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Effect of PGPR and BCA on Quality Seed Production of Bell Pepper (*Capsicum annuum* L.) under Open Field Conditions

Sujata Kumari[1*], Narender K. Bharat[1], Ashok K. Thakur[1] and Rajesh Kaushal[2]

[1]Dept. of Seed Science and Technology, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, HP (173 230), India.
[2]Additional Director of Research, V C S G Uttarakhand University of Horticulture and Forestry, Bharsar, Pauri Garhwal, Uttrakhand (246 123) India

Corresponding Author

Sujata Kumari
e-mail: sujatasst1990@gmail.com

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Abstract

A field experiment was conducted during two consecutive seasons of 2016 and 2017 at experimental farm of Department of Seed Science and Technology, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan-173230 (HP). The effect of Plant growth promoting rhizobacteria (PGPR) and biocontrol agent (BCA) was evaluated by applying as seedling root dip and soil application alone and in various combinations. The study revealed that plant growth, crop yield and seed yield parameters like maximum plant height (75.43 cm), minimum days to 50% flowering (54.34 days), maximum number of fruitsplant^{-1} (7.75), maximum average fruit weight (48.46 g), fruit length (6.78 cm), fruit width (6.48 cm), fruit size (44.37 cm^2) , minimum days to first picking (102.43), maximum harvest duration (41.97 days), maximum number of fruit pickings (9.10), highest fruit yield plant^{-1} (1038.54 g), fruit yield plot^{-1} (15.58 kg) and fruit yield ha^{-1} (450.37 q), maximum number of seeds fruit^{-1} (177.51), seed yield plant^{-1} (15.78 g), seed yield plot^{-1} (236.63 g), seed yield ha^{-1} (673.50 kg) were recorded maximum with treatment T_5 PGPR (seedling root dip)+*Trichoderma harzianum* (soil application).The effect of all the treatments was significantly higher during the trial conducted in 2016 as compared to the trial conducted in 2017.

Keywords: Bell pepper, BCA, PGPR, Seed, *Trichoderma*

1. Introduction

Bell pepper (*Capsicum annuum* L.), a Solanaceous fruit vegetable, is most popularly grown for its delicacy and pleasant flavour coupled with rich content of ascorbic acid, other vitamins and minerals (Sreedhara et al., 2013). In India, bell pepper is cultivated in an area of 30000 ha with a production of 171000 MT (NHB, 2015) while in Himachal Pradesh, it is an important summer and rainy season crop of mid hills which covers an area of 2070 ha and having production of 34130 MT (NHB, 2014). Bell pepper is commercially high valued crop due to its high nutritional and medicinal properties. The capsicum fruit is rich in vitamin C content which is about 118.6 mg 100g^{-1}. Other vitamins like vitamin A, B_6, B_{12} and E are also present (Korel et al., 2002). It has medicinal properties such as antioxidant and antimicrobial properties; improves immune system, enhanced metabolism and even for cancer treatment (Yang et al., 2010).

A number of biotic stresses, particularly diseases hampers bell pepper production in term of productivity as well as quality. In order to meet the growing demand of burgeoning population, large amounts of insecticides, pesticides and fertilizers are being applied to the fields to achieve higher production leading to deleterious environmental effects. Use of antagonists for plant disease control has been considered as viable alternative method. Since biological control is the suppression of damaging activities of one organism by another organism, is environmentally safe and are species specific i.e., acts only on target organism. The term PGPR derived by Kloepper et al. (1988) is a group of plant-beneficial rhizobacteria, potentially useful for stimulating plant growth and increasing crop yields. In the last few years, the number of GPRs has been found to increase mainly due to their role in the rhizosphere. PGPR are effective, environmentally safe and non-toxic naturally occurring microorganisms (Sharma et al., 2013). However, *Trichoderma* species are well-organized biocontrol agents that are used to prevent development of several soil pathogenic fungi. The antagonistic potential is the base for effective applications of different *Trichoderma* strains as an alternative to the chemical control against a wide set of fungal plant pathogens (Chet, 1987; Harman and Bjorkman, 1998).

