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Influence of beneficial microbial interactions on morphological traits of plants

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Abstract

Plant growth and development in legumes are strongly influenced by rhizosphere microbial activity, particularly by symbiotic and associative microorganisms. The present study evaluated the effect of Rhizobium and rhizobacterial inoculation, individually and in consortium form, on key plant growth parameters of green gram (*Vigna radiata* L.). Growth attributes such as plant height, number of branches per plant, root length, shoot length, and biomass accumulation were recorded at different growth stages. The results indicated significant variation among treatments, with microbial consortia exhibiting superior performance compared to single inoculations and uninoculated controls. Enhanced vegetative growth was attributed to improved nutrient availability, phytohormone production, and efficient root system development mediated by beneficial microorganisms. Among the treatments, selected microbial consortia consistently recorded maximum values for most plant growth parameters, demonstrating synergistic effects among compatible strains. The study highlights the role of microbial inoculation in improving early plant vigor and overall growth performance of green gram.

Keywords: Green gram, microbial consortia, plant growth parameters, Rhizobacteria, *Rhizobium* inoculation

Introduction

Green gram (*Vigna radiata* L.) is one of the most important short-duration pulse crops cultivated across tropical and subtropical regions, particularly in South and Southeast Asia. In India, it occupies a prominent position among grain legumes due to its high protein content (22-24%), digestibility, low input requirement, and suitability for diverse cropping systems. Major green gram-growing states include Rajasthan, Maharashtra, Andhra Pradesh, Telangana, Karnataka, Madhya Pradesh, Tamil Nadu, Odisha, and Uttar Pradesh. Owing to its short life cycle and adaptability, green gram is widely grown during kharif, rabi, and summer seasons, contributing significantly to nutritional security and soil fertility through biological nitrogen fixation.

Despite its agronomic and nutritional importance, the productivity of green gram remains relatively low compared to its potential yield. The national average productivity is constrained by several factors, including poor soil fertility, erratic rainfall, drought stress, inadequate nutrient availability, low responsiveness to chemical fertilizers, and limited use of high-performing bio-inputs. Morphological traits such as plant height, shoot and root growth, biomass accumulation, leaf area development, and branching pattern play a crucial role in determining crop establishment, light interception, nutrient uptake, and final yield. Any adverse impact on early vegetative growth directly translates into reduced productivity.

In recent years, the use of beneficial microbial inoculants, particularly *Rhizobium* and plant growth-promoting rhizobacteria (PGPR), has emerged as an eco-friendly and sustainable strategy to enhance crop growth. These microorganisms influence plant morphology through multiple mechanisms, including biological nitrogen fixation, solubilization of nutrients, production of phytohormones (such as auxins, gibberellins, and cytokinins), enhancement of root architecture, and improvement of soil-root interactions. Enhanced root length, root biomass, shoot growth, and overall plant vigour resulting from microbial inoculation are critical for efficient water and nutrient acquisition, especially under sub-optimal soil conditions.

The effectiveness of microbial inoculation, however, largely depends on the selection of efficient and compatible strains or consortia that can successfully colonize the rhizosphere and express plant growth-promoting traits. The need of the hour is to identify and evaluate efficient microbial strains and strain combinations that consistently improve morphological attributes of green gram across growth stages. Such improvements not only enhance early crop establishment but also provide a strong foundation for improved physiological functioning and yield realization.

Therefore, the present study focuses on evaluating the morphological influence of microbial inoculants on plant growth traits of green gram, including plant height, shoot and root length, fresh and dry biomass, leaf area, stem thickness, and branching pattern. Understanding the extent to which selected microbial strains and consortia modulate these growth attributes

is essential for developing effective bio-inoculant strategies aimed at sustainable green gram production.

