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IMPACT OF MICROBIAL CONSORTIA ON GROWTH, YIELD AND NUTRIENT UPTAKE OF SOYBEAN IN VERTISOLS OF CENTRAL INDIA

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ABSTRACT

Microbial inoculation represents a new way to more sustainable and efficient agriculture. Furthermore, this investigation was conducted to find out the effects of microbial consortia on soybean crop attributes. A field-laboratory experiment was conducted at the Department of Soil Science at Jabalpur during *Kharif* (rainy season) with 3 replications and 16 treatments (T1 to T16) inoculating different seven beneficial microbial combinations (*Rhizobium* sp., *Bacillus* sp., *Streptomyces* sp., *Rhodopseudomonas* sp., *Lactobacillus* sp., *Saccharomyces* sp., *Aspergillus* sp.) and two types of control plots established as fertilized uninoculated control (FUI) and unfertilized uninoculated control (UFUI). A significant improvement was received by the treatment T14 (consortia of all seven microbes) in growth traits i.e., plant height, plant dry biomass, nodule number, nodule dry biomass, leghemoglobin content of nodules, leaf chlorophyll performed best at 25, 45 and 65 days after sowing (DAS) and the highest percentage increase was recorded at 65 DAS for all parameters except nodulation studies i.e., 44.59, 63.25, 82.99, 39.40, 50.49, 53.32 %, respectively over the FUI control and the T14 treatment is also superiorly for the nutrients uptake and yields over the FUI. Thus, it is plausible that seed biofertilization with different co-inoculations promotes diazo-trophy, nutrient solubilization, hormonal activity, and lateral roots thereby increasing nodulation, nutrient uptake, and soybean yield.

Keywords**:** Chlorophyll, Consortia, Leghemoglobin, Nutrient uptake, Rhizobium, Soybean

Introduction

Soybean [(*Glycine max* (L) Merrill] is an important oilseed cum pulse crop grown for its edible oil and protein in India as well as the world. The soybean also known as the 'golden crop', due to its diverse uses as oil and other industrial food also considered the "Protein hope of future" (Choudhary *et al.,* 2024). It contains over 40% protein, 20% oil, and 25-30% carbohydrate (Thoke *et al.,* 2022). In MP soybean cover 11.39 M hectares area with 13.64 MT (matric ton) production along with 1200 kg ha^{-1} productivity (Directors Report, IISR, 2019-20). This crop majorly grown in the states of Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, Andhra Pradesh, and Chhattisgarh. These states together contribute to about 99.99% of the total soybean production in our country. The growth and production of soybean can be promoted by improving soil fertility in terms of physical, chemical and biological conditions. To achieve such conditions the use of various beneficial microorganisms such as Rhizobium, Bacillus, Actinomycetes, etc. is in vogue either as solo or co-inoculant. Different microbial consortia inoculants i.e., *Rhizobium sp.* is a Gram-negative soil bacterium that fixes the atmospheric N_2 symbiotically in the root's nodule of legumes in an economically and agronomically effective manner. (Chiduwa, 2021). *Rhodopseudomonas sp.* is a rod-shaped Gram-Negative having the ability to switch over between four different modes of metabolism (like: chemo-heterotrophic, chemo-autotrophic, photo-heterotrophic, and photo-autotrophic). The oxidative phosphorylation in the eukaryotic cells is very similar to photosystems, including ATP synthase. Additionally, it has saprophytic and diazotrophic abilities is widely distributed in nature and considered a fascinating beneficial microorganism (Chen *et al.,* 2020))

