

Response of phosphorus and biofertilizers on growth, yield attributes and economic indices of black gram (*Vigna mungo* L. Hepper)

Abstract

Field experiment was conducted during the *kharif* season of year 2019 to study the response of phosphorus and biofertilizers on growth, yield attributes and economic indices of black gram (*Vigna mungo* L. Hepper). The initial soil parameter status were pH 4.6, OC 1.16%, medium in available soil N (256.99 kg ha⁻¹), low in available P (18.95 kg ha⁻¹) and medium in available K (212.56 kg ha⁻¹). The soil was well drained and sandy loam in texture. The experiment was laid out in Factorial Randomized Block Design with three replications. The treatments consisted of four levels of phosphorus *i.e.* 0, 20, 40, 60 kg P₂O₅ ha⁻¹ and four levels of biofertilizer *i.e.* uninoculated, *Rhizobium*, PSB, *Rhizobium* + PSB. Among the various treatment levels and sources, 60 kg P₂O₅ ha⁻¹ with dual inoculation of seeds along with *Rhizobium* + PSB significantly increased the growth and yield attributes such as plant height, plant population, Leaf Area Index (LAI), number of leaves plant⁻¹, number of branches plant⁻¹, Crop Growth Rate (CGR), number of pods plant⁻¹ (30.72), pod length (4.68 cm), number of seeds pod⁻¹ (7.20), seed yield (1120.35 kg ha⁻¹), stover yield (2401.54 kg ha⁻¹) and harvest index (31.80 %) over rest of the treatments. Results further indicated that a higher net return of ₹ 39,811 and B:C ratio of 1.45 were also observed with the application of 60 kg P₂O₅ ha⁻¹ along with dual inoculation of seeds with *Rhizobium* and PSB.

Keywords: *Rhizobium*, PSB, Growth, Yield, Yield Attributes, B:C ratio

1. Introduction

Black gram is widely grown in India and other Asian countries as a pulse crop. About 19% area in India accounts for total pulse growing area contributing 23% of total production of pulse crops. The area and production of black gram in India during 2020-21 were 4.6 million hectares and 24.5 lakh tons (Anonymous, 2020). Tamil Nadu is the leading producer of black gram in India (Anand *et al.*, 2022).

It is highly nutritious and contains 60% carbohydrates, 24% protein, 1.3% fats, minerals (3.2%), vitamin A, B₁ and B₃ and is 5-10 times richer in phosphoric acid (385 mg/100g) among pulses (Sasidhar *et al.*, 2022). Due to its richness in protein and affordable to all including those of low income group people, it is therefore known as poor man's meat (Aslam *et al.*, 2010).

It is a drought resistant crop but intolerant to frost and water logging (Jothimani and Arulbalachandran, 2020). Apart from this, black gram has the ability to restore the soil fertility and fix about 22.10 kg of atmospheric N to meet the nitrogen demand through its root nodules (Saren *et al.*, 2017). Thus, this crop has been proved to require less amount of nitrogen due to its nodulation (Pandey *et al.*, 2018). It is generally a warm season crop but it can be grown both in summer and winter in India.

Phosphorus is an important macronutrient required by the plants right from the seedling stage to maturity. It plays significant role in growth with extensive root spread, flowering, enhanced nodulation, pod development and yield in legumes (Balyan *et al.*, 2005, Yamuna *et al.*, 2022). The deficiency of phosphorus in the soil adversely affect the growth, nodulation and yield in crops and global food security (Alikhani *et al.*, 2006, Weikard 2016 and Heuer *et al.*, 2017). Hence, phosphorus has been known as an important macronutrient element for yield increase, nutritional standard and for promoting earlier and more uniform maturity in legume crops (Singh *et al.*, 2022).

