Consortia of entomo-pathogenic fungi and bio-control agents improve the agro-ecological conditions for brinjal cultivation of Assam

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Abstract

A liquid consortial formulation with three compatible biocontrol agents viz., *Trichoderma harzianum*, *Beauveria bassiana* and *Metarhizium anisopliae* was prepared with already standardized additives (Assam Agricultural University (AAU), Jorhat, Assam). Pot and field experiments conducted to test the efficacy of six different IPDM (Integrated Pests and Disease Management) modules with the prepared consortia showed that module-6 (seed treatment + seed bed treatment in nursery + soil application in main field + seedling dip treatment with consortia of biofertilizer, *Rhizobium* sp., *Azotobacter* sp. strain 52, *Azospirillum* sp. strain 71 and *Bacillus* sp. strain 5 W + spraying of consortia) was the best for the management of three important diseases of brinjal viz., *Phomopsis* leaf blight and fruit rot, *Alternaria* leaf spot, and *Fusarium* wilt. Field experiment repeated in the second year utilizing six different modules revealed the module 6 as best in reduction of disease incidence and increasing the growth parameters and yield of the crop. Result of pooled analysis of field experiments showed a yield of 570.97q/ha with B:C ratio 3.99. The module was also found effective in improving the nutrient status with significant increase in P and K status of soil as well as microbial biomass carbon in both the years of experimentation (2014–2015 and 2015–2016). The module can be used by the farmers for organic cultivation of brinjal after further confirmation in multi locations of diverse agroecological condition of Assam.

Keywords *Beauveria bassiana* · Biofertilizer · Compatibility · Consortia · Entomopathogenic fungi · *Metarhizium anisopliae*

Introduction

Brinjal, *Solanum melongena* L. is an economically important vegetable among the small scale growers and low income consumers of India which is grown over 17,670 ha with a production of 286.43 thousand MT (Ministry of Agriculture & Farmers' Welfare, Government of India, 2017). Due to long fruiting and harvesting period, it ensures some assured source of income to the resource poor farmers throughout

the year. In the state of Assam, the productivity is 16.20 MT/ha which is less as compared to the national productivity (18.50 MT/ha). Lower productivity in the state may be due to attack of pests and diseases in different growth stages of the crop. The important diseases which cause major losses are damping off (*Pythium aphanidermatum* (Eds.) Fitz., *Phytophthora* spp. and *Rhizoctonia* spp.), *Alternaria* leaf spot (*Alternaria melongenae* Rang. & Samb and *A. solani* (El. & Mart) Jones and Grouet), *Cercospora* leaf spot (*Cercospora melongenae* Welles and *C. solani-melongenae* Chupp) *Phomopsis* blight and fruit rot (*Phomopsis vexans* (Sacc & Syd) Harter), *Sclerotinia* blight (*Sclerotinia sclerotiorum* (Lib.) de Bary), *Verticillium* wilt (*Verticillium dahlia* Kleb.), bacterial wilt (*Ralstonia solanacearum* Yabuuchi et al. 1995), little leaf (mycoplasma) and mosaic (Tymovirus group). All these may cause yield loss more than 70%. The pests like fruit and shoot borer (*Leucinodes orbonalis* Guenee), jassid (*Amrasca biguttula biguttula* Ishida), aphids (*Aphis gossypii* Glover), white spotted flea beetle (*Monolepta signata* Olivier and *Chaetocnema basal*

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Baly), leaf miner (*Phytomyza atricornis* Goureau), hadda beetle (*Henosepilachna vigintioctopunctata* Fabricus) and white fly (*Bemisia tabaci* Genn) (Thakur et al. 2012) are also responsible for lower productivity of the crop.

For the management of these pests and diseases, farmers of Assam usually use pesticides like Carbofuran, Flubendiamide, Spinosad, Emamectin Benzoate, Chlorfenapyr, Novaluron, Lufenuron, Methoxyfenozide, Chlorpyrifos, Quinalphos, Cypermethrin, Bavistin (Carbendazim 50WP), Indofil M-45 (Mancozeb), Ridomil MZ (Metalaxyl 8% + Mancozeb 64%) etc. But the ill effect of indiscriminate use of synthetic pesticides can't be ignored. Biological control on the other hand is considered as an alternative and eco friendly way to combat pests problem. Four biocontrol agents, two best entomopathogens viz., *Beauveria bassiana* and *Metarhizium anisopliae*, two best biocontrol agents viz., *T. harzianum* and *T. asperellum* were selected based on earlier studies (Upamanya and Dutta 2018), against different pests and pathogens of brinjal. For the present study, we have considered the compatible combination of entomopathogens and biocontrol agents with an aim to prepare a consortium of both and was tested along with consortia of biofertilizer in pot and field condition in different Integrated Pests and Disease Management modules against naturally infested diseases of brinjal. The main aim of the present study was to find out the best module in terms of efficacy for the management of the diseases, their role in growth parameter, yield, B:C ratio and post treatment physico-chemical properties, nutrient status, microbial biomass of soil.

Materials and methods

Compatibility of biocontrol agents and entomopathogenic fungi

Compatibility amongst biocontrol agents viz., *B. bassiana*, *M. anisopliae*, *T. harzianum* and *T. asperellum* was done by standard co-culture method in potato dextrose agar (PDA) medium to find out the compatible combination of biocontrol agents for development of consortium. Interaction between opposition colonies visually assessed as per the method described by Mohammad et al. (2011). For this experiment, the fungal bio control agents were classified into two groups: slow and fast growing fungi. The fungi covered the full plate within 3 days and those needed more than 3 days were considered as fast growing and slow growing fungi, respectively. For each interaction, the fast growing fungi were inoculated 3 days later once the slow growing fungi started to grow and were incubated at 28 ± 2 °C. Among the compatible combinations, the best mycopathogens and the best entomopathogens combinations were selected for preparation of consortia.

Efficacy of liquid consortia along with consortia of biofertilizers against disease complex of brinjal

Compatible combination of mycopathogens and entomopathogens was used to prepare liquid formulation supplemented with standardized additives (adjuvants, stickers, surfactants, UV protectant). The consortia was tested along with consortia of biofertilizer in pot and field condition in different Integrated Pests and Disease Management (IPDM) modules against naturally infested diseases of brinjal with an aim to find out the best module for the management of the diseases and study the effect on plant growth parameters, yield, B:C ratio and post treatment physico-chemical properties, nutrient status, microbial biomass of soil.

Efficacy of consortia in nursery condition

Raised bed nursery (1.25 m × 1 m × 10 cm, LXWXH) was prepared to fine tilth. Brinjal seeds [brinjal hybrid (NBH Usha Kiran), Noble Seeds Pvt. Limited, Bangalore] were sown in the nursery bed at the organic plots of Experimental Farm, Department of Horticulture, Assam Agricultural University (AAU), Jorhat and in the farm of Krishi Vigyan Kendra (KVK), Barpeta, Howly, Assam. The experiment was laid out by keeping four nursery conditions in a randomized block design with 6 replicates in each condition. The four nursery conditions were denoted as N1: Control, N2: Seed treatment with microbial consortia (@ 5 ml/kg of seed), N3: Treatment of raised nursery bed by soil drenching with liquid form of the consortia @ 5 ml/L of water 3 days before seed sowing (4 L of final spray solution/m²), N4: N₂ + N₃. Observation on germination percentage, seedling vigor index and percent disease incidence was recorded.

