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Influence of Fertility Levels, Biofertilizers and Stress Extenuating Chemicals on Growth and Yield of Mungbean (*Vigna Radiata* L.)

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Abstract

A field experiment was conducted during the *kharif* seasons of 2023 and 2024 at Suresh Gyan Vihar University, Jaipur, to evaluate the effects of integrated nutrient management and stress-mitigating treatments on mungbean (*Vigna radiata* L.). The experiment was laid out in a split-plot design with three replications, comprising 36 treatment combinations. Main plots consisted of four fertility levels: control, 50%, 75%, and 100% of the Recommended Dose of Fertilizers (RDF). Sub-plots included nine treatments involving *Rhizobium*, Phosphate Solubilizing Bacteria (PSB), thiourea (500 ppm), and salicylic acid (200 ppm), applied individually and in combination. The results indicated that the application of 100% RDF recorded significantly superior growth, physiological parameters, and yield attributes, resulting in the highest seed yield (895 kg ha^{-1}), straw yield (2104 kg ha^{-1}), biological yield (2997 kg ha^{-1}), and harvest index (29.74%). Its performance was statistically at par with 75% RDF. Among the biofertilizer and chemical treatments, the combination of *Rhizobium* + PSB + salicylic acid (200 ppm) proved most effective, producing the highest seed yield (880 kg ha^{-1}) and harvest index (29.71%), though it was statistically comparable to *Rhizobium* + PSB + thiourea (500 ppm). The study concludes that 75–100% RDF, integrated with dual inoculation of *Rhizobium* and PSB along with foliar application of either salicylic acid or thiourea, can significantly enhance mungbean productivity by improving growth, physiological efficiency, and yield components under semi-arid conditions.

Keywords: Mungbean; Integrated Nutrient Management; Salicylic Acid; Thiourea; Biofertilizers

1. Introduction

Mungbean (*Vigna radiata* L.) is one of the major pulse crops grown across various agro-ecological areas globally (Khan *et al.,* 2012). It is valued for its rich protein and vitamin A content and helps provide a balanced diet when consumed along with cereals that are generally low in protein (Rahman *et al.,* 2008). It is a short-tenure and drought-forbearing crop, well adapted to harsh environmental conditions, and can be successfully cultivated in rainfed regions (Anjum *et al.,* 2011). Mungbean is cultivated globally on an estimated 7.3 million hectares, with an average productivity of 721 kg ha^{-1}, resulting in a total production of approximately 5.3 million tonnes. Nearly one-third of this global output originates from India and Myanmar, while other significant contributors include China, Indonesia, Thailand, Kenya, and Tanzania (Nair et al., 2020). Mungbean is cultivated on an average of 3.7 million hectares during the *kharif* season in India, producing approximately 1.76 million tonnes, with an average yield of 476 kg ha^{-1}. Among *kharif* pulses, mungbean constitutes about 27% of the area under cultivation and contributes around 22% of total production. The major mungbean-growing states include Rajasthan, Maharashtra, Karnataka, Gujarat, Telangana, Odisha, Madhya Pradesh, Haryana, Jharkhand, and Tamil Nadu (DES, 2024).

Greengram [*Vigna radiata* (L.) Wilczek] cultivation is frequently constrained by suboptimal vegetative growth and reduced seed yield, challenges predominantly related to inadequate nutrient management and diminished soil fertility. Key factors include nitrogen losses from leaching and volatilization, alongside phosphorus immobilization due to soil