Biofertilizers are derived either from nodules of plants or rhizosphere and are capable of mobilizing the nutrients required by plants through natural process like atmospheric N fixation, solubilisation of P and also promote the growth of the plants by producing anti metabolites and hormones (Bhardwaj *et al.*, 2014 and Mitter *et al.*, 2021). It also increases the phosphorus availability to the plants through reducing P fixation, thus enhancing soil fertility (Arbad and Ismail, 2011). It has been used to promote sustainable agriculture through replacing chemical fertilizers (Wu *et al.*, 2005) and enhanced shelf life without affecting the ecosystem adversely (Sahoo *et al.*, 2014). Rhizobium is predominantly use for inoculating the black gram seeds which increases the N availability to plants and boost the growth as well as yield of the crop (Korir *et al.*, 2017) since it establishes symbiotic relationship with legume crops through nodulation and N fixation (Khuntia *et al.*, 2022 and Masson-Boivin and Sachs, 2018). Similarly, inoculating the black gram seeds with Phosphate Solubilizing Bacteria (PSB) plays a vital role in supplementing P required by the crop. It helps in dissolving the interlocked phosphates by bringing out more amounts of unavailable and fixed phosphates in soil into soluble form and makes it available to plants (Elhaissoufi *et al.*, 2022 and Barroso *et al.*, 2006).

Application of phosphatic fertilizers along with PSB is found to solubilise phosphate in the soil and increase the phosphorus uptake by plants and thereby positively influenced the yield of the crop (Kalayu, 2019). Use of adequate fertilizers along with correct strain of biofertilizers play a pivotal role in achieving higher yield as well as higher economic return from black gram (Kumawat *et al.*, 2013). Thus, proper fertilization with proportionate amount of micro and macro nutrients is required to increase the productivity of pulse crops. Keeping in view the above discussion, the present experiment was conducted to observe the response of phosphorus and biofertilizers on growth, yield attributes and economic indices of black gram (*Vigna mungo* L. Hepper).

2. Materials and Methods

A field experiment was conducted during the *kharif* season (August to October) of 2019 in the experimental farm of School of Agricultural Sciences and Rural Development (SASRD), Nagaland University, Medziphema campus, India. The physicochemical properties of the initial soil were pH 4.6, OC 1.16%, medium in available soil N (256.99 kg ha⁻¹), low in available P (18.95 kg ha⁻¹) and medium in available K (212.56 kg ha⁻¹). The soil was well drained and sandy loam in texture.

The experiment was laid out in Factorial Randomized Block Design with three replications. The treatment consisted of four different levels of phosphorus (0, 20, 40, 60 kg P₂O₅ ha⁻¹) and four different levels of biofertilizer *i.e.* uninoculated, *Rhizobium*, PSB, *Rhizobium* + PSB. Black gram variety PU-31 was sown @ seed rate of 15 kg ha⁻¹. The seeds were sown in lines with a spacing of 30 cm × 10 cm apart at a depth of 3-4 cm. Recommended dose of N @ 20 kg ha⁻¹, K @ 20 kg ha⁻¹ and P levels @ 20, 40, 60 kg ha⁻¹ were applied in the soil a day before sowing. The biofertilizer treatments *i.e.* *Rhizobium* and Phosphate Solubilizing Bacteria (PSB) were applied through seed treatment just before sowing @ 20 g kg⁻¹ seeds. Intercultural operations and plant protection steps were carried out as per required.

Various growth parameters, phenological observation and yield attributes were observed and recorded. All the obtained data from the experiment were processed, classified, tabulated and systematically analysed using Anova statistical method.

3. Result and Discussion

3.1. Growth Attributes

3.1.1. Plant height

The plant height of black gram was increased significantly with increase in the levels of phosphorus as well as by inoculation of seeds with *Rhizobium* + PSB and 60 kg P₂O₅ ha⁻¹ (Table 1). The highest was recorded at T₁₆ which was at par with 40 kg P₂O₅ ha⁻¹ + *Rhizobium* + PSB (T₁₂). This increased in plant height might be due to the involvement of P in the rhizosphere environment and plant system by enhancing the photosynthetic activity and plant metabolism thereby improving the plant growth and its development (Hakim *et al.* 2021) and due to the synergistic effect between phosphorus and biofertilizers converting the insoluble phosphates into soluble form for plant absorption (Jayshree and Umesha, 2021)

3.1.2. Plant population

The individual treatment with P as well as with dual inoculation of seeds with *Rhizobium* + PSB and 60 kg P₂O₅ ha⁻¹ was found to decrease the mortality rate of plant population (T₁₆) significantly as compared to control (T₁) (Table 1). This might be due to the increasing levels of phosphorus application along with dual inoculation of seeds with *Rhizobium* + PSB which results in better root development and root proliferation thereby reducing the plant mortality after germination (Gebremariam *et al.*, 2021).