Efficacy of consortia in field and pot condition

For field experiment, the land was prepared as per recommendation. Consortia enriched vermicompost @ 2 t/ha (5 L consortia in 2 t vermicompost) was added in all the plots except control. For the pot experiment, the potting mixture consisted of garden soil, sand and consortia enriched vermicompost (5 L consortia in 2 t vermicompost) was used at the ratio 3:1:1 in all the treatments except control. Only garden soil and sand in the ratio of 3:1 was added in the pots used for control. Crop was maintained by following the recommended package and practices. Irrigation was done to maintain optimum soil moisture. Liquid consortia comprising mycopathogens and entomopathogens along with the consortia of biofertilizer (*Rhizobium* sp. + *Azotobacter* sp. Strain 52 + *Azospirillum* sp. Strain 71 + *Bacillus* sp. Strain 5 W) were tested for their efficacy in pot condition at AAU, Jorhat and field condition for two seasons (first season at

AAU, Jorhat and second season at KVK, Barpeta) against the targeted pathogens and pests of brinjal. Observations recorded were similar with the previous experiment. Each replication in the pot experiment consisted of 5 pots. The treatments used for the pot and field study were, T1: Control (Seedling of N1 nursery), T2: Seedling of N2 nursery + application of 2 t vermicompost with 5.0 L of liquid consortia/ha + root dip treatment of seedlings with biofertilizer consortia @ 100 g/L + spraying of liquid consortia @ 3 ml/L at 15, 30, 45, 60 days after transplanting (DAT), T3: Seedling of N2 nursery + application of 2 t vermicompost with 5.0 L of liquid consortia/ha + spraying of liquid consortia @ 3 ml/L at 15, 30, 45, 60 DAT, T4: Seedling of N3 nursery + application of 2 t vermicompost with 5.0 L of liquid consortia/ha + root dip treatment of seedlings with biofertilizer consortia @ 100 g/L + spraying of liquid consortia @ 3 ml/L at 15, 30, 45, 60 DAT, T5: Seedling of N3 nursery + application of 2 t vermicompost with 5.0 L of liquid consortia/ha + spraying of liquid consortia @ 3 ml/L at 15, 30, 45, 60 DAT, T6: Seedling of N4 nursery + application of 2 t vermicompost with 5.0 L of liquid consortia/ha + root dip treatment of seedlings with biofertilizer consortia @ 100 g/L + spraying of liquid consortia @ 3 ml/L at 15, 30, 45, 60 DAT and T7: Seedling of N4 nursery + application of 2 t vermicompost with 5.0 L of liquid consortia/ha + spraying of liquid consortia @ 3 ml/L 128 at 15, 30, 45, 60 DAT. Observations of *Phomopsis* leaf blight was recorded at 30, 60, 90 and 120 DAT of seedlings and fruit rot intensity were recorded at 90 and 120 DAT in the field experiment taking 10 samples from the field. The per cent disease intensity of leaf blight and per cent disease intensity of *Phomopsis* fruit rot were recorded using 1–12 point scale proposed by Horsefall and Baratt (1945) and 1–8 scale given by Kumar (1998), respectively. Data on incidence of *Fusarium* wilt of brinjal was calculated by the following formula as given by Rahman et al. (2011). Per cent disease incidence of *Alternaria* leaf spot was calculated by counting the total number of leaves and number of leaves infected on randomly selected ten numbers of plants in field condition and five plants in pot condition as the method given by Bhat et al. (2013). Observation on plant growth parameters like plant height, root length, number of leaves/plant, number of shoots/plant, fresh weight of root and shoot were recorded at maturity of the crop for all the treatments. Number of flowers/plant, number of fruits/plant and yield/ha were counted in each plot at harvest and B:C ratio was worked out for each of the treatment. Pre and post treatment soil samples were collected from all the locations of experimental sites for both the seasons using soil auger from 0–30 cm depth as per the standard method. The same method was followed after harvest of the crop from each plot for determining the nutrient status after the treatment. pH of the soil was determined in 1:2.5 soil–water suspension (Jackson 1973) using glass

electrode pH meter (Eutech Instruments, pH 700). Organic carbon (%) content was estimated by wet digestion method (Walkley and Black 1934) as described by Jackson (1973). Available N in soil was determined by alkaline potassium permanganate method (Subbiah and Asija 1956). Available P content of soil was determined by Bray and Kurtz No. 1 method (Jackson 1973). Available K was estimated by ammonium acetate extraction method using flame photometer (128 µc, Systronics). International pipette method as described by Piper (1966) was used for determination of mechanical composition of soil. Bulk density was determined in undisturbed soil core, and water holding capacity was determined by Keen–Rackzowski Box method referring the textbook of Baruah and Borthakur (1997). Soil microbial biomass carbon (SMBC) was estimated using chloroform fumigation incubation method (Jenkinson and Powlson 1976). Here, collected soil samples (20 g in dry weight) were fumigated with ethanol free chloroform vapour in sealed desiccators lined with moist filter paper for 24 h at 25 °C. After fumigation, extraction was done with 0.5 M K₂SO₄ (1:4 soil:solution ratio) for 1 h and stored the extracts at 4–5 °C till further assay. Thus, the increase in organic C following the fumigation of soil samples was used to estimate the amount of C held in the soil microbial biomass. Control samples were also maintained with non-fumigated soil samples keeping in desiccators lined with moist filter paper for 24 h at 25 °C.

Results and discussion

Compatibility of mycopathogens and entomopathogens in vitro

The combination-I (*T. harzianum* + *B. bassiana*; *T. harzianum* + *M. anisopliae*; *B. bassiana* + *M. anisopliae* and *T. harzianum* + *B. bassiana* + *M. anisopliae*) and the combination-II (*T. asperellum* + *B. bassiana*; *T. asperellum* + *M. anisopliae*; *B. bassiana* + *M. anisopliae* and *T. asperellum* + *B. bassiana* + *M. anisopliae*) were found compatible in mixed culture (Table 1 and Fig. 1). Earlier workers also studied the compatibility among the biocontrol agents to achieve better management of pests and diseases. Siciua et al. (2014) found in vitro compatibility of *Bacillus licheniformis*-77.1 s with the entomopathogenic fungi *B. bassiana* DSM 62075. They also observed compatibility between *M. anisopliae* DSM 1496 with *B. licheniformis* 77.1. In another work *Streptomyces griseorubens*, *Gliocladium virens* and *T. harzianum* were found compatible while grown on PDA media. The compatibility among the microorganisms might be due to lack of production of secondary metabolites by the individual organism to harm each other while grown in same media (Suryaminarsih et al. 2015).