Materials and Methods

The present pot culture experiment was conducted at green house conditions during February 2024-April 2024, this particular season was selected because during this period environmental conditions were much similar to paddy fallows in farmers’ fields where higher temperature and moisture stress conditions were seen. By evaluating the consortium in similar conditions, under pot culture there will be selection of effective consortium suitable to actual field can be done. The environmental parameters were collected from records of agricultural meteorology department recorded during February to April as follows

Table 1: Weather data during pot culture experiment

Month	Max. Temperature (°C)	Min. Temperature (°C)	Max. Relative humidity (%)	Min. Relative humidity (%)	Rainfall mm	Wind speed Km/hr
February	33.7	17.0	58.4	28.6	0.0	4.4
March	35.9	20.2	59.1	33.6	0.1	6.4
April	37.3	22.0	74.6	40.8	38.31	7.5
				Total	42.01	

The treatments of the present study were designed after a series of plant growth promoting traits. At 30, 45 and 60 DAS, plants were uprooted to examine complete plant height. Plant height was measured from base of the plant (root tip) up to the tip of the fully opened top leaf. The mean values were expressed in centimeter. Dry weight of shoot and root were recorded at 30, 45 and 60 DAS after separating the shoot from root. For dry weight the samples were dried at 75 °C until there was no reduction in weight and the mean values were expressed in gram per plant. The leaf area of plants was measured using graph sheets and area was recorded. The mean values were expressed in centimeters. The stem width of plants was measured using vernier caliper scale at ground level of shoot and the mean values were expressed in centimeters. The branches from plants of each treatment’s replications were manually counted and the average of this was noted as the number of branches per plant

recorded at 30, 45 and 60 DAS in triplicates and the results are presented in Table 1. Inoculation of consortium for green gram varieties, increased the plant height of green gram at 30, 45 and 60 DAS when compared to controls. Among all observation recorded at different DAS i.e., 30, 45 and 60 the treatment M7 inoculum (53.15, 57.25, 59.09) shown highest plant height in centimeters when compared to other treatments followed by M5 inoculum (48.89, 56.29, 57.58), M6 inoculum (48.14, 54.10, 55.17) and least plant height among all treatments was shown by M9 inoculum (37.73, 49.01, 51.16) whereas, M1 inoculum with NC-92 showed plant height of 41.67, 51.23, 53.25cm. Among the varieties, DGGV-2 with an average of 49.05, 56.64, 57.16 shown higher plant height in centimeters when compared to DGG-96(40.41, 49.29, 52.60) at 30, 45 and 60 DAS respectively. The interaction effect of microbial inoculum with varieties DGGV-2 and DGG-96 was found significant in plant height at 30, 45 and 60 DAS with a range of 54.00-33.78, 60.49-45.00, 60.67-48.67 cm. The treatment M7 with DGGV-2 recorded significantly highest plant height in centimeters of 54.00, 60.49 and 60.67 at 30, 45 and 60 DAS respectively.