3.1.3. Number of branches plant⁻¹

Number of branches plant⁻¹ were significantly influenced with increasing levels of phosphorus as well as with dual inoculation of seeds with *Rhizobium* + PSB and 60 kg P₂O₅ ha⁻¹ (T₁₆) as shown in table 1. Similar finding was also reported by Kant *et al.*, (2016).

3.1.4. Number of leaves plant⁻¹

The number of leaves plant⁻¹ at harvest was found to be non-significant with the application of phosphorus and biofertilizers (Table 1).

3.1.5. Leaf Area Index (LAI)

The Leaf Area Index (LAI) of the plant was significantly influenced with increased in the levels of phosphorus as well as with dual inoculation of seeds with *Rhizobium* + PSB and 60 kg P₂O₅ ha⁻¹ (T₁₆) as shown in table 1. This might be due to the increase in the vegetative growth leading to more light interception and increasing the leaf area index of the plants. Similar findings were also reported by

3.1.6. Crop Growth Rate (CGR) (g m⁻² day⁻¹)

The Crop Growth Rate (CGR) significantly increased with different levels of phosphorus treatment as well as with dual inoculation of seeds with *Rhizobium* + PSB and 60 kg P₂O₅ ha⁻¹ (T₁₆) which was found at par with treatment (T₁₂) (Table 1). This result was in close conformity with the work done by Yadav *et al.* (2017).

3.1.7. Relative Growth Rate (RGR) (g g⁻¹ day⁻¹)

The RGR was non-significant in all the treatments individually or in combinations of phosphorus and biofertilizers at all the crop growth stages (Table 1).

3.1.8. Days to 50% flowering

The application of phosphorus and biofertilizers showed non-significant effect in all treatments with or without interactions on days to 50% flowering as shown in table 1.

3.1.9. Days to maturity

It was observed that the effect of phosphorus and biofertilizers had a non-significant effect in all treatments with or without interactions on days to maturity of plants as shown in table 1.

Phosphorus × Biofertilizer	Plant height (cm)	Plant population (m ⁻²)		Number of branches plant ⁻¹	Number of leaves plant ⁻¹	LAI	CGR (g m ⁻² day ⁻¹)	RGR (mg g ⁻¹ day ⁻¹)	Days to 50% flowering	Days to maturity
	At harvest	30 DAS	60 DAS	At harvest	At harvest	60 DAS	30-60 DAS	30-60 DAS		
T ₁ (control)	33.00	30.89	29.22	4.20	4.07	1.12	2.18	0.022	41.00	68.00
T ₂ (Control + <i>Rhizobium</i>)	36.07	34.55	32.66	4.47	4.20	1.23	2.97	0.023	40.33	68.00
T ₃ - P ₀ B ₂	38.87	34.11	31.77	4.33	4.27	1.26	2.90	0.023	40.67	68.00

