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Gunjan Mahajan
Student, Faculty of Agricultural Sciences, DAV University, Jalandhar, Punjab, India

Puja Rattan
Associate Professor, Faculty of Agricultural Sciences, DAV University, Jalandhar, Punjab, India

Ashutosh Sharma
Associate Professor, Faculty of Agricultural Sciences, DAV University, Jalandhar, Punjab, India

Corresponding Author:
Puja Rattan
Associate Professor, Faculty of Agricultural Sciences, DAV University, Jalandhar, Punjab, India

Effect of microbial inoculants on growth, yield and quality attributes of tomato (*Solanum lycopersicum*)

Gunjan Mahajan, Puja Rattan and Ashutosh Sharma

Abstract
Present investigations were conducted at the experimental farm of Faculty of Agricultural Sciences, DAV University, Jalandhar during summer season of 2021. The main objective of the study was to evaluate the effect of microbial inoculants on growth, yield and quality attributes of tomato. The experiment was laid out in Factorial Randomized Block Design with three replication and 8 treatment combinations, comprising of control and 3 microbial inoculants *viz*., T_1 (*Trichoderma*), T_2 (*Pseudomonas*) and T_3 (*Rhizobium*) and two varieties *viz*., V_1 (Punjab Ratta) and V_2 (Punjab Gourav). Significant influence of all the treatments was observed on all the characters during Analysis of Variance (ANOVA). The characters studied were days to first flowering, days to 50% flowering, plant height, number of primary branches, number of secondary branches, stem diameter, days to fruit set, number of fruits per cluster, number of fruits per plant, fruit length, fruit diameter, average fruit weight (g), fruit yield per plot (Kg), total soluble solids (^{0}Brix), ascorbic acid(mg/100ml) and titratable acidity (%).Minimum number of days to first flowering and days to 50% flowering and maximum TSS was observed with the application of T_2 (*Pseudomonas*). Whereas T_3 (*Rhizobium*) resulted in maximum plant height, number of primary branches per plant, number of secondary branches per plant, number of fruits per cluster, number of fruits per plant, fruit length, fruit diameter, average fruit weight, yield per plot and quality parameters *viz*., ascorbic acid and titratable acidity and minimum days to fruiting. T_1 (*Trichoderma*) resulted in maximum stem diameter. Among the cultivars, V_1 (Punjab Ratta) was proved best when treated with microbial inoculants *viz*., *Trichoderma*, *Pseudomonas* and *Rhizobium*. In the interactions the treatment T_3 x V_1 (*Rhizobium* x Punjab Ratta) gave best results for plant height, number of primary branches per plant, number of secondary branches per plant, number of fruits per plant, fruit length, fruit diameter, average fruit weight, yield per plot, TSS, ascorbic acid and titratable acidity. T_2 x V_1 (*Pseudomonas* x Punjab Ratta) resulted in minimum days to first flowering whereas, T_2 x V_2 (*Pseudomonas* x Punjab Gourav) took minimum days to 50% flowering. T_3 x V_1 (*Rhizobium* x Punjab Ratta) resulted in maximum stem diameter while, maximum fruits per cluster were recorded in T_1 x V_2 (*Trichoderma* x Punjab Gourav).

Keywords: Microbial inoculants, *Rhizobium, Trichoderma, Pseudomonas,* growth, yield, quality, tomato

Introduction
Tomato (*Lycopersicon esculentum*) is a member of Solanaceae family with chromosome number (2n=24) and believed to be originated from Peru-equator. It is one of the most important solanaceous vegetables having wide adaptability and is cultivated throughout the world for fresh and processing purposes. It is grown for its fruits which are either eaten raw or processed as sauce, ketchup, puree, paste and soups etc. It occupies an important place in the economy of human societies because of its high nutritive value added products and its wide spread production in different agro climatic condition. It also have special place in the food plates of all the strata of society i.e. from the highly sophisticated modern to the poor man, thus not wrongly called as poor man's orange. It's richness in nutrition also makes it protective food. It is rich in total sugar (2.5-5%), starch (0.6-1.2) and minerals like potassium, calcium, sodium, magnesium, phosphorus, iron, etc. It is also enriched with healthy acids like citric, malic and acetic acid Baba *et al*. [1] and lycopene which is known for its antioxidant properties. In India tomato is grown in an area of 865 thousand hectares with a production of 21056 thousand MT [2]. In Punjab tomato is grown in an area of 10.28 thousand Hectares with a production of 266.91 thousand Tones [3].

Tomato is a sensitive crop as environmental factors such as temperature, light and relative humidity in the atmosphere has greater influence on its production. It is a warm season crop and thus resistant to heat and drought to certain extent. Owing to its wider adaptability, it can be grown under wide range of soil and temperature but the most optimum range of temperature is 20-24 ºC. To meet the ever increasing demand of tomatoes, there is need to increase the production as well as productivity, which can be done by way of using, high yielding varieties, use of proper cultural practices like supplying quality inputs, spacing, sowing time etc. Green Revolution emphasized on the use of chemical fertilizers in a judicious manner, which has lead to increase in production of tomato manifolds but has also led to soil sickness, ecological hazards and depletion of non- renewable sources of energy. Moreover, they deteriorate the quality of the produce and are expensive too, leading to reduction in net profit returns to the farmers [4].

