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RESEARCH

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Effect of entomopathogenic fungi, *Beauveria bassiana* and *Metarhizium anisopliae*, on *Thrips tabaci* Lindeman (Thysanoptera: Thripidae) populations in different onion cultivars

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Abstract

Background: *Thrips tabaci* Lindeman (Thysanoptera: Thripidae) is the key pest of onions that causes economic yield losses in commercial onion production in Pakistan. In this study, potential of the entomopathogenic fungi (EPF), *Beauveria bassiana* and *Metarhizium anisopliae*, as a bio agent was evaluated to manage buildup of thrips population on onion crop.

Results: Efficacy tests for EPF were conducted against *T. tabaci* infesting 3 different onion varieties (Phulkara, Swat 1, and Virio 7). Commercial formulations of *B. bassiana* strain GHA and *M. anisopilae* strain ESC-1, were evaluated at 4 different concentrations (10^8, 10^9, 10^{10}, and 10^{11} conidia/ml) under field conditions for 2 years. The efficacy was assessed 3, 5, 7, and 10 days after spray application of the whole onion plant. Efficacy expressed as *T. tabaci* (nymphs and adults) percent population reduction in comparison to controls. Maximum corrected percent population reduction was observed in onion plants treated with *B. bassiana* 10^{11} conidia/ml, i.e., 86.62, 84.59, and 86% in Phulkara, Swat 1, and Virio 7 onion varieties respectively, after 10 days of spray application. While onion plants treated with *M. anisopliae* 10^8 conidia/ml showed minimum corrected percent population reduction, i.e., 69.42, 68.45, and 69.11% in Phulkara, Swat 1, and Virio 7 onion varieties respectively, after 10 days of spray.

Conclusions: *Beauveria bassiana* could significantly reduce thrips population and could provide a better long-term management of *T. tabaci* on onion. *B. bassiana* had a high toxic effect against offspring production of the *T. tabaci* under field conditions than *M. anisopliae*.

Keywords: *Beauveria bassiana*, *Metarhizium anisopliae*, *Thrips tabaci*, Onion, Biological control

Background

Growth and yield of the onion crop is significantly stressed by various factors including sap sucking insects. The onion thrips (*Thrips tabaci* Lindeman, Thysanoptera: Thripidae) cause the main pest for onion crops whose feeding results in reduced growth and yield for onion plants (Ananthakrishnan, 1993). The onion thrips (*Thrips tabaci* Lindeman.) cause extensive economic losses to onion crops in field and greenhouse vegetable production (Diaz-Montano et al. 2011). At nymphal and adult stages, thrips cause direct damage by feeding/sucking cell sap through their modified mouthparts and indirectly disseminate/vector viral pathogens which cause diseases such as yellow spot viral disease (Gent et al. 2004).

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In Pakistan, sucking insect pests is the major reason of decrease in onion production. These pests include thrips as major pest and onion maggot (*Delia antiqua*), leaf minors (*Lyriomyza* spp.), and cutworm (*Agrotis ipsilon*) as minor pests (Khan et al. 2015). The demand for organic horticulture products that are safe for environment and consumers are increasing. Non-chemical methods such as biotechnical methods and intercropping (Trdan et al. 2006), late planting, physical barriers, and mulching are identified control methods for *T. tabaci* on onion crop (Gawande et al. 2010). However, all the above tactics could form one component of integrated pest management. Biological control in onion fields faces an immense difficulty because onion is treated intensively with insecticides. In organic horticulture, biological control is recognized as a basic component of IPM in which microbial control is a preferred technique due to its positive attributes such as amenable to production, broad spectrum effectiveness, and long-term storage (Dinesh 2017).