2. Materials and Methods

2.1. Experimental condition and layout

The experiment was carried out at experimental farm of Department of Seed Science and Technology, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh (India) during two consecutive *kharif* seasons of 2016 and 2017 using bell pepper variety Solan Bharpur. The experiment was laid out in randomized block design (RBD) with nine treatments replicated thrice. The climate of the area is sub-tropical to sub-temperate and semi-humid. During the crop seasons 2016 and 2017, the highest average maximum temperature (30.5 °C, 30.5 °C) was recorded in the month of May and lowest average minimum temperature in January (2.3 °C, 3.1 °C); the average rainfall was maximum in August (164.1 mm, 233.8 mm) and minimum in January (4.0 mm), November (2.4 mm) and the average relative humidity was maximum in August (83%, 82%) and lowest in (41.0% in November, 44.0% in April), respectively.

2.2. Treatments

The treatments were comprised of T_1; PGPR (seedling root dip), T_2 (*Trichoderma harzianum*(seedling root dip), T_3;PGPR (soil application), T_4; *T. harzianum* (soil application), T_5; PGPR (seedling root dip)+*T. harzianum* (soil application),T_6;PGPR (soil application)+*T. harzianum*(seedling root dip), T_7; PGPR (seedling root dip)+PGPR (soil application), T_8;*T. harzianum*(seedling root dip)+*T. harzianum*(soil application) and T_9; (untreated control). For soil treatment, well rotten FYM was mixed with 10% molasses and then talc formulation of *T. harzianum* (incubated for 1 week prior) was mixed with it separately. The mixture was covered with moist jute bags for one week and applied in the plots (1 kg m^{-2}). While, seedling root dip was done 20 minutes before transplanting in the suspension of the respective bio-agent. The cell count at the time of application was observed 10^8 cfu g^{-1} in PGPR and 10^6 cfu g^{-1} in *T. harzianum*.

2.3. Observations

The observations were recorded on ten randomly selected seedlings $plant^{-1}$ in each replication for all characters under study. Under field conditions various characters such as plant height (cm), days to 50% flowering, number of fruits $plant^{-1}$, average fruit weight (g), fruit length (cm), fruit width (cm), fruit size (cm^2, length×width), days to first picking (days), harvest duration (days), number of fruit pickings, fruit yield plant (g), fruit yield $plot^{-1}$ (kg), fruit yield ha^{-1} (q), number of seeds $fruit^{-1}$, seed yield $plant^{-1}$ (g), seed yield $plot^{-1}$ (g) and seed yield ha^{-1} (kg) were recorded.

2.4. Statistical analysis

The data was recorded from field and analyzed using MS-Excel and OPSTAT as per the design of experiment for working out the following values as per Gomez and Gomez (1984).

3. Results and Discussion

3.1. Plant height

The data presented in Table 1 revealed that all the treatments of bio-agents including seedling root dip, soil application and their combinations resulted in increase of plant height in bell pepper seed crop as compared to untreated control. Amongst various treatments, maximum plant height of 75.43 cm was recorded in T_5 [PGPR (seedling root dip)+*T. harzianum* (soil application)] followed by 73.07 cm in T_6 [PGPR (soil application)+*T. harzianum* (seedling root dip)], 71.84 cm in T_7 [PGPR (seedling root dip)+PGPR (soil application)] and minimum plant height of 63.52 cm was recorded in untreated control. The effect of all the treatments was significantly higher during the trial conducted in 2016 as compared to the trial conducted in 2017 crop season. Under present investigation, the seedling root dip with PGPR along with soil application with *T. harzianum* provided highest increase in plant height of bell pepper seed crop. In literature there is no report on the effect of combined application of PGPR as seedling root dip and *T. harzianum* as soil application on increase in plant height in bell pepper grown for seed purpose, hence present investigation is new in this regard. However,

Table 1: Effect of seedling root dip and soil application of PGPR and *Trichoderma* on plant height and Days to 50% flowering in bell pepper