PSB (*Bacillus sp.*) a Gram-positive bacterium converts the insoluble forms of phosphorus (tri-calcium phosphate and hydroxyl apatite) and other nutrient elements like, Fe to available forms in plants and suppression of various pathogen as a biocontrol agent (Singh *et al.,* 2021). *Saccharomyces sp.* is a saprophytic phyto-stimulator single-celled, egg-shaped fungi (yeast) usually larger than the bacterium which grows on sugary solutions, grapes and produces fermented wine, beer, etc; and is also known to contribute to the pleasant smell of bread. This is a new promising plant growth-promoting yeast with properties of good root colonizer and anti-phytopathogenicity (Venugopal, 2016), ultimately a significant increase in growth and yield quality. Actinomycetes (*Streptomyces sp.*) are a versatile group of microorganisms extensively distributed in arable dry-soils as well as work on Phyto-immunity inducers and prevent the invasion of harmful microbes by the production of siderophores, phosphate solubilizers, plant growth promotion, decomposition of organic matter and antibiotic production (Bercovich *et al.,* 2022) and also reported that these Gram-positive mycelial bacteria are of use to produce a widespread variety of industrially and medically relevant compounds (such as antibiotics, fungicides and herbicides). *Lactobacillus sp.* (lacto-bacterium) is a Gram-positive, rod-shaped and saprophytic bacterium that groups in pairs and short-chains, depending upon the growth conditions appears ovoid with a typical length of 0.5 - 1.5 µm and produces lactic-acid to improve the soil for controlling disease and seed germination; and also reduces abiotic stress of the crops (Cataldo *et al.,* 2022). Fungi (*Aspergillus sp.*) work as an aerobic organic matter decomposers by producing citric-acid and enzymes, and also reduce the negativity of different chemical fertilizer and proliferate easily in two-distinct forms of mycelial and pelleted (Al-Ani *et al.,* 2021). The application of these helpful microorganisms as co-inoculation on seeds with bio-inoculants in different consortia rather than the solo-inoculation might probably encouragement the crop growth as well as soil physical, chemical, and biological properties through direct and indirect mechanisms; and enhance different growth parameters such as plant height, chlorophyll, nutrients uptake and yields of the soybean crops. The better soil biological activity is also known to play a key role in suppressing pest and disease problems in the crops.

Materials and Methods

Study area and Climate

A field and laboratory-based study was conducted at the Research Farm of the Department of Soil Science, JNKVV, Jabalpur. Geographically, Jabalpur is located in the south-eastern part of Madhya Pradesh at 23° N latitude, 79° E longitudes at an altitude of 411.78 meters above mean sea levels and the tropic of cancer passes through the middle of the district. It's lies in the "Kymore Plateau and Satpura hills" Agro-Climatic Zone of Madhya Pradesh having sub-tropical climates with hot dry summer and cool dry winters. The mean monthly minimum and maximum temperatures is 26.15 ℃ and 39.82 ℃, respectively and this temperature varies between 4 ℃ in January to 45.4 ℃ in May and June. The total average rainfall received during the whole crop period was about 1642.3 mm, which was mainly concentrated from June to September.

Experimental Soil

The soil of experimental site was medium black which belongs to the order of Vertisol belonging to fine montmorillonite, Hyperthermic family of Typic *Haplusterts* that was generally known as "black cotton soil". Initial chemical properties of the soil were analysed with 7.23 pH, 0.26 dS m^{-1} electrical conductivity and 4.91 g kg^{-1} organic carbon. The available soil status N, P and K were 218.5, 14.92 and 259.7 kg ha^{-1}, respectively.

Seed Treatment and Microbial Inoculation

Soybean seeds (cv. JS 20-69) were sown @ 80 kg ha^{-1} with inoculation of different microbes as consortia of *Rhizobium sp.*, PSB (*Bacillus sp.*), actinomycetes (*Streptomyces sp.*), *Rhodopseudomonas sp.*, *Lactobacillus sp.*, *Saccharomyces sp.*, and *Aspergillus sp.* as per the prescribed treatments. The seed treatment and microbial inoculation were carried out by using 1 ml of the liquid formulation of each microbe combination transferred in bags than apply the sterilized gum acacia (about 2%) was used as sticker solution. The plot-wise inoculated seeds in polythene bags were initial slightly moistened, then treated with carbendazim fungicide @ 2g kg^{-1} of seed. The seeds were little allowed to air dry, then 1 ml of gum acacia sticker solution was poured on the seed of each polythene bag and the seed treatment was completed in the shade then sown manually as early as possible.

Experimental details

The trails were conducted in randomized complete block design (RCBD) with three replications and consisted of sixteen treatments as per the prescribed format (Table 1) by the inoculation of seven different types of beneficial microorganisms by the compatibility test. The soybean crop was nourished with RDF 20:80:20 (N: P_2O_5:K_2O kg ha^{-1}) at basal dose through urea, single super phosphate (SSP) and muriate of potash (MOP), respectively.