Among entomopathogenic microbial agents, fungal pathogens EPF isolated from different thrips species and proven to be pathogenic to *T. tabaci* include *Metarhizium anisopliae* (Metschn.) Sorokin., *Beauveria bassiana* (Bals.) Vuill., *Neozygites cucumeriformis*, *Zoophthora radicans*, *Entomophthora thripidum*, *Verticillium lecanii*, and *Paecilomyces fumosoroseus* (Butt and Brownbridge 1997). EPF are developed for the management of onion thrips *T. tabaci*, western flower thrips *Frankliniella occidentalis* and legume thrips *Megalurothrips sjostedti* in leguminous crops, ornamental plants, and vegetables (Maniania et al. 2002). Biopesticide usage for integrated crop pest management has increased in last few years (Sahayaraj and Namasivayam 2008). Various EPF have been industrialized as formulated products such as (i) *Beauveria* as BotaniGard® ES, Beauverin®, and Mycotrol® WPO, Betel®; (ii) *M. anisopliae* as Met52® EC, Bio-Catch-M® SL, and Green Muscle® SU; (iii) *M. flavoviride* as Biogreen® L; and (iv) *Isaria fumosorosea* as Preferal® WG and Priority® WP (Faria and Wraight 2007). These formulated products are being used to manage a wide range of pests such as thrips, whiteflies, aphids, mealybugs, psyllids, plant bugs, scarab beetles, and weevils (Copping 2009). These EPF have potential to be used in integrated insect pest management programs due to their less persistent nature, low mammalian toxicity, and natural occurrence (Lee et al. 2016). Although EPF formulated products have been developed, there is a little or no information about their evaluation in Pakistan farmer's greenhouse and field conditions.

The present study focused on determining the efficacy of these EPF against *T. tabaci* under field conditions, in order to generate knowledge for their use as a component in organic farm production.

Methods

Experimental site

Field trials were conducted at Chak Shahzad, Islamabad, where vegetables are grown through the year. This site is situated at longitude 33° 40 N, latitude 73° 8.9 E and with elevation 499 meters ASL. The minimum and maximum average temperature of the area is 10 and 38 °C, respectively. Crops grown in the surroundings of the experimental area were wheat in the South, brassica and canola in the West, cabbage in the East, and bamboos in the North.

Nursery sown

Seeds of onion varieties (Phulkara, Swat 1, and Virio 7) were acquired from Ayub Agriculture Research Institute, Faisalabad. Nursery of these three varieties was raised after soil preparation during the October 2018 and 2019. Fertilizer was applied in 3 split concentrations: at the time of nursery raising, at transplanting stage, and at bulb initiation stage for better yield. Nursery was transplanted in December 2018 and 2019 for the winter season at 4-5 leaf stage after 8 weeks of emergence.

Experimental layout

The plot layout was a randomized complete block design for onion varieties Phulkara, Swat 1, and Virio 7 with 3 replications. Each experimental plot consisted of (3 m × 3 m) with distance of 10 cm between seedlings with 30 cm distance between rows. To avoid contamination and drift hazards among treatments, each experimental plot was separated by a distance of 1.5 m.

Formulations of entomopathogenic fungi

The *B. bassiana* WP and *M. anisopliae* WP formulations contained active ingredient based on 2.01×10^{10} cfu/g of product. Commercial formulations of *B. bassiana* strain GHA and *M. anisopliae* strain ESC-1 were added in distilled water to make spray solution (Maniania et al. 2003). Spore germination rates of these EPF were tested on PDA at 25 °C after 24 h for 80% germination. The conidial concentration of EPF was determined by a hemocytometer.

EPF were applied after the 7th week of transplantation. Treatments were sprayed to onion plants infested with thrips with the help of Solo 418-One Hand Pressure Sprayer. Surfactant (0.02% tween 80) was mixed to the spray solution to enhance the adjuvant ability of solution and for better spread of entomopathogens. Treatments were sprayed during the evening times to lessen the ultraviolet radiation adverse effects on spore germination (Morley et al. 1996) and providing better conditions regarding humidity and temperature for fungal growth. Experimental plots were irrigated before spray of EPF to maintain relative humidity. Entomopathogens and insecticide were sprayed with the help of separate hand sprayer to avoid contamination. Five randomly selected onion plants were observed for thrips population density in each experimental plot before and after application of treatments. Following experimental treatments were prepared:

Treatments	Entomopathogenic fungi	Concentrations (conidia/ml)
T1	*M. anisopliae*	1×10^{8}
T2	*B. bassiana*	1×10^{8}
T3	*M. anisopliae*	1×10^{9}
T4	*B. bassiana*	1×10^{9}
T5	*M. anisopliae*	1×10^{10}
T6	*B. bassiana*	1×10^{10}
T7	*M. anisopliae*	1×10^{11}
T8	*B. bassiana*	1×10^{11}
T9	Bifenthrin 10 EC	330 ml/acre
T10	Untreated control (distill water + surfactant)	1.5 l + 0.02% tween 80

(Ganga and Krishnamoorthy 2012)

Control plants were sprayed by water and surfactant as a negative control and recommended insecticide (Bifenthrin) as positive control. Entomopathogens were applied in the evening.

Statistical analysis

Conidial application of these EPF was made 3 times at 10 days interval as experiment replication. The results were presented as onion thrips (%) population reduction pooled means of these replications. Thrips population reduction percentage in comparison to control treatments were calculated by the Henderson-Tilton's formula (Henderson and Tilton 1955).

Thrips counts before treatment application were used in population reduction percentage calculation by Henderson-Tilton's formula for each treatment. Pretreatment and post-treatment means were analyzed by using the statistical software (Statistix 8.1) for ANOVA. Means were compared at 0.05 probability levels by Tukey's Honest Significant Difference test (HSD).

Results

The present study was carried out, using 2 EPF, with 4 different concentrations on 3 onion varieties, i.e., Phulkara, Swat 1, and Virio 7. Effect of EPF on thrips population's percentage in 3 different onion varieties is shown in Fig. 1. Maximum thrips population reduction percentages were recorded in Swat 1 onion variety after application.

Onion thrips corrected population reduction percentage on Phulkara variety

Effect of EPF on thrips population reduction percentage during 2019 at Phulkara onion variety is presented in Table 1. High corrected population reduction percentage was recorded in case of high concentrations of EPF. Among all the treated onion plots, the highest reduction in thrips population (89.14 %) was observed in bifenthrin-treated plots. Results revealed that *B. bassiana* treatment of onion plots at the concentration of 10^{11} conidia/ml showed the highest thrips population reduction (22.03%), which is at par with *M. anisopliae* at