Treatment	Plant height (cm)			Days to 50% flowering		
	2016	2017	Mean	2016	2017	Mean
T_1	72.27	65.36	68.81	55.33	58.33	56.83
T_2	71.82	63.41	67.74	54.40	59.62	57.01
T_3	72.75	65.65	69.70	55.00	58.00	56.50
T_4	73.67	67.81	70.74	54.67	57.75	56.29
T_5	77.69	73.17	75.43	52.00	56.67	54.34
T_6	75.33	70.81	73.07	53.67	57.00	55.34
T_7	73.82	69.86	71.84	54.33	57.33	55.83
T_8	73.98	68.88	71.43	54.17	57.60	55.89
T_9	66.8	60.23	63.52	58.00	60.67	59.34
Mean	73.13	67.46	70.48	54.62	58.12	56.37
CD (p=0.05)						
Year			1.98			1.03
Treatment			4.19			1.48
Year× treatment			NS			NS

T_1: PGPR (seedling root dip); T_2: *Trichoderma harzianum* (seedling root dip); T_3: PGPR (soil application); T_4: *T. harzianum* (soil application); T_5: PGPR (seedling root dip)+ *T. harzianum* (soil application); T_6: PGPR (soil application) +*T. harzianum* (seedling root dip); T_7: PGPR (seedling root dip)+PGPR (soil application); T_8: *T. harzianum* (seedling root dip)+*T. harzianum* (soil application); T_9: Untreated control;

some reports on the effect of individual application of either PGPR or *Trichoderma* spp. on capsicum growth existed in some citations. Seed treatment with PGPR was found effective in increasing plant height in capsicum by Gupta et al. (2015) and Mandyal et al. (2012). The other workers (Rini and Sulochna, 2006; Subash et al., 2014) have also demonstrated that *T. harzianum* increased plant growth in capsicum after soil application.

3.2. Days to 50% flowering

Data contained in Table 1 showed that all the treatments including seedling root dip, soil application and their combinations resulted in early flowering in bell pepper seed crop as compared to untreated control. Amongst different treatments, minimum days to 50% flowering (54.34) days was observed in T_5 [PGPR (seedling root dip)+*T. harzianum* (soil application)] followed by 55.34 days in T_6 [PGPR (soil application)+*T. harzianum* (seedling root dip)], 55.83 days in T_7 [PGPR (seedling root dip)+PGPR (soil application)] and maximum days (59.34) was recorded in untreated control. The effect of all the treatments was significantly higher during the trial conducted in 2016 as compared to the trial conducted in 2017. In the present study, treatment T_5 [PGPR (seedling root dip)+*T. harzianum* (soil application)] took minimum days to 50% flowering which may be due to the better absorption of nutrient that enhanced the plant growth and which caused earlier flowering. Earlier flowering might be due to the effect of PGPR which increased the availability of nutrients especially nitrogen in the soil and secreted growth promoting substances which accelerated the physiological process like synthesis of carbohydrates. The present findings are in line with the findings of Sajan et al. (2002) in chilli and Basavaraju et al. (2002) in radish.

3.3. No. of fruits plant^{-1}

Perusal of data presented in Table 2 revealed that all the bio-agents treatments including seedling root dip, soil application and their combinations resulted in increase of number of fruitsplant^{-1} as compared to untreated control. Amongst different treatments, maximum number of fruitsplant^{-1} of 7.75 was observed in T_5 [PGPR (seedling root dip) + *T. harzianum* (soil application)] followed by 7.42 in T_6 [PGPR (soil application) + *T. harzianum* (seedling root dip)], 7.15 in T_7 [PGPR (seedling root dip)+PGPR (soil application)] and minimum number (4.62) of fruitsplant^{-1} was recorded with untreated control. The effect of all the treatments was significantly higher during the trial conducted in 2016 as compared to the trial conducted in 2017. The present findings are in agreement with the findings of Mandyal et al. (2012) who have also observed similar results upon applications of bio-agents in chilli. More the number of fruits plant^{-1}, more will be the yield and hence, more returns. Therefore, number of fruits plant^{-1} is directly correlated with yield. In the present studies, the numbers of fruit were more on the plants receiving PGPR (seedling root dip) in combination with *T. harzianum* (soil application).