Table 1 Visual observations of compatibility of mycopathogens and entomopathogens in co-culture plate

	Interacting species	Observation	Compatibility reaction
Combination-I			
a	<i>T. harzianum</i> + <i>B. bassiana</i>	The mycopathogen and the entomopathogen grew mutually and overlapped each other	Compatible
b	<i>T. harzianum</i> + <i>M. anisopliae</i>	The mycopathogen and the entomopathogen grew mutually and overlapped each other	Compatible
c	<i>B. bassiana</i> + <i>M. anisopliae</i>	Both the entomopathogens grew mutually and overlapped each other	Compatible
d	<i>T. harzianum</i> + <i>B. bassiana</i> + <i>M. anisopliae</i>	Mutual growth of <i>T. harzianum</i> and the both the entomopathogens were observed with mutual overlapping	Compatible
Combination-II			
e	<i>T. asperellum</i> + <i>B. bassiana</i>	The mycopathogen and the entomopathogen grew mutually and overlapped each other	Compatible
f	<i>T. asperellum</i> + <i>M. anisopliae</i>	The mycopathogen and the entomopathogen grew mutually and overlapped each other	Compatible
g	<i>B. bassiana</i> + <i>M. anisopliae</i>	Both the entomopathogens grew mutually and overlapped each other	Compatible
h	<i>T. asperellum</i> + <i>B. bassiana</i> + <i>M. anisopliae</i>	The mycopathogen <i>T. asperellum</i> and the both the entomopathogens grew mutually and overlapped each other	Compatible

Fig. 1 Compatibility amongst the biocontrol agents used in the study

Zegeye et al. (2011) observed compatibility of *T. viride* and *Pseudomonas fluorescens*. Thilagavathi et al. (2007) found no any inhibition zone between of *T. viride* (TV1 and TV13) and *P. fluorescens* (Pf1 and PY15) in dual culture indicating the compatibility. Mohammad et al. (2011) found *T. viride* and *Penicillium* sp., *T. viride* and Basidiomycete M1, *T. reesei* and *P. tigrinus* M609RQY were compatible and could be used to develop consortia for faster composting process. Since in the present study *T. harzianum* was found superior over *T. asperellum* in dual culture experiment as recorded in our earlier study (Upamanya and Dutta 2018) in inhibiting the radial growth of pathogen causing diseases in brinjal,

the combination-I was used to prepare the liquid consortia for further study.

Efficacy of consortia against disease and other growth parameters in nursery

The per cent disease incidence of damping off disease at 10, 20 and 30 days after sowing in the first and second year indicated that the treatment of consortia in seed + seed bed treatment resulted significant reduction of the disease followed by seed bed treatment, seed treatment and control in both year of experiments (Table 2). However, all the treatments

Table 2 Efficacy of the consortia against damping off of brinjal in nursery

Treatments	Disease incidence (%) 10DAS			Reduction of disease over control (%)			Disease incidence (%) 20DAS			Reduction of disease over control (%)			Disease incidence (%) 30DAS			Reduction of disease over control (%)		
	1st season	2nd season	Pooled	1st season	2nd season	Pooled	1st season	2nd season	Pooled	1st season	2nd season	Pooled	1st season	2nd season	Pooled	1st season	2nd season	Pooled
Control	18.25 (25.28) ^a	18.92 (25.77) ^a	18.59 (25.53) ^a	–	–	–	22.03 (27.98) ^a	22.73 (28.46) ^a	22.38 (28.22) ^a	–	–	–	27.26 (31.46) ^a	30.08 (33.25) ^a	28.67 (32.36) ^a	–	–	–
Seed treatment	9.12 (17.57) ^b	9.33 (17.78) ^b	9.23 (17.68) ^b	50.03	50.69	50.35	9.72 (18.16) ^b	9.72 (18.16) ^b	9.72 (18.16) ^b	55.88	57.23	56.57	9.46 (17.91) ^b	9.33 (17.78) ^b	9.40 (17.85) ^b	65.30	68.98	67.21
Nursery bed treatment	7.13 (15.48) ^c	7.20 (15.56) ^c	7.17 (15.53) ^c	60.93	61.95	61.43	7.17 (15.52) ^c	7.20 (15.56) ^c	7.19 (15.55) ^c	67.45	68.32	67.87	7.54 (15.93) ^c	7.35 (15.72) ^c	7.45 (15.83) ^b	72.34	75.57	74.01
Seed + Nursery bed treatment	5.03 (12.95) ^d	5.08 (13.02) ^d	5.06 (12.99) ^d	72.44	73.15	72.78	4.37 (12.06) ^d	4.60 (12.38) ^d	4.49 (12.23) ^d	80.16	79.76	79.93	4.86 (12.73) ^d	4.86 (12.73) ^d	4.86 (12.73) ^c	82.17	83.84	83.05
SED(±)	0.89	1.30	0.98				0.99	1.06	1.00				0.93	0.97	1.17			
CD at 0.05	1.83	2.66	2.01				2.03	2.16	2.05				1.91	1.98	2.39			

Data are mean of six replications

Data within parentheses are arc sine transformed value

showed significantly effective in reducing the damping off incidence as compared to untreated check in both the years. The pooled data analysis (Table 2) indicated that application of consortia in seed + seed bed showed disease incidence of 5.06%, 4.49% and 4.86% at 10, 20 and 30 days after sowing (DAS), respectively, which was found significantly superior over all the treatments. The pooled data indicated that the reduction of damping off incidence over control was found to be 83.05% in seed + seed bed treatment at 30 DAS followed by seed bed treatment (74.01%) and seed treatment (67.21%). Previous studies have showed that the biopriming of tomato seeds with *Trichoderma* isolates (*T. viride* and *T. harzianum*) and bacterial antagonist *P. fluorescens* in combination with FYM 200 q/ha + *Azospirillum* + PSB + *T. harzianum* (4 kg/ha each) recorded highest seed germination (93.1%) with a vigor index of 953.33. This treatment also showed 45.6% and 58.0% reduction of pre and post emergence damping off, respectively, over control (Thakur and Tripathi 2015). Similar findings of effectiveness of biocontrol agents against disease, improvement in seedling vigor, seedling emergence were recorded in cauliflower (Sharma and Sain 2005), capsicum and tomato (Pietr et al. 2002). The significant increase in growth parameters including the seedling vigor index might be due to the inherent capacity of bioagents which was observed to protect the seed from diseases as well as providing nutrients to the germinating seeds by well decomposed organic matter. Secretion of hormones and release of nutrients from the soil organic matters had been proposed as a mechanism involved in the plant growth promotion (Windham et al. 1986; Kleifeld and Chet 1992). The present findings of per cent damping off incidence in seed treatment, nursery bed treatment and seed + nursery bed treatment with consortia of BCA are similar with the findings of Bunkar and Mathur (2001), where application of antagonistic fungus, *Trichoderma* as seed and soil treatment agent had significant effect in reducing the damping off incidence over control. The result of highest germination percentage observed in seed + seed bed treatment with consortia was in agreement with the findings of Bhagat and Pan (2012) who observed the highest percentage of germination of brinjal seed (89%) with seed + soil application of *T. harzianum* (ThrAN-5), and the lowest collar rot incidence in brinjal was noted in seed + soil application of *T. harzianum* (ThrWB-1). The effectiveness of simultaneous application of *Trichoderma* both as seed priming and soil application might be due to formation of protective cover in the seed coat by rapid multiplication in the spermatosphere, and soil application of the biocontrol agents could outcompete other microorganisms or directly parasitized in situ (Bhagat and Pan 2012).