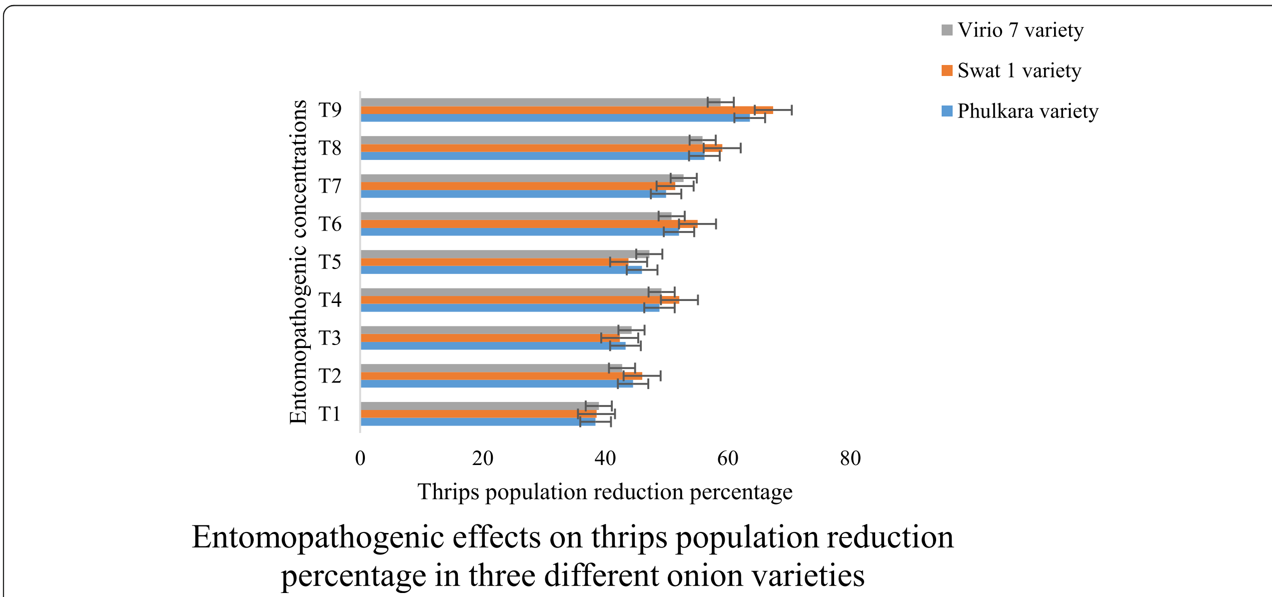

Fig. 1 Entomopathogenic effects on thrips population reduction percentage in three different onion varieties

Table 1 Entomopathogenic fungi on thrips population reduction percentage on Phulkara onion variety during 2019

Treatments (conidia/ml)	Reduction (%) of onion thrips			
	(3rd day)	(5th day)	(7th day)	(10th day)
Metarhizium anisopliae 10^8	13.43d	24.65c	40.32b	69.42d
M. anisopliae 10^9	15.96cd	26.14c	56.11ab	72.61cd
M. anisopliae 10^{10}	14.16d	30.28bc	44.76b	72.75cd
M. anisopliae 10^{11}	18.00bcd	33.92bc	62.20ab	77.72bc
Beauveria bassiana 10^8	16.15cd	34.33bc	56.26ab	74.07cd
B. bassiana 10^9	19.85bc	38.32b	67.29a	81.31ab
B. bassiana 10^{10}	21.92b	35.47bc	61.71ab	81.66ab
B. bassiana 10^{11}	22.03b	41.15b	73.33a	86.62a
Bifenthrin	89.14a	79.62a	54.73ab	38.58e
HSD value	5.6	11.0	13.49	6.68

Columns having same letter are not statistically different ($P \geq 0.05$, ANOVA)

10^{10} conidia/ml (21.92%) after 3 days of application. Thrips population significantly reduced after 5 to 7 days of EPF application. After 5 days, all the fungal treatments significantly reduced onion thrips population in comparison to control plots. Population reductions between 35.47 and 41.15% were observed in the treatments *M. anisopliae* 10^{10} and *B. bassiana* 10^{11} conidia/ml, respectively. After 7 days of EPF application, the highest reduction in populations was observed in *B. bassiana* at the concentration of 10^{11} conidia/ml (73.33%) treated onion plots.

Significant differences ($F = 5.21$; $P = 0.00$) were observed among treatments after 7 days of EPF application. After 10 days, the highest population reduction percentage found was induced by *B. bassiana* 10^{11} conidia/ml (86.62%) treatment, followed by *M. anisopliae* 10^{11} conidia/ml (81.66%) and *B. bassiana* 10^{10} conidia/ml (81.31%) treatments ($F = 5.88$; $P = 0.00$). A significant difference in population reduction percentage was observed at all the treatments at different level of entomopathogen concentrations for *T. tabaci.*

Effect of EPF on thrips population reduction percentage during 2020 in Phulkara onion variety is presented in Table 2. The thrips density recorded before treatment varied from 10 to 36 nymphs/plant. Large differences among treatments were observed in the start-up populations of the thrips. The rate of reduction in thrips population was significantly higher in insecticide-treated plots after 24 h of treatment application as compared to the EPF treatments. Application of *B. bassiana* caused a high reduction in the thrips population after 7th and 10th day than the other EPF treatments.To PO.PNGys of EPF applications, thrips population was significantly reduced among all the tested entomopathogenic fungi treatments. The highest population reduction was observed in *B. bassiana* 10^{11} conidia/ml ($F = 4.98$; $P = 0.00$). Results showed that after 3 days of application,