Table 2: Effect of seedling root dip and soil application of PGPR and *Trichoderma* on number of fruits plant^{-1} and average fruit weight in bell pepper

Treatment	No. of fruits plant^{-1}			Fruit weight (g)		
	2016	2017	Mean	2016	2017	Mean
T_1	6.30	5.33	5.85	47.10	43.67	45.39
T_2	7.83	5.00	6.42	46.07	42.65	44.36
T_3	7.57	5.67	6.62	47.52	43.63	45.58
T_4	6.90	5.00	5.95	47.47	42.67	45.07
T_5	8.83	6.67	7.75	50.41	46.51	48.46
T_6	8.50	6.33	7.42	50.07	46.17	48.12
T_7	8.30	6.00	7.15	49.40	45.50	47.45
T_8	7.43	5.66	6.54	48.73	44.83	46.78
T_9	5.57	3.67	4.62	43.40	39.50	41.45
Mean	7.47	5.49	6.48	47.80	43.90	45.85
CD (p=0.05)						
Year			0.57			1.35
Treatment			1.21			2.65
Year× treatment			NS			NS

This may be because of the availability of optimum dose of nutrients for plants to complete various reproductive stages. Similar results were also reported by Datta et al. (2011) who reported that inoculation of capsicum plants with rhizospheric *Bacillus* spp. resulted in increased number of fruits plant^{-1}, as compared to control.

3.4. Ripe fruit weight

It is extrapolated from Table 2 that all the treatments of bio-agents applied as seedling root dip, soil application and their combinations resulted in increased ripe fruit weight (g) in bell pepper seed crop as compared to untreated control. Amongst different treatments, maximum ripe fruit weight of 48.46 g was observed in T_5 [PGPR (seedling root dip)+*T. harzianum* (soil application)] followed by 48.12 g in T_6 [PGPR (soil application)+*T. harzianum* (seedling root dip)], 47.45 g in T_7 [PGPR (seedling root dip)+PGPR (soil application)] and minimum fruit weight (41.45 g) was recorded with untreated control. The effect of all the treatments was significantly higher during the trial conducted in 2016 as compared to the trial conducted in 2017. In the present investigations, it was found that combined application of PGPR and *T. harzianum* viz.,PGPR (seedling root dip)+*T. harzianum* (soil application) was significantly better in increasing the ripe fruit weight in treated bell pepper plants. The present results were in close agreement with the findings of Kanchana et al. (2014) who have reported that the inoculation of PGPR's increased the growth and yield parameters of chilli when compared to un-inoculated control. Similar to present findings, Datta et al.

(2011) also observed significant increase in plant growth and yield attributes such as total number of fruits and fruit weight under field condition.

3.5. *Fruit length, fruit width and fruit size*

The data presented in Table 3 revealed that all the treatments including seed treatment, soil application and their combinations resulted in increase of fruit length (cm) as compared to untreated control. Amongst different treatments, maximum fruit length (cm) of 6.78 was recorded in T_5 [PGPR (seedling root dip) + *T. harzianum* (soil application)] followed by 6.46 cm in T_6 [PGPR (soil application)+*T. harzianum* (seedling root dip) and minimum (4.85 cm) was recorded in untreated control. Similarly, it can be inferred that all the treatments including seedling root dip, soil application and their combinations resulted in increase of fruit width (cm) as compared to untreated control. Data presented in Table 3 showed that maximum fruit width of 6.48 cm was recorded in T_5 [PGPR (seedling root dip)+*T. harzianum* (soil application)] followed by 6.19 cm in T_6 [PGPR (soil application)+*T. harzianum* (seedling root dip)] and minimum was recorded in untreated control. Analysis of data depicted in Table 3 showed that maximum fruit size (cm) of 44.37 was recorded in T_5 [PGPR (seed treatment)+*T. harzianum* (soil application)] followed by 40.43 cm in T_6 [PGPR (soil application)+*T. harzianum* (seed treatment)] and minimum fruit size (20.58 cm) was recorded with untreated control. The effect of all the treatments on fruit size was significantly higher during the trial conducted in 2016 as compared to the trial conducted in 2017 crop season. These results are in line with the findings of Kanchana et al. (2014) who have observed the same effect of bio-agents on the fruit size of capsicum**.** However, they have reported the effect of individual application of these bio-agents but under present study the effect of dual application of bio-agents through seed and soil was observed and hence, this is a new observation.