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fixation. These nutrient limitations become particularly acute during the critical reproductive phases of flowering and pod formation, often manifesting in significant flower and pod abortion, which curtails final yield potential. The crop requires a greater nitrogen supply during its reproductive phase; however, nutrient uptake after flowering tends to slow down or cease because of reduced root activity. An adequate and balanced source of nitrogen and phosphorus tremendousely influences the growth and yield of mungbean, with both nitrogenous and phosphatic fertilization contributing to improved productivity in summer-grown crops. (Singh and Meena, 2020). In the early growth stages, before the development of branches, mungbean plants are unable to effectively fix atmospheric nitrogen due to the limited presence or absence of rhizobia. Supplying nitrogen fertilizer during this initial phase enhances vegetative growth and establishes favorable conditions for achieving higher yields (Yanni *et al.,* 2001). Phosphorus (P) fertilization stimulates root development, strengthens disease resistance, and improves drought tolerance. It also enhances the capacity of seedlings to absorb water and nutrients, particularly after depletion of their endosperm reserves (Jian *et el*., 2014). Potassium (K) fertilization is crucial for optimizing physiological functions that directly impact crop performance. Potassium enhances sugar metabolism, regulates cellular osmotic balance, and maintains turgor pressure in stomatal guard cells to facilitate stomatal movement. These roles underpin its essential contribution to photosynthesis and improved drought tolerance, culminating in increased crop yield (Debbarma *et al*., 2020).

One of the major focuses of modern agricultural research is to reduce dependence on expensive agrochemicals and synthetic fertilizers. The extreme application of these chemicals has drastic results on both environment and human fitness. Although chemical fertilizers are mainly applied to replenish nitrogen in the soil, their continuous use presents several drawbacks. They are costly when applied in large amounts and contribute significantly to environmental pollution through soil and water contamination. This situation highlights the urgent need for sustainable and eco-friendly agricultural practices that are both cost-effective and beneficial to human health and the environment (Singh *et al.,* 2013). Biofertilizers play a crucial role in improving plant nutrition by converting atmospheric nitrogen into forms that are readily available to plants. In addition to being cost-effective, they are environmentally sustainable sources of essential nutrients and can effectively complement chemical fertilizers. Their use helps reduce dependence on synthetic fertilizers, thereby promoting sustainable agricultural practices (Meena et al., 2020). Biofertilizers constitute a class of microbial inoculants comprising specific, effective strains of bacteria or fungi. These microorganisms enhance soil fertility through biological processes, primarily atmospheric nitrogen fixation and the solubilization of otherwise inaccessible phosphate compounds. These microorganisms, derived from living organic cells, transform essential nutrients from forms that are otherwise unavailable into forms easily absorbed by plants. To maximize their benefits, biofertilizers are applied to the soil, increasing the population of these beneficial microbes. This enhanced microbial activity improves nutrient availability, allowing plants to efficiently take up these nutrients and support better growth and development (Sood *et al.,* 2023).

Biotic stresses, including diseases caused by bacteria and viruses, along with abiotic stresses like drought, high temperatures, and salinity, are crucial factors which reduce crop yield (Singh and Meena, 2020). Among environmental factors, water stress is the most significant constraint on crop production. Ensuring sustainable crop yields under conditions of water scarcity is a critical global challenge. Rainfed agriculture holds a special position in Indian farming, covering 56.1% of the cultivated area and contributing 24.5% of food grain production and 31.6% of livestock output (Singh and Meena, 2019). Water is essential for achieving optimal mungbean yields. Various stress-mitigating chemicals are applied in agriculture to improve crop productivity by enhancing water use efficiency. These compounds help improve the partitioning of assimilates and support higher yields under conditions of water deficiency and environmental stress (Hayat et al., 2009). Thiourea (TU) contains a sulfhydryl (–SH) group, with 42.10% sulfur (S) and 36.80% nitrogen (N). Foliar application of thiourea (TU) serves as a key management strategy for enhancing crop productivity and improving water use efficiency (WUE). Research also indicates that the loss of reactive –SH groups in membrane proteins may be a key mechanism underlying water stress in plants (Anjum *et al.,* 2011). Thiourea (TU) functions as a chemical catalyst within the plant, enhancing both physiological and reproductive performance. It improves sucrose transport and increases the plant's tolerance to water stress (Dadhich *et al.,* 2014). Salicylic acid (SA) is an endogenous phenolic phytohormone that plays a pivotal role in regulating key physiological processes, including plant growth, development, fruit ripening, and responses to both abiotic stress and pathogen defense. Research suggests that SA has significant agronomic potential for enhancing water stress tolerance in important crop species (Khan *et al.,* 2015). Foliar application of SA at low concentrations enhances photosynthesis, growth, and other physiological and biochemical mechanism in plants, while increased dose level can induce water stress (Hayat *et al.,* 2010). SA can elevate the free radical scavenging capacity of plants and stimulate the production of defence-related compounds, thereby improving their tolerance to water stress (Fayez and Bazaid, 2014).