Results

Influence of rhizobial isolates on plant growth parameters of green gram

Plant height (cm): The observations on plant height were

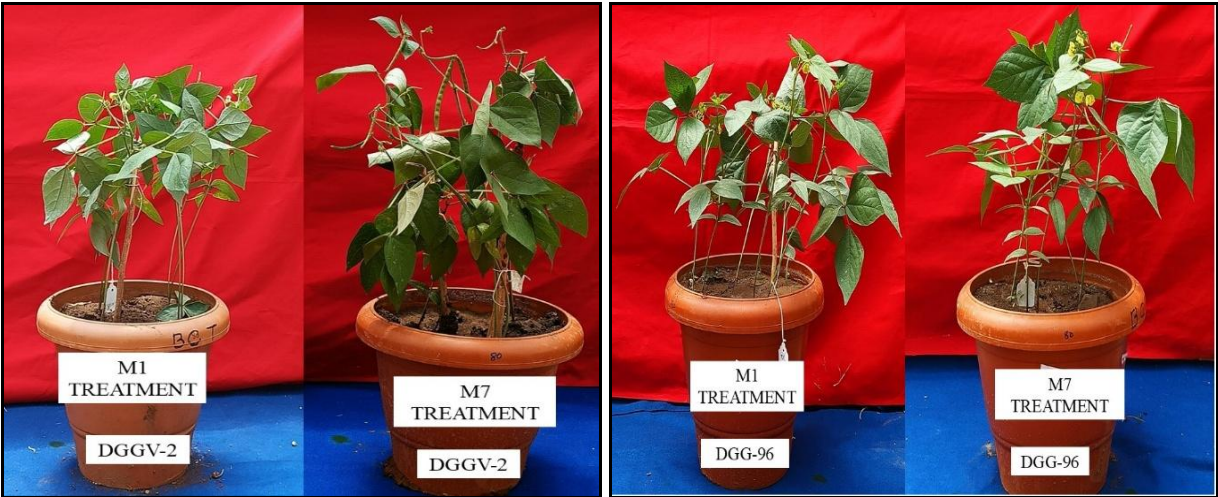


Plate 1: Effect of microbial inoculation on plant growth promotion in green gram genotype

Shoot Dry weight

The shoot dry weight of plant samples was recorded at 30, 45 and 60 DAS and the results are presented in Table 2. Inoculation of consortium for green gram varieties, increased the shoot dry weight of green gram at 30, 45 and 60 DAS when compared to control. Among all observation recorded at different DAS *i.e.*, 30, 45 and 60 the M7 inoculum (0.89, 6.66, 4.93) shown highest shoot dry weight in grams when compared to other treatments followed by M5 inoculum (0.90, 4.72, 4.19), M6 inoculum (0.63, 4.01, 3.88) and least shoot dry weight among all treatments was shown by M9 inoculum (0.23, 2.07, 2.13) whereas, M1 inoculum with NC-92 showed shoot dry weight of 0.36, 2.50, 2.54 grams.

Among the varieties, DGGV-2 with an average of 0.73, 3.75, 3.55 g shown higher shoot dry weight in grams when compared to DGG-96 (0.33, 3.23, 2.93) at 30, 45 and 60 DAS respectively. The interaction effect of microbial inoculum with varieties DGGV-2 and DGG-96 was found significant in shoot dry weight at 30, 45 and 60 DAS with a range of 1.20-0.16, 7.78-1.85, 5.12-2.09g. The treatment M7 with DGGV-2 recorded significantly highest shoot dry weight in grams of 1.22, 7.78, 5.12 g at 30, 45 and 60 DAS respectively.

Root dry weight

All sampled plants in triplicates for a treatment at 30, 45 and 60 DAS were recorded for dry weight of root was measured and the results are presented. (Table 3) Inoculation of consortium for green gram varieties, increased the root dry weight of green gram at 30, 45 and 60 DAS when compared to controls. Among all observation recorded at different DAS *i.e.*, 30, 45 and 60 the treatment M7 inoculum (1.34, 2.67, 1.31) shown highest root dry weight in grams when compared to other treatments followed by M5 inoculum (0.74, 2.37, 1.08), M6 inoculum (0.64, 1.97, 0.96) and least root dry weight among all treatments was shown by M9 inoculum (0.23, 0.77, 0.44) whereas, M1 inoculum with NC-92 showed root dry weight of 0.36, 1.12, 0.59 grams.

Among the varieties, DGGV-2 with an average of 0.80, 1.73, 0.89 shown higher root dry weight in grams when compared to DGG-96(0.31, 1.58, 0.72) at 30, 45 and 60 DAS respectively. The interaction effect of microbial inoculum with varieties DGGV-2 and DGG-96 was found significant in root dry weight at 30, 45 and 60 DAS with a range of 2.11-0.17, 2.84-0.79, 1.34-0.38g. The treatment M7 with DGGV-2 recorded significantly highest root dry weight in grams with values of 2.11, 2.84, 1.34 at 30, 45 and 60 DAS respectively

Table 2: Influence of *Rhizobium* and rhizobacteria on plant height in green gram varieties DGGV-2 and DGG-96