Table 1: Treatment combinations

Treatment	Combination	Treatment	Combination
T_1	Rhizobium +PSB	T_9	T2+T4
T_2	Streptomyces +PSB	T_{10}	T3+T4
T_3	Rhodopseudomonas+Lactobacillus	T_{11}	T1+T2+T3
T_4	Saccharomyces+Aspergillus	T_{12}	T1+T3+T4
T_5	T1+T2	T_{13}	T2+T3+T4
T_6	T1+T3	T_{14}	T1+T2+T3+T4
T_7	T1+T4	T_{15}	FUI
T_8	T2+T3	T_{16}	UFUI

Data collection

Growth attributes

Growth parameters (plant height, nodulation studies, leghaemoglobin content, and leaf chlorophyll) was noted at different crop growth stages of crop at 25, 45 and 65 DAS. Plant height and nodule number counted manually and dry biomass by dried in a hot air oven at the 60 ℃ for 4-5 days (till constant weight), leghaemoglobin concentration was determined by the cyanmethemoglobin method given by Wilson and Reisenauer (1963), this method based on the spectrophotometric measurement, and use Drabkin's solution (prepared with 52 mg KCN, 198 mg K_8Fe $(CN)_6$ and 1 g $NaHCO_3$ dissolved in distilled water) with nodules was crushed by this solution and its absorbance measure at wavelength 540 nm in a spectrophotometer. The leaf chlorophyll content (a, b and total) was estimated by acetone extraction method (Arnon's 1949). In this method fresh plant leaves is crushed by mortar with enough quantity of 80% acetone to allow the tissue to get thoroughly homogenized and all the chlorophyll was extracted and the solutions optical density was determined by spectrophotometer at 663 nm and 645 nm.

Nutrient uptake by seed and stover

Major nutrients uptake of seed and stover was measured by dry weight basis and expressed in kg ha^{-1}. Total nitrogen (N) estimated by adopting the modified Kjeldahl's method given by Piper (1966). N was estimated by digesting 0.5 g plant material (seed and straw each) with 10 ml concentrated sulfuric acid in the presence of a digestion mixture (Selenium dioxide, Copper sulphate, Potassium sulphate, and Mercuric oxide). For total phosphorus (P) and potassium (K) content take 0.5g sample was wet-digested in tri-acid mixture of HNO_3, $HClO_4$, and H_2SO_4 in the ratio of 9:3:1 as drawn by Piper (1966). The P was determined by Vanado-molybdate phosphoric yellow colour method in nitric acid system described by Koeing and Jackson (1942) and potassium (K) content was estimated by flame photometer methods (Raghupathi and Bhargava, 1984).

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{Nutrient content (\%)} \times \text{Yield (kg ha}^{-1})}{100}$$

Statistical analyses

The experimental data recorded for growth, yield and other characters were subjected to statistical analysis in accordance with the "Analysis of Variance" technique suggested by (Fisher, 1950). Fitting standard error for each of the factors was worked out. Significance of differences between treatment effects was tested by "F" test. Critical difference (CD) was worked out, where the difference was found significant at 5.0 per cent level of significance.

Result and Discussion

Plant height and its dry biomass

The data related to plant height and dry biomass of soybean are presented in Table 2 revealed that the highest response toward plant height of soybean at 25, 45, 65 days after sowing (DAS) and at harvest stage was observed with the treatment of T14 for 30.70, 55.25, 70.75 and 73.09 cm with the 92.28, 42.77, 44.59 and 43.49% more response over FUI control treatment, respectively. This treatment followed by the response of T13, T12 and T11 over the FUI control treatment. Similarly, in case of dry biomass of soybean, the consortium of T14 was gained with maximum value 2.15, 5.47, 10.63 and 10.74 g plant^{-1} over that of control FUI, respectively. The above results were similar to the finding of Gopalakrishnan *et al.* (2015) and Yaduwanshi *et al.* (2019). They concluded that the inoculation of *Bradyrhizobium japonicum*, PSB (*Bacillus*) and *Streptomyces* strains with RDF was conducive to improve the vegetative growth and quality of soybean through the production of different kinds acids *viz*., Indole-3-acetic acid (IAA), phosphate solubilization, siderophore production, phytohormone production, ammonia production, exhibiting antifungal activity etc. In addition to N2-fixation in legumes, rhizobia such as species of Rhizobium and Azotobacter with PSB produce molecules (auxins, cytokinin's, abscisic acids, lumichrome, riboflavin, lipochito oligosaccharides and vitamins) that endorse plant growth attributes and its dry biomass of soybean crop reported by Sengupta and Gunri (2015).