Thus, it has been proved that the combined application of fertilizers, biofertilizers, and stress-mitigating chemicals enhances nutrient uptake, thereby improving crop growth and yield. The positive effects of these stress chemicals on growth traits may be attributed to their stimulatory impact on physiological processes, including enhanced photosynthetic efficiency, which collectively contribute to overall improvements in growth, yield components, and plant water status. In light of these considerations, the current experimental work was carried.

2. Materials and Methods

A field experiment was conducted during the *kharif* seasons of 2023 and 2024 at the Agricultural Research Farm of the School of Agriculture, Suresh Gyan Vihar University, Jaipur. The soil at the experimental site was loamy in texture, with an average pH of 8.3 and 8.2 for the respective years. Initial soil analysis revealed the following nutrient status: organic carbon (0.14% in 2023 and 0.13% in 2024), available nitrogen (126.5 and 128.5 kg ha^{-1}), phosphorus (16.7 and 17.2 kg ha^{-1}), potassium (176.6 and 178.2 kg ha^{-1}), and sulfur (8.47 and 9.40 mg kg^{-1}). The research work was done out in a split-plot design with 3 replications. The trial comprised 36 treatment combinations, structured in a split-plot design with four fertility levels assigned to the main plots. control, RDF (50%, 75% and 100% respectively), while 9 biofertilizers and stress mitigating chemicals in sub-plot *viz.,* (i) *rhizobium*, (ii) *rhizobium* + thiourea 500 ppm, (iii) *rhizobium* + salicylic acid 200 ppm, (iv) PSB, (v) PSB + thiourea 500 ppm, (vi) PSB + salicylic acid 200 ppm, (vii) *rhizobium* + PSB (viii) *Rhizobium* + PSB + thiourea 500 ppm and (ix) *Rhizobium* + PSB + salicylic acid 200 ppm. The mungbean (*Vigna radiata* L.) variety 'RMG 975' was sown at a seed rate of 20 kg ha^{-1} with a spacing of 30 cm between rows and 10 cm between plants. The suggested dose of NPKS 20-50-50-25 kg ha^{-1} were applied through urea, Diammonium phosphate (DAP), muriate of potash (MOP), and elemental S, respectively. Crop was grown totally based on rainfall. The foliar application of Thiourea solution of 500 mg L^{-1} and Salicylic acid 200 mg L^{-1} was applied at flower initiation and pod formation stage. Knapsack sprayer with a flat fan nozzle was used for foliar application. To control the attack of insects, application of insecticides such as 0.5% monocrotophos @1.5 ml $litre^{-1}$ water and chloropyriphos 50% @ 2 ml $litre^{-1}$ water, respectively. All standard agronomic practices for mungbean cultivation, except the imposed experimental treatments, were uniformly maintained across all plots.

3. Results and Discussion

3.1. Growth Parameters

3.1.1. Effect of Fertility Levels

The application of different fertility levels significantly enhanced key growth parameters in the pooled analysis (Table 1; Fig. 1). Specifically, plant height (cm), number of branches and nodules ($plant^{-1}$), and dry matter accumulation (DMA) (g $plant^{-1}$) measured at 30, 45 days after sowing (DAS), and at harvest were increased. Furthermore, crop growth rate (CGR) (g $plant^{-1}$ day^{-1}), relative growth rate (RGR), and net assimilation rate (NAR) (g g^{-1} day^{-1}), during the 30-45 DAS and 45 DAS-to-harvest intervals were also significantly improved.

