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Influence of co-inoculation of different bacterial cultures with *Rhizobium phaseoli* on nutrient content and uptake in blackgram (*Vigna mungo*)

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Abstract
A field experiment was conducted during *kharif* season of 2018 at Research farm, Department of Soil Science and Agricultural Chemistry, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani to evaluate co-inoculation effect of different bacterial cultures with *Rhizobium phaseoli* on nutrient content and uptake in blackgram, grown in vertisols. Experiment consist of ten treatments in which eight pre-evaluated bacterial cultures in laboratory (*Rhizobium phaseoli, Bacillus megaterium, Bacillus subtilis, Bacillus polymyxa, Pseudomonas striata, Pseudomonas flurescens, Azotobacter chroococcum and Azospirilllum lipoferum*) and were used with RDF in randomized block design. Seed treatment of black gram was done with bacterial cultures along with application RDF at the time of sowing. Results emerged out indicated that the both macronutrient and micronutrient content and uptake were significantly improved by co-inoculation over non-inoculation and single inoculation of *Rhizobium phaseoli*. The co-inoculation of *Rhizobium phaseoli* + *Bacillus megaterium*, *Rhizobium phaseoli* + *Pseudomonas striata* and *Rhizobium phaseoli* + *Pseudomonas flurescense* found to be at par with each other and having more potential than the other combinations.

Keywords: Blackgram, nutrient content, nutrient uptake, co-inoculation, bacterial cultures

Introduction
Blackgram (*Urad*) is annual pulse crop and native to Central Asia. At national level it is the 3rd important crop, was cultivated over an area of 5.44 Mha (kharif + rabi) and recorded a production of 3.56 Mt at a productivity level of 655 kg ha^{-1}. Major contributing states have been Madhya Pradesh, Rajasthan, Andhra Pradesh, Uttar Pradesh, Tamil Nadu, Maharashtra, Jharkhand and Gujarat. Maharashtra contribute 9.62 per cent (4.84 lakh ha) to the total area under blackgram and 5.39 per cent (1.77 lakh tones) to the total production (Anonymous 2018). This crop is endowed with many desirable characters like, short in duration, restorative (soil fertility building crops), low water requiring and highly suitable to be grown in mixed or intercropping systems and also as a catch crop to scavenge the residual soil moisture and fertility. It is rich source of deity protein (24%), carbohydrate (67%), Fibre (3.5%), fat (1.74%) and major portion of lysine in a vegetarian diet (Elangaimannan *et al*. 2008). Black gram is rich in potassium, phosphorous, calcium, sodium and vitamins (retinoic acid, thiamine, riboflavin). It has several therapeutic properties like curing diabetes, sexual dysfunction, and nervous hair and digestive system disorders. These properties are based on nutrient uptake potential of blackgram which directly influence the nutrient content. Keeping these points in view the present study were carried out by using different bacterial cultures. Different bacterial genera are vital components of soils. They are involved in various biotic activities of the soil ecosystem to make it dynamic for nutrient turn over and sustainable for crop production. In the rhizosphere the synergism between various bacterial genera such as *Bacillus*, *Pseudomonas* and *Rhizobium* has been demonstrated to promote plant growth and development. Compared to single inoculation, co-inoculation has improved the absorption of nitrogen, phosphorus and mineral nutrients by plants (Dashadi *et al*. 2011) [8].

Materials and Methods
A field experiment was conducted during *kharif* season of 2018 at Research farm, Department of Soil Science and Agricultural Chemistry, Vasantrao Naik Marathwada Krishi Vidyapeeth Parbhani to assess the co-inoculation effect of different bacterial cultures with *Rhizobium phaseoli* on nutrient dynamics.