(Control + PSB)										
T ₄ - P ₀ B ₃ (Control + Rhizobium + PSB)	42.73	35.11	33.33	4.53	4.40	1.30	3.15	0.020	40.33	68.00
T ₅ - P ₁ B ₀ (20 kg P ₂ O ₅ ha ⁻¹)	35.83	34.77	33.00	4.27	4.33	1.22	2.95	0.022	41.00	68.00
T ₆ - P ₁ B ₁ (20 kg P ₂ O ₅ ha ⁻¹ + Rhizobium)	45.03	35.66	34.11	4.60	4.60	1.50	3.62	0.020	40.00	67.33
T ₇ - P ₁ B ₂ (20 kg P ₂ O ₅ ha ⁻¹ + PSB)	43.00	35.44	33.77	4.53	4.67	1.52	3.34	0.021	40.00	67.33
T ₈ - P ₁ B ₃ (20 kg P ₂ O ₅ ha ⁻¹ + Rhizobium + PSB)	48.10	36.22	34.66	4.73	4.87	2.02	3.50	0.023	39.33	66.67
T ₉ - P ₂ B ₀ (40 kg P ₂ O ₅ ha ⁻¹)	37.07	35.00	33.44	4.40	4.47	1.40	3.45	0.025	40.33	68.00
T ₁₀ - P ₂ B ₁ (40 kg P ₂ O ₅ ha ⁻¹ + Rhizobium)	49.57	36.00	34.89	4.67	4.80	1.84	3.87	0.023	40.33	66.67
T ₁₁ - P ₂ B ₂ (40 kg P ₂ O ₅ ha ⁻¹ + PSB)	45.97	35.78	34.22	4.67	4.73	1.92	3.72	0.021	39.33	66.67
T ₁₂ - P ₂ B ₃ (40 kg P ₂ O ₅ ha ⁻¹ + Rhizobium + PSB)	53.10	37.44	36.11	5.13	5.20	2.30	4.58	0.026	39.00	66.00
T ₁₃ - P ₃ B ₀ (60 kg P ₂ O ₅ ha ⁻¹)	41.53	35.55	34.00	4.53	4.53	1.65	3.67	0.021	39.67	67.33
T ₁₄ - P ₃ B ₁ (60 kg P ₂ O ₅ ha ⁻¹ + Rhizobium)	50.10	36.55	35.66	5.00	4.80	2.07	4.08	0.023	39.33	66.00
T ₁₅ - P ₃ B ₂ (60 kg P ₂ O ₅ ha ⁻¹ + PSB)	49.83	36.55	35.44	4.80	4.80	2.22	4.05	0.023	39.67	66.00
T ₁₆ - P ₃ B ₃ (60 kg P ₂ O ₅ ha ⁻¹ + Rhizobium + PSB)	55.00	38.00	36.66	5.33	5.07	2.62	4.58	0.023	39.00	66.00
SEm±	1.14	0.43	0.34	0.07	0.12	0.05	0.12	0.003	0.29	0.55
CD (p=0.05)	3.30	1.25	0.99	0.20	NS	0.15	0.33	NS	NS	NS

3. Result and discussion

3.2. Yield and Yield Attributes

3.2.1. Number of pods plant⁻¹

The effect of different levels of phosphorus as well as dual inoculation of seeds with Rhizobium + PSB and 60 kg P₂O₅ ha⁻¹ increased the no. of pods plant⁻¹ significantly with maximum being recorded at T₁₆ and closely followed by T₁₂. The lowest was recorded at control (T₁) (Table 2). This increased in the no. of pods plant⁻¹ might be due

to the enhance activity of nitrogenase, nitrate reductase, N and P availability to the plant which led to increase growth and yield attributes (Gajera *et al.*, 2014).

3.2.2. Pod length (cm)

The length of pod was significantly increased by application of different levels of phosphorus as well as with dual inoculation of *Rhizobium* + PSB and 60 kg P₂O₅ ha⁻¹ at harvest as compared to control and individual seed inoculation. Length of the pods were recorded maximum in treatment (T₁₆) - 60 kg P₂O₅ ha⁻¹ + *Rhizobium* + PSB) and remained at par with treatment (T₁₂) - 40 kg P₂O₅ ha⁻¹ + *Rhizobium* + PSB (Table 2). This increased in length of the pods might be due to the vital role played by phosphorus in flowering, fruiting and seed development along with combine inoculation of *Rhizobium* + PSB that resulted in achieving higher number of pods per plant as well as pod length (Table 2). This might be because of the readily available soil nutrients to the plant and soil micro-organisms which thereby fixed N and positively affecting the nodulation, growth and yield attributes (Kumar., 2011).

3.2.3. Number of seeds pod⁻¹

It was observed that different levels of phosphorus as well as with dual inoculation of *Rhizobium* + PSB and 60 kg P₂O₅ ha⁻¹ significantly affect the no. of seeds pod⁻¹. The highest was recorded at T₁₆ over the rest of the treatments (Table 2). Phosphorus plays an important role in enhancing the photosynthesis and photosynthetic activity, biomass production and translocation in various plant parts thereby increasing the no. of seeds pod⁻¹ (Bilal *et al.*, 2021).

3.2.4. Test weight (g)

The effect of phosphorus and biofertilizers had a non-significant effect on test weight (1000 seed) of black gram as shown in table 2. This is due to the fact that the plant genetic characters controlled the test weight of seed (Gajera *et al.*, 2014).

3.2.5. Seed yield (kg ha⁻¹)

Application of phosphorus at various levels as well as with dual inoculation of seed with *Rhizobium* + PSB and 60 kg P₂O₅ ha⁻¹ recorded the highest grain yield significantly at T₁₆ over alone inoculation and control (Table 2). Treating the seeds with *Rhizobium* increases the fixation of atmospheric nitrogen and on the other hand PSB plays an important role in solubilizing the native phosphorus resulting in more phosphorus availability to the plants. There is a synergistic effect between the yield and growth attributes which ultimately led to the increased in seed yield with increased in the other counterparts (Kumawat *et al.*, 2013).