Table 3: Effect of seedling root dip and soil application of PGPR and *Trichoderma* on fruit length, fruit width and fruit size in bell pepper

Treatment	Fruit length (cm)			Fruit width (cm)			Fruit size (cm^2)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
T_1	6.33	5.23	5.78	5.95	4.35	5.15	37.66	22.75	30.21
T_2	6.27	5.17	5.72	5.93	4.33	5.13	37.18	22.39	29.78
T_3	6.04	4.94	5.49	6.02	4.42	5.22	36.36	21.83	29.10
T_4	6.47	5.49	5.98	6.16	4.56	5.36	41.09	25.40	33.24
T_5	7.33	6.23	6.78	7.28	5.68	6.48	53.36	35.39	44.37
T_6	7.01	5.91	6.46	6.99	5.39	6.19	49.00	31.85	40.43
T_7	6.67	5.57	6.12	6.51	4.91	5.71	42.64	27.40	35.02
T_8	6.77	5.67	6.22	6.59	4.99	5.79	44.07	27.84	35.96
T_9	5.4	4.3	4.85	4.51	3.91	4.21	24.35	16.81	20.58
Mean	6.48	5.39	5.93	6.22	4.73	5.47	40.64	25.74	33.19
CD (p=0.05)									
Year			0.20			0.23			2.24
Treatment			0.42			0.48			4.75
Year× treatment			NS			NS			NS

3.6. *Days to first picking*

Data presented in Table 4 revealed that all the treatments of bio-agents i.e. seedling root dip, soil application and their combinations resulted minimum days to first ripe fruit picking as compared to untreated control. Amongst different treatments, minimum days to first ripe fruit picking of 102.43 days was observed in T_5 [PGPR (seedling root dip)+*T. harzianum* (soil application)] followed by 102.77 days in T_6 [PGPR (soil application)+*T. harzianum* (seedling root dip)], 103.97 in T_7 [PGPR (seedling root dip)+PGPR (soil application)] and maximum 107.70 days was recorded in untreated control. The effect of all the treatments was significantly higher during the trial conducted in 2016 as compared to the trial conducted in 2017 crop season. The present study correlates with the findings of Handelsman and Stabb (1996), Nehl et al. (1996) and Cartieaux et al. (2003), who stated that PGPR promoted plant growth by direct mechanisms i.e. nitrogen fixation, solubilization of phosphorus, sequestering of iron by production of siderophores, production of phytohormones such as auxins, cytokinins, gibberellins and lowering of ethylene concentration due to the availability of optimum dose of nutrients for plants to complete various reproductive stages of growth which cause early picking.

3.7. *Harvest duration and number of fruit pickings*

Data embedded in Table 4 revealed that all the treatments

Table 4: Effect of seedling root dip and soil application of PGPR and Trichoderma on days to first picking, harvest duration and number of pickings in bell pepper

Treatment	Days to first picking			Harvest duration (days)			Number of pickings		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
T_1	101.71	107.20	104.45	40.20	37.27	38.73	9.27	6	7.64
T_2	102.80	107.60	105.20	41.47	38.47	39.97	9.35	6.35	7.85
T_3	102.60	106.40	104.50	39.07	36.07	37.57	7.87	5.93	6.90
T_4	100.47	106.27	104.75	41.47	38.53	40.00	9.35	5.42	7.39
T_5	99.53	105.33	102.43	43.47	40.47	41.97	10.53	7.67	9.10
T_6	99.87	105.67	102.77	43.1	40.3	41.70	10.07	7.27	8.67
T_7	100.30	107.63	103.97	41.87	38.87	40.37	9.73	7	8.37
T_8	100.94	107.33	104.14	41.67	38.67	40.17	9.8	6.87	8.34
T_9	106.80	108.60	107.70	38.27	35.27	36.77	5.63	4.71	5.17
Mean	101.80	107.07	104.43	41.23	38.28	39.75	9.07	6.36	7.71
CD (p=0.05)									
Year		0.94			0.13			0.54	
Treatment		2.00			0.28			1.14	
Year× treatment		NS			NS			NS	