Table 2: Effect of microbial consortia on plant height of soybean at different growth stages

Treatment Combination	Plant height (cm)				Plant biomass (g plant^{-1})			
	25 DAS	45 DAS	65 DAS	At harvest	25 DAS	45 DAS	65 DAS	At harvest
T1 (Rhizo+PSB)	20.93	47.77	58.50	61.04	1.78	4.36	7.87	7.98
T2 (Strepto+PSB)	18.95	42.27	54.33	56.33	1.75	4.23	7.51	7.61
T3 (Rhodo+Lacto)	19.54	44.73	56.43	58.01	1.72	4.06	7.18	7.34
T4 (Saccharo+Aspergil)	17.63	41.31	52.60	54.60	1.70	4.01	7.04	7.15
T5 (T1+T2)	21.97	49.83	59.07	62.03	1.82	4.51	8.01	8.13
T6 (T1+T3)	23.50	52.07	64.07	67.20	1.98	4.92	8.73	8.85
T7 (T1+T4)	25.73	52.40	63.07	66.08	1.95	4.80	8.40	8.52
T8 (T2+T3)	22.91	51.73	62.30	64.30	1.87	4.69	8.02	8.14
T9 (T2+T4)	24.60	50.50	59.83	61.83	1.83	4.54	8.10	8.22
T10 (T3+T4)	24.00	51.27	61.07	62.41	1.85	4.71	8.17	8.31
T11 (T1+T2+T3)	26.59	53.12	65.77	67.77	2.06	5.04	9.49	9.62
T12 (T1+T3+T4)	27.10	52.77	66.03	68.38	2.03	5.18	9.31	9.49
T13 (T2+T3+T4)	29.47	54.72	68.37	70.37	2.11	5.29	10.35	10.48
T14 (T1+T2+T3+T4)	30.70	55.25	70.75	73.09	2.15	5.47	10.63	10.74
T15 (FUI)	15.97	38.70	48.93	50.93	1.46	3.75	6.51	6.65
T16 (UFUI)	9.26	31.34	40.41	41.96	1.30	3.15	5.18	5.30
SEm±	1.565	2.703	3.215	3.121	0.119	0.247	0.478	0.433
LSD (p= 0.05)	4.55	7.86	9.35	9.08	0.34	0.72	1.39	1.26

Nodulation Studies

Nodulation data of soybean is given in Table 3. Highest response on nodule number of soybeans at 25, 45 and 65 DAS was observed with the treatment combination of T14 for 18.67, 59.13, and 46.23 nodules plant^{-1} over that of control (10.97, 37.50 and 25.26 nodules plant^{-1}), respectively. While, at 25, 45 and 65 DAS, the maximum dry biomass (0.73, 1.72 and 1.56 g plant^{-1}, respectively) of nodules exhibited consortia of T14 with 48.98, 37.14 and 39.40% increment over that of FUI control, respectively. It is followed by T13, T11 and T12 treatment. The above results on nodule enumeration were similar to the findings of Tyagi *et al.* (2003) and Gopalakrishnan *et al.* (2015). They observed the co-inoculation *Rhizobium*+PSB most effective in terms of nodule number (27.66 nodules plant^{-1}), nodule fresh weight (144.90 mg plant^{-1}), nodule dry weight (74.30 mg plant^{-1}). The significant increase in nodule number and its biomass was also observed under inoculation with *Bradyrhizobium*, *Streptomyces* and *Bacillus* through the production of different kinds of acids *viz.* indole acidic acid (IAA), phosphate solubilization, siderophore production, NH_4 production, production of 1-Aminocyclopropane-1-carboxylate deaminase (ACC), phyto-hormone production, exhibiting antifungal activity, etc. Bhardwaj *et al.* (2014) and Jaybhay *et al.* (2017) reported that the actinomycetes consortium (consortium of different strains of actinomycetes), consortium of Rhizobium consortia, and PSB (*Bacillus* strains) were most effective among microbial inoculants in respect of symbiotic parameters including nodule number and its biomass and also exhibited the positive effect in enhancing all the yield attributing parameters like seed and stover yields. Amule *et al.* (2018) similarly agreed that the consortia of Brady-rhizobia (*B. japonicum*) and PSB (*Pseudomonas sp.)* as liquid inoculants on soybean improved the nodule number, fresh weight and dry weight of nodules.