The term biofertilizer is a popular misnomer. Biofertilizers are natural fertilizers consisting of micro organisms like bacteria, algae, fungi alone or in combination, as microbial inoculants. These contain carrier based (solid form or liquid form) living micro-organisms that are agriculturally useful as they helps in fixing N, solubilization of P and mobilization of nutrient. Solubilization of insoluble phosphate by acidification, chelation and exchange reaction are done by phosphate solubilizing microorganisms (PSMs). Some of the powerful phosphate solubilizers are several strains of bacteria (*Pseudomonas, Bacillus, Rhizobium, Enterobacter* etc.) and fungi (*Aspergillus* and *Penicillium*). Besides sustaining the P supply for growth of plants, PSB are also observed to enhance nitrogen fixation. and Abbas *et al*., [5] reported that PSB also increase the availability of other trace elements by synthesizing important growth promoting substances like siderophores, antibiotics, etc., and produce plant hormones such as auxins, cytokinins, gibberellins. *Trichoderma* species not only acts as act as biological agent against different soil-borne pathogens but are also pretentious, avirulent plant symbionts. *Pseudomonas* is well known for its abilities of nutrient solubilization and thus plays an important role in plant growth promotion. It is also used as biological control of insect pest and plant pathogens and is also known for degradation of certain organic and inorganic pollutants to bioremediation of heavy metals and pesticides.

With the application of biofertilizers majority of agricultural and horticultural crops have gained benefits thereby reasonably decreasing the farmers' dependency on harmful chemical fertilizers and thus sustaining the increased production by use of natural resources. Desirable results can be obtained with the application of a small dose of biofertilizer as at least 10 million viable cells of a specific strain are present in each gram of carrier of biofertilizers [6]. The present investigation was planned and executed by keeping in view of importance of the crop and role of microbial inoculants in increasing the yield and quality of tomato. The main aim of the study was to evaluate the effect of microbial inoculants on growth, yield and quality attributes of tomato.

Materials and Methods

Experimental Farm of Faculty of Agricultural Sciences, DAV University, Jalandhar was used to carry out the said experiment during summer season of 2021-2022. The varieties grown for the investigation was Punjab Ratta and Punjab Gaurav. Total eight treatment combinations consisting of different varieties and microbial inoculants *viz*. T_0 x V_1 (Control x Punjab Ratta), T_0 x V_2 (Control x Punjab Gourav), T_1 x V_1 (*Trichoderma* x Punjab Ratta), T_1 x V_2 (*Trichoderma* x Punjab Gourav), T_2 x V_1 (*Pseudomonas* x Punjab Ratta), T_2 x V_2 (*Pseudomonas* x Punjab Gourav), T_3 x V_1 (*Rhizobium* x Punjab Ratta) and T_3 x V_2 (*Rhizobium* x Punjab Gourav). Randomized Block Design was used for the layout of the experiment with three replications. Recommendations as per the package of practices of Punjab Agricultural University were followed for applying the organic manure (FYM) and inorganic fertilizers (urea) and the cultural practices in the experimental field. Standard methods were followed to record all the observations on growth yield and quality attributes *viz*., days to first flowering, days to 50% flowering, plant height (cm), number of primary branches per plant, number of secondary branches per plant, stem diameter (mm), Days to fruit set, number of fruits/cluster, number of fruits/plant, Fruit length (cm), fruit diameter (cm), average fruit weight (g), fruit yield per plot (kg), total soluble solids (TSS) (ºB), ascorbic acid (mg/100g fresh weight) and titratable acidity (%). Analysis of variance method for factorial randomized block design described by Panse and Sukhatme [7] was used for the statistical analysis of data recorded during the course of investigation for all the characters.

Results and Discussion

Analysis of variance

Analysis of variance (ANOVA) showed that that all the characters under study were significantly influenced by the microbial inoculants, varieties and their interactions as presented in Table 1.

Days to first and 50% flowering

Data (Table 2) revealed that the minimum number of days to first flowering (29.17 days) and 50% flowering (43.50 days) was recorded in T_2 (*Pseudomonas*) which was significantly earliest than the remaining treatments whereas, the maximum number of days to first flowering (33.67 days) were recorded when T_1 (*Trichoderma*) was supplied to the plants. The treatment T_3 (*Rhizobium*) and T_0 (Control) were found to be at par with T_1 with 32.83 and 33.00 days to flowering, respectively. While, T_0 (Control) resulted in the maximum number of days to 50% flowering (48.33 days) which was significantly late among all the microbial inoculants. Among varieties the minimum number of days to first flowering (30.75 days) and 50% flowering (45.08 days) was recorded in V_2 (Punjab Gourav) which was significantly lowest V_1 (Punjab Ratta) (33.58 days to first flowering and 46.58 days to 50% flowering). Interaction effect of microbial inoculants and varieties on days first and 50% flowering as presented in Table 3 showed that T_2 x V_1 (*Pseudomonas* x Punjab Ratta) earliest flowering (28.00 days). The treatment T_0 x V_2 (Control x Punjab Gourav) (30.00 days) and T_2 x V_2 (*Pseudomonas* x Punjab Gourav) (30.33 days) were found to be at par with T_2 x V_1. While, maximum number of days to first flowering (36.12 days) were recorded in T_0 x V_1 (Control x Punjab Ratta). The treatment T_3 x V_1 (*Rhizobium* x Punjab Ratta) (34.33) and T_1 x V_1 (*Trichoderma* x Punjab Ratta) (36.00) were found to be at par with T_0 x V_1. Whereas T_2 x V_2 (*Pseudomonas* x Punjab Gourav) took minimum days to 50% flowering (41.66 days) which was significantly lowest among

all the interactions. The maximum number of days to 50% flowering (49.00 days) was observed in T_0 x V_1 (Control x Punjab Ratta). The treatment T_1 x V_1 (*Trichoderma* x Punjab Ratta) and T_0 x V_2 (Control x Punjab Gourav) were found to be at par with T_0 x V_1 with 47.33 and 47.68 days to 50% flowering, respectively.

