. 2018). According to Arora et al. (2000), entomopathogens control white grubs by invasive characteristics, poisons, enzymes, and other compounds. EPF attracted greater attention than other families of microbial organisms with the potential to be used in white grub management.

The present study clearly indicated that minimum plant mortality due to white grub was recorded in the plot treated with soil application of vermicompost @ 1

ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and it was at par with castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha, followed by *B. bassiana* enriched with organic amendments. The current findings are line with the observations of other researchers, such as Mohi-Ud-Din et al. (2006), who indicated that *M. Anisopliae*, *B. bassiana* and *B. brongniartii* were very efficient against white grubs in Kashmir at 1 × 10<sup>8</sup> spores/ml. After 20–24 days of therapy, these cultures resulted in overall mortality of 100%. Kulye and Pokharkar (2009) studied the efficacy of *M. anisopliae* and *B. bassiana* against *H. consanguinea* infesting potato. Use of *M. anisopliae* @ 2 × 10<sup>12</sup>



**Table 8** Effect of entomopathogenic fungi enriched with organic amendments against white grub on yield of groundnut (Pooled over seasons)

Tr. no	Treatments	Yield (kg/ha)			Pooled over seasons
		2018	2019	2020	
1	Neem cake @ 1 ton/ha	1426 <sup>abc</sup>	1358 <sup>b</sup>	1367 <sup>b</sup>	1384 <sup>b</sup>
2	Neem cake @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1440 <sup>ab</sup>	1400 <sup>b</sup>	1422 <sup>b</sup>	1421 <sup>b</sup>
3	Neem cake @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1585 <sup>a</sup>	1650 <sup>a</sup>	1664 <sup>a</sup>	1633 <sup>a</sup>
4	Poultry manure @ 1 ton/ha	1197 <sup>bcd</sup>	1207 <sup>bcd</sup>	1237 <sup>bc</sup>	1215 <sup>c</sup>
5	Poultry manure @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1225 <sup>bcd</sup>	1242 <sup>bc</sup>	1260 <sup>bc</sup>	1242 <sup>c</sup>
6	Poultry manure @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1396 <sup>abc</sup>	1417 <sup>b</sup>	1431 <sup>b</sup>	1415 <sup>b</sup>
7	Vermicompost @ 1 ton/ha	988 <sup>de</sup>	997 <sup>de</sup>	1049 <sup>cd</sup>	1011 <sup>d</sup>
8	Vermicompost @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1049 <sup>de</sup>	1083 <sup>cde</sup>	1105 <sup>cd</sup>	1079 <sup>d</sup>
9	Vermicompost @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1628 <sup>a</sup>	1675 <sup>a</sup>	1704 <sup>a</sup>	1669 <sup>a</sup>
10	Castor cake @ 1 ton/ha	853 <sup>ef</sup>	867 <sup>ef</sup>	927 <sup>de</sup>	882 <sup>e</sup>
11	Castor cake @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1174 <sup>cd</sup>	1191 <sup>bcd</sup>	1219 <sup>bc</sup>	1195 <sup>c</sup>
12	Castor cake @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP (1 × 10 <sup>8</sup> cfu/g) @ 2 kg/ha	1599 <sup>a</sup>	1660 <sup>a</sup>	1688 <sup>a</sup>	1649 <sup>a</sup>
13	Neem cake @ 1 ton/ha	720 <sup>f</sup>	758 <sup>f</sup>	801 <sup>e</sup>	760 <sup>f</sup>
S.Em. ±	T	78.47	75.41	70.80	38.102
	Y	–	–	–	20.790
	T × Y	–	–	–	74.958
C. D. at 5%	T	229.02	220.10	206.66	106.96
	T × Y	–	–	–	NS
C.V. (%)		10.85	10.29	9.45	10.20

1. DAG: Days after germination; Treatment means with the letter(s) in common are not significant by DNMR at 5% level of significance

conidia/ha showed average efficacy of 46.74%, with 44.44% mycosis of grubs. Similarly, Yadava and Sharma (1995) reported that *M. anisopliae* and *B. bassiana* are pathogenic to white grubs and effective in suppressing their population under field conditions. Application of *M. anisopliae* in sugarcane @ 4 × 10<sup>9</sup> conidia/ha registered 92% reduction in grub population of *Holotrichia serrata* (Fab) in Tamil Nadu on 60<sup>th</sup> DAT (Manisegaran et al. 2011). Among the treatments imposed at the time of sowing, *M. anisopliae* @ 5.0 × 10<sup>13</sup> spores/ha mixed with FYM was found effective, followed by *B. bassiana* @ 5.0 × 10<sup>13</sup> spores/ha applied in FYM enriched field and registered 93.60 and 88.09% decrease in white grub damage and 77.22 and 74.08% decrease in white grub population (Visalakshi et al. 2015). Avasthy (1967) reported good control of white grubs in India by *M. anisopliae*. Contrary to this, Chandel and Mehta (2005) tested a Jaipur culture of *B. bassiana* and *M. anisopliae* @ 5 × 10<sup>13</sup> conidia/ha against potato white grubs (*Brahmina coriacea* Hope) in Shimla hills, but neither of these fungi were found to be effective. Similarly, Chandel et al. (2005) did not find satisfactory control of *B. coriacea* grubs in potato in Shimla hills with the application of *B. bassiana* and *M. anisopliae* dusts.