Table 2 Entomopathogenic fungi on thrips population reduction percentage on Phulkara onion variety during 2020

Treatments (conidia/ml)	Reduction (%) of onion thrips			
	(3rd day)	(5th day)	(7th day)	(10th day)
Metarhizium anisopliae 10^8	24.08b	31.21b	44.4b	60.01ab
M. anisopliae 10^9	25.10b	36.60b	56.43a	67.55ab
M. anisopliae 10^{10}	18.32b	38.67b	58.1a	69.52ab
M. anisopliae 10^{11}	21.47b	40.19b	65.63a	71.76ab
Beauveria bassiana 10^8	15.27b	36.49b	62.2a	73.49ab
B. bassiana 10^9	22.13b	40.78b	70.63a	76.05ab
B. bassiana 10^{10}	23.68b	30.12b	67.79a	77.16a
B. bassiana 10^{11}	35.48b	37.64b	74.20a	79.19a
Bifenthrin	75.43a	67.99a	53.95a	49.47b
HSD value	24.55	24.25	22.01	27.44

Columns having same letter are not statistically different ($P \geq 0.05$, ANOVA)

Reduction of thrips population was recorded up to 35.48% by the application of *B. bassiana* at the concentration of 10^{11} conidia/ml. Thrips population further reduced after 5 and 7 days of EPF application. *B. bassiana* 10^{11} conidia/ml induced the population reduction (74.20%), followed by *B. bassiana* 10^{10} conidia/ml (70.63%) and *M. anisopliae* 10^{11} conidia/ml (67.79%) after 7 days of EPF application ($F = 0.59$; $P = 0.77$). Maximum reduction in thrips population was observed after 10 days of EPF application. For treated onion plots, *B. bassiana* at the concentration of 10^{11} conidia/ml showed the highest thrips population reduction 79.19% which is at par with *M. anisopliae* 10^{11} conidia/ml (77.16%) ($F = 2.46$; $P = 0.06$) after 10 days of EPF application.

Population counts were undertaken before treatment application ranged between 69 and 135 thrips per 5 plants. Thrips densities reduced in both insecticide- and EPF-treated plots in comparison to untreated control plots during the trials (Table 2).

Onion thrips population reduction percentage on Swat 1 variety

The population reduction percentage after the application of EPF on Swat 1 variety during 2019 is presented in Table 3 and Fig. 1. After 3 days of EPF application, the highest population reduction percentage observed was induced by *B. bassiana* 10^{11} conidia/ml (24.43%), followed by *B. bassiana* 10^{10} conidia/ml (22.36%) treatments. Significant difference in population reduction percentage of onion thrips was observed after 5 days of spray. The highest population reduction percentage observed was induced by *B. bassiana* 10^{11} conidia/ml (40.83%) followed by *B. bassiana* 10^{10} conidia/ml (37.04%) and *M. anisopliae* 10^{11} conidia/ml (36.45%) treatment ($F = 7.91$; $P = 0.00$) after 5 days of spray. Significant differences were observed among treatments after 7 days of application. After 7 days, the highest population reduction percentage observed was induced by *B. bassiana* 10^{11} conidia/ml (76.50%), followed by *B. bassiana* 10^{10} conidia/ml (65.22%) treatments. After 10 days of EPF application, the highest population reduction percentage observed was induced by *B. bassiana* 10^{11} conidia/ml (84.59%), followed by *M. anisopliae* 10^{11} conidia/ml (84.16%) treatment and *B. bassiana* 10^{10} conidia/ml (82.90%) treatments ($F = 6.38$; $P = 0.00$). A significant difference in population reduction percentage was observed at all the treatments at different level of concentrations for *T. tabaci.* After EPF applications, thrips numbers were reduced in treated plots than the untreated control plots. However, significant differences were observed in the treatments applied at different concentration.