Table 3: Effect of microbial consortia on nodulation attributes of soybean at different growth stages

Treatment	Nodule enumeration (No. plant^{-1})			Nodule biomass (g plant^{-1})		
	25 DAS	45 DAS	65 DAS	25 DAS	45 DAS	65 DAS
T1 (Rhizo+PSB)	14.90	46.87	32.97	0.62	1.50	1.34
T2 (Strepto+PSB)	13.25	44.16	29.74	0.60	1.48	1.29
T3 (Rhodo+Lacto)	13.84	44.83	30.95	0.57	1.46	1.30
T4 (Saccharo+Aspergil)	11.87	43.83	28.76	0.56	1.41	1.28
T5 (T1+T2)	15.40	47.80	34.45	0.63	1.53	1.36
T6 (T1+T3)	17.09	53.43	41.90	0.68	1.59	1.45
T7 (T1+T4)	16.74	51.77	40.09	0.67	1.58	1.43
T8 (T2+T3)	16.04	51.13	38.45	0.64	1.57	1.41
T9 (T2+T4)	15.46	48.27	35.42	0.65	1.56	1.38
T10 (T3+T4)	15.63	49.90	36.51	0.65	1.55	1.39
T11 (T1+T2+T3)	17.47	57.70	45.14	0.70	1.69	1.51
T12 (T1+T3+T4)	17.71	56.70	43.94	0.69	1.68	1.49
T13 (T2+T3+T4)	18.39	57.07	45.67	0.71	1.71	1.52
T14 (T1+T2+T3+T4)	18.67	59.13	46.23	0.73	1.72	1.56
T15 (FUI)	10.97	37.50	25.26	0.49	1.26	1.12
T16 (UFUI)	6.83	28.90	17.58	0.43	1.19	1.06
SEm±	1.089	3.126	1.979	0.041	0.080	0.066
LSD (p= 0.05)	3.17	9.09	5.75	0.12	0.23	0.19

Chlorophyll content

The data of chlorophyll content in the leaf are presented in Figure 1. The maximum total chlorophyll content (3.55, 4.04 and 4.01 mg g^{-1} of leaf) at 25, 45 and 65 DAS was observed in T14 over FUI control treatment, respectively. The inoculants such as *Rhizobium*, PSB (*Bacillus sp.), Pseudomonas*, *Actinomycetes*, *Lactobacillus* and *S. cerevisiae* increased contents of photo-synthetic pigments (chlorophyll a and b) and protein when contrasted through the un-inoculated one due to secretion of indole acetic acid (IAA) or organic acids, gibberellin (GA_3) and reduction in abscisic acid (ABA) contents towards enhancement of the protein and RNA synthesis confirmed by Mathivanan *et al.* (2017). Kumawat *et al.* (2019) confirmed that the inoculation of *Pseudomonas* with *Bradyrhizobium* has a synergistic effect on total leaf chlorophyll which was higher as compared to alone and un-inoculated control, possibly due to the action of better plant growth promotion (PGP) trait like secretion of IAA and siderophore, cell wall degrading enzymes and pathogenicity, biofilm formation and solubilization of nutrients like p and Zn relative to the single inoculant treatment.