The highest values for plant height (17.23, 38.76, and 56.19 cm at 30 DAS, 45 DAS, and harvest, respectively), branches per plant (4.41, 8.55, and 9.25), and nodules per plant (15.15, 22.85, and 5.35) were recorded with the application of 100% of the Recommended Dose of Fertilizers (RDF). These results were statistically at par with those obtained from the 75% RDF treatment in the pooled analysis (Table 1). The enhance in these growth components appears to be associated with a higher availability of growth substances and naturally occurring phytohormones resulting from improved nutrient supply. The enhanced auxin levels under higher fertility conditions likely contributed to this increase. This enhancement can be attributed to the improved and timely availability of nitrogen and phosphorus in the rhizosphere. This favourable nutrient regime created an optimal root-zone environment, thereby supporting robust vegetative growth and development. These nutrients are among the most essential for plant growth and development. These results are in agreement with the findings of Chattopadhyay and Dutta (2003) in cowpea, Choudhary and Yadav (2011) in cowpea, Jagtap et al. (2022) in green gram, Kalsaria et al. (2017) in green gram and Patel et al. (2016).

Furthermore, DMA was significantly higher with the application of 100% RDF (0.93, 4.95, and 11.33 g $plant^{-1}$ at 30 DAS, 45 DAS, and harvest, respectively), a result that remained statistically at par with 75% RDF. This can be attributed to the enhanced plant height and branch number, which collectively increased the photosynthetic leaf area, thereby boosting overall dry matter production. The enhanced availability of nitrogen in otherwise nutrient-poor soils likely increased both cell number and cell size, leading to improved plant growth in terms of height and dry weight residues. Nitrogen also boosts the photosynthetic rate, thereby increasing carbohydrate supply to the plant and contributing to higher dry matter production. Similarly, the increased availability of phosphorus, a crucial nutrient for all living organisms, has importance in energy conservation and transfer during metabolic reactions, including biological energy transformations. Higher fertility levels may also have elevated auxin concentrations, further promoting dry matter accumulation and biomass production. The observed vigorous plant growth can be attributed to the enhanced energy supply from photosynthesis and carbohydrate metabolism, which is stored in compounds like ATP and ADP. These findings align with previous research on mungbean, which similarly links improved energy status to increased vegetative growth (Dongare et al., 2016; Luikham et al., 2005; Kumawat et al., 2010; Mathur et al., 2007).

Furthermore, the application of 100% RDF significantly enhanced key growth rates in the pooled analysis. It resulted in the highest crop growth rate (CGR: 0.268 g plant^{-1} day^{-1} at 30-45 DAS and 0.426 g plant^{-1} day^{-1} from 45 DAS to harvest), relative growth rate (RGR: 0.117 g g^{-1} day^{-1} at 30-45 DAS and 0.185 g g^{-1} day^{-1} from 45 DAS to harvest), and net assimilation rate (NAR: 0.0318 g g^{-1} day^{-1} at 30-45 DAS and 0.0792 g g^{-1} day^{-1} from 45 DAS to harvest). These values were statistically at par with those obtained from the 75% RDF treatment (Fig. 1). As mentioned above the elevating echelons of fertility increased in quantity of branches (Table 1) that results in dry weight residues (Table 1). These parameters increased the CGR, RGR, and NAR of the crop. The result of the present investigation conforms with the findings of Sammauria et al. (2009) in clusterbean, Singh et al. (2017) in mungbean and Saini et al. (2017) in green gram.