Table 3 Effect of consortia on seed germination (%), growth parameters and seedling vigour index of brinjal

Treatments	Germination percentage			Root length (cm)			Shoot length (cm)			No of days required for germination			Seedling vigour index		
	1st season	2nd season	Pooled	1st season	2nd season	Pooled	1st season	2nd season	Pooled	1st season	2nd season	Pooled	1st season	2nd season	Pooled
Control	72.48 (58.34) ^c	72.28 (58.21) ^c	72.40 (58.28) ^c	1.92 ^c	2.14 ^c	2.03 ^c	3.70 ^c	3.64 ^d	3.67 ^c	8.0 ^a	7.4 ^a	7.7 ^a	406.88	421.94	412.68
Seed treatment	86.33 (68.28) ^b	86.70 (68.58) ^b	86.52 (68.43) ^b	3.42 ^b	3.44 ^b	3.43 ^b	4.50 ^b	4.52 ^c	4.51 ^b	5.8 ^b	6.0 ^b	5.9 ^b	682.70	686.15	686.99
Nursery bed treatment	83.96 (66.67) ^b	83.76 (66.21) ^b	83.69 (66.15) ^b	4.00 ^a	4.10 ^a	4.05 ^a	5.34 ^a	5.34 ^b	5.34 ^a	4.6 ^c	4.6 ^c	4.6 ^c	790.86	792.96	785.85
Seed + Nursery bed treatment	90.85 (72.36) ^a	92.43 (74.00) ^a	91.64 (73.16) ^a	4.22 ^a	4.22 ^a	4.22 ^a	5.58 ^a	5.72 ^a	5.65 ^a	4.4 ^c	4.6 ^c	4.5 ^c	889.84	906.53	904.49
SEd(±)	2.12	2.53	1.88	0.15	0.28	0.29	0.21	0.23	0.34	0.48	0.45	0.41			
CD at 0.05	4.54	5.18	3.84	0.32	0.58	0.60	0.44	0.47	0.69	0.97	0.92	0.84			

Data are mean of six replications

Data within parentheses are sine transformed value

Effect of consortia on seed germination, growth parameters and seedling vigour index

Plant growth parameters were found significantly superior in seed treatment, seed bed treatment and seed + seed bed treatment over control (Table 3 and Fig. 2). Seed germination percentage in seed + seed bed treatment was significantly highest (90.85% in first year, 92.43% in second year and pooled 91.64%) among all the treatments in both the years of experiment. Plant growth parameters and the days required for germination was found statistically at par in seed bed and seed + seed bed treatment in first year of experimentation. In the second year, both the treatments were statistically at par in respect to root length and days required for germination, and seed + seed bed treatment was significantly superior with respect to shoot length over other treatments. Pooled data indicated longer shoot length (5.65 cm), root length (4.22 cm) and less number of days required for seed germination (4.5 days) in the seed + seed bed treatment which was significant over seed treatment and control. Highest seedling vigour index was observed in seed + seed bed treatment followed by seed bed treatment, seed treatment and control in both the years and in pooled result (904.49, 785.85, 686.99 and 412.68, respectively).

Effect of consortia of biocontrol agents and biofertilizer against diseases of brinjal in pot condition

In pot experiment, *Phomopsis* fruit rot and *Alternaria* leaf spot disease were recorded. All the treatments significantly reduced the severity of *Phomopsis* fruit rot over control (28.32%) (Table 4). Out of all the treatments, T6 was found most effective in reducing the severity of *Phomopsis* fruit rot (6.89%), which was followed by T7 (8.00%) and T4 (10.63%). However, T6, T7 and T4, T7 were statistically at par with each other in respect of *Phomopsis* fruit rot severity. The lowest disease incidence of *Alternaria* leaf spot was recorded in T6 (0.78%) followed by T4 (1.92%), T7 (2.38%) and T5 (3.86%). However, T6, T4 and T5, T7 were statistically non significant in respect of *Alternaria* leaf spot disease incidence with highest (19.40%) in the control.

Effect of consortia of biocontrol agents and biofertilizer against diseases of brinjal in field condition

In field condition, disease intensity (%) of *Phomopsis* leaf blight in the first season was significantly highest at 30, 60, 90 and 120 DAT in T1 (control) (Fig. 3) and the lowest in T6 among all the treatments. However, the per cent disease intensity in T7 was at par with T6 at 30 DAT and in T4, T5, T7 at 60, 90 120 DAT. Significant reduction in intensity of

Fig. 2 Growth pattern of seedlings in nursery under different treatment conditions

Table 4 Effect of consortia of BCA and biofertilizer against *Phomopsis* fruit rot (%) and *Alternaria* leaf spot incidence (%) of brinjal in pot condition

Treatments	Intensity of <i>Phomopsis</i> fruit rot (%)	<i>Alternaria</i> leaf spot incidence (%)
Control	28.32 (32.14) ^a	19.40 (26.12) ^a
ST + main field (consortia in soil + biofertilizer + Spraying)	14.27 (22.19) ^{bc}	6.08 (14.27) ^{bc}
ST + main field (consortia in soil + spraying)	15.55 (23.22) ^b	6.73 (15.03) ^b
SBT + main field (consortia in soil + biofertilizer + spraying)	10.63 (19.02) ^{de}	1.92 (7.95) ^{ef}
SBT + main field (consortia in soil + spraying)	11.23 (19.57) ^{cd}	3.86 (11.33) ^{cd}
ST + SBT + main field (consortia in soil + biofertilizer + spraying)	6.89 (15.21) ^f	0.78 (5.08) ^f
ST + SBT + main field (consortia in soil + spraying)	8.00 (16.43) ^{ef}	2.38 (8.87) ^{de}
SEd(±)	1.52	2.05
CD at 5%	3.12	3.20

ST Seed treatment, SBT Seed bed treatment

Data are mean of three replications. Data within parentheses are arc sine transformed value

Phomopsis fruit rot was observed in T6 at 90 and 120 DAT over T1 (control), T2 and T3 (Fig. 4). However, T4, T7 were at par with T6 at 90 DAT and T4, T5, T7 at 120 DAT with regard to *Phomopsis* fruit rot intensity. In the second season, all the treatments were found to have significantly superior in reducing the intensity of *Phomopsis* leaf blight and fruit rot caused by *P. vexans* over control. It was observed that T6 was significantly better in reducing the per cent intensity of *Phomopsis* leaf blight (Fig. 3). With regard to *Phomopsis* fruit rot, all the treatments tested significantly reduced the fruit rot intensity over control which was minimum in T6 at 90 and 120 DAT (Fig. 4). The disease intensity was

significantly less over T1, T2, T3, T5 at 90 DAT and T1, T2, T3 at 120 DAT. On the other hand T4, T7 at 90 DAT and T4, T5, T7 at 120 DAT was at par with T6 in respect of *Phomopsis* fruit rot intensity. (Fig. 4). Similar trends were observed in pooled data (Figs. 3, 4). Among the treatments, T6 was most effective in reducing the disease intensity of *Phomopsis* leaf blight at 30, 60, 90 and 120 DAT and fruit rot at 90 and 120 DAT. Maximum disease incidence of *Alternaria* leaf spot was recorded in control and it was significantly the highest among all the treatments (Fig. 5). T6 was significantly superior over other treatments in reducing the *Alternaria* leaf spot incidence followed by T7 (Fig. 5). Similarly,

Fig. 3 Effect of consortia of BCA and biofertilizer against *Phomopsis* leaf blight of brinjal

Fig. 4 Effect of consortia of BCA and biofertilizer against *Phomopsis* fruit rot of brinjal