3.2.6. Stover yield (kg ha⁻¹)

With the application of different levels of phosphorus as well as with dual inoculation of seed with *Rhizobium* + PSB and 60 kg P₂O₅ ha⁻¹, the stover yield was increased significantly. The maximum stover yield was recorded at T₁₆ (Table 2). This increased in stover yield was due to the positive effect of P, Rhizobium and PSB in growth attributes with its absorption by the plant and rhizosphere (Jakhar *et al.*, 2018).

3.2.7. Harvest Index (%)

Data revealed that application phosphorus at various levels as well as with dual inoculation of seed with *Rhizobium* + PSB and 60 kg P₂O₅ ha⁻¹ affect the harvest index significantly. The maximum was recorded at T₁₆ while the lowest harvest index was recorded in treatment (T₁) as shown in table 2. This might be due to the involvement of the physiological activity in photosynthesis and its translocation to various parts of the plant having economic benefits (Nikfarjam *et al.*, 2015).

Phosphorus × Biofertilizer	Number of pods plant ⁻¹	Pod length (cm)	Number of seeds pod ⁻¹	Test weight (g)	Seed yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Harvest index (%)
T ₁ (control)	16.96	4.10	5.67	36.96	638.30	1955.66	24.60
T ₂ (Control + Rhizobium)	18.92	4.22	6.10	38.20	696.82	1999.75	25.86
T ₃ - P ₀ B ₂ (Control + PSB)	17.86	4.15	6.06	37.93	689.03	1996.60	25.65
T ₄ - P ₀ B ₃ (Control + Rhizobium +	21.33	4.33	6.23	38.72	719.12	2011.45	26.32

PSB)							
T ₅ - P ₁ B ₀ (20 kg P ₂ O ₅ ha ⁻¹)	20.60	4.12	5.96	38.00	679.20	1983.54	25.50
T ₆ - P ₁ B ₁ (20 kg P ₂ O ₅ ha ⁻¹ + Rhizobium)	23.67	4.40	6.32	38.97	831.55	2210.16	27.33
T ₇ - P ₁ B ₂ (20 kg P ₂ O ₅ ha ⁻¹ + PSB)	24.25	4.34	6.25	38.90	821.00	2186.52	27.30
T ₈ - P ₁ B ₃ (20 kg P ₂ O ₅ ha ⁻¹ + Rhizobium + PSB)	25.28	4.50	6.55	39.32	866.28	2235.30	27.92
T ₉ - P ₂ B ₀ (40 kg P ₂ O ₅ ha ⁻¹)	23.12	4.23	6.12	38.96	731.70	2012.57	26.67
T ₁₀ - P ₂ B ₁ (40 kg P ₂ O ₅ ha ⁻¹ + Rhizobium)	25.62	4.54	6.60	39.30	885.58	2266.00	28.10
T ₁₁ - P ₂ B ₂ (40 kg P ₂ O ₅ ha ⁻¹ + PSB)	24.78	4.48	6.48	39.28	863.56	2257.25	27.67
T ₁₂ - P ₂ B ₃ (40 kg P ₂ O ₅ ha ⁻¹ + Rhizobium + PSB)	28.72	4.62	6.85	39.52	1012.78	2300.36	30.56
T ₁₃ - P ₃ B ₀ (60 kg P ₂ O ₅ ha ⁻¹)	25.60	4.37	6.17	39.12	788.17	2072.90	27.54
T ₁₄ - P ₃ B ₁ (60 kg P ₂ O ₅ ha ⁻¹ + Rhizobium)	28.12	4.54	6.70	39.40	977.45	2276.72	30.03
T ₁₅ - P ₃ B ₂ (60 kg P ₂ O ₅ ha ⁻¹ + PSB)	27.95	4.52	6.62	39.35	960.08	2274.85	29.67
T ₁₆ - P ₃ B ₃ (60 kg P ₂ O ₅ ha ⁻¹ + Rhizobium + PSB)	30.72	4.68	7.20	39.82	1120.35	2401.54	31.80
SEM±	0.40	0.03	0.06	0.23	23.70	36.69	0.39
CD (<i>p</i> =0.05)	1.15	0.08	0.18	NS	68.46	105.98	1.11

3.3. Economic Analysis

The economics data on the response of phosphorus levels as well as dual inoculation of seed with *Rhizobium* + PSB and 60 kg P₂O₅ ha⁻¹ on black gram is shown in table 3. The common cost of cultivation for all the treatment was recorded at ₹ 25,830 ha⁻¹.