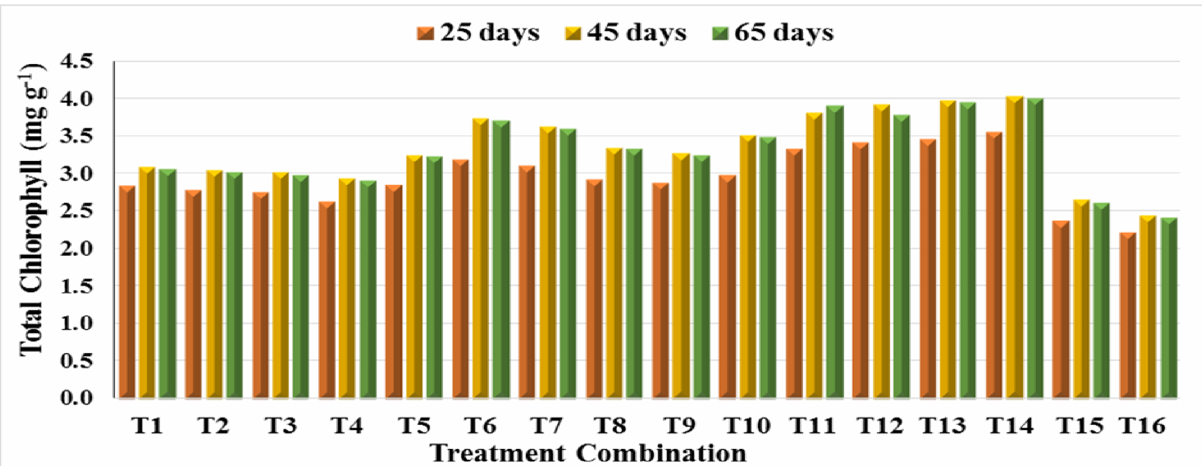

Fig. 1: Effect of microbial consortia on total chlorophyll content inleaves of soybean at different growth stages

Leghaemoglobin content in nodules

The data on leghaemoglobin content in fresh nodules of soybean at 25, 45 and 65 DAS are illustrated in Figure 2 and this was recorded maximum (3.40, 3.72 and 3.56 mg g^{-1} nodule) with the treatment consortium of T14 with 46.83, 51.29 and 50.49% more response over FUI (2.31, 2.46 and 2.36 mg g^{-1} nodule, respectively), followed by T13, T11 and T12 treatments. The application of microbial consortium enhanced nodule size, biomass, and leghaemoglobin content mediated by production of siderophores (iron-chelating metabolites). Siderophores deliver iron to the producer organisms or such chelates are absorbed by plant roots in the rhizosphere. Even though siderophores do not directly promote plant growth, they deliver iron that is usually in short supply in soil to plants and increase nodulation attributes as well as provide plant's nutrition (N, P, K, Ca and Mg) to stimulate plant growth of soybean (Hattori and Johnson, 1985).

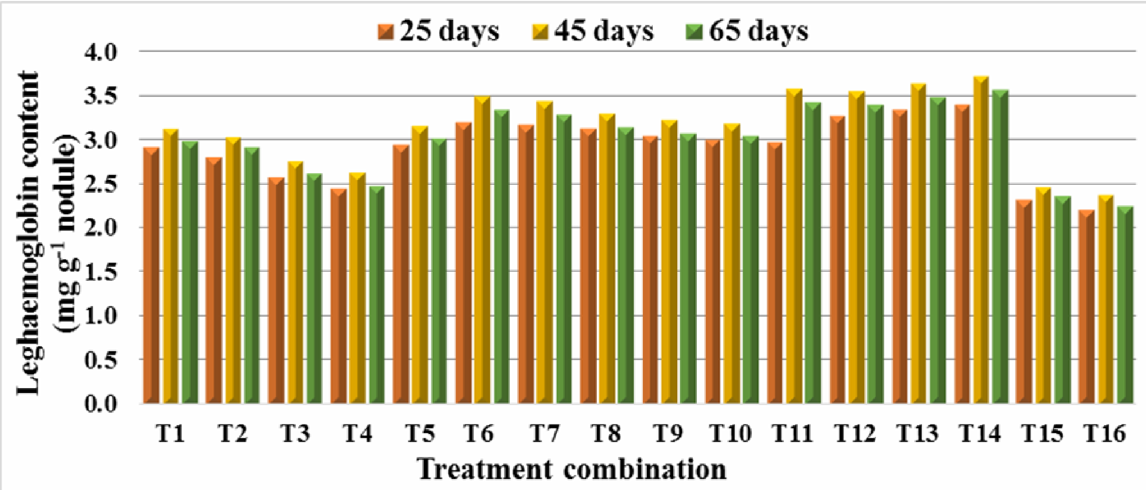

Fig. 2: Effect of microbial consortia on Leghaemoglobin content in nodules of soybean at different growth stages