Days to flowering is a parameter that depicts the earliness. Earlier the flowering in the crop, earlier will be fruit setting leading to early fruit maturity and harvesting. Early harvesting will be helpful in fetching good price in the market. From the data taken, the result revealed that earliness was observed when *Pseudomonas* was applied to plants. Accelerated photosynthesis and rapid translocation of photosynthates effect of *Pseudomona* can be attributed to the flower buds initiation and early flowering [8]. Early flowering with the application of biofertilizers in tomato was also observed by Brar *et al.*, [1], Angadi *et al*, [9] and Meena *et al.*, [10]. Singh and Thakur, [11] and Singh *et al.*, [12] in Brinjal and Kumbar *et al*., [13] and Khurshid *et al.*, [14] in chilli. Significant differences for early flowering were also observed among varieties, this could be due to genotypic differences among them. The results were in line with the findings of earlier Researchers *viz*. Khan and Samadia. [15], Ullah *et al*., [16] and Shobna, [17].

Table 1: Analysis of variance for growth, yield and quality parameters of tomato

Observations	MSS Factor A	MSS Factor B	MSS Factor A x B	Error
Days to first flowering	48.17*	24.79*	20.06*	3.15
Days to 50% flowering	13.50*	23.67*	8.06*	1.45
Plant height (cm)	28.17*	32.57*	21.27*	1.37
No. of primary branches	1.85*	1.40*	3.39*	0.26
No. of secondary branches	2.76*	0.99*	2.38*	0.13
Stem diameter	0.04*	0.59*	0.27*	0.01
Days to fruiting	54.00*	16.50*	46.78*	1.54
No. of fruits per cluster	12.13*	0.62*	1.95*	0.16
No. of fruits per plant	20.10*	13.88*	5.40*	0.06
Fruit length (mm)	7.17*	2.03*	4.80*	2.54
Fruit diameter (mm)	5.66*	3.72*	4.62*	3.02
Average fruit weight	3.25*	5.03*	4.70*	0.78
Fruit yield per plot (kg)	0.34*	3.05*	1.78*	0.03
TSS (^{0}Brix)	0.58*	0.37*	0.76*	0.06
Ascorbic acid (mg/100g)	1.34*	1.28*	1.90*	0.06
Titratable acidity (%)	0.01*	0.02*	0.05*	0.00

Factor A= Cultivars Factor B= Microbial inoculants

Table 2: Effect of different microbial inoculants and cultivars on growth, yield and quality of tomato (*Solanum lycopersicum*)

Treatments	Days to first flowering	Days to 50% flowering	Plant height (cm)	No. of primary branches	No. of secondary branches	Stem diameter	Days to fruit set	No. of fruits per cluster	No. of fruits per plant	Fruit length (mm)	Fruit diameter (mm)	Average fruit weight(g)	Fruit yield per plot (Kg)	Total soluble solids (TSS)	Ascorbic acid	Titratable acidity
Microbial inoculants																
T_0(*Control*)	33.00	48.33	82.17	12.28	18.68	13.31	58.33	6.23	16.80	42.89	46.61	39.77	10.99	4.40	21.61	0.60
T_1 (*Trichoderma*)	33.67	46.00	117.17	12.24	19.52	14.59	60.83	6.57	18.43	41.78	44.07	39.36	11.57	4.44	21.34	0.63
T_2 (*Pseudomonas*)	29.17	43.50	90.87	11.31	19.27	13.56	59.00	6.82	19.04	45.80	47.58	40.11	12.04	4.44	22.20	0.61
T_3 (*Rhizobium*)	32.83	45.50	123.87	12.29	19.56	14.41	56.83	6.97	20.47	46.62	49.78	47.69	12.67	4.34	22.28	0.64
CD (5%)	2.22	1.51	1.46	0.64	0.45	0.21	1.55	0.50	0.30	1.99	2.17	1.11	0.21	0.30	0.31	0.01
SE(d)	1.02	0.70	0.68	0.30	0.21	0.10	0.72	0.23	0.14	0.92	1.00	0.51	0.10	0.14	0.14	0.01
Cultivars																
V_1(Punjab Ratta)	33.58	46.58	102.43	12.31	18.92	13.89	60.25	5.94	17.77	42.16	45.49	42.72	11.70	4.36	21.61	0.61
V_2(Punjab Gaurav)	30.75	45.08	104.60	11.76	19.56	14.05	57.25	7.36	19.60	46.38	48.53	40.75	11.94	4.67	22.09	0.64
CD(5%)	1.57	1.07	1.03	0.45	0.32	0.15	1.10	0.35	0.21	1.41	1.54	0.78	0.15	0.21	0.22	0.01
SE (d)	0.72	0.49	0.48	0.21	0.47	0.07	0.51	0.16	0.10	0.65	0.71	0.36	0.07	0.10	0.10	0.01