Fig. 5 Effect of consortia of BCA and biofertilizer against *Alternaria* leaf spot and *Fusarium* wilt incidence of brinjal

highest incidence of *Fusarium* wilt was recorded in control (33.33%) which was significantly the highest among all the treatments tested. There was no incidence of *Fusarium* wilt in the T6, T7, T4 and T6, T7 during first and second season (Fig. 5). Pooled data (Fig. 5) showed T6 as significantly superior in reducing the *Alternaria* leaf spot incidence over T1 (Control), T2 and T5 are statistically at par with T4 and T7. However, all the treatments were significantly effective over control in reducing the *Alternaria* leaf spot incidence. In case of *Fusarium* wilt also, all the treatments were effective over control (Fig. 5). It is noteworthy that there was no incidence of *Fusarium* wilt in T6 and T7. All the modules with regard to *Phomopsis* fruit rot intensity and *Alternaria* leaf spot incidence in pot experiment showed better performance over control. However, the module-6 consisting seed + seed bed treatment with consortia of BCA, root dip treatment with consortia of biofertilizer, soil application and spraying of consortia of BCA was found best in reduction of the disease. Same trend was observed in the field experiment with regard to the intensity of *Phomopsis* leaf blight and fruit rot as well as incidence of *Alternaria* leaf spot and *Fusarium* wilt. In the field experiment, all the modules showed better performance over control in reducing the disease. In field also module-6 performed best among all the treatments against those diseases. The modules of Sharma and Razdan (2012) comprising FYM treated *T. viride* (JMU-24) + soil solarization + seed treatment with *T. viride* (JMU-24) was better over control in reducing *Phomopsis* leaf blight and fruit rot intensity which was in conformity with our

results. The better performance of BCA against *Phomopsis* leaf blight and fruit rot might be due to increased soil suppressiveness and better plant growth. In controlling early blight of tomato caused by *Alternaria solani*, the findings of Zghair et al. (2014) achieved from seed treatment and foliar spray of *T. harzianum* (24.33%) as against control (33.47%) were comparable with the performance of our consortia of BCA. In this case, *T. harzianum* might have affected spore germination and mycelium development of the pathogen that resulted into inhibition of disease producing activity and induced resistance in the plant (Zghair et al. 2014). Similar findings were also reported by several workers (Osowski 2003; Raziq and Ishtiaq 2010; Pawar et al. 2013). Zhang et al. (2014) found the lowest incidence of *Fusarium* wilt of banana due to application of matured compost mixed with *Bacillus amyloliquefaciens* N6, *T. harzianum* T 37 and *Paenibacillus polymyxa* SQR-2. These findings are comparable with our results, where lowest incidence of *Fusarium* wilt was recorded in the consortia of BCA and biofertilizer. The soil application of *P. fluorescens* with neem cake gave best result against *Fusarium* wilt of banana (Saravanam et al. 2003). Kay and Stewart (1994) also reported significant biocontrol of white rot disease of onion by the application of mixture of organic fertilizer and antagonist. Production of pathogenesis related (PR) proteins like Chitinase and β -1,3 glucanase in host plant not only hydrolyze chitin and β -1, 3 glucan of cell walls of fungi but also stimulates various defense responses in plant (Dutta et al. 2008). Usually the beneficial microbes induce accumulation of such PR

Table 5 Effect of consortia of BCA and biofertilizers on growth parameters and yield of brinjal in pot condition

Treatments	Plant height (cm)	Root length (cm)	No of leaves/plant	No of shoots/plant	No of flowers/plant	No of fruits/plant	Weight/fruit (g)	Fresh weight of root/plant (g)	Fresh weight of stem/plant (g)	Fruit yield /plant (g)
Control	37.87 ^d	15.67 ^c	28.00 ^d	4.15 ^e	3.30 ^e	2.00 ^d	147.10 ^d	26.30 ^d	73.50 ^e	294.20 ^d
ST + main field (consortia in soil + biofertilizer + spraying)	47.87 ^{ab}	21.57 ^{ab}	49.69 ^{bc}	6.35 ^d	6.32 ^{cd}	4.35 ^c	177.10 ^c	41.20 ^{bc}	177.43 ^c	825.17 ^{bc}
ST + main field (consortia in soil + spraying)	41.37 ^{cd}	20.40 ^b	40.63 ^c	6.00 ^d	5.33 ^d	3.69 ^c	185.30 ^{bc}	36.67 ^c	156.77 ^d	679.97 ^c
SBT + main field (consortia in soil + biofertilizer + spraying)	49.07 ^{ab}	23.60 ^{ab}	55.00 ^{ab}	6.65 ^{cd}	7.65 ^{bc}	5.60 ^{ab}	196.27 ^{abc}	44.23 ^{ab}	205.30 ^{ab}	1111.20 ^a
SBT + main field (consortia in soil + spraying)	43.80 ^{bcd}	20.60 ^b	47.70 ^{bc}	7.63 ^{bc}	8.00 ^b	4.62 ^{bc}	186.80 ^{bc}	38.17 ^c	192.17 ^{bc}	870.87 ^b
ST + SBT + main field (consortia in soil + biofertilizer + spraying)	52.90 ^a	25.03 ^a	59.65 ^a	9.58 ^a	9.59 ^a	6.00 ^a	212.67 ^a	46.67 ^a	212.53 ^a	1134.20 ^a
ST + SBT + main field (consortia in soil + spraying)	44.87 ^{bc}	20.57 ^b	50.00 ^{abc}	8.35 ^b	8.30 ^{ab}	4.30 ^c	201.47 ^{ab}	44.37 ^{ab}	195.80 ^{abc}	872.97 ^b
SEd(±)	3.06	1.80	2.73	0.56	0.79	0.57	9.90	2.33	9.12	87.36
CD at 0.05	6.27	3.69	5.60	1.14	1.62	1.18	20.46	4.76	18.68	178.92

Data are mean of three replications

ST seed treatment, SBT seed bed treatment

proteins in plants against the invading pathogen (Pieterse and Van Loon 1999).

Effect of consortia of biocontrol agents and biofertilizer on yield and growth parameters

Consortia of biocontrol agents and biofertilizers significantly influenced the growth parameters and yield of brinjal in pot experiment (Table 5). All the treatments showed significant improvement in plant height and root length in comparison to the control. Plant height and root length was significantly influenced by the root dip treatment of seedling with consortia of biofertilizer. Maximum plant height (52.90 cm) and root length (25.03 cm) were observed in T6 and this followed by T4 and T2. There was no significant difference among these treatments in respect of plant height and root length. Similarly, maximum numbers of leaves per plant was observed in T6 (59.65) followed by T4, T7, T2, T5, T3 and least in T1 (28.00). There was no significant difference in number of leaves per plant among T4, T6 and T7. Numbers of shoots per plant was also significantly highest in T6 (9.58) this was followed by T7. Lowest numbers of shoots per plant was recorded in control (4.15). Significantly least numbers of flowers per plant (3.30) was observed in control, whereas maximum numbers of flowers were observed in T6 (9.59) followed by T7. But both the treatments were found statistically at par in respect of numbers of flowers per plant. Highest numbers of fruits per plant were recorded in T6 (6.00) followed by T4 (5.60). Lowest numbers of fruits per plant was recorded in control pots (2.00). Maximum weight of the fruit (212.67 g) was recorded in T6, whereas minimum weight per fruit was observed in control (147.10 g). Fresh weight of stem and root was found significantly highest in T6 (212.53 g, 46.67 g). Maximum yield of brinjal per plant was recorded in T6 (1134.20 g) and this was followed by T4 (1111.20 g). However, all the treatments were significantly superior over control. Effect of nursery treatments (seed + seedbed treatment) and application of biofertilizer by seedling dip treatments provided significant effect on plant height in field experiment (Table 6 and Fig. 6). Maximum plant height was observed in T6 (70.47 cm) followed by T4 (68.43 cm) and T7 (67.67 cm) in first season which were statistically at par and significantly different from the rest of the treatments. Similar trend of result was also noticed in case of root length (Table 6). In the second season, there was no significant difference in plant height in T6 (70.33 cm), T4 (69.50 cm) and T7 (70.33 cm). However, all the above treatments were significantly superior in plant height over control, T2, T3 and T5 (Table 7). Highest numbers of leaves, shoots, flowers and fruits per plant was recorded in T6. The growth parameters obtained in pooled results (Table 8) showed that T6 as the best treatment. Like plant height, longest root length was recorded in T6 (39.97 cm) which