Application of 60 kg P₂O₅ ha⁻¹ + Rhizobium + PSB (T₁₆) recorded the highest cost of cultivation (₹ 27,410.0 ha⁻¹) while, the lowest cost of cultivation (₹ 25,830 ha⁻¹) was recorded in control (T₁). It was observed that highest gross return (₹ 67,221.0 ha⁻¹) was observed with application of 60 kg P₂O₅ ha⁻¹ + Rhizobium + PSB (T₁₆). The reason behind the higher gross return is due to higher input cost as compared to the rest of the treatment.

The highest net return (₹ 39,811.0 ha⁻¹) was recorded under the same treatment *i.e.* 60 kg P₂O₅ ha⁻¹ + Rhizobium + PSB (T₁₆). The increase in net return in treatment (T₁₆) is due to higher seed yield and straw yield over control. The highest B:C ratio (1.45) was recorded in application of 60 kg P₂O₅ ha⁻¹ + Rhizobium + PSB (T₁₆) while, the lowest (0.48) was recorded in control (T₁). The above mention economic results were supported by the findings done by Gajera *et al.* (2014).

Treatment	Cost of cultivation (₹ ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B:C ratio
T ₁ - P ₀ B ₀	25,830	38,298	12,468	0.48
T ₂ - P ₀ B ₁	25,870	41,809.2	15,939.2	0.61
T ₃ - P ₀ B ₂	25,870	41,341.8	15,471.8	0.59
T ₄ - P ₀ B ₃	25,910	43,147.2	17,237.2	0.66
T ₅ - P ₁ B ₀	26,330	40,752.0	14,422	0.54

T ₆ - P ₁ B ₁	26,370	49,893.0	23,523	0.89
T ₇ - P ₁ B ₂	26,370	49,260.0	22,890	0.86
T ₈ - P ₁ B ₃	26,410	51,976.8	25,566.8	0.96
T ₉ - P ₂ B ₀	26,830	43,902.0	17,072	0.63
T ₁₀ - P ₂ B ₁	26,870	53,134.8	26,264.8	0.97
T ₁₁ - P ₂ B ₂	26,870	51,813.6	24,943.6	0.92
T ₁₂ - P ₂ B ₃	26,910	60,766.8	33856.8	1.25
T ₁₃ - P ₃ B ₀	27,330	47,290.2	19960.2	0.73
T ₁₄ - P ₃ B ₁	27,370	58,647.0	31,277	1.14
T ₁₅ - P ₃ B ₂	27,370	57,604.8	30,234.8	1.10
T ₁₆ - P ₃ B ₃	27,410	67,221.0	39,811	1.45
SEm±	-	1422.19	1422.26	0.05
CD (p=0.05)	-	4107.58	4107.80	0.15

4. Conclusion

Based on the results of the experiment, it can be concluded that the application of 60 kg P₂O₅ ha⁻¹ along with dual inoculation of seeds with *Rhizobium* and Phosphorus Solubilising Bacteria found to have a significant effect on improving the growth attributes, yield attributes as well as providing a higher net monetary return over the rest of the treatments observed in black gram (*Vigna mungo* L. Hepper).