including seedling root dip, soil application and their combinations resulted in increase of harvest duration (days) as compared to untreated control. Amongst different treatments, maximum harvest duration 41.97 days was recorded in T_5 [PGPR (seedling root dip)+*T. harzianum* (soil application)] followed by 41.70 days in T_6 [PGPR (soil application)+*T. harzianum* (seeding root dip)], 40.37 days in T_7 [PGPR (seeding root dip) + PGPR (soil application)] and minimum 36.77 days was recorded in untreated control. Similarly, the data presented in Table 4 showed that maximum number of pickings 9.10 was recorded in T_5 [PGPR (seeding root dip)+*T. harzianum* (soil application)] followed by 8.67 in T_6 [PGPR (soil application)+*T. harzianum* (seed treatment)], 8.37 in T_7 [PGPR (seeding root dip)+PGPR (soil application)], 8.34 T_8 [*T. harzianum* (seeding root dip)+*T. harzianum* (soil application)] and minimum (5.17) number of pickings was recorded with untreated control. The effect of all the treatments was significantly higher during the trial conducted in 2016 as compared to the trial conducted in 2017.In the present study, longer harvest duration ripe fruits a well as more number of ripe fruit pickings during crop season was recorded with application of [PGPR (seeding root dip)+*T. harzianum* (soil application)] which may be due to increased growth and optimized physiological processes in plants through beneficial microbial inoculations.

The beneficial microbes promote plant growth involving direct mechanisms i.e. fixing of nitrogen, solublizing of phosphorus, sequestering of iron by production of siderophores, production of phytohormones such as auxins, cytokinins, gibberellins (Handelsman and Stabb, 1996; Nehl et al., 1996; Cartieaux et al., 2003) and indirect mechanism i.e. antibiotic production, depletion of iron from the rhizosphere, synthesis of antifungal metabolites, production of fungal cell wall lysing enzymes, competition for sites on roots and induced systemic resistance (Weller and Cook, 1986; Dunne et al., 1993; Kloepper et al., 1988; Liu et al., 1995; Glick et al., 1999). In addition, *T. harzianum* prevent the deleterious effects of plant pathogens on plants by production of antibiotics or by increasing the natural resistance of the host. So, the increase in harvest duration might be due to all of the positive effects of both the microbial inoculants which have led to longer plant growth and development phase.

3.8. *Fruit yield*

Analysis of data depicted in Table 5 revealed that all the treatments of bio-agents including seed treatment, soil application and their combinations resulted in increase of ripe fruit yield plant^{-1} (g) as compared to untreated control. Amongst different treatments, maximum ripe fruit yield plant^{-1} of 1038.54 g was recorded in T_5 [PGPR (seeding root dip) + *T. harzianum* (soil application)] followed by 988.54 g in T_6 [PGPR (soil application)+*T. harzianum* (seeding root dip)], 966.63 g in T_7 [PGPR (seeding root dip)+PGPR (soil application)] and minimum (696.87 g) was recorded with untreated control. Similar trend of result was followed in ripe fruit yieldplot^{-1} (kg) and ripe fruit yield ha^{-1} (q) presented in Table 5. The data indicated that application of the bio-agents through seed treatment as well as soil application proved to be more effective in increasing ripe fruit yield as compared to their alone treatment. The effect of all the treatments on ripe fruit yield was significantly higher during the trial conducted in

Table 5: Effect of seedling root dip and soil application of PGPR and *Trichoderma* on ripe fruit yield in bell pepper