Treatments	Plant height (cm)								
	30 DAS			45 DAS			60 DAS		
Microbial inoculants	DGGV-2	DGG-96	Mean values	DGGV-2	DGG-96	Mean values	DGGV-2	DGG-96	Mean values
M1: NC-92 (Reference strain)	45.83	37.50	41.67	55.00	47.45	51.23	55.50	51.00	53.25
M2: HR-73	45.78	38.33	42.06	56.67	48.00	52.34	56.80	52.67	54.74
M3: BR-29	41.77	36.13	38.95	54.00	46.25	50.13	54.80	50.67	52.74
M4: HR-73+ BR-29	50.89	38.33	44.61	56.50	48.00	52.25	58.00	51.13	54.57
M5: HR-73+ AUDP 203+ AUDP 279	53.89	43.89	48.89	59.17	53.40	56.29	59.15	56.00	57.58
M6: BR-29+ AUDP 203 + AUDP 279	53.17	43.10	48.14	58.00	50.20	54.10	58.14	52.20	55.17
M7: HR-73+ BR-29+ AUDP 203 + AUDP 279	54.00	52.30	53.15	60.49	54.00	57.25	60.67	57.50	59.09
M8: NC-92 + AUDP 203 + AUDP 279	51.78	41.00	46.39	56.87	50.00	53.44	57.70	53.33	55.52
M9: UIC	41.67	33.78	37.73	53.01	45.00	49.01 ^j	53.64	48.67	51.16
M10: HR-73 + BR-29 + NC-92	51.67	39.78	45.73	56.67	50.60	53.64	57.20	52.87	55.04
Mean of variety	49.05	40.41		56.64	49.29		57.16	52.60	
Comparison of	S. Em. (+)		CD (p = 0.01)	S. Em. (+)		CD (p = 0.01)	S. Em. (+)		CD (p = 0.01)
V (Variety)	0.02		0.08	0.02		0.09	0.01		0.02
R (Isolates and consortia)	0.05		0.19	0.05		0.19	0.02		0.05
Interaction V*R (Variety *Isolates)	0.07		0.26	0.07		0.28	0.02		0.07

Table 3: Influence of *Rhizobium* and rhizobacteria on shoot dry weight in green gram varieties DGGV-2 and DGG-96

Treatments	Shoot dry weight (gm)								
	30 DAS			45 DAS			60 DAS		
Microbial inoculants	DGGV-2	DGG-96	Mean values	DGGV-2	DGG-96	Mean values	DGGV-2	DGG-96	Mean values
M1: NC-92 (Reference strain)	0.51	0.21	0.36	2.52	2.47	2.50	2.79	2.29	2.54
M2: HR-73	0.55	0.26	0.41	2.65	2.47	2.56	3.10	2.35	2.73
M3: BR-29	0.46	0.19	0.33	2.57	2.40	2.49	2.75	2.11	2.43
M4: HR-73+ BR-29	0.61	0.24	0.43	3.59	2.65	3.12	3.47	2.69	3.08
M5: HR-73+ AUDP 203+ AUDP 279	1.27	0.61	0.94	4.77	4.67	4.72	4.73	3.65	4.19
M6: BR-29+ AUDP 203 + AUDP 279	0.90	0.36	0.63	4.40	3.62	4.01	4.45	3.31	3.88
M7: HR-73+ BR-29+ AUDP 203 + AUDP 279	1.20	0.57	0.89	7.78	5.54	6.66	5.12	4.73	4.93
M8: NC-92 + AUDP 203 + AUDP 279	0.79	0.38	0.59	3.80	3.39	3.60	3.67	3.24	3.46
M9: UIC	0.30	0.16	0.23	1.85	2.29	2.07	2.16	2.09	2.13
M10: HR-73 + BR-29 + NC-92	0.71	0.28	0.50	3.61	2.85	3.23	3.27	2.84	3.06
Mean of variety	0.73	0.33		3.75	3.24		3.55	2.93	
Comparison of	S. Em. (+)		CD (p = 0.01)	S. Em. (+)		CD (p = 0.01)	S. Em. (+)		CD (p = 0.01)
V (Variety)	0.01		0.04	0.01		0.03	0.01		0.02
R (Isolates and consortia)	0.03		0.09	0.02		0.06	0.02		0.05
Interaction V*R (Variety *Isolates)	0.04		0.13	0.03		0.09	0.02		0.07