3.1.2. Effect of biofertilizers and stress mitigating chemical

The application of different biofertilizers and stress-mitigating chemicals significantly enhanced mungbean growth parameters in the pooled analysis (Table 1 & Fig. 1). These treatments improved vegetative growth, as evidenced by increased plant height (cm), number of branches and nodules (plant^{-1}), and DMA (g plant^{-1}) measured at 30 and 45 DAS and at harvest. Furthermore, key physiological rates were also positively affected, including the CGR (g plant^{-1} day^{-1}), RGR, and NAR (g g^{-1} day^{-1}), during the 30–45 DAS and 45 DAS-to-harvest intervals. The significantly maximum plant height, number of branches plant^{-1}, number of nodules plant^{-1}, DMA, CGR, RGR and NAR were observed with the application of *Rhizobium* +PSB+ salicylic acid 200 ppm and was found statistically at par with the application of *Rhizobium* +PSB+ thiourea 500 ppm in pooled analysis (Table 1). This enhancement can be attributed to improved nutrient supply during the initial growth stages and increased nodulation by *Rhizobium*. The resulting rhizosphere microbial activity facilitates physiological modifications in the plant, which in turn improves nutrient acquisition and availability in the root zone (Adhithya et al., 2023). The modification of phosphorus into plant-available forms during the vegetative growth stage, facilitated by phosphate-solubilizing bacteria (PSB) inoculation, likely enhanced the uptake of both macro- and micronutrients, contributing to an increased number of branches per plant, as reported by Prakash et al. (2012). Salicylic acid, supports growth and development by regulating key physiological and hormonal processes, including physiological growth of seeds, vegetative development, photosynthesis, respiration, thermogenesis, flowering, seed production, and cell death. Bisht et al. (2000) observed that foliar spray of salicylic acid enhanced the net photosynthetic rate. SA also functions as a key signalling molecule, increasing plant tolerance to abiotic stresses. It plays an important role in plant growth, as well as in the uptake and transport of ions. Additionally, SA participates in endogenous signalling pathways that activate plant defences against pathogens. The enhancement of growth parameters following salicylic acid (SA) application is attributed to its role in stimulating key physiological processes, including cell division and elongation, photosynthetic efficiency, and the translocation of nutrients and photosynthates. This positive influence of SA on vegetative growth aligns with previous findings (Ali & Mahmoud, 2013; Majeed et al., 2016; Sher et al., 2017).

Table 1 Effect of fertility levels, biofertilizers and stress mitigating chemicals on growth parameters of mungbean at successive growth stages (Pooled)

Treatment	Plant height (cm)			Number of branches plant^{-1}			Number of nodules plant^{-1}			Dry matter accumulation (g plant^{-1})		
	30 DAS	45 DAS	At harvest	30 DAS	45 DAS	At harvest	30 DAS	45 DAS	At harvest	30 DAS	45 DAS	At harvest
Fertility Levels												
Control	11.71	26.30	38.16	2.99	5.81	6.28	10.30	15.52	3.64	0.63	3.37	7.65
50 % RDF	14.67	32.98	47.82	3.75	7.28	7.87	12.90	19.45	4.56	0.79	4.22	9.62
75 % RDF	16.73	37.61	54.56	4.27	8.30	8.98	14.71	22.19	5.20	0.90	4.81	10.99
100 % RDF	17.23	38.76	56.19	4.41	8.55	9.25	15.15	22.85	5.35	0.93	4.95	11.33
SEm±	0.16	0.34	0.41	0.03	0.06	0.07	0.12	0.17	0.04	0.01	0.04	0.09
CD (P=0.05)	0.51	1.05	1.26	0.11	0.19	0.21	0.37	0.53	0.13	0.02	0.11	0.27
Biofertilizers + Stress Mitigating Chemicals												