Plant height (cm)

Plant height (cm) was significantly influenced by microbial inoculants and varieties as depicted from the analysis of the data (Table 2). The significantly tallest plants (123.87 cm) were obtained with T_3 (*Rhizobium*) among all the microbial inoculants while, the significantly shortest plants (82.17 cm) were obtained with T_0 (Control). Among the varieties the significantly tallest plants (104.60 cm) were obtained in V_2 (Punjab Gourav). The interaction effect of microbial inoculants and varieties on plant height (cm) (Table 3) showed that tallest plants (134.28 cm) were observed in T_3 x V_1 (*Rhizobium* x Punjab Ratta) which were significantly taller than all other interaction effects. However, significantly shortest plants (75.80 cm) were recorded in T_0 x V_1 (Control x Punjab Ratta).

In fruit vegetables, taller plants are desired as it is directly proportional to number of nodes which in turn increases the yield. From the result it was observed that the tallest plants

were obtained when *Rhizobium* was applied to plants. The plants were 66% taller than control. Biofertilizers are known to synthesize the growth promoting substances besides nitrogen fixation which could have lead to increase in plant height and thus the plant have shown luxurious growth [18]. Similar results with the application of other biofertilizers were also obtained by earlier researchers *viz*., Meena *et al*., [10], Kamal *et al*., [19], Singh *et al*., [11], Gou *et al*., [20], Sani *et al*., [21] and Cabrera, [22] in tomato; Solanki *et al*., [23], Devi *et al*., [25] in brinjal and Abdiani *et al*., [25] in green pepper. Significant differences for plant height were also obtained among varieties which could be due to genotypic constitution of these varieties. The results corroborates to the findings of other researchers *viz*., Khan and Samadia., [15], Kumar *et al*., [26], by Ramandeep *et al*., [27] and Kerketta and Bahadur, [28] in potato.

Table 3: Interaction effect of microbial inoculants and cultivars on growth of tomato (*Solanum lycopersicum*)

Treatments	Days to first flowering		Days to 50% flowering		Plant height		No. of primary branches		No. of secondary branches		Stem diameter		Days to fruit set	
Microbial inoculants	**Cultivars**													
	V_1	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**
T_0(*Control*)	36.12	30.00	49.00	47.68	75.80	88.53	12.10	12.47	18.13	18.22	13.53	13.09	62.33	56.00
T_1(*Trichoderma*)	36.00	31.33	47.33	44.66	115.73	118.60	11.75	12.73	18.44	19.19	14.60	14.58	64.67	57.00
T_2(*Pseudomonas*)	28.00	30.33	45.33	41.66	83.93	97.80	12.47	10.15	19.25	19.29	12.86	14.27	58.00	60.00
T_3(*Rhizobium*)	34.33	31.33	44.66	46.33	134.28	113.47	12.92	11.67	19.85	20.67	14.55	14.26	53.33	57.67
CD(5%)	3.14		2.13		2.07		0.90		0.64		0.30		2.20	
SE(d)	1.45		0.98		0.95		0.42		0.29		0.14		1.02	

Number of primary and secondary branches per plant

Significant effect of microbial inoculants, varieties and their interactions on number of primary branches per plant was observed as presented in Table 1. Among inoculants it was maximum (12.39) in T_3 (*Rhizobium*) which were at par with T_1 (*Trichoderma*) and T_0 (Control) which resulted in 12.24 and 12.28 primary branches per plant, respectively. Whereas, number of secondary branches per plant was maximum (19.56) in T_3 (*Rhizobium*) which were statistically at par with T_1 (*Trichoderma*) and T_2 (*Pseudomonas*) producing 19.52 and 19.27 secondary branches per plant. While, significantly minimum number of primary branches (11.31) were recorded with T_2 (*Pseudomonas*) and minimum number of secondary branches (18.68) was recorded in the T_0 (Control). Among varieties the number of primary branches per plant were significantly maximum in V_1 (Punjab Ratta) i.e 12.31 and number of secondary branches per plant were significantly maximum (19.60) in V_2 (Punjab Gourav) (Table 2). Interaction effect of microbial inoculants and varieties on number of primary and secondary branches per plant as presented in (Table 3) revealed that T_3 x V_1 (*Rhizobium* x Punjab Ratta) resulted in the maximum number of primary branches per plant (12.92) which was at par with T_1 x V_2 (*Trichoderma* x Punjab Gourav) (12.73), T_2 x V_1 (*Pseudomonas* x Punjab Ratta) (12.47), T_0 x V_2 (Control x Punjab Gourav) (12.47) and T_0 x V_1 (Control x Punjab Ratta) (12.10). The significantly minimum number of primary branches (10.15) were observed in T_2 x V_2 (*Pseudomonas* x Punjab Gourav) among all the interaction effects. For number of secondary branches significantly maximum number (20.67) was observed in T_3 x V_2 (*Rhizobium* x Punjab Gourav) among all the interaction effects. The minimum number of secondary branches (18.13) was observed in T_0 x V_1 (Control x Punjab Ratta) which was at par with T_1 x V_1 (*Trichoderma* x Punjab Ratta) (18.44) and T_0 x V_2 (Control x Punjab Gourav) (18.22). Branch and reproductive structures are more dependent on cell division. Nutrients uptake at early stages of growth by the plants generally determines the number of braches per plant. More the uptake of nutrients more will be the cell division resulting in more number of branches per plant. From the present investigation, it was observed that *Rhizobium* resulted in maximum primary and secondary branches per plant. It can be attributed to more optical growth induction effect of biofertilizers as compared to control, which leads to effectively absorption of nutrients by roots [29]. The similar results with the use of other biofertilizers were also recorded by Kamal *et al*., [19] in tomato; Solanki *et al*., [23], Mishra *et al*., [30], Devi *et al*., [24], Sherpa *et al*., [31], Ullah *et al*., [32]; Padhiary and Dubey, [33] in Brinjal; Singh and Sharma, [34] and Gokul *et al*., [35] in chilli and Abdiani *et al*., [25] in green pepper. Differences for number of primary and secondary branches were significantly obtained among varieties which could be due to their genetic variation as also observed by Khan and Samadia, [15], Kumar *et al*., [26] and Thapa *et al*., [37].