Significant differences ($F = 21.68$; $P = 0.00$) in corrected population reduction percentage of onion thrips were observed after 3 days of treatment application on Swat 1 variety (Table 4). The highest population reduction percentage (89.46%) was observed in 3 days after spraying with bifenthrin. After 5 days, the highest population reduction percentage observed was induced by *B. bassiana* 10^{11} conidia/ml (60.62%), followed by *B. bassiana* 10^{10} conidia/ml (59.89 %) treatments. After 7 days, the highest population reduction percentage observed was induced by *B. bassiana* 10^{11} conidia/ml (87.92%), followed by *B. bassiana* 10^{10} conidia/ml (81.22%) and *M. anisopliae* 10^{11} conidia/ml (78.70%) treatments ($F = 3.62$; $P = 0.01$). After 10 days of entomopathogenic application, the highest percent population reduction observed was induced by *B. bassiana* 10^{11} conidia/ml (76.58%) followed by *B. bassiana* 10^{10} conidia/ml (75.76%) treatment ($F = 9.61$; $P = 0.04$). A significant difference in population reduction percentage was observed for all the treatments at different level of doses for *T. tabaci* on Swat 1 onion variety.

Table 3 Entomopathogenic fungi on thrips population reduction percentage on Swat 1 onion variety during 2019

Treatments (conidia/ml)	Reduction (%) of onion thrips			
	(3rd day)	(5th day)	(7th day)	(10th day)
Metarhizium anisopliae 10^8	14.25e	20.62f	41.65f	68.45c
M. anisopliae 10^9	16.49de	27.36e	53.25de	70.82c
M. anisopliae 10^{10}	15.06e	28.14de	46.36ef	75.12bc
M. anisopliae 10^{11}	17.75de	34.35cd	60.62bcd	77.99ab
Beauveria bassiana 10^8	16.35de	33.96cd	57.39bcd	80.64ab
B. bassiana 10^9	22.36bc	37.04bc	65.22b	82.90a
B. bassiana 10^{10}	19.36cd	36.45bc	63.72bc	84.16a
B. bassiana 10^{11}	24.43b	40.83b	76.50a	84.59a
Bifenthrin	81.01a	76.63a	52.60cde	39.31d
HSD value	3.99	6.48	9.92	6.69

Columns having same letter are not statistically different ($P \geq 0.05$, ANOVA)

Table 4 Entomopathogenic fungi on thrips population reduction percentage on Swat 1 onion variety during 2020

Treatments (conidia/ml)	Reduction (%) of onion thrips			
	(3rd day)	(5th day)	(7th day)	(10th day)
Metarhizium anisopliae 10^8	17.85b	25.85b	53.65b	66.35ab
M. anisopliae 10^9	18.29bc	46.66b	64.11ab	71.30ab
M. anisopliae 10^{10}	20.09bc	27.94b	56.79ab	69.42ab
M. anisopliae 10^{11}	28.48bc	51.64ab	71.35ab	74.78a
Beauveria bassiana 10^8	6.19c	26.08b	57.01ab	72.86ab
B. bassiana 10^9	16.40bc	59.89ab	81.22ab	75.76a
B. bassiana 10^{10}	19.11b	35.99b	78.70ab	74.06ab
B. bassiana 10^{11}	21.68bc	60.62ab	87.92a	76.58a
Bifenthrin	89.46a	84.29a	71.01ab	45.22b
HSD value	26.17	36.36	31.89	29.39

Columns having same letter are not statistically different ($P \geq 0.05$, ANOVA)

Thrips population before spray ranged between 65 and 170 thrips/5 plants. After 1 week of treatment applications, decline in thrips population density was more in EPF treatments than in insecticide-treated plots (Table 4). Average hourly temperature and RH measurements ranged from 23.2 to 31.3 °C and 28 to 76%, respectively, during the study.