Leaf area

The leaf area of all treatments were assessed using graph sheets at 45 DAS and the results are presented in Table 4. Inoculation of consortium for green gram varieties, increased the leaf area of green gram significantly as compared to controls. Among all observation recorded across all different treatments, microbial consortium with M7 inoculum shown highest leaf area (81.25) in centimeters followed by M5(71.34), M6(68.29) when compared to other treatments and least leaf area among all treatments was shown by uninoculated control (M9) with a value of 37.75 cm whereas, M1 inoculum with NC-92 showed leaf area of 41.75cm.

Among the varieties, DGGV-2 with an average of 58.88 shown higher leaf area in centimeters when compared to DGG-96 (51.22) at 45 DAS. The interaction effect of *Rhizobium* and rhizobacteria for varieties DGGV-2 and DGG-96 was found

significant at 45 DAS with a range of 90.00-35.92 cm. The treatment M7 with DGGV-2 recorded significantly highest leaf surface area at 45 DAS with value of 90.00 cm.

Stem width

The stem width of treatments was measured using vernier caliper at 45 DAS and the results are presented in (Table 4). Inoculation of consortium for green gram varieties, increased the stem width of green gram significantly as compared to controls. Among all observation recorded across all different treatments, microbial consortium with M7 inoculum (1.88) shown highest stem width in centimeters when compared to other treatments followed by M5 inoculum (1.78), M6 inoculum (1.73) and least stem width among all treatments was shown by M9 inoculum (1.18) whereas, M1 inoculum with NC-92 showed stem width of 1.45 cm.

Table 4: Influence of *Rhizobium* and rhizobacteria on root dry weight in green gram varieties DGGV-2 and DGG-96

Treatments	Root dry weight (gm)								
	30 DAS			45 DAS			60 DAS		
Microbial inoculants	DGGV-2	DGG-96	Mean values	DGGV-2	DGG-96	Mean values	DGGV-2	DGG-96	Mean values
M1: NC-92 (Reference strain)	0.51	0.21	0.36	1.01	1.23	1.12	0.74	0.44	0.59
M2: HR-73	0.75	0.24	0.50	1.40	1.32	1.36	0.75	0.63	0.69
M3: BR-29	0.51	0.18	0.35	0.83	1.23	1.03	0.60	0.36	0.48
M4: HR-73+ BR-29	0.60	0.22	0.41	1.75	1.35	1.55	0.86	0.75	0.81
M5: HR-73+ AUDP 203+ AUDP 279	0.97	0.51	0.74	2.40	2.34	2.37	1.10	1.05	1.08
M6: BR-29+ AUDP 203 + AUDP 279	0.93	0.35	0.64	2.15	1.78	1.97	1.05	0.86	0.96
M7: HR-73+ BR-29+ AUDP 203 + AUDP 279	2.11	0.57	1.34	2.84	2.50	2.67	1.34	1.27	1.31
M8: NC-92 + AUDP 203 + AUDP 279	0.66	0.32	0.49	2.10	1.68	1.89	1.06	0.73	0.90
M9: UIC	0.28	0.17	0.23	0.74	0.79	0.77	0.50	0.38	0.44
M10: HR-73 + BR-29 + NC-92	0.70	0.29	0.50	2.07	1.57	1.82	0.95	0.75	0.85
Mean of variety	0.80	0.31		1.73	1.58		0.90	0.72	
Comparison of	S. Em. (±)		CD (p = 0.01)	S. Em. (±)		CD (p = 0.01)	S. Em. (±)		CD (p = 0.01)
V (Variety)	0.01		0.03	0.01		0.03	0.01		0.02
R (Isolates and consortia)	0.02		0.06	0.02		0.07	0.01		0.03
Interaction V*R (Variety *Isolates)	0.03		0.08	0.03		0.09	0.02		0.05