Experiment consist of ten treatments in which eight pre-evaluated bacterial cultures in laboratory (*Rhizobium phaseoli, Bacillus megaterium, Bacillus subtilis, Bacillus polymyxa, Pseudomonas striata, Pseudomonas flurescens, Azotobacter chroococcum and Azospirilllum lipoferum*) and were used with recommended dose of fertilizer (25:50:00:10 N:P:K and S kg ha^{-1} respectively) in randomized block design. Seed treatment of black gram was done with bacterial cultures along with application RDF at the time of sowing. The data obtained were statistically analyzed and appropriately interpreted as per the methods described by Panse and Sukhatme (1985). Appropriate standard error (S.E.) and critical differences (C.D.) at 5 per cent levels were worked out for interpretation of result. The treatment wise plant samples of black gram were collected at harvest stage and by following standard procedures the prepared samples were stored in polythene bags with proper labelling for chemical analysis (Bhargava and Raghupathi, 2001). The chemical analysis for determination of nutrient contents in blackgram was carried out as per standard methods. The data obtained were statistically analyzed and appropriately interpreted as per the methods described by Panse and Sukhatme (1985). Appropriate standard error (S.E.) and critical differences (C.D.) at 5 per cent levels were worked out for interpretation of result.

Result and Discussion

Effect on Macronutrient Content

The data presented in Table 1 indicates influence of co-inoculation of different bacterial cultures with *Rhizobium phaseoli* on macronutrient content i.e. nitrogen (N), phosphorous (P) and potassium (K) in seed and straw of blackgram.

Effect on Nitrogen (N) Content

The treatment T_7 receiving co-inoculation of *Rhizobium phaseoli* with *Pseudomonas striata* is significantly superior over other treatments in case of seed (3.75%) and straw nitrogen content (1.68%) and treatment T_4 receiving co-inoculation of *Rhizobium phaseoli* and *Bacillus megaterium* (3.69%) and T_8 receiving co-inoculation of *Rhizobium phaseoli* and *Pseudomonas flurescens* (3.57%) was found at par with T_7 in case of straw nitrogen.

In line of our work, Yadav *et al.* (2008) [23] found that combined inoculation of *Rhizobium* isolates along with PSB and PGPR increases the nitrogen content in black gram. Also, Verma *et al.* (2010) [22] reported that maximum nitrogen in grain and straw in dual inoculation of *Rhizobium sp.* and *P. flurescens* over uninoculated control. Qureshi *et al.* (2011) [17] also estimated co-inoculation enhanced the N content in plant matter (1.22 and 1.25%) which was at par with *Bacillus* and rhizobial inoculation alone. Further, Badawi *et al.* (2011) [6] exhibited that the percentage increases in the shoot N-content were 66.38%, 59.74% and 60.34%, in the first season and 108.25%, 65.90% and 82.92%, in the second season, due to co-inoculation with *S. marcescens*, *T. harzianum* and their mixture, respectively, above the uninoculated control. Singh *et al.* (2016) [19] resulted that dual inoculation of *Rhizobium* + PSB recorded the maximum nitrogen content (3.68 and 0.62%) and found superior to control (2.93 %).

Effect on Phosphorous (P) content

Maximum phosphorous content was observed under treatment T_8 (RDF + *Rhizobium phaseoli* + *Pseudomonas flurescens*) in seed (0.36 %) and straw content (0.43 %) black gram which significantly differed from all other treatments at 5 per cent level of significance. Treatment T_4 (RDF + *Rhizobium phaseoli* + *Bacillus megaterium*) and T_7 (RDF + *Rhizobium phaseoli* + *Pseudomonas striata*) with 0.35 per cent (seed) and 0.41 per cent (straw) were found at par with T_8.

Table 1. Effect of co-inoculation of different bacterial cultures with *Rhizobium phaseoli* on macronutrient content in black gram