Major nutrients uptake by soybean at harvest

The total uptake of major nutrients (nitrogen, phosphorus and potassium) in seed and stover of soybean are existing in Table 4 and the data related to soybean yield trait was illustrated in figure 3. The consortium T14 were recorded maximum nitrogen (N), phosphorus (P) and potassium (K) uptake of 144.9, 12.1 and 47.2 kg ha^{-1} by seed of soybean, respectively. Similarly, nutrients uptake in stover the consortium T14 were recorded highest N, P and K uptake of 92.0, 14.4 and 72.1 kg ha^{-1} by stover of soybean over the FUI control treatment, followed by T13, T11 and T12. According to Nimnoi *et al.* (2014), the plant growth development, nodulation and nutrient uptakes (NPK) were improved with inoculation of Rhizobium, Actinomycetes and PSB due to production of auxins, cytokinin's, and gibberellins. Root physiology and architecture were also changed finally root surface area increased with more root hairs and nodules in legume leading to an increase in mineral uptake as well as more nutrient uptakes of plant. The yeast (*S. cerevisiae*) laterally with the *Rhizobium* when added as inoculants in soil would increase potentially the efficiency of the N uptake thus leading to a faster and better growth in the plant of study Souza *et al.* (2015). Singh *et al.* (2015) reported that the application of *Rhodobacter sphaeroides*, *Lactobacillus plantarum* and *S. cerevisiae* improved potential K and P nutrition and growth of the crops through better hormones, amino acids and mineral nutrients. The enhancements might be due to yeast hormonal activity of IAA on root formation growth and lateral roots leading to increased nodulation and nutrient uptakes of N, P and K, and subsequently increase in yield of soybean. The similar finding found by Kravchenko *et al*. (2013), Jaybhay *et al.* (2017), Marinkovic *et al.* (2018) and Singh *et al.* (2021).

Table 4: Effect of microbial consortia on uptake of nutrients (N, P and K) by seed and stover of soybean at harvest

Treatment	Uptake of nutrients (kg ha^{-1})								
	Seed			Stover			Total Uptake		
	N	P	K	N	P	K	N	P	K
T1 (Rhizo+PSB)	108.8	8.1	35.2	63.6	9.5	51.5	172.5	17.6	86.7
T2 (Strepto+PSB)	94.2	8.0	31.3	54.4	8.9	45.2	148.6	16.9	76.4
T3 (Rhodo+Lacto)	99.2	6.9	31.2	56.5	7.6	47.0	155.8	14.5	78.2
T4 (Saccharo+Aspergil)	95.1	6.6	30.3	50.3	6.8	41.9	145.4	13.4	72.1
T5 (T1+T2)	108.9	8.1	35.3	64.8	9.9	52.2	173.7	18.0	87.5
T6 (T1+T3)	119.5	9.2	39.1	75.2	12.0	60.5	194.6	21.2	99.6
T7 (T1+T4)	115.8	8.9	37.8	72.7	10.9	58.1	188.5	19.8	95.9
T8 (T2+T3)	112.9	8.5	36.7	68.7	10.2	56.3	181.6	18.7	93.0
T9 (T2+T4)	109.1	8.1	35.3	67.5	10.0	54.2	176.5	18.1	89.6
T10 (T3+T4)	110.5	8.2	36.2	69.0	10.2	55.1	179.5	18.5	91.3
T11 (T1+T2+T3)	134.8	10.9	44.0	85.6	12.7	67.0	220.4	23.6	110.9
T12 (T1+T3+T4)	129.2	10.4	42.3	79.7	12.2	63.7	208.9	22.6	106.0
T13 (T2+T3+T4)	141.3	11.7	45.8	88.7	13.2	69.5	230.0	24.9	115.3
T14(T1+T2+T3+T4)	144.9	12.1	47.2	92.0	14.4	72.1	236.9	26.4	119.2
T15 (FUI)	86.6	5.6	27.7	47.2	6.5	39.6	133.8	12.1	67.3
T16 (UFUI)	78.6	4.9	25.1	42.6	5.3	36.4	121.2	10.3	61.5
SEm±	7.66	0.83	2.56	4.73	0.80	3.60	10.41	1.37	5.16
LSD (p= 0.05)	22.1	2.4	7.4	13.7	2.3	10.5	30.3	4.0	15.0