was at par with T4, T7 and significantly superior over T2, T3, T5 and control. Highest numbers of leaves per plant was obtained in T6 (163.92) followed by T4 (162.74). Also highest numbers of flowers (28.04) and fruits (17.62) per plant were recorded in T6 followed by T7. Both the treatments were significantly superior over rest of the treatments. Weight per fruit (Table 8) was found highest in T6 (231.14 g) followed by T4, T7 and T2 and all the treatments were at par. T6 (689.43 g) and T4 (672.27 g) was at par with regard to the fresh weight of stem per plant and significantly superior over rest of the treatments. In the field experiment, the highest yield (568.50 q/ha and 573.43 q/ha) over rest of the treatments was recorded in T6 with the best B:C ratio of 3.97 and 4.00, respectively, for first and second season (Tables 6 and 7). This was followed by T7 (Yield = 443.43 q/ha and 397.45 q/ha & B:C ratio = 3.83 and 3.90). Similar trend was obtained in pooled data (Table 8). Highest yield with best B:C ratio was recorded in T6 (Yield = 570.97 q/ha, B:C ratio = 3.99) which was significantly better over other treatments. This was followed by T7 (Yield = 447.63 q/ha & B:C ratio = 3.86), T4 (Yield = 443.00 q/ha & B:C ratio = 3.48) and the lowest B:C ratio (2.06) was recorded in control.

Effect of consortia of biocontrol agents and biofertilizer on nutrient status, soil physicochemical properties and microbial properties of soil

The findings on post treatment nutrient status (Table 9) indicated that there was a positive effect of treatment of consortia of biocontrol agent in combination with consortia of biofertilizer on NPK status of soil. The highest available N in soil was observed in T6 (368.63 kg/ha) followed by T2 and T4. However, all the treatments were not significant with regard to available N content in soil. The post treatment soil P was found significantly high in T6 with 28.43 kg/ha followed by T4 and T2. Lowest amount of P (23.23 kg/ha) was recorded in control which was less than the pre treatment record (24.90 kg/ha). Similarly, available K was significantly superior in T6 (188.83 kg/ha) followed by T2, T4 and T7, whereas it was significantly lowest in control plots (156.07 kg/ha). In case of post treatment physicochemical properties of soil viz., pH, organic carbon (%), bulk density (g/cm^3) and water holding capacity (WHC %), no significant difference was observed among the treatments. With regard to microbial biomass carbon, T6, T4 and T2 remained statistically at par, but significantly higher than rest of the treatments. Lowest microbial biomass carbon (333.64 $\mu\text{g/g}$) of soil was recorded in control. The post treatment nutrient status, soil physicochemical properties and microbial properties of soil estimated in the second season at KVK,

Table 6 Effect of consortia of BCA and biofertilizers on growth parameters, yield and B:C ratio of brinjal in field (first season)

Treatments	Plant height (cm)	Root length (cm)	No of leaves/ plant	No of shoots/ plant	No of flowers/ plant	No of fruits/ plant	Weight/fruit (g)	Fresh weight of root/plant (g)	Fresh weight of stem/plant (g)	Yield/ha	B:C ratio
Control	45.07 ^c	21.60 ^d	75.00 ^c	12.30 ^d	10.30 ^e	6.30 ^f	164.17 ^c	57.40 ^c	389.50 ^d	172.27 ^c	2.02
ST + main field (consortia in soil + bioferti- lizer + spraying)	58.17 ^b	32.20 ^{bc}	131.37 ^{bc}	18.00 ^{bc}	16.00 ^d	10.65 ^{de}	192.90 ^b	65.77 ^{ab}	530.43 ^c	329.93 ^c	2.30
ST + main field (consortia in soil + spraying)	56.50 ^b	29.37 ^c	109.50 ^d	17.00 ^c	15.35 ^d	9.35 ^e	184.27 ^{bc}	64.30 ^{bc}	524.50 ^c	267.47 ^d	2.31
SBT + main field (consortia in soil + bioferti- lizer + spraying)	68.43 ^a	37.50 ^a	146.30 ^{ab}	20.58 ^b	23.00 ^{bc}	13.25 ^c	200.63 ^{ab}	68.90 ^{ab}	665.17 ^{ab}	440.10 ^b	3.47
SBT + main field (consortia in soil + spraying)	55.43 ^b	29.90 ^c	118.00 ^{cd}	20.00 ^b	22.30 ^c	11.24 ^d	194.23 ^{ab}	66.10 ^{ab}	576.50 ^{bc}	329.27 ^c	2.84
ST + SBT + main field (consortia in soil + biofer- tilizer + spray- ing)	70.47 ^a	38.90 ^a	149.00 ^a	25.77 ^a	26.31 ^a	17.00 ^a	214.90 ^a	72.13 ^a	676.43 ^a	568.50 ^a	3.97
ST + SBT + main field (consortia in soil + spray- ing)	67.67 ^a	36.80 ^{ab}	132.00 ^{bc}	27.00 ^a	24.0 ^b	15.00 ^b	203.50 ^{ab}	65.43 ^{ab}	593.17 ^{abc}	443.43 ^b	3.83
SEd(±)	3.75	2.37	7.25	1.30	1.62	0.81	10.52	3.41	43.58	21.78	
CD at 0.05	7.68	4.85	14.84	2.67	3.33	1.66	21.55	6.98	89.26	44.61	

Data are mean of three replications

ST seed treatment, SBT seed bed treatment

Fig. 6 Effect of consortia of BCA and biofertilizers on growth parameters of brinjal

Barpeta (Table 10) also revealed similar trend as recorded in the previous season at AAU, Jorhat.

All the treatments of the consortia of biocontrol agents with or without root dip treatment of seedlings in the consortia of biofertilizer were efficient in increasing the growth parameters like plant height, root length, numbers of leaves per plant, numbers of shoots per plant, numbers of flowers per plant, numbers of fruits per plant, weight per fruit, fresh weight of root and stem per plant and yield per plant (pot condition), yield per hectare and B:C ratio (under field condition) over control. However, the module-6 was best in increasing growth parameter, yield and B:C ratio followed by the module-7 and 4. It is worth mentioning that the best module (T6) consist of the seed + seed bed treatment in nursery with consortia of BCA, root dip treatment of seedling with consortia of biofertilizer, soil treatment in main field and spraying with consortia of BCA. Influence of biofertilizers on the growth parameters, yield and quality of brinjal were proved by Doifode and Nandkar (2014) based on the superior performance of the *Azotobacter chroococcum* plus *Bacillus polymyxa* treated plants over control. The additive effect of biofertilizer consortia on growth parameters and yield might have attributed due to the growth hormones secreted by the organisms thereby increased the availability of nutrients and moisture (Manjusha 1996). Latha et al. (2014) also observed positive effect on the plant growth parameters by applying consortium of *Azospirillum*, phosphobacteria and potassium mobilizer @ 5 g per pot. Prabhu