Sr. No.	Treatment	N content (%)		P content (%)		K content (%)	
		Seed	Straw	Seed	Straw	Seed	Straw
T_1	Absolute control	2.86	1.28	0.31	0.38	1.18	1.77
T_2	Only RDF	3.09	1.38	0.32	0.39	1.20	1.91
T_3	RDF + *Rhizobium phaseoli*	3.23	1.43	0.32	0.39	1.22	1.93
T_4	T_3 + *Bacillus megaterium*	3.69	1.63	0.35	0.41	1.28	2.38
T_5	T_3 + *Bacillus subtilis*	3.49	1.52	0.34	0.40	1.27	2.19
T_6	T_3 + *Bacillus polymyxa*	3.30	1.43	0.33	0.39	1.24	2.10
T_7	T_3 + *Pseudomonas striata*	3.75	1.68	0.35	0.41	1.31	2.68
T_8	T_3 + *Pseudomonas flurescens*	3.57	1.62	0.36	0.43	1.28	2.44
T_9	T_3 + *Azotobacter chroococcum*	3.43	1.42	0.33	0.40	1.22	2.13
T_{10}	T_3 + *Azospirillum lipoferum*	3.40	1.37	0.33	0.39	1.21	2.17
	S.Em.±	0.06	0.03	0.003	0.003	0.007	0.03
	C.D. at 5 %	0.18	0.09	0.01	0.01	0.02	0.08

Our results are similar to the results reported by Verma *et al.* (2010) [22] that maximum phosphorous in grain 52.78 and 34.21% and in straw 36.04 and 33.04% in inoculation of *Rhizobium sp*. and *P. flurescens* over un-inoculated control respectively. Qureshi *et al.* (2011) [17] also estimated highest grain P-content (0.28 and 0.30%) by co-inoculation over control. Singh *et al.* (2016) [19] resulted that dual inoculation of *Rhizobium* + PSB recorded the maximum phosphorous content (1.30 and 0.59%) and found superior to control (1.03 and 0.48 %).

Effect on Potassium (K) content

The treatment T_7 receiving co-inoculation of *Rhizobium phaseoli* with *Pseudomonas striata* shows maximum K content in seed (1.31 %) and straw (2.68 %) which significantly differ from rest of treatments and it followed by T_4 receiving co-inoculation of *Rhizobium phaseoli* with *Bacillus megaterium* (1.28 and 2.38 %) and T_8 receiving co-inoculation of *Rhizobium phaseoli* with *Pseudomonas flurescens* (1.28 and 2.44 %).

Mishra *et al.* (2011) [13] analyzed K contents of shoot for various treatments after the harvest of crop and found dual inoculations of *Pseudomonas spp*. and *R. leguminosarum*-PR1 had significantly higher levels of shoot K compared to *R. leguminosarum*-PR1 alone. Similarly, Singh *et al.* (2016) [19] noted that dual inoculation of *Rhizobium* + PSB recorded the

maximum potassium content (0.49 and 1.20 %) and found superior to control (0.46 and 1.16 %).

Effect on Macronutrient Uptake (N, P and K)

Effect on Nitrogen (N) Uptake

Significantly highest value of N uptake i.e. by seed, straw and total uptake was recorded in T_4 (23.49, 23.00 and 46.48 kg ha^{-1} respectively) over rest of treatments and treatment T_7 (22.60, 23.26 and 45.86 kg ha^{-1} respectively) and T_8 (21.92, 21.20 and 43.13 kg ha^{-1} respectively) found at par with T_4. The lowest value was recorded in treatment T_1 (absolute control). The co-inoculation enhanced the N-fixation in all the treatments as compared to T_1 and T_2.

Earlier, Singh *et al.* (2007) [20] showed that the dual as well as multi inoculation of biofertilizers with or without FYM increased the uptake of nitrogen while Similarly, Amule *et al.* (2013) found that N uptake increases by 25%, due to co-inoculation over mono-inoculation. Patil *et al.* (2013) [15] also reported that finger millet treated with dual inoculum of AM fungi and *Azosprillium sp.* showed higher N uptake (12.40 kg ha^{-1}) when compared to control plants (9.36 kg ha^{-1}) respectively. Singh et al. (2016) [19] reported that the maximum uptake of N by black gram grain (48.61 kg ha^{-1}), straw (14.14 kg ha^{-1}), and total (62.75 kg ha^{-1}) was found in treatment *Rhizobium* + PSB which was significantly superior over rest of the treatments.