Among the varieties, DGGV-2 with an average of 1.63 shown higher stem width in centimeters when compared to DGG-96(1.58) at 45 DAS. The interaction effect of microbial inoculum with varieties DGGV-2 and DGG-96 was found significant in stem width at 45 DAS with a range of 1.90-1.13cm. The treatment M7 with DGGV-2 recorded significantly highest stem width in centimeters 1.90 at 45 DAS.

Number of branches per plant

Number of branches per plant were counted manually at 45 DAS and the results are presented. (Table 4) Inoculation of consortium for green gram varieties, increased the no. of branches of green gram significantly as compared to controls. Among all observation recorded across all different treatments, microbial consortium with M7 inoculum (8.80) shown highest no. of branches when compared to all treatments followed by M5 inoculum (7.25), M6 inoculum (6.80) and least no. of branches among other treatments was shown by M9 inoculum (4.65) whereas, M1 inoculum with NC-92 showed number of branches per plant of 5.21cm.

Among the varieties, DGGV-2 with an average of 6.40 shown

higher no. of branches when compared to DGG-96 (5.83) at 45 DAS. The interaction effect of microbial inoculum with varieties DGGV-2 and DGG-96 was found significant in number of branches per plant at 45DAS with a range of 9.00-4.30. The treatment M7 with DGGV-2 recorded significantly higher no. of branches per plant 9.00 at 45 DAS

Discussion

The consortia were evaluated in terms of plant growth promotion with host crop as green gram. Green gram varieties DGGV-2 which is a ruling variety, most suitable for paddy fallow along and susceptible for green gram yellow mosaic virus and DGG-96 (pipeline variety) with resistance to green gram yellow mosaic virus, anthracnose disease were selected for pot culture studies. The experiment consisted inoculation of NC-92 (M1), HR-73 (M2), BR-29 (M3), HR-73+ BR-29 (M4), HR-73+ AUDP 203+ AUDP 279 (M5), BR-29+ AUDP 203 + AUDP 279 (M6), HR-73+ BR-29+ AUDP 203 + AUDP 279 (M7), NC-92 + AUDP 203 + AUDP 279 (M8), HR-73 + BR-29 + NC-92 (M10), Un inoculated Control (M9) to varieties of green gram (DGGV-2 and DGG-96).

Table 5: Influence of *Rhizobium* and rhizobacteria on vegetative parameters at 45 DAS in green gram varieties DGGV-2 and DGG-96

Treatments	45 DAS								
	a. Leaf area(cm)			b. Stem width (cm)			c. Number of branches/plants		
Microbial inoculants	DGGV-2	DGG-96	Mean values	DGGV-2	DGG-96	Mean values	DGGV-2	DGG-96	Mean values
M1: NC-92 (Reference strain)	41.00	42.50	41.75	1.47	1.43	1.45	5.27	5.14	5.21
M2: HR-73	43.01	44.42	43.72	1.63	1.65	1.64	5.40	5.27	5.34
M3: BR-29	40.50	39.42	39.96	1.37	1.40	1.39	5.18	4.60	4.89
M4: HR-73+ BR-29	59.00	50.25	54.63	1.76	1.58	1.67	6.25	5.67	5.96
M5: HR-73+ AUDP 203+ AUDP 279	77.92	64.75	71.34	1.80	1.75	1.78	8.00	6.50	7.25
M6: BR-29+ AUDP 203 + AUDP 279	77.41	59.17	68.29	1.75	1.70	1.73	7.10	6.50	6.80
M7: HR-73+ BR-29+ AUDP 203 + AUDP 279	90.00	72.50	81.25	1.90	1.85	1.88	9.00	8.60	8.80
M8: NC-92 + AUDP 203 + AUDP 279	60.75	52.70	56.73	1.67	1.73	1.70	6.50	5.87	6.19
M9: UIC	39.58	35.92	37.75	1.23	1.13	1.18	5.00	4.30	4.65
M10: HR-73 + BR-29 + NC-92	59.58	50.58	55.08	1.72	1.55	1.64	6.27	5.83	6.05
Mean of variety	58.88	51.22		1.63	1.58		6.40	5.83	
Comparison of	S. Em. (+)		CD (p = 0.01)	S. Em. (+)		CD (p = 0.01)	S. Em. (+)		CD (p = 0.01)
V (Variety)	0.01		0.02	0.01		0.02	0.01		0.03
R (Isolates and consortia)	0.02		0.05	0.01		0.03	0.03		0.08
Interaction V*R (Variety *Isolates)	0.02		0.07	0.02		0.05	0.04		0.11