Stem diameter (mm)

Data presented in Table 2 shows that T_1 (*Trichoderma*) resulted in maximum stem diameter (14.59 mm) which was statistically at par with T_3 (*Rhizobium*) (14.41cm) while, T_0 (Control) resulted in significantly minimum stem diameter (13.31mm) among all the microbial inoculants. Among varieties the stem diameter was significantly maximum (14.05 mm) in V_2 (Punjab Gourav) whereas V_1 (Punjab Ratta) produced plants with 13.89 mm diameter.

Among interaction effects of microbial inoculants and cultivars on stem diameter (Table 3) the maximum stem diameter was observed in T_1 x V_1 (*Trichoderma* x Punjab Ratta) i.e 14.60mm which was statistically at par with T_1 x V_2 (*Trichoderma* x Punjab Gourav) and T_3 x V_1 (*Rhizobium* x Punjab Ratta) resulting in 14.58mm and 14.55mm stem diameter, respectively. The minimum stem diameter (12.86mm) was observed in T_2 x V_1 (*Pseudomomas* x Punjab Ratta) which was statistically at par with T_0 x V_2 (Control x Punjab Gourav) (13.09mm).

Stem diameter is greatly influenced by secretion of growth hormones and availability of nutrients and moisture. From the observed data, the stem diameter was recorded maximum in *Trichoderma* followed by *Rhizobium* over control. The observed findings are similar to those observed with the use of other biofertilizers by Kamal *et al*., [19]; Gou *et al*., [20] and Nurlila *et al*. [37] in tomato and Doifode and Nandkar, [38] in Brinjal. Due to genotypic variation the differences in stem

diameter were also observed in varieties and maximum stem diameter was observed in Punjab Gourav. The results corroborates with the findings of Thapa *et al*., [36].

Days to fruit set

The data on days to fruit set as influenced by different microbial inoculants and varieties is presented in Table 2. Minimum number of days to fruit set (56.83) was observed in T_3 (*Rhizobium*) and T_0 (Control) (58.33) was statistically at par with it while T_1 (*Trichoderma*) resulted in maximum number of days to fruit set (60.83days). The treatment T_2 (*Pseudomonas*) (59.00) and T_0 (Control) (58.33) were at par with T_1 (*Trichoderma*). Among varieties V_2 (Punjab Gourav) (57.25) resulted in significantly minimum number of days to fruit set.

Interaction effect of microbial inoculants and varieties on days to fruit set (Table 3) revealed significantly lowest days to fruit set (53.33) was observed in T_3 x V_1 (*Rhizobium* x Punjab Ratta). T_1 x V_1 (*Trichoderma* x Punjab Ratta) resulted in significantly maximum number of days to fruit set (64.67) among all the interaction effects.

Early fruit setting resulting in early fruit maturity and harvesting, leads to great opportunity of fetching good price in the market. From the different applied treatments *Rhizobium* resulted in early initiation of fruiting. As *Rhizobium* act as a nutrilink to plants and increase hormonal, nutritional condition thus could be the reason of earliness [12]. Significant genotypic differences for number of days to fruit set was also observed by earlier Researchers *viz*., Thapa *et al*., [36] and Shobna, [17].

Number of fruits per cluster

Number of fruits per cluster as affected by different microbial inoculants and varieties (Table 2) indicated that T_3 (*Rhizobium*) resulted in the maximum number of fruits per cluster (6.97) and was at par with T_2 (*Pseudomonas*) and T_1 (*Trichoderma*) which resulted in 6.82 and 6.57 fruits per cluster while, T_0(6.23) resulted in minimum number of fruits per cluster. The treatment T_1 (*Trichoderma*) (6.57) was found to be at par with T_0. Among varieties V_2 (Punjab Gourav) resulted in significantly higher number of fruits per cluster (7.36) than V_1 (Punjab Ratta) (5.94).

Table 4 represents the interaction effect of microbial inoculants and varieties on number of fruits per cluster. It revealed maximum number of fruits per cluster (7.61) in T1 x V_2 (*Trichoderma* x Punjab Gourav) which was statistically at par with number of fruits per cluster observed in T_0 x V_2 (Control x Punjab Gourav) (7.53), T_2 x V_2 (*Pseudomonas* x Punjab Gourav) (7.29), T_3 x V_2 (*Rhizobium* x Punjab Gourav) (7.00) and T_3 x V_1 (*Rhizobium* x Punjab Ratta) (6.93). Minimum number of fruits per cluster (4.93) were recorded in T_0 x V_1 (Control x Punjab Ratta). The treatment T_1 x V_1 (*Trichoderma* x Punjab Ratta) (5.53) was found to be at par with T_0 x V_1 (Control x Punjab Ratta).