Table 2: Effect of co-inoculation of different bacterial cultures with *Rhizobium phaseoli* on macronutrient uptake in black gram

Sr. No.	Treatment	N uptake (kg ha^{-1})			P uptake (kg ha^{-1})			K uptake (kg ha^{-1})		
		Seed	Straw	Total	Seed	Straw	Total	Seed	Straw	Total
T_1	Absolute control	13.94	12.04	25.98	1.87	2.95	4.82	5.77	16.62	22.39
T_2	Only RDF	15.96	14.43	30.40	2.00	3.30	5.29	6.23	20.01	26.24
T_3	RDF + *Rhizobium phaseoli*	18.47	17.68	36.14	2.23	3.97	6.20	6.96	23.85	30.81
T_4	T_3 + *Bacillus megaterium*	23.49	23.00	46.48	2.60	4.92	7.52	8.14	33.50	41.65
T_5	T_3 + *Bacillus subtilis*	20.06	17.52	37.58	2.29	3.89	6.18	7.30	25.27	32.57
T_6	T_3 + *Bacillus polymyxa*	16.35	15.57	31.92	1.93	3.58	5.51	6.14	23.00	29.13
T_7	T_3 + *Pseudomonas striata*	22.60	23.26	45.86	2.54	4.55	7.09	7.86	37.09	44.96
T_8	T_3 + *Pseudomonas flurescens*	21.92	21.20	43.13	2.61	4.94	7.55	7.82	31.97	39.79
T_9	T_3 + *Azotobacter chroococcum*	17.11	15.79	32.90	1.97	3.65	5.63	7.96	23.77	32.83
T_{10}	T_3 + *Azospirillum lipoferum*	18.63	15.56	34.19	2.16	3.77	5.93	6.65	24.68	31.34
	S.Em.±	0.58	0.70	1.14	0.07	0.16	0.21	0.23	0.86	1.00
	C.D. at 5 %	1.72	2.07	3.38	0.22	0.47	0.62	0.67	2.55	2.96

Effect on Phosphorus (P) uptake

Significantly highest value of P uptake i.e. by seed, straw and total was recorded in treatment T_8 (2.61, 4.94 and 7.55 kg ha^{-1}, respectively) and treatment T_4 (2.60, 4.92 and 7.52 kg ha^{-1}, respectively) and T_7 (2.54, 4.55 and 7.09 kg ha^{-1}, respectively) found at par with T_8. The lowest values in case of both content and uptake were recorded under treatment T_1 (absolute control).

Phosphorus solubilizers along with *Rhizobium* increased the availability thereby improved phosphorus nutrition of plant and uptake of nutrient manifested in increased concentration (Mir *et al.* 2011). Similarly, Amule *et al.* (2013) found that P uptake increases by 17%, due to co-inoculation over mono-inoculation. Moreover, Patil *et al.* (2013) [15] reported that finger millet treated with dual inoculum of AM fungi and azosprillium showed higher P uptake (6.77 kg ha^{-1}) when compared to control plants (4.86 kg ha^{-1}). Singh et al. (2016) [19] found that the maximum uptake of P by black gram by grain (17.17 kg ha^{-1}), straw (13.45 kg ha^{-1}) and its total uptake (30.62 kg ha^{-1}) was found in treatment *Rhizobium* + PSB which was significantly superior over rest of the treatments. Further, Tiwari *et al.* (2018) [21] reported that treatment RDF + 25 kg ZnSO4 ha^{-1} + Seed inoculation with *Rhizobium* + PSB + 1.0 g ammonium molybdate kg^{-1} seed in lentil recorded significant uptake of P (8.57 kg ha^{-1}) over rest of treatments.

Effect on Potassium (K) uptake

Significantly highest value of K uptake i.e. seed, straw and total uptake was recorded in treatment T_7 (7.86, 37.09 and 44.96 kg ha^{-1}, respectively) and followed by treatment T_4 (8.14, 33.50 and 41.65 kg ha^{-1}, respectively). The lowest values for both content and uptake in black gram were recorded under treatment T_1 (absolute control).

Earlier, Singh *et al.* (2007) [20] conducted a field experiment on soybean and result showed that the dual as well as multi inoculation of biofertilizers with or without FYM increased the uptake of K. Amule *et al.* (2013) also found that K uptake increases by 9 %, due to co-inoculation over mono-inoculation. Singh et al. (2016) [19] revealed that the maximum total uptake of K by black gram (33.84 kg ha^{-1}) was found in treatment *Rhizobium* + PSB which was significantly superior over rest of the treatments.