The using microbial inoculants for green gram variety as significantly increased plant growth in terms of overall plant height, shoot length, root length, shoot fresh and dry weight, root fresh and dry weight,

Microbial consortium inoculation to green gram varieties has significantly increased Plant height, shoot length, root length, number of branches per plant when compared to positive controls (NC-92, HR-73, BR-29) and uninoculated control at 30,45,60 DAS. The increased vegetative parameters then compared to controls could be due to synergistic effects of consortium and synthesis of phytohormones like auxin and antagonistic activity against pathogenic microorganism.

The results revealed that vegetative parameters (Plant height) when observed at 30,45 and 60 DAS were highest for DGGV-2 then DGG-96 among the varieties and among microbial inoculum plants with M7 (HR-73+ BR-29+ AUDP 203 + AUDP 279) treatment shown highest vegetative parameters. The interaction effect of *Rhizobium* and rhizobacteria was positively correlated in green gram varieties. Interaction effect in DGGV-2 variety with M7 treatment shown highest vegetative parameters in overall when compared to all other treatments because of synergistic effects of consortia promoted overall vegetative parameters.

Green gram being an annual crop the highest vegetative parameters were recorded at 45 DAS because of its plants were entered to flowering and just started pod filling indicating the completion of vegetative stage. These findings are in similar with Tejasree *et al.* (2024) ^[3] who reported that seed biopriming with bacterial consortia in green gram at Maharashtra has significantly improved average plant height (65.66 cm), average number of leaves per plant (22.79), average number of branches (5.23), average number of pods per plant (30.93). Mir *et al.* (2024) ^[2] conducted a greenhouse experiment at Osmania University, Hyderabad using *Rhizobium* sps (as *Rhizobium tropici* IHTF1 and *Rhizobium mayense* IHTF-2) and reported that two strains, exhibit superior PGP traits in *Phaseolus vulgaris* with both individual and consortium mode of inoculations. Root, shoot length and fresh and dry biomass were increased in inoculated plants when compared to non-inoculated control plants.

Plant parameters like shoot dry weight and root dry weight, stem width showed significant differences at 30,45 and 60 DAS. Inoculating seeds with efficient consortium will promote the mobilization of nutrients. When plants were inoculated with AUDP 203 and AUDP 279 which are proven nutrient (N, P, K,

Zn) solubilizing and mobilizing strains enhances nutrient availability for plant and contributes for growth promotion and plant health management. On the other hand, efficient *Rhizobium* strain establishes symbiotic relationship with host plants and fixes atmospheric N₂ to NH₃. Ammonia will be utilized by plants for metabolic activity.