In the present study, EPF in combination with organic amendments, such as vermicompost, neem cake and

castor cake gave effective results against damage caused by the white grub. Literature scanning revealed that information pertaining to the evaluation of mixture of EPF and organic amendments against white grub is scanty. Hence, this study will be established as a future reference for further investigations on these combined products against the white grub and other soil-dwelling insect-pests. The study indicated that all the test products had variable insecticidal properties and may be used for the pest control at the time of sowing of the crop. According to the results of present study, the maximum net realization and net gain was obtained in the soil treatment of vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha and highest ICBR was recorded in the treatment of castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP (1 × 10<sup>8</sup> cfu/g) @ 2 kg/ha (1: 6.88). Results of the present study are supported by Manisegaran et al. (2011) who observed higher incremental benefit–cost ratio (IBCR) with *M. anisopliae* (7.58) as compared to other chemical treatments.

## Conclusions

White grubs are the most damaging soil pests inflicting damage to a groundnut crop, resulting in economic yield losses in India's commercial groundnut production. The ability of two EPF viz., *M. anisopliae* and *B.*

**Table 9** Economics of entomopathogenic fungi enriched with organic amendments evaluated against white grub in groundnut

Tr. no	Treatments	Cost of material (Rs. /ha)	Labor charges (Rs. /ha)	Total cost of treatment (Rs. /ha)	Yield (Kg/ha)	Gross realization (Rs. /ha)	Net realization over control (Rs. /ha)	Net gain (Rs. /ha)	PCBR
1	Neem cake @ 1 ton/ha	12,000	648	12,648	1384	73,006	32,916	20,268	1: 1.60
2	Neem cake @ 1 ton/ha + <i>Beauveria bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	12,300	648	12,948	1421	74,958	34,868	21,920	1: 1.69
3	Neem cake @ 1 ton/ha + <i>Metarhizium anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	12,300	648	12,948	1633	86,141	46,051	33,103	1: 2.56
4	Poultry manure @ 1 ton/ha	5000	648	5648	1214	64,039	23,949	18,301	1: 3.24
5	Poultry manure @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	5300	648	5948	1242	65,516	25,426	19,478	1: 3.27
6	Poultry manure @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	5300	648	5948	1415	74,641	34,551	28,603	1: 4.81
7	Vermicompost @ 1 ton/ha	6000	648	6648	1011	53,330	13,240	6592	1: 0.99
8	Vermicompost @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	6300	648	6948	1079	56,917	16,827	9879	1: 1.42
9	Vermicompost @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	6300	648	6948	1669	88,040	47,950	41,002	1: 5.90
10	Castor cake @ 1 ton/ha	5000	648	5648	882	46,526	6436	788	1: 0.14
11	Castor cake @ 1 ton/ha + <i>B. bassiana</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	5300	648	5948	1195	63,036	22,946	16,998	1: 2.86
12	Castor cake @ 1 ton/ha + <i>M. anisopliae</i> 1.15 WP ( $1 \times 10^8$ cfu/g) @ 2 kg/ha	5300	648	5948	1649	86,985	46,895	40,947	1: 6.88
13	Neem cake @ 1 ton/ha	–	–	–	760	40,090	–	–	–

Neem cake: 12 Rs/kg; *Beauveria bassiana*: 150 Rs/kg

Poultry manure: 5 Rs/kg; *Metarhizium anisopliae*: 150 Rs/kg

Vermicompost: 6 Rs/kg; Groundnut: 52.75 Rs/kg

Castor cake: 5 Rs/kg; Labor cost: 324 Rs/day

Labor required: 2/day/ha

*bassiana*, supplemented with various organic amendments, to regulate the establishment of white grub populations in groundnut crops was investigated in this study. Based on the minimum plant mortality due to white grub, minimum white grub per one meter row length, highest pod yield, net realization and net gain, the treatment with soil application of vermicompost @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha, castor cake @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha and neem cake @ 1 ton/ha + *M. anisopliae* 1.15 WP ( $1 \times 10^8$  cfu/g) @ 2 kg/ha were found the most effective treatments for the management of white grub in groundnut. Results indicated that *M. anisopliae* enriched with various organic

amendments, such as vermicompost, castor cake, and neem cake are better alternatives for the management of white grubs in endemic areas at the time of sowing of the crop.

#### Abbreviations

ha: Hectare; g: Gram; kg: Kilogram; WP: Wettable powder; cfu: Colony-forming unit; mm: Millimeter; m: Meter; IPM: Integrated pest management; SDAU: Sardarkrushinagar Dantiwada agricultural university; ft: Feet; ASL: Above sea level; GG-2: Gujarat groundnut-2; cm: Centimeter; ICBR: Incremental cost-benefit ratio; FYM: Farm yard manure; DAG: Day after germination.

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**Authors' contributions**

PSP performed field trials, analyzed and interpreted the data of the work and prepared the original manuscript; SD conducted field trials, analyzed the data, reviewed and edited the writing. PHR assisted in conduction of field trials, analyzed the data. MJJ assisted in field trials, analyzed the data, reviewed and edited the manuscripts. The authors read and approved the final manuscript.

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**Availability of data and materials**

All data generated and analyzed for the current study are presented in this manuscript, and the corresponding authors have no objection to the availability of data and materials.

**Declarations****Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

The authors agreed to publish this paper. The data have not been published partially or completely in any other journal.

**Competing interests**

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