Effect on Micronutrient Content (Zn, Cu, Fe and Mn)

The data presented in Table 3a. and 3b. indicates that the concentration of zinc (Zn) and ferrous (Fe) and copper (Cu) and manganese (Mn) respectively, in blackgram seed and straw as influenced by co-inoculation of different bacterial cultures with *Rhizobium phaseoli*.

Effect on Zinc (Zn) content

The Zn content of seed and straw found maximum in treatment T_7 receiving co-inoculation of *Rhizobium phaseoli* and *Peudomonas striata* (75.68 and 64.07 mg kg^{-1}, respectively) which significantly differed from other treatments and treatment T_4 having co-inoculation of *Rhizobium phaseoli* and *Bacillus megaterium* (71.59 and 61.32 mg kg^{-1}, respectively) and T_8 having o-inoculation of *Rhizobium phaseoli* and *Pseudomonas flurescens* (72.64 and 63.07 mg kg^{-1}, respectively) found at par with T_7 (Table 3a.).

Our findings were matched with Mishra *et al.* (2011) [13] that lentil cultivar receiving single or dual inoculations of *Pseudomonas sp*. and *R. leguminosarum*-PR1 had significantly higher levels of shoot Zn compared to the *R. leguminosarum*-PR1 alone. Whereas, Dashadi *et al.* (2011) [8] observed that mixed inoculation of faba bean with *Rhizobium* and *Azospirillum* and *Rhizobium* and *Azotobacter* combinations led to changes in total Zn content. Similarly, Selvakumar *et al.* (2012) [18] also reported co-inoculation of Sorghum with *Azospirillum* and *Glomus* significantly

increased Zn content. Tiwari *et al.* (2018) [21] found that treatment RDF + 25 kg ZnSO4 ha^{-1} + Seed inoculation with *Rhizobium* + PSB + 1.0 g ammonium molybdate kg^{-1} seed in lentil recorded significant total Zn content over control treatment and was found at par with RDF + Seed inoculation with *Rhizobium* + PSB + 1.0 g ammonium molybdate kg^{-1} seed.

Table 3a: Effect of co-inoculation of different bacterial cultures with *Rhizobium phaseoli* on micronutrient content (Zn and Fe) in black gram

Sr. No.	Treatment	Zn content (mg kg^{-1})		Fe content (mg kg^{-1})	
		Seed	Straw	Seed	Straw
T_1	Absolute control	58.85	52.63	203.29	170.62
T_2	Only RDF	59.43	55.15	205.53	177.41
T_3	RDF + *Rhizobium phaseoli*	64.97	55.39	204.77	178.65
T_4	T_3 + *Bacillus megaterium*	71.59	61.32	232.94	202.84
T_5	T_3 + *Bacillus subtilis*	67.88	59.15	219.08	192.38
T_6	T_3 + *Bacillus polymyxa*	66.41	56.95	210.81	190.71
T_7	T_3 + *Pseudomonas striata*	75.68	64.07	240.87	206.66
T_8	T_3 + *Pseudomonas flurescens*	72.64	63.07	224.43	202.12
T_9	T_3 + *Azotobacter chroococcum*	63.74	59.53	215.04	192.24
T_{10}	T_3 + *Azospirillum lipoferum*	67.17	60.41	209.35	192.17
	S.Em.±	1.60	1.70	4.43	4.45
	C.D. at 5 %	4.75	5.06	13.17	10.25

Effect on Ferrous (Fe) content

The Fe content of seed and straw found maximum in treatment T_7 receiving co-inoculation of *Rhizobium phaseoli* and *Pseudomonas striata* (240.87 and 206.66 mg kg^{-1}, respectively) over other treatments followed by treatment T_4 having co-inoculation of *Rhizobium phaseoli* and *Bacillus megaterium* (232.94 and 202.84 mg kg^{-1}, respectively) and T_8 having co-inoculation of *Rhizobium phaseoli* and *Pseudomonas flurescens* (224.43 and 202.12 mg kg^{-1}, respectively) (Table 3a.).