Treatment	Ripe Fruit yield plant^{-1} (g)			Ripe Fruit yield plot^{-1} (kg)			Ripe Fruit yield ha^{-1} (q)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
T_1	996.26	806.12	901.19	14.94	12.09	13.52	442.67	358.22	400.44
T_2	1017.24	827.10	922.17	15.26	12.41	13.83	452.15	367.50	409.82
T_3	961.12	770.98	866.05	14.42	11.56	12.99	427.26	342.52	384.89
T_4	1003.81	813.67	908.74	15.06	12.21	13.63	446.22	361.78	404.00
T_5	1133.61	943.47	1038.54	17.00	14.15	15.58	481.48	419.26	450.37
T_6	1083.61	893.47	988.54	16.25	13.40	14.83	472.00	397.04	434.52
T_7	1061.70	871.56	966.63	15.93	13.07	14.50	503.70	361.78	432.74
T_8	1050.54	860.40	955.47	15.76	13.20	14.33	466.96	391.11	429.04
T_9	791.94	601.80	696.87	11.88	9.03	10.45	352.00	267.56	309.78
Mean	1011.09	820.95	916.02	15.17	12.35	13.76	449.38	362.97	406.18
CD (p=0.05)									
Year		39.01			0.53			27.27	
Treatment		82.76			1.12			40.54	
Year× treatment		NS			NS			NS	

2016 as compared to the trial conducted in 2017. The study is in close agreement with the findings of Herman et al. (2008) and Minorsky (2008) who reported earlier that the bioagents like PGPRs and *Trichoderma* enhanced growth and crop yield and contributed to the protection of plants against certain pathogens and pests following various mechanisms of their interactions with the host plants. These results are also in line with the findings of other workers like Lugtenberg and Kamilova (2009), Couillerot et al. (2009) and Ali et al. (2011) who have reported that the application of PGPR in bell pepper have played a significant role in improvement of ripe fruit yield in pepper seed crop.

3.9. Number of seeds fruit^{-1}

Analysis of data depicted in Table 6 revealed that all the bio-agents treatments i.e. seedling root dip, soil application and their combinations resulted in increase of number of seedsfruit^{-1}as compared to untreated control. Amongst different treatments, maximum number of seedsfruit^{-1}of 177.51 was recorded in T_5 [PGPR (seeding root dip) + *T. harzianum* (soil application)] followed by 175.67 in T_6 [PGPR (soil application) + *T. harzianum* (seeding root dip)], 173.34 in T_7 [PGPR (seeding root dip)+PGPR (soil application)] and minimum 163.67 g) was recorded in untreated control. The effect of all the treatments was significantly higher during the trial conducted in 2016 as compared to the trial conducted in 2017. Yadegari and Rahmani (2010) have observed the effect of co-inoculation with PGPR and *Rhizobium* on number of seed pod^{-1} in common bean and found that treatment with PGPR significantly increased number of seeds pod^{-1}. They have attributed that effect to all the above-mentioned beneficial mechanisms of these bio-agents.

Table 6: Effect of seed treatment and soil application of PGPR and *Trichoderma* on number of seeds fruit^{-1} in bell pepper

Treatment	No. of seeds fruit^{-1}		
	2016	2017	Mean
T_1	174.92	167.36	171.14
T_2	174.07	165.16	169.62
T_3	175.16	166.65	170.91
T_4	177.20	170.88	172.04
T_5	179.84	175.17	177.51
T_6	178.53	172.81	175.67
T_7	176.87	169.81	173.34
T_8	177.03	171.86	174.45
T_9	168.11	159.23	163.67
Mean	175.53	168.55	172.04
CD (p=0.05)			
Year		1.98	
Treatment		4.18	
Year× treatment		NS	