et al. (2003) achieved enhanced plant height by application of organics and biofertilizers that helped in efficient nutrients uptake by the plant leading to enhancement of chlorophyll content and carbohydrate synthesis and increased activity of hormones produced by *Azospirillum* and PSB. Besides, the phosphobacteria increased phosphate availability in soil in turn helped better proliferation of root growth and uptake of available nutrients to the greater extent. The enlargement of cell size and cell division were reported to boost up plant height, numbers of leaves, branches and fruits per plant (Nathkumar and Veeraraghavathatham 2000). Production of organic acids and growth hormones might be other reasons behind the performance of PGPR in increasing the plant growth parameters and yield. The application of *Bacillus megaterium* TV-3D, *B. megaterium* TV-91C, *Pantoea agglomerans* RK-92, *B. subtilis* TV-17C, *B. megaterium* TV-87A, *B. megaterium* KBA-10 showed high levels of amino and organic acid content (from 9.63 to 186.02%) and promoted significantly better growth of cauliflower (Ekinici et al. 2014). The organic acid like fumaric, malic and citric acids can also chelate Fe and Mn in iron and manganese oxides, respectively, thus making them easily available for uptake by the plant (Ohwaki and Hirata 1992; Marschner 1995). Most of the microorganisms (80%) isolated from the rhizosphere of various crops possess the ability to synthesize and release auxins as secondary metabolites (Patten and Glick 1996). These bacterial IAA expand root surface area, and thereby provides the plant greater access to soil nutrients. On the

Table 7 Effect of consortia of BCA and biofertilizers on growth parameters, yield and B:C ratio of brinjal in field (Second season)

Treatments	Plant height (cm)	Root length (cm)	No of leaves/ plant	No of shoots/ plant	No of flowers/ plant	No of fruits/ plant	Weight/fruit (g)	Fresh weight of root/plant (g)	Fresh weight of stem/plant (g)	Yield/ha	B:C ratio
Control	46.47 ^c	24.07 ^d	95.80 ^c	12.00 ^e	12.17 ^d	9.43 ^c	152.83 ^c	57.87 ^b	391.13 ^d	179.13 ^c	2.10
ST + main field (consortia in soil + biofertilizer + spraying)	56.80 ^b	33.57 ^{bc}	148.17 ^b	17.25 ^{cd}	18.47 ^c	12.77 ^{bc}	212.43 ^b	67.23 ^{ab}	541.37 ^{bc}	344.60 ^c	2.41
ST + main field (consortia in soil + spraying)	55.20 ^{bc}	31.20 ^c	135.10 ^b	16.55 ^d	16.67 ^c	10.17 ^{bc}	211.30 ^b	66.50 ^{ab}	491.77 ^c	272.70 ^d	2.35
SBT + main field (consortia in soil + biofertilizer + spraying)	69.50 ^a	39.27 ^a	179.17 ^a	21.00 ^{bc}	24.83 ^b	13.17 ^b	233.70 ^{ab}	72.67 ^a	679.37 ^a	445.90 ^b	3.48
SBT + main field (consortia in soil + spraying)	55.90 ^{bc}	33.40 ^{bc}	134.83 ^b	21.00 ^{bc}	25.13 ^b	12.83 ^{bc}	218.66 ^{ab}	71.30 ^a	573.53 ^b	350.03 ^c	3.02
ST + SBT + main field (consortia in soil + biofertilizer + spraying)	70.33 ^a	41.03 ^a	178.83 ^a	24.60 ^{ab}	29.77 ^a	18.23 ^a	247.37 ^a	76.23 ^a	702.43 ^a	573.43 ^a	4.00
ST + SBT + main field (consortia in soil + spraying)	70.33 ^a	38.53 ^{ab}	152.93 ^b	25.30 ^a	25.47 ^b	17.60 ^a	210.30 ^b	71.43 ^a	574.97 ^b	451.83 ^b	3.90
SEd(±)	4.70	2.62	11.10	2.04	1.65	1.69	16.75	4.99	39.45	22.86	
CD at 0.05	9.63	5.37	22.74	4.18	3.38	3.46	34.30	10.21	80.80	46.82	

Data are mean of three replications

ST seed treatment, SBT seed bed treatment

Table 8 Effect of consortia of BCA and biofertilizers on growth parameters, yield and B:C ratio of brinjal in field (Pooled)

Treatments	Plant height (cm)	Root length (cm)	No of leaves/ plant	No of shoots/ plant	No of flowers/ plant	No of fruits/ plant	Weight/fruit (g)	Fresh weight of root/plant (g)	Fresh weight of stem/plant (g)	Yield/ha	B:C ratio
Control	45.77 ^d	22.84 ^d	85.40 ^d	12.15 ^d	11.23 ^d	7.87 ^d	158.50 ^c	57.64 ^c	390.32 ^d	175.70 ^c	2.06
ST + main field (consortia in soil + bioferti- lizer + spraying)	57.48 ^{bc}	32.89 ^{bc}	139.77 ^{bc}	17.63 ^{bc}	17.24 ^c	11.71 ^{bc}	202.67 ^{ab}	66.50 ^b	535.90 ^{bc}	337.27 ^c	2.36
ST + main field (consortia in soil + spraying)	55.85 ^{cd}	30.29 ^c	122.30 ^c	16.78 ^c	16.01 ^c	9.76 ^{cd}	197.79 ^b	65.40 ^b	508.14 ^c	270.09 ^d	2.33
SBT + main field (consortia in soil + bioferti- lizer + spraying)	68.97 ^{ab}	38.39 ^{ab}	162.74 ^a	20.79 ^b	23.92 ^b	13.21 ^b	217.17 ^{ab}	70.79 ^{ab}	672.27 ^a	443.00 ^b	3.48
SBT + main field (consortia in soil + spraying)	55.67 ^{cd}	31.65 ^c	126.42 ^{bc}	20.50 ^b	23.72 ^b	12.04 ^{bc}	203.33 ^b	68.70 ^{ab}	575.02 ^b	339.65 ^c	2.93
ST + SBT + main field (consortia in soil + biofer- tilizer + spray- ing)	70.40 ^a	39.97 ^a	163.92 ^a	25.19 ^a	28.04 ^a	17.62 ^a	231.14 ^a	74.18 ^a	689.43 ^a	570.97 ^a	3.99
ST + SBT + main field (consortia in soil + spray- ing)	69.00 ^a	37.67 ^{ab}	142.47 ^b	26.15 ^a	24.74 ^{ab}	16.30 ^a	206.90 ^{ab}	68.43 ^{ab}	584.07 ^b	447.63 ^b	3.86
SEd(±)	4.98	2.89	9.53	1.72	2.00	1.47	12.91	4.47	30.67	22.80	
CD at 5%	10.19	5.91	19.51	3.53	4.10	3.01	26.44	9.16	62.81	46.70	

Data are mean of three replications

ST seed treatment, SBT seed bed treatment

Table 9 Effect of consortia of BCA and biofertilizers on physico chemical characters, nutrient status and total microbial biomass of soil (First season)