In line of our works, Mishra *et al.* (2011) [13] analyzed Fe contents of shoot for various treatments after the harvest of crop at 40 and 60 days after sowing (DAS) and results revealed that lentil cultivar receiving single or dual inoculations of *Pseudomonas spp*. and *R. leguminosarum*-PR1 had significantly higher levels of shoot Fe compared to the *R. leguminosarum*-PR1 alone at 40 DAS. Further, Dashadi *et al.* (2011) [8] observed that mixed inoculation of faba bean with *Rhizobium* / *Azospirillum* and *Rhizobium* / *Azotobacter* combinations led to changes in total content of Fe. Selvakumar *et al.* (2012) [18] also reported co-inoculation of sorghum with *Azospirillum* and *Glomus* significantly increased Fe content.

Effect on Copper (Cu) content

The Cu content of seed and straw was found maximum in treatment T_7 receiving co-inoculation of *Rhizobium phaseoli* with *Pseudomonas striata* (53.72 and 43.93 mg kg^{-1}, respectively) which significantly superior over other treatments and followed by treatment T_4 (RDF + *Rhizobium phaseoli* + *Bacillus megaterium*) (53.61 and 43.49 mg kg^{-1}), T_5 (RDF + *Rhizobium phaseoli* + *Bacillus subtilis*) (51.57 an 41.87 mg kg^{-1}), T_6 (RDF + *Rhizobium phaseoli* + *Bacillus polymyxa*) (50.60 and 40.63 mg kg^{-1}), T_8 (RDF + *Rhizobium phaseoli* + *Pseudomonas flurescens*) (53.40 and 43.37 mg kg^{-1}), T_9 (RDF + *Rhizobium phaseoli* + *Azotobacter chroococcum*) (51.66 and 41.63 mg kg^{-1}) and T_{10} (RDF + *Rhizobium phaseoli* + *Azospirillum lipoferum*) (50.47 and 40.38 mg kg^{-1}) (Table 3b.).

These findings corroborated with results of Dashadi *et al.* (2011) [8] recorded that mixed inoculation of faba bean with *Rhizobium* and *Azospirillum* and *Rhizobium* and *Azotobacter* combinations led to changes in total content of Cu. Further, Selvakumar *et al.* (2012) [18] reported co-inoculation of sorghum with *Azospirillum* and *Glomus* significantly enhances the Cu content of grain and straw.

Table 3b: Effect of co-inoculation of different bacterial cultures with *Rhizobium phaseoli* on micronutrient content (Cu and Mn) in black gram

Sr. No.	Treatment	Cu content (mg kg^{-1})		Mn content (mg kg^{-1})	
		Seed	Straw	Seed	Straw
T_1	Absolute control	39.54	29.49	50.55	43.21
T_2	Only RDF	41.79	31.61	52.89	44.25
T_3	RDF + *Rhizobium phaseoli*	47.71	37.71	55.63	45.21
T_4	T_3 + *Bacillus megaterium*	53.61	43.49	60.69	50.10
T_5	T_3 + *Bacillus subtilis*	51.57	41.87	58.61	49.96
T_6	T_3 + *Bacillus polymyxa*	50.60	40.63	58.29	48.17
T_7	T_3 + *Pseudomonas striata*	53.72	43.93	64.06	54.88
T_8	T_3 + *Pseudomonas flurescens*	53.40	43.37	63.61	53.67
T_9	T_3 + *Azotobacter chroococcum*	51.66	41.63	58.66	48.66
T_{10}	T_3 + *Azospirillum lipoferum*	50.47	40.38	56.38	49.74
	S.Em.±	1.24	1.17	1.53	0.75
	C.D. at 5 %	3.69	3.45	4.55	2.23

Effect on Manganese (Mn) Content

The Mn content of seed and straw found maximum in treatment T_7 receiving co-inoculation of *Rhizobium phaseoli* with *Pseudomonas striata* (64.06 and 54.88 mg kg^{-1}, respectively) which significantly superior over other treatments and treatments T_4 receiving co-inoculation of *Rhizobium phaseoli* with *Bacillus megaterium* (60.69 and 50.10 mg kg^{-1}, respectively) and T_8 having dual inoculation of *Rhizobium phaseoli* with *Pseudomonas flurescens* (63.61 and 53.67 mg kg^{-1}) found at par with T_7 (Table 3b.).