Onion thrips population reduction percentage on Virio 7 variety

A high population reduction percentage was recorded at high concentrations of EPF during 2019 (Table 5). Results revealed that the maximum population reductions were 23.74% and 40.97% after 3 and 5 days of *B. bassiana* 10^{11} conidia/ml application, respectively. Further population reduction of thrips was observed after 7 days of spray. *B. bassiana* at the concentration of 10^{11} conidia/ml treated onion plants showed the highest population reduction 71.91% which is at par with *M. anisopliae* 10^{11} conidia/ml (67.14%) ($F = 20.40$; $P = 0.00$). Significant differences were observed in treatments after 7 days of application. After 10 days, the highest population reduction percentage observed was induced by *B. bassiana* 10^{11} conidia/ml (86.00%), followed by *M. anisopliae* 10^{11} conidia/ml (82.70%) and *B. bassiana* 10^{10} conidia/ml (80.58%) treatments ($F = 6.97$; $P = 0.00$). A significant difference in population reduction percentage was observed at all the treatments at different level of doses for *T. tabaci.*

Significant difference in population reduction percentage of onion thrips was observed after 3 days of application on Virio 7 variety (Table 6). The highest population reduction percentage (80.78%) observed was induced by application of bifenthrin ($F = 7.47$, $P = 0.00$) after 3 days of spray. After 5 days, the highest population reduction percentage observed was induced by *B. bassiana* 10^{11} conidia/ml (49.93%) followed by *M. anisopliae* 10^{11} conidia/ml (45.53%) treatment ($F = 0.92$; $P = 0.52$). Thrips generations showed peak populations after 5 to 6 weeks in control treatments. There were significant differences

Table 5 Entomopathogenic fungi on thrips population reduction percentage on Virio 7 onion variety during 2019

Treatments (conidia/ml)	Reduction (%) of onion thrips			
	(3rd day)	(5th day)	(7th day)	(10th day)
Metarhizium anisopliae 10^8	14.68f	23.66d	42.89f	69.11d
M. anisopliae 10^9	16.37ef	28.40d	50.97de	70.33d
M. anisopliae 10^{10}	17.89de	28.97d	48.23ef	75.33cd
M. anisopliae 10^{11}	18.26cde	35.51bc	59.60bc	79.57bc
Beauveria bassiana 10^8	19.93cd	34.72c	56.67cd	78.65bc
B. bassiana 10^9	21.01bc	37.47bc	65.03ab	80.58abc
B. bassiana 10^{10}	20.86bc	36.49bc	67.14a	82.70ab
B. bassiana 10^{11}	23.74b	40.97b	71.91a	86.00a
Bifenthrin	78.14a	74.47a	49.11cde	31.69e
HSD value	3.22	5.9	6.38	6.41

Columns having same letter are not statistically different ($P \geq 0.05$, ANOVA)

Table 6 Entomopathogenic fungi on thrips population reduction percentage on Virio 7 onion variety during 2020

Treatments (conidia/ml)	Reduction (%) of onion thrips			
	(3rd day)	(5th day)	(7th day)	(10th day)
Metarhizium anisopliae 10^8	16.63b	32.04a	51.0a	61.68ab
M. anisopliae 10^9	20.57b	33.92a	58.93a	62.59ab
M. anisopliae 10^{10}	22.27b	37.04a	57.07a	67.12ab
M. anisopliae 10^{11}	33.75b	38.09a	57.77a	71.14ab
Beauveria bassiana 10^8	21.28b	36.43a	55.12a	74.97a
B. bassiana 10^9	25.61b	41.47a	56.00a	76.96a
B. bassiana 10^{10}	26.42b	45.53a	65.51a	77.95a
B. bassiana 10^{11}	26.70b	49.93a	68.65a	79.41a
Bifenthrin	80.78a	66.81a	54.77a	35.21b
HSD value	34.77	56.4	36.14	38.54

Columns having same letter are not statistically different ($P \geq 0.05$, ANOVA)

observed in treatments after 5 days of application. After 7 days of application, the highest population reduction percentage was induced by *B. bassiana* 10^{11} conidia/ml (68.65%) followed by *M. anisopliae* 10^{11} conidia/ml (65.51%) treatment..