Seed and stover yield of soybean

The data on the soybean yields of seed and stover at harvest are illustrated in the Figure 3. Maximum seed and stover yield of soybean 2414 and 4384 kg ha^{-1} was harvested with the treatment of T14 with the increment of 57.79 and 65.53% more over that of FUI (1530 and 2649 kg ha^{-1}), followed by the treatments of T13, T11, T12 and T6. The augmentation in yields of soybean with the treatments of inoculation of beneficial rhizobia and PSB might be attributed to healthier nodulation, N_2-fixation, crop growth attributes and seed yield (2600 kg ha^{-1}) as compared to the uninoculated control plot (Kravchenko *et al.* 2013). Besides, the co-inoculation of *Bradyrhizobium* and PSB along with P2O5 enhanced the seed yield of soybean by 26.8 q ha^{-1} in field experiments (Jaga and Sharma, 2015). Enlarged root physiology, its manner and surface area with more root-hairs and nodules improved various mineral uptake and plant growth of soybean stated by Singh *et al.* (2021).

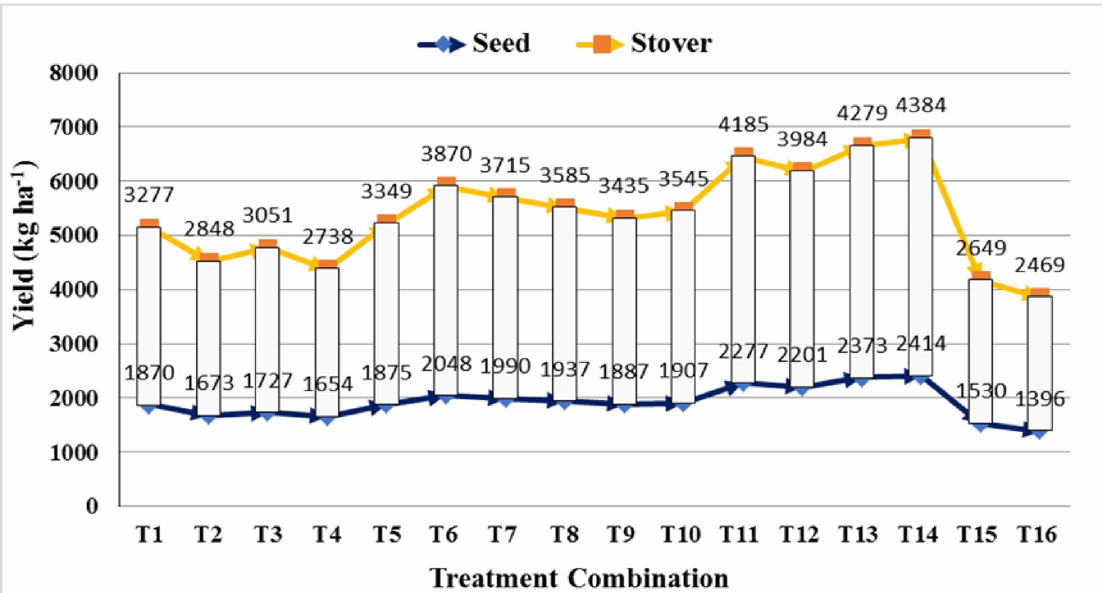

Fig. 3: Effect of microbial consortia on yields (seed and stover) of soybean

Conclusions

The result of the study revealed that the application of the consortium T14 (consortia of all seven microbes) as seed inoculation achieved the best consortium for the growth parameter *i.e.,* plant height and dry biomass, nodulation, leaf chlorophyll and leghemoglobin content in the nodule. Similarly, same treatment combination performed significantly better towards for the uptake of N, P and K content in seed and stover as well as seed and stover yield of soybean at the post-harvest. In each situation, the treatment combinations of T13, T11 and T12 exhibited as the subsequent group. Hence, it may be concluded that the application of various co-inoculation on seeds with bio-inoculants in diverse consortia rather than the solo-inoculation might believably encouragement the crop through direct and indirect mechanisms and boosted different growth attributes such as plant height, chlorophyll, nutrients uptake, yields of the soybean.

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