Our findings matched with the studies of Dashadi *et al.* (2011) [8] that mixed inoculation of faba bean with *Rhizobium* and *Azospirillum* and *Rhizobium* and *Azotobacter* combinations led to changes in total content of Mn. Similarly, Kranthikumar *et al.* (2017) [11] reported that content of Fe, Zn, Mn and kg^{-1} in grain and 43.7 mg kg^{-1} in straw) and Cu by soybean was found highest in treatment RDF+ *Rhizobium* + *Trichoderma viride*.

Effect on Micronutrient Uptake (Zn, Cu, Fe and Mn)

Effect on Zinc (Zn) uptake

The Zn uptake by seed under treatment T_8 (46.43 g ha^{-1}) found maximum over rest of treatments and treatment T_4 (45.43 g ha^{-1}) and treatment T_7 (43.76 g ha^{-1}) showed at par values with treatment T_8. However, Zn uptake by straw and total uptake was found maximum in T_8 (87.29 and 131.05 g ha^{-1} respectively) which significantly differed from other treatments and treatment T_4 (86.28 and 131.05 g ha^{-1}) and T_7 (83.91 and 130.34 g ha^{-1}) found at par with T_8. The lowest values for Zn content and uptake were observed in treatment T_1 (absolute control). Tiwari *et al.* (2018) [21] found that the maximum uptake of Zn (654.66 g ha^{-1}) in lentil in treatment receiving RDF + Seed inoculation with *Rhizobium* + PSB + 1.0 g ammonium molybdate kg^{-1} seed.

Table 4a: Effect of co-inoculation of different bacterial cultures with *Rhizobium phaseoli* on micronutrient uptake (Zn and Fe) in black gram

Sr. No.	Treatment	Zn uptake (g ha^{-1})			Fe uptake (g ha^{-1})		
		Seed	Straw	Total	Seed	Straw	Total
T_1	Absolute control	28.66	49.48	78.14	99.03	160.16	259.19
T_2	Only RDF	30.77	57.53	88.30	106.48	185.61	292.09
T_3	RDF + *Rhizobium phaseoli*	37.16	68.27	105.40	117.02	220.25	337.27
T_4	T_3 + *Bacillus megaterium*	45.43	86.28	131.05	148.33	285.53	433.86
T_5	T_3 + *Bacillus subtilis*	39.05	68.05	107.01	126.02	221.44	347.46
T_6	T_3 + *Bacillus polymyxa*	32.87	62.22	95.08	104.46	209.14	313.60
T_7	T_3 + *Pseudomonas striata*	46.43	83.91	130.34	147.74	270.49	418.22
T_8	T_3 + *Pseudomonas flurescens*	43.76	87.29	131.72	135.15	279.69	414.84
T_9	T_3 + *Azotobacter chroococcum*	31.82	66.53	98.35	107.28	214.69	321.97
T_{10}	T_3 + *Azospirillum lipoferum*	36.84	68.65	105.49	114.98	218.30	333.28
	S.Em.±	1.19	2.80	3.39	4.80	8.69	12.30
	C.D. at 5 %	3.54	8.31	10.06	14.26	25.81	36.53

Effect on Ferrous (Fe) Uptake

In case of Fe uptake i.e. by seed, straw and total was found maximum in T_4 having co-inoculation of *Rhizobium phaseoli* with *Bacillus megaterium* (148.33, 285.53 and 433.86 g ha^{-1}) which significantly differed from other treatments and treatment T_7 (147.74, 270.49 and 418.22 g ha^{-1}) and T_8 (135.15, 279.69 and 414.84 g ha^{-1}) found at par with T_4. The lowest value observed in treatment T_1 (absolute control).