Number of fruits per cluster is an important yield contributing traits. *Rhizobium* was observed to increase the number of fruits per cluster. This might be due to enhanced nutrients availability to plants, better vegetative growth, more synthesis of proteins, fats and carbohydrates that might have influenced the number of fruits per cluster. The results corroborates with the findings of earlier researchers who also obtained increased number of fruits per cluster with the application of other biofertilizers like Sani *et al*., [21]. Genotypic differences among varieties could be the cause of significant varietal differences for number of fruits per cluster. The results are supported with the findings of Ullah *et al*., [16].

Table 4: Interaction effect of microbial inoculants and cultivars on yield and quality of tomato (*Solanum lycopersicum*)

Treatment	No. of fruits per cluster		No. of fruits per plant		Fruit length		Fruit diameter		Average fruit weight		Fruit yield per plot		Total soluble solids (TSS)		Ascorbic acid		Titratable acidity	
Microbial inoculants	**Cultivars**																	
	V_1	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**
T_0(*Control*)	4.93	7.93	15.13	18.47	37.93	47.84	43.63	49.58	34.38	45.17	10.33	11.65	3.78	5.02	20.89	22.27	0.58	0.64
T_1(*Trichoderma*)	5.53	7.61	16.80	20.07	37.13	46.42	40.63	47.50	41.42	37.31	11.05	12.08	4.47	4.41	20.58	22.10	0.59	0.67
T_2(*Pseudomonas*)	6.35	7.29	18.34	19.74	45.14	48.11	47.08	48.09	45.55	34.68	12.45	11.64	5.08	4.68	22.42	21.99	0.61	0.61
T_3(*Rhizobium*)	6.93	7.00	20.81	20.13	48.43	43.17	50.61	48.96	49.53	45.84	12.96	12.38	4.11	4.57	22.56	21.99	0.66	0.63
CD(5%)	0.71		0.42		2.82		3.07		1.57		0.30		0.43		0.43		0.02	
SE(d)	0.33		0.19		1.30		1.42		0.72		0.14		0.20		0.20		0.01	

Number of fruits per plant

Significantly highest number of fruit per plant (20.47) was observed inT_3 (*Rhizobium*) while, it was significantly minimum (18.43) in T_1 (*Trichoderma*). Among varieties, number of fruits per plant were observed significantly higher in V_2 (Punjab Gourav) (19.60) than V_1 (Punjab Ratta) (17.77). (Table 2)

Perusal of data (Table 4) depicted that T_3 x V_1 (*Rhizobium* x Punjab Ratta) resulted in produced was significantly highest number of fruits per plant i.e (20.81) than all other interaction effects while, significantly lowest number of fruits per plant was observed in T_0 x V_1 (Control x Punjab Ratta) (15.13).

The number of fruits per plant directly affects the yield of the plant. Highest number of fruits per plant were recorded under the *Rhizobium* treatment. It can be attributed to the enhanced pollen germination as a result of improved mother plant nutritional balance which might have ultimately resulted in increasing the fruit set [9]. The resulted are supported by the findings of earlier researchers *viz*., Ramakrishan and Selvakumar, [39], Brar *et al*., [4], Meena *et al*., [10], Kamal *et al*., [19] in tomato and Solanki *et al*., [23], Devi *et al*., [24] in Brinjal. Significant varietal differences for number of fruits per plant can be attributed to their genetic makeup. Similar results were also observed by Khan and Samadia, [15], Thapa *et al*., [36], Kerketta and Bahadur, [28] and Shobna *et al*., [17].

Fruit length (mm) and diameter (mm)

Table 2 represents the data on the influence of microbial inoculants and variety on fruit length and fruit diameter. The maximum fruit length (46.62 mm) and fruit diameter (49.78 mm) was observed in T3 (*Rhizobium*). The treatment T_2 (*Pseudomonas*) were found to be at par with T_3 which

produce fruits with 45.80 mm fruit length while, it was significantly maximum for fruit diameter. The minimum fruit length (41.78 mm) and fruit diameter (44.07 mm) was observed in T_1 (*Trichoderma*). The treatment T_0 (Control) produced fruits with fruit length of 42.89 mm which was at par with T_1 while, T_1 (*Trichoderma*) resulted in significantly lowest fruit diameter among all the microbial inoculants. Among varieties the significantly maximum fruit length (46.38 mm) and fruit diameter (48.53 mm) was observed in V_2 (Punjab Gourav) whereas V_1 (Punjab Ratta) produced fruits with fruit length of 42.16 mm and (45.49 mm) fruit diameter.