3.10. Seed yield

The data presented in Table 7 revealed that all the treatments of bio-agents including seed treatment, soil application and their combinations resulted in increase of seed yieldplant^{-1} (g) as compared to untreated control. Amongst different treatments, maximum seed yield plant^{-1} of 15.78 g was observed in T_5 [PGPR (seedling root dip)+*T. harzianum* (soil application)] followed by 15.01 g in T_6 [PGPR (soil application)+*T. harzianum* (seedling root dip)], 14.60 g in T_7 [PGPR (seedling root dip)+PGPR (soil application)] and minimum (10.29 g) was recorded with untreated control. Analysis of data revealed that maximum seed yieldplot^{-1}of 236.63 g was recorded in T_5 [PGPR (seedling root dip)+*T. harzianum* (soil application)] followed by 225.23 g in T_6 [PGPR (soil application)+*T. harzianum* (seedling root dip)], 219.00 in T_7 [PGPR (seedling root dip)+PGPR (soil application)] and minimum (154.28 g) was recorded with untreated control (Table 7). Similarly, maximum seed yieldha^{-1} of 673.50 kg was observed in T_5 [PGPR (seedling root dip)+*T. harzianum* (soil application)] followed by 656.00 kg in T_6 [PGPR (soil application)+*T. harzianum* (seedling root dip)], 609.00 kg in T_7 [PGPR (seedling root dip)+PGPR (soil application)] and minimum (482.00 kg) was recorded with untreated control (Table 7). The effect of all the treatments was significantly higher during the trial conducted in 2016 as compared to the trial conducted in 2017. The present findings are in agreement with the findings of Polyanskaya et al. (2002) who have found the positive effect of PGPR on growth and yield of chilli. The increased seed yield was attributed to be due to the increased physiological activities like synthesis of cholorophyll, carbohydrates, amino acids and translocation of photosynthates into developing fruits and seeds in inoculated plants. There is no report on the increase in seed yield in bell pepper upon co-inoculation with PGPR as seedling root dip and *Trichoderma* as soil application. Hence, this investigation is new in this regard. However, Yadegari and Rahmani (2010) have observed that co-inoculation with plant growth-promoting rhizobacteria and *Rhizobium* increased seed yield in common bean and they have attributed that effect to all the above-mentioned beneficial mechanisms of these bio-agents.

Table 7: Effect of seed treatment and soil application of PGPR and *Trichoderma* on seed yield in bell pepper

Treatment	Ripe Fruit yield plant^{-1} (g)			Ripe Fruit yield plot^{-1} (kg)			Ripe Fruit yield ha^{-1} (q)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
T_1	15.23	11.20	13.22	228.45	168.00	198.23	686.00	448.00	567.00
T_2	15.45	12.33	13.89	231.75	184.95	208.35	682.00	493.00	587.50
T_3	13.95	12.47	13.21	209.25	187.05	198.15	644.00	504.00	574.00
T_4	14.40	12.73	13.57	216.00	190.95	203.48	661.00	472.00	566.50
T_5	17.82	13.73	15.78	267.30	205.95	236.63	798.00	549.00	673.50
T_6	16.63	13.40	15.01	249.45	201.00	225.23	776.00	536.00	656.00
T_7	16.00	13.20	14.60	240.00	198.00	219.00	695.00	523.00	609.00
T_8	15.68	12.80	14.24	235.20	192.00	213.60	684.00	542.00	613.00
T_9	11.1	9.47	10.29	166.50	142.05	154.28	545.00	419.00	482.00
Mean	15.25	12.48	13.87	227.10	185.55	206.33	685.67	498.44	592.06
CD (p=0.05)									
Year		0.73			10.91			30.76	
Treatment		1.54			23.15			65.26	
Year× treatment		NS			NS			NS	

4. Conclusion

PGPR and BCA is an alternative way to replace agrochemicals i.e. chemical fertilizers, pesticides, and supplements; most of the microbial strains result in a significant enhance plant biomass, yield and quality of produce. Similarly, in this field experiment PGPR (10^8 cfu ml^{-1}) as seedling root dip+*T. harzianum* (10^6 cfu g^{-1}) as soil application mixed with FYM @ 2% w/w applied before transplanting in bell pepper cv. Solan Bharpur enhanced plant growth, fruit quality, ripe fruit yield and seed yield.

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