Treatments	Available N (Kg/ha)	Available P (Kg/ha)	Available K (Kg/ha)	pH	Organic C (%)	Bulk density (g/cm ³)	Water holding capacity (%)	MBC (µg/g of soil)
Pre treatment status	354.8	24.90	158.40	5.2	0.63	1.26	28.4	312.31
Post treatment status								
Control	347.50	23.23 ^d	156.07 ^c	5.2	0.63 (4.54)	1.34	27.73 (31.76)	333.64 ^c
ST + main field (consortia in soil + biofertilizer + spraying)	364.47	27.70 ^{ab}	187.54 ^{ab}	5.6	0.67 (4.68)	1.31	31.55 (34.16)	831.94 ^a
ST + main field (consortia in soil + spraying)	354.10	25.90 ^{bc}	172.43 ^b	5.6	0.65 (4.63)	1.34	28.42 (32.20)	735.37 ^b
SBT + main field (consortia in soil + biofertilizer + spraying)	363.77	28.23 ^a	187.53 ^{ab}	5.7	0.67 (4.69)	1.30	31.50 (34.13)	836.37 ^a
SBT + main field (consortia in soil + spraying)	354.73	25.27 ^{cd}	173.20 ^b	5.6	0.66 (4.66)	1.33	28.65 (32.35)	742.37 ^b
ST + SBT + Main field (consortia in soil + biofertilizer + spraying)	368.63	28.43 ^a	188.83 ^a	5.7	0.68 (4.72)	1.29	31.81 (34.32)	840.70 ^a
ST + SBT + main field (consortia in soil + spraying)	355.50	25.73 ^{bc}	183.67 ^{ab}	5.7	0.66 (4.65)	1.32	28.91 (32.51)	742.63 ^b
SEd(±)		1.08	7.39					40.91
CD at 0.05	NS	2.21	15.14	NS	NS	NS	NS	83.79

Data are mean of three replications. Data within parentheses are arc sine transformed value

ST seed treatment, SBT seed bed treatment

other hand, rhizobacterial IAA loosens plant cell walls and as a result facilitates an increasing amount of root exudation that provides additional nutrients to support the growth of rhizosphere bacteria (Glick 2012). The module comprising the consortia of BCA and root dip treatment of seedlings combined with consortia of biofertilizer showed better performance in nutrient status, i.e., NPK content. There was significant increase in phosphorus and potassium status in the modules in which both the consortia of BCA and biofertilizers were applied. Although no significant difference in N content was observed among the treatments, still the treatment 6, 4 and 2 showed superior performances in post treatment available N status in soil. Similar observations were also noted by Khan et al. (2013) who found better performance of N, P and K status in soil after harvesting of cowpea in the treatment of seed inoculated with *Rhizobium* + PSB. The higher efficiency of the modules having BCA and biofertilizer with respect to increased P and K might have occurred due to improvement of soil physical properties and

microorganisms driven mineralization of soil nutrients. The beneficial effects of microorganisms on potassium availability include minimization of losses from leaching through the action of organic acids released during decomposition and also due to fixation (Dhaksinamoorthy et al. 2000). Our finding on increased N, P and K status in the biofertilizer consortia module was in agreement with Shailaja et al. (2011) who observed the highest post treatment N, P and K status in soil applied with *Azotobacter* + *Azospirillum* + PSB and 3/4th of recommended dose of NPK in *Emblia officinalis* cultivated soil. An increased trend of organic carbon percentage was noticed after application of the consortia of BCA and biofertilizers. But, there was no significant difference among the treatments. Earlier, Kaushik (2015) also observed increased organic carbon (0.31% and 0.27% to 0.59% and 0.34% at 15 and 30 cm soil depth, respectively) after application of *M. anisopliae* in organic tea ecosystem. Post treatment p^H indicated the increased trend in all modules except in control which supports the findings of Kaushik (2015). The

Table 10 Effect of consortia of BCA and biofertilizers on physico chemical characters, nutrient status and total microbial biomass of soil (Second season)

Treatments	Available N (Kg/ha)	Available P (Kg/ha)	Available K (Kg/ha)	pH	Organic C (%)	Bulk density (g/cm ³)	Water holding capacity (%)	MBC (µg/g of soil)
Pre treatment status	391.5	22.37	121.50	6.1	0.96	1.22	29.2	353.27
Post treatment status								
Control	376.03	20.87 ^c	122.57 ^d	6.1	0.91 (5.47)	1.29	29.08 (32.62)	355.03 ^d
ST + main field (consortia in soil + biofertilizer + spraying)	392.07	26.10 ^a	151.00 ^a	6.3	0.94 (5.57)	1.15	32.35 (34.65)	835.50 ^{abc}
ST + main field (consortia in soil + spraying)	384.83	23.30 ^b	139.13 ^c	6.2	0.93 (5.54)	1.17	31.19 (33.94)	758.63 ^{bc}
SBT + main field (consortia in soil + biofertilizer + spraying)	393.20	26.93 ^a	151.83 ^a	6.4	0.95 (5.59)	1.13	33.22 (35.18)	841.97 ^{ab}
SBT + main field (consortia in soil + spraying)	384.37	23.27 ^b	149.40 ^{ab}	6.3	0.94 (5.56)	1.16	30.98 (33.81)	757.70 ^c
ST + SBT + main field (consortia in soil + biofertilizer + spraying)	396.90	27.33 ^a	155.30 ^a	6.5	0.96 (5.61)	1.12	30.95 (35.79)	849.77 ^a
ST + SBT + main field (consortia in soil + spraying)	385.67	23.73 ^b	141.37 ^{bc}	6.4	0.95 (5.58)	1.16	31.32 (34.02)	759.27 ^{bc}
SEd(±)		0.83	3.99					40.85
CD at 0.05	NS	1.70	8.17	NS	NS	NS	NS	83.66

Data are mean of three replications. Data within parentheses are arc sine transformed value

ST seed treatment, SBT seed bed treatment

consortia of BCA and biofertilizer showed significantly higher value of SMBC over rest of the treatments. Kaushik (2015) also reported increased microbial biomass carbon after application of *M. anisopliae* in organic tea ecosystem. Yadav et al. (2009) found higher SMBC using trash mulch @ 8 tonnes/ha + *T. viride* @ 2 kg/ha in sugarcane ratoon crop. Banerjee et al. (2006) suggested 100% organic source treatment with biofertilizer to increase SMBC which can not be achieved without biofertilizer. In the present study, increase in SMBC in the modules of seedling root dipping in biofertilizer might have resulted by N- fixer and P solubilizers which play role in improving chemical properties of soil including organic carbon and total carbon (Wu et al. 2005). Although the WHC and bulk density of soil were at par in all the treatments, WHC of the post treated soil was high and bulk density was decreased in the module with biofertilizer dipped seedlings. Similar results, i.e., high WHC and low bulk density of the soil were evidenced by Ganiger et al. (2012) after planting the bell pepper seedlings dipped in the slurry of biofertilizers (*Azospirillum* + *Mycorrhiza* + PSB). They (Ganiger et al. 2012) assumed that the biofertilizers have directly influenced in the improvement of soil particles aggregation and texture that brought out such changes in the bulk density and WHC of soil.

Present study demonstrated the compatibility among two important entomopathogens, *B. bassiana* and *M. anisopliae* and the mycopathogen, *T. harzianum* and also exhibited the possibility to develop a consortial bioformulation that could be effectively used for management of both pests and diseases of brinjal. In our earlier work the formulation was proved effective against important pests of brinjal like fruit and shoot borer, jassid, aphids, and hadda beetle (Upamanya and Dutta 2018). The consortia in the form of an IPDM module (seed + seed bed treatment with consortia of BCA, root dip treatment with consortia of biofertilizer, soil application and spraying of the consortia of BCA) also improved the growth parameters of brinjal plants along with yield and B:C ratio. Further, the additional merits of the consortia were improvement in soil nutrient status especially the increased P, K and microbial biomass carbon. Hence the brinjal growers may adopt this organic approach (module) for the management of pests and diseases together which will offer better harvest and higher economic returns.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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