5. References

- Alikhani, H.A., Saleh, R.N. and Antoun, H. 2006. Phosphate solubilisation activity of rhizobia native to Iranian soils. *Plant Soil*, 287: 35- 41.
- Anand, A., Umesha, C., Sanodiya, L. K., 2022. Effect of phosphorous and molybdenum on yield and economic of black gram (*Vigna mungo* L.). *The Pharma Innovation Journal* 11 (5), 1417-1420.
- Anonymous. 2020. Blackgram outlook report – January to May 2021. Department of Agriculture & Farmers Welfare. Directorate of Economics and Statistics, Government of India. <https://agricoop.nic.in>.
- Arbad, B. K., Ismail S., 2011. Effect of integrated nutrient management on soybean (*Glycine max*) - safflower (*Carthamus tinctorius*) cropping system. *Indian Journal of Agronomy* 56, 340-345.
- Aslam, M., Hussain, N., Zubair, M., Hussain, S. B., Baloch, M. S., 2010. Integration of organic and inorganic sources of phosphorus for increased productivity of mung bean (*Vigna radiata* L.). *Pakistan Journal of Agriculture science* 47 (2), 111 -114.
- Balyan, J. K., Singh, M., 2005. Effect of seed inoculation, different levels of irrigation and phosphorus on nodulation and root growth development of lentil. *Research on Crops* 6, 323.
- Barroso, C.V., Pereira, G.T. and Nahas, E., 2006. Solubilization of CaHPO₄ and AlPO₄ by *Aspergillus niger* in culture media with different carbon and nitrogen sources. *Brazilian Journal of Microbiology* 37, 434-438.
- Bhardwaj, D., Ansari, M.W., Sahoo, R.K. 2014. Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell Factories* 13, 66. <https://doi.org/10.1186/1475-2859-13-66>.

- Bilal, S., Hazafa, A., Ashraf, I., Alamri, S., Siddiqui, M. H., Ramzan, A., Qamar, N., Sher, F., Naeem, M., 2021. Comparative Effect of Inoculation of Phosphorus-Solubilizing Bacteria and Phosphorus as Sustainable Fertilizer on Yield and Quality of Mung Bean (*Vigna radiata* L.). *Plants (Basel)* 10 (10), 2079.
- Elhaissofi, W., Ghoulam, C., Barakat, A., Zeroual, Y., Bargaz, A., 2022. Phosphate bacterial solubilization: A key rhizosphere driving force enabling higher P use efficiency and crop productivity. *Journal of Advanced Research* 38, 13-28.
- Gajera, R.J., Khafi, H.R., Raj, A.D., Yadav, V., Lad, A.N., 2014. Effect of phosphorus and biofertilizers on growth, yield and economics of summer green gram (*Vigna radiata* L. Wilczek). *Agriculture Update* 9 (1), 98–102.
- Gebremariam, M., Tesfay, T., 2021. Effect of P Application Rate and Rhizobium Inoculation on Nodulation, Growth, and Yield Performance of Chickpea (*Cicer arietinum* L.). *International Journal of Agronomy* <https://doi.org/10.1155/2021/8845489>.
- Hakim, S., Naqqash, T., Nawaz, M. S., Larai, I., Siddique, M. J., Zia, R., Mirza, M. S., Imran, A., 2021. Rhizosphere Engineering with Plant Growth-Promoting Microorganisms for Agriculture and Ecological Sustainability. *Frontiers in Sustainable Food System* <https://doi.org/10.3389/fsufs.2021.617157>.
- Heuer, S., Gaxiola, R., Schilling, R., Herrera-Estrella, L., López-Arredondo, D., Wissuwa, M., 2017. Improving phosphorus use efficiency: a complex trait with emerging opportunities. *Plant Journal* 90, 868–885. doi:10.1111/tbj.13423.
- Jakhar, S. R., Kumar, V., Mitra, N. G., 2018. Effect of seed inoculation with liquid and carrier based Rhizobium cultures and phosphorus levels on rhizobia population and yield of soybean (*Glycine max*). *Annals of Plant and Soil Research* 20 (2), 197–202.
- Jayshree, P., Umesha, C., 2021. Effect of biofertilizers and phosphorus on growth parameters and yield of Cowpea (*Vigna unguiculata* (L.) Walp.) in sandy loam soil. *Environment Conservation Journal* 22 (1&2), 137-141.
- Jothimani, K., Arulbalachandran, D., 2020. Physiological and biochemical studies of black gram (*Vigna mungo* (L.) Hepper) under polyethylene glycol induced drought stress. *Biocatalysis and Agricultural Biotechnology* 29, 101777.
- Kalayu, G., 2019. Phosphate Solubilizing Microorganisms: Promising Approach as Biofertilizers. *International Journal of Agronomy* <https://doi.org/10.1155/2019/4917256>.
- Kant, S., Kumar, A., Kumar, S., Kumar, V., Pal, Y., Shukla, A.K., 2016. Effect of Rhizobium, PSB and P-levels on Growth, Yield Attributes and Yield of Urdbean (*Vigna mungo* L.). *Journal of Pure and Applied Microbiology* 10(4), 3093-3098.
- Khuntia, D., Panda, N., Mandal, M., Swain, P., Sahu, S. G., Pattanayak, S. K., 2022. Symbiotic Effectiveness of Acid Tolerant Nodulating Rhizobia on Growth, Yield and Nutrient Uptake of Pigeon pea (*Cajanus cajan* L.) in Acidic Alfisols. *International Journal of Bio-resource and Stress Management* 13 (1), 403 – 410.
- Korir, H., Mungai, N. W., Thuita, M., Hamba, Y., Masso, C., 2017. Co-inoculation Effect of Rhizobia and Plant Growth Promoting Rhizobacteria on Common Bean Growth in a Low Phosphorus Soil. *Frontiers of Plant Sciences*. <https://doi.org/10.3389/fpls.2017.00141>
- Kumar, J., 2011. Effect of phosphorus and rhizobium inoculation on the growth, nodulation and yield of garden pea (*Pisum Sativum* L.) CV. “Mattar Ageta-6” *Legume Research* 34 (1), 20–25.