The interaction effect of microbial inoculants and varieties on fruit length revealed that maximum fruit length (48.43 mm) was observed in T_3 x V_1 (*Rhizobium* x Punjab Ratta) which was statistically at par with T_2 x V_2 (*Pseudomonas* x Punjab Gourav), T_0 x V_2 (Control x Punjab Gourav) and T_1 x V_2 (*Trichoderma* x Punjab Gourav) which produced fruits with fruit length of 48.11 mm, 47.84 mm and 46.42 mm, respectively. The minimum fruit length (37.13 mm) was observed in T_1 x V_1 (*Trichoderma* x Punjab Ratta) which was statistically at par with T_0 x V_1 (Control x Punjab Ratta) (37.93 mm). Fro fruit diameter T_3 x V_1 (*Rhizobium* x Punjab Ratta) resulted in maximum fruit diameter (50.61 mm) which were statistically at par with T_0 x V_2 (Control x Punjab Gourav), T_3 x V_2 (*Rhizobium* x Punjab Gourav) and T_2 x V_2 (*Pseudomonas* x Punjab Gourav) which resulted in fruits with 49.58 mm, 48.96 mm and 48.09 mm fruit diameter respectively. The minimum fruit diameter was observed in T_1 x V_1 (*Trichoderma* x Punjab Ratta) (40.63 mm) which was statistically at par with T_0 x V_1 (Control x Punjab Ratta) (43.63 mm). (Table 4).

Strong and positive correlation of fruit yield with the fruit length and weight have been observed which suggests that increased tomato yield productivity per unit area can be enhanced with improvement in individual fruit size. The observed data showed maximum fruit length and fruit diameter with the application of *Rhizobium*. The results are in corroboration with the findings of Singh and Thakur, (2018), Padhiary and Dubey, [33], Singh *et al*., [12] Hossain and Akter [40] and Sachan *et al*., [41] in Brinjal.

Significant variation among varieties for fruit length and fruit diameter were also observed by other researchers *viz*., Balcha *et al*., [42], Karketta and Bahadur, [28] and Shobna [17].

Average fruit weight (g)

The effect of microbial inoculants and varieties on average fruit weight has been presented in Table 2. It showed that among microbial inoculants, significantly maximum average fruit weight (47.69g) was observed in T_3 (*Rhizobium*) while, minimum average fruit weight (39.36 g) was observed in T_1 (*Trichoderma*) which was statistically at par with T_0 (Control) (39.77). Among varieties significantly higher average fruit weight (42.72g) was observed in V_1 (Punjab Ratta).

Significantly maximum average fruit weight (49.53g) was observed in T_3 x V_1 (*Rhizobium* x Punjab Ratta) among all the interaction effects while, minimum average fruit weight (34.38g) was observed in T_0 x V_1 (Control x Punjab Ratta) which was statistically at par with T_2 x V_2 (*Pseudomonas* x Punjab Gourav) (37.31).

Increase in fruit weight results in increased yield. From the observed data the maximum fruit weight was recorded under application of *Rhizobium*. Application of biofertilizers enhances the root development and thereby improves the nutrient uptake potential of roots. These are also observed to fix nitrogen to some extent. Similar results were also observed by Brar *et al*., [4], Sani *et al*., [21] and Cabrera [22] in tomato and Mishra *et al*., [30] and Singh *et al*., [12] in Brinjal. Significant varietal differences for fruit weight was also observed by Khan and Samadia, [15].

Fruit yield per plot (Kg)

Maximum fruit yield per plot (12.67 kg) among microbial inoculants was observed in T_3 (*Rhizobium*) which was significantly highest among all microbial inoculants. While it was significantly minimum (10.99 kg) T_0 (Control). Among varieties V_2 (Punjab Gourav) (11.94 kg) produced significantly higher fruit yield per plot than V_1 (Punjab Ratta) (11.70 kg). (Table 2)

Table 4 representing the interaction effect of microbial inoculants and varieties on fruit yield per plot depicted significantly highest fruit yield per plot (12.96 kg) in T_3 x V_1 (*Rhizobium* x Punjab Ratta) and significantly lowest fruit yield per plot (10.33 kg) in T_0 x V_1 (Control x Punjab Ratta) among all the interaction effects.

Rhizobium resulted in the highest yield per plot which is significantly higher than the control. Generally, yield depends on different yield contributing factors *viz*., number of fruits per plant, fruit length, fruit diameter and weight of the fruit. Higher scales of these characters were also observed with the application of *Rhizobium*. This positive effect of *Rhizobium* application in terms of increased yield can be attributed to the improved root development, enhanced photosynthesis efficiency and food accumulation. Microbial inoculants 's ability to increase atmospheric nitrogen and soil phosphorus availability and synthesis of plant growth hormones at all stages of growth and development also add up to their contribution in improving the yield potential of the crop. The findings are in corroboration with Brar *et al*., [4] Gou *et al*., [20] and Cabrera [22] in tomato; Mishra *et al*., [30] in Brinjal and Khan *et al*., [15] in chilli.

As all the varieties differ in their genetic makeup thus significant differences for fruit yield per plot among varieties could be due to their different genetic potential. These results corroborates with the findings of earlier researchers *viz*., Ullah *et al*., [16] and Shobna [17].