The environment parameters like Temperature, availability of moisture, Relative humidity will significantly affect plant growth promotion. According to Van't Hoff's rule increase in every 10 °C will double the metabolic rate; plant exposed to higher temperatures under optimum conditions will increase the metabolic activities. When adequate nutrients are available for plant growth along with sufficient moisture content, increase in temperature will result in better yields. Green gram being able to grow between temperatures 15⁰ to 40 °C was positively responded when they grown during February to April with an temperature range of 17.0-37.3 °C and relative humidity range of 28.6-74.6 (%) under greenhouse conditions. A part from environment conditions occurrence of low disease incidence during experiment could be enhanced yield over un inoculated control. Low disease incidence could be due to antagonistic property of rhizobial isolates and PGPR strains.

The results of pot culture experiment under greenhouse conditions revealed that shoot dry weight and root dry weight at 30,45 and 60 DAS stem width at 45 DAS were significantly higher for DGGV-2 then DGG-96. Among microbial inoculums, M7 microbial inoculum (HR-73+ BR-29+ AUDP 203 + AUDP 279) shown highest values then other microbial inoculum and un treated control. The interaction effect of *Rhizobium* and rhizobacteria was positively correlated in green gram varieties. Interaction effect in DGGV-2 variety with M7 microbial inoculum treatment shown highest relative chlorophyll content, shoot fresh weight, shoot dry weight and root fresh weight and root dry weight when compared to all other treatments. At 45 DAS (flowering and pod filling) the plants of all treatments shown highest values of relative chlorophyll content, shoot fresh weight, shoot dry weight and root fresh weight and root dry weight indicating peaking metabolic activity then at 30 DAS (vegetative stage). The decline in metabolic activities at 60 DAS indicates the start of senescence period of plants.

Similar results were recorded by Mbaka *et al.* (2022) ^[1] who reported that inoculation of *Rhizobium* in Kenya has increased shoot dry biomass (52.01 g/plant), root dry biomass (7.60 g/plant), total dry biomass (146.4 g/plant), number of pods (84/plant) and yield (2158 kg/ha). Musyoka *et al.* (2020) ^[5]

conducted a pot experiment in Kenya and reported co-inoculation of *Bradyrhizobium* and arbuscular mycorrhizal fungi (AMF) significantly enhanced shoot and root dry weights as well as phosphorus content compared to *Bradyrhizobium* alone and control plants, across all watering regimes. Singh *et al.* (2022) ^[4] conducted a field experiment in Uttar Pradesh and reported that applying NPK Consortia and Zinc Solubilizing Bacteria (ZSB) at rate of 20ml/kg on Mung Bean (*Vigna radiata* L.) resulted in the highest plant density (331229 plants/ha), tallest plants (67.7 cm/plant), most trifoliate leaves per plant (12.7), highest number of branches per plant (4.5), greatest dry matter accumulation per plant (18.7 g/plant), highest leaf area index (5.72), and fastest crop growth rate (7.6 g/m²/day) at harvest. This treatment also yielded the highest grain production at 1106 kg/ha, and led to a 59.8% increase in dry matter accumulation per plant compared to the control. Kumar *et al.* (2023) ^[6] conducted experiment in Tamil Nadu and reported that inoculation of *Rhizobium mayense* sp. nov., to finger millet (*Eleusine coracana*) and green gram (*Vigna radiata*) under pot conditions has increased the total plant growth and dry weight compared to the control. The chlorophyll content of green gram and finger millet was estimated to be 19.54±0.2784 mg/L and 15.3±0.0035 mg/L which suggested that *Rhizobium* sp. possesses high nitrogenase activity.

Conclusion

The findings of this study demonstrate that inoculation with *Rhizobium* and rhizobacteria significantly enhances plant growth parameters of green gram. Microbial consortia were more effective than single inoculants in promoting plant height, branching, root development, and biomass accumulation. The improved growth response can be attributed to synergistic microbial interactions that enhance nutrient uptake and stimulate plant physiological processes. These results emphasize the importance of consortium-based bioinoculants in improving vegetative growth and crop establishment. Further validation under field conditions will help in translating these benefits into practical applications for sustainable pulse cultivation.

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