Effect on Copper (Cu) uptake

The Cu uptake by seed, straw and total in black gram was found maximum in T_4 (34.16, 61.24 and 95.41 g ha^{-1}) which significantly differed from other treatments and treatment T_7 (32.98, 57.62 and 90.60 g ha^{-1} respectively) and T_8 (32.19, 60.09 and 92.28 g ha^{-1} respectively) found at par with T_4. The lowest values of content and uptake observed in treatment T_1 (absolute control) (Table 4b).

Table 4b: Effect of co-inoculation of different bacterial cultures with *Rhizobium phaseoli* on micronutrient uptake (Cu and Mn) in black gram

Sr. No.	Treatment	Cu uptake (g ha^{-1})			Mn uptake (g ha^{-1})		
		Seed	Seed	Total	Seed	Straw	Total
T_1	Absolute control	50.55	50.55	47.17	24.68	41.25	65.93
T_2	Only RDF	52.89	52.89	54.76	27.42	47.04	74.46
T_3	RDF + *Rhizobium phaseoli*	55.63	55.63	73.73	31.80	57.44	89.24
T_4	T_3 + *Bacillus megaterium*	60.69	60.69	95.41	38.62	70.32	108.94
T_5	T_3 + *Bacillus subtilis*	58.61	58.61	77.83	33.72	58.04	91.76
T_6	T_3 + *Bacillus polymyxa*	58.29	58.29	69.63	28.85	52.77	81.62
T_7	T_3 + *Pseudomonas striata*	64.06	64.06	90.60	39.29	70.48	109.77
T_8	T_3 + *Pseudomonas flurescens*	63.61	63.61	92.28	38.31	74.25	112.55
T_9	T_3 + *Azotobacter chroococcum*	58.66	58.66	72.19	29.27	54.26	83.53
T_{10}	T_3 + *Azospirillum lipoferum*	56.38	56.38	73.59	31.02	56.47	87.49
	S.Em.±	1.53	1.53	3.66	1.42	2.04	2.92
	C.D. at 5 %	4.55	4.55	10.89	4.22	6.07	8.67

Effect on Manganese (Mn) Uptake

The Mn uptake by seed was recorded maximum under the influence of treatment T_7 (39.29 mg kg^{-1}) and treatment T_4 (38.62 mg kg^{-1}) and T_8 (38.31 mg kg^{-1}) found at par with treatment T_7 but in case of straw and total Mn uptake treatment T_8 (74.25 and 112.55 g ha^{-1}) found significantly superior at 5 per cent level of significance over other treatments and treatment T_4 (70.32 and 108.94 g ha^{-1}) and T_8 (70.48 and 109.77 g ha^{-1}) found at par with T_8. The lowest value observed in treatment T_1 (absolute control) (Table 4b).

In case of nutrient uptake of Fe (1102 g ha^{-1}), Zn (196.6 g ha^{-1}), Mn (266.6 g ha^{-1}) and Cu (133.9 g ha-1) the treatment receiving RDF+ *Rhizobium* + *Trichoderma viride*. showed the significant result over the other (Kranthikumar *et al.* 2017) [11]. Various mechanisms have been suggested to explain the phenomenon of plant growth promotion. These include increase in the nitrogen fixation, solubilization of phosphorus, increase in availability of nitrate, extra cellular production of antibiotics, lytic enzyme, hydrocyanic acid, increase in root permeability, strict competition for the available and root sites, suppression of deleterious rhizobacteria and

enhancement in the uptake of essential plant nutrients (Selvakumar *et al*. 2012) [18].

Conclusions

The content and uptake of nitrogen, phosphorus and potassium in black gram was found to be enhanced significantly by co-inoculation with *Pseudomonas striata.* The data shows that the values of nutrient content and their uptake found strongly at par with RDF + *Rhizobium phaseoli* + *Pseudomonas striata* and RDF + *Rhizobium phaseoli* + *Pseudomonas flurescens* over rest of the treatments. The content and uptake of zinc, iron, copper and manganese in black gram was found to be enhanced significantly with seed co-inoculation with *Pseudomonas striata.* The data shows increase in nutrient content and their uptake by black gram with RDF + *Rhizobium phaseoli* + *Pseudomonas striata* over rest of the treatments.

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