Total soluble solids (TSS) (^{0}B)

Total Soluble Solids (TSS) as affected by microbial inoculants and varieties are presented in Table 2. It was observed significantly highest (4.88) in T_2 (*Pseudomonas*) among all microbial inoculants while, it was minimum (4.34) in T_3 (*Rhizobium*) and at par with T_0 (Control) (4.40) and T_1 (*Trichoderma*) (4.44). Among varieties the significantly higher TSS (4.67) was observed in V_2 (Punjab Gourav) than V_1 (Punjab Ratta) (4.36)

The interaction effect of microbial inoculants and varieties on TSS (Table 4) reveals maximum TSS (5.08) was observed in T_2 x V_1 (*Pseudomonas* x Punjab Ratta) which was statistically at par with T_0 x V_2 (Control x Punjab Gourav) (5.02) and T_2 x V_2 (*Pseudomonas* x Punjab Gourav) (4.68) and T_3 x V_2 (*Rhizobium* x Punjab Gourav) (4.57). Minimum TSS (3.78) was observed in T_0 x V_1 (Control x Punjab Ratta) which was statistically at par with T_3 x V_1 (*Rhizobium* x Punjab Ratta) (4.11).

Total soluble solids (TSS) is an important quality parameter

for processing tomatoes. *Pseudomonas* was observed to increase the TSS in the present study. Nutritional, stimulatory and therapeutic behavior of biofertilizers could be attributed to the improvement in quality attributes like TSS as reported by Brar *et al*., [4]; Gou *et al*., [20] and Sani *et al*., [21] in tomato; Mishra *et al*., [30]; Singh and Thakur *et al*., [11]; Ramnathan *et al*., [43] and Singh *et al*., [12] in Brinjal and Bade *et al*., [44] in chilli. Significant varietal differences for TSS was also observed by Khan and Samadia, [15], Rai *et al*., [45].

Ascorbic acid (mg/100ml)

The influence of microbial inoculants and varieties on ascorbic acid (Table 2) depicted that T_3 (*Rhizobium*) resulted in maximum ascorbic acid (22.28) which was statistically at par with T_2 (*Pseudomonas*) (22.20). The minimum ascorbic acid (21.34) was observed in T_1 (*Trichoderma*) which was at par with T_0 (Control) (21.61). Among varieties V_2 (Punjab Gourav) showed significantly higher ascorbic acid content (22.09) than V_1 (Punjab Ratta) (21.61).

The interaction effect of microbial inoculants and varieties on ascorbic acid (Table 4) revealed maximum ascorbic acid in T_3 x V_1 (*Rhizobium* x Punjab Ratta) (22.56) which was statistically at par with T_2 x V_1 (*Pseudomonas* x Punjab Ratta) (22.42) and T_0 x V_2 (Control x Punjab Gourav) (22.27). The minimum ascorbic acid (20.58) was observed in T_1 x V_1 (*Trichoderma* x Punjab Ratta) which was at par with T_0 x V_1 (Control x Punjab Ratta) (20.89).

Rhizobium application resulted in maximum ascorbic acid (Vitamin C) content in present study. Slow but continuous supply of all major and micro nutrients with the application of biofertilizers could have resulted in accelerated assimilation of carbohydrates and in turn synthesis of ascorbic acid. The results are supported by earlier findings of Gosavi *et al*., [46]; Meena *et al*., [10]; Brar *et al*., [4] and Gou *et al*., [20] in tomato; Muhammad *et al*., [47] and Mishra *et al*., [30] in Brinjal and Bade *et al*., [47] in chilli. Significant difference for ascorbic acid among varieties were also observed by Kumar *et al*., [26], Thapa *et al*., [36] and Shobna [17].

Titratable acidity (%)

The effect of microbial inoculants and varieties on titratable acidity (Table 2) revealed that T_3 (*Rhizobium*) resulted in the maximum titratable acidity (0.64) and was statistically at par with T_1 (*Trichoderma*) (0.63). Minimum titratable acidity (0.60) were observed in T_0 which was at par with T_2 (*Pseudomonas*) (0.61). Among varieties the significantly higher titratable acidity (0.64) was observed in V_2 (Punjab Gourav) than V_1 (Punjab Ratta) (0.61).

The interaction effect of microbial inoculants and varieties on titratable acidity (Table 4) revealed that T_1 x V_2 (*Trichoderma* x Punjab Gourav) resulted in maximum titratable acidity (0.67) which was statistically at par with T_3 x V_1 (*Rhizobium* x Punjab Ratta) (0.66). Minimum titratable acidity was observed in T_0 x V_1 (Control x Punjab Ratta) (0.58) which was at par with T_1 x V_1 (*Trichoderma* x Punjab Ratta) (0.59).

Among the different microbial inoculants tried, the maximum titratable acidity was registered with the application of *Rhizobium* and minimum under control. *Rhizobium* helps in accelerated solubilisation of native and applied nutrients and their subsequent uptake by the plant with increased root proliferation and influenced activity of number of enzymes physiologically. This could have resulted in increased vegetative growth and balanced C:N ratio thereby increasing the titratable acidity. The results are similar to the findings of Ramnathan *et al*., [43] in Brinjal. Varietal differences for titratable acidity could be due to their genetic variation. The results corroborates with the findings of Kumar *et al*., [26], Thapa *et al*., [36].

Conclusion

The results and discussion of the present investigation on the effect of microbial inoculants on growth, yield and quality attributes of tomato revealed that use of microbial inoculants can effectively enhance the performance of cultivars in terms of growth, yield and quality attributes. Punjab Ratta showed the best results for growth, yield and quality attributes among the varieties studied. Whereas among different microbial inoculants *Rhizobium* resulted in improved growth, yield and quality attributes while, *Pseudomonas* showed their best in earliness. Thus, it can be concluded that Punjab Ratta when treated with *Rhizobium* and *Pseudomonas* performed better.

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