Discussion

Obtained results highlighted the prospective of EPF for controlling onion thrips. In particular, more than 80% thrips population reduction was recorded by *B. bassiana* and *M. anisopliae* application field trials.

The EPF species used against *T. tabaci* varied in their efficacy to reduce pest's populations. *B. bassiana* concentration (1×10^{11} conidia/ml) tested was more effective than any *M. anisopliae* treatments. The results are in agreement with Neves and Alves (2000). *B. bassiana* is an efficient alternative method for use in biocontrol against the onion thrips (Maniania et al. 2003). In this study, *B. bassiana* showed 86.62 ± 1.43 population reduction percentage after 10 days of treatment application which are similar to Ansari et al. (2008) who stated that *Beauveria* spp. were the most efficient, causing 54-84% onion thrips corrected population reduction percentage after 11 days of application. Low population reduction percentage by *M. anisopliae* application might be due to the more time required for conidial germination on insect body as compared with filtrate. Some other factors like viability of conidia, rate of germination, hyphae growth rate, and environmental factors such as temperature, humidity, and UV light could also affect spore production and virulence of fungal isolates on different insects (Molenaar 1984).

Results showed that EPF induce an immediate effect on thrips populations to obtain 2-3 thrips/onion leaf (Diaz-Montano et al. 2011) economic threshold levels in field conditions. However, a lot of variations in thrips counts were observed during the field trial. Environmental factors like rainfall had a significant effect on the population densities of thrips by washing or dislodging them from the plants. Results also showed that thrips populations were reduced at insecticidal-treated plots, which is in agreement with Ghelani et al. (2014) findings. Although EPF formulations were efficient in reducing the thrips numbers, they caused moderate population reduction as compared to insecticides. The highest efficacy of *B. bassiana* against thrips is in accordance with Boopathi et al. (2011) who stated that among different EPF *B. bassiana* gave better results in reducing the population of thrips. For maximum benefits, therefore, this approach should be integrated with other thrips management strategies, such as the use of resistant varieties, polythene mulches, proper sanitation, sticky traps, and botanicides (Maniania et al. 2003).

T. tabaci population on vegetables may be controlled well with entomopathogens at concentration of 1×10^{11} conidia/ha in field crops. But there is one limitation in the use of these EPF that they are relatively less persistent (Inglis et al. 1997). Results showed that these EPF were able to persist for 10 days under the field conditions. The present results showed also that *B. bassiana*, *M. anisopliae*, and bifenthrin had great potentials for use as important component in developing integrated insect pest management packages against thrips on onion (Nyasani et al. 2015). Further studies are required to standardize concentrations of these EPF at different stages of onion thrips infestations under field conditions.

Conclusion

Entomopathogenic fungi *B. bassiana and M. anisopliae* significantly reduced thrips population build up in onion crop after 7-10 days post applications. The fungal species used against *T. tabaci* varied in their ability to reduce its populations. *B. bassiana* as EPF was much against the onion thrips than the *M. anisopliae.* Use of EPF to control thrips populations could reduce the application of insecticide thereby preventing and/or delaying the population buildup of resistant thrips progenies. It is suggested that EPF can provide a better long-term management of *T. tabaci* on onion under field conditions.

Abbreviations
T. tabaci: *Thrips tabaci*; *B. bassiana*: *Beauveria bassiana*; *M. anisopliae*: *Metarhizium anisopliae*; EPF: Entomopathogenic fungi

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Authors' contributions
Q and AM conceived, planned, and carried out the experiments, while MN helps in statistical analyses of data. GS contributed to the interpretation of the results during manuscript writing. All authors provided critical feedback and helped shape the research, analysis and manuscript. The authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable

Consent for publication
Not applicable

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

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