- Kumawat, P.K., Tiwari, R. C., Golada, S. L., Garhwal, R. K., Choudhary, R., 2013. Effect of phosphorus sources, levels and biofertilizers on yield attributes, yield and economics of black gram [*Phaseolus mungo* (L.)]. *Legume Research* 36 (1), 70-73.
- Masson-Boivin, C., Sachs, J. L., 2018. Symbiotic nitrogen fixation by rhizobia — the roots of a success story. *Current Opinion in Plant Biology* 44, 7–15.
- Mitter, E. K., Tosi, M., Obregón, D., Dunfield, K. E., Germida, J. J., 2021. Rethinking Crop Nutrition in Times of Modern Microbiology: Innovative Biofertilizer Technologies. *Frontiers in Sustainable Food System* <https://doi.org/10.3389/fsufs>. Vol.5.
- Nikfarjam, S.G., Aminpanah, H., 2015. Effect of phosphorus fertilization and pseudomonas fluoresces strains on the growth and yield of faba bean (*Vicia faba*). *Idesia* 33 (4), 15–21.
- Pandey, D., Tomar, S. S., Singh, A., Pandey, A. K., Kumar, M. 2018. Effect of land configuration and nutrient management regimes on performance and productivity of black gram (*Vigna mungo* L.). *Annals of Plant and Soil Research* 20 (2), 125–129.
- Sahoo, R. K., Ansari, M. W., Pradhan, M., Dangar, T. K., Mohanty, S., Tuteja, N., 2014. Phenotypic and molecular characterization of efficient native Azospirillum strains from rice fields for crop improvement. *Protoplasma*. doi:10.1007/s00709-013-0607-7.
- Saren, S., Mishra, A., Dey, P., 2017. Integrated nutrient management and formulation of targeted yield equations for black gram (*Vigna mungo* L.). *Current Science* 113, 314-17.
- Sasidhar, P., Singh, S., Sanodiya, L. K., 2022. Effect of spacing and biofertilizer on growth and yield of black gram (*Vigna mungo* L.). *The Pharma Innovation Journal* 11 (2), 2866-2869.
- Singh, J., Bhatt, R., Dhaliwal, S. S., Dhillon, B. S., AlHuqail, A. A., Alfagham, A., 2022. Integrated use of phosphorus, farmyard manure and biofertilizer improves the yield and phosphorus uptake of black gram in silt loam soil. *PLoS ONE* 17 (4).
- Weikard, H. P., 2016. Phosphorus recycling and food security in the long run: a conceptual modelling approach. *Food Security* 8, 405–414. doi:10.1007/s12571-016-0551-4.
- Wu, S. C., Cao, Z. H., Li, Z. G., Cheung, K. C., Wong, M.H., 2005. Effects of biofertilizer containing N-fixer, P and K solubilizers and AM fungi on maize growth: A greenhouse trial. *Geoderma*, 125, 155-166.
- Yamuna, P., Solanki, R. M., Malam, K. V., 2022. Response of fenugreek (*Trigonella foenum-graecum* L.) to varying fertilizer levels and bio-fertilizer inoculations under South Saurashtra conditions. *The Pharma Innovation Journal* 11(5), 2401-2407.