Rhizobium	13.58	30.47	44.26	3.47	6.74	7.29	11.94	18.00	4.22	0.73	3.91	8.89
Rhizobium+ thiourea 500ppm	15.20	34.18	49.57	3.88	7.55	8.16	13.37	20.16	4.72	0.82	4.37	9.98
Rhizobium+ salicylic acid 200ppm	15.43	34.69	50.30	3.94	7.66	8.28	13.57	20.46	4.79	0.83	4.44	10.13
PSB	13.09	29.42	42.68	3.35	6.50	7.02	11.52	17.36	4.07	0.70	3.77	8.57
PSB+ thiourea 500ppm	14.25	32.04	46.47	3.64	7.08	7.65	12.54	18.90	4.43	0.77	4.10	9.34
PSB+ salicylic acid 200ppm	14.54	32.68	47.39	3.71	7.22	7.80	12.79	19.28	4.52	0.78	4.18	9.53
Rhizobium **+**PSB	15.92	35.79	51.90	4.07	7.90	8.54	14.00	21.11	4.95	0.86	4.58	10.45
Rhizobium +PSB+ thiourea 500ppm	16.76	37.70	54.67	4.30	8.32	9.00	14.74	22.23	5.21	0.90	4.82	11.01
Rhizobium +PSB+ salicylic acid 200ppm	16.99	38.21	55.41	4.34	8.43	9.12	14.94	22.53	5.28	0.91	4.88	11.17
SEm±	0.10	0.18	0.27	0.02	0.04	0.04	0.07	0.11	0.03	0.00	0.02	0.06
CD (P=0.05)	0.27	0.51	0.75	0.06	0.11	0.12	0.21	0.31	0.07	0.01	0.06	0.16

3.2. Yield Attributes and Yield

3.2.1. Effect of Fertility Levels

In the pooled analysis, the different fertility levels significantly improved all measured yield attributes and final yields of mungbean (Table 2). This included the number of pods plant^{-1}, seeds pod^{-1}, pod length (cm), test weight (g), as well as the seed, straw, and biological yields (kg ha^{-1}), and harvest index (HI %). Specifically, the maximum number of pods per plant (20.13) was recorded with the application of 100% of the Recommended Dose of Fertilizers (RDF). This result was statistically at par with the 75% RDF treatment. This effect may be attributed to increased branching and improved nutrient availability, which promoted better flower retention and their conversion into fertile pods. As discussed earlier, adequate nitrogen supply during the early stages of plant growth is crucial for rapid vegetative development and biomass accumulation. Consequently, nitrogen fertilization enhanced seed setting and improved yield-related traits in mungbean. These findings align with previous reports demonstrating the positive influence of optimal fertility on legume yield attributes in crops such as green gram (Yakadri et al., 2002), cowpea (Patel et al., 2003), and clusterbean (Meena et al., 2018).

Moreover, the application of 100% RDF resulted in the highest values for seeds pod^{-1} (8.58), pod length (8.55 cm), and test weight (32.95 g). These results were statistically at par with those from the 75% RDF treatment in the pooled analysis. As established earlier, phosphorus is instrumental in cellular energy transfer and storage, processes that are fundamental to reproductive development and seed filling. During certain developmental stages, plants produce more assimilates than are immediately required for growth, with the excess being stored in reserve compounds. Subsequently, during the reproductive phase, when the demand for assimilates in developing pods and seeds exceeds the supply from concurrent photosynthesis, these stored reserves are remobilized to the active sinks. This process enhances pod set and seed number. Furthermore, nutrients including carbohydrates, nitrogen, phosphorus, and other mobile elements are translocated from senescing leaves to adjacent sinks, primarily the seeds, promoting seed filling and increasing test weight. Similar mechanisms of nutrient remobilization contributing to reproductive yield have been reported in mothbean (Patel et al., 2004), green gram (Salvi et al., 2004; Karwasra et al., 2006), and mungbean (Ibrahim & Al-Bassyuni, 2012).

Furthermore, the application of 100% of the RDF, significantly increased mungbean seed yield (895 kg ha^{-1}), straw yield (2104 kg ha^{-1}), and biological yield (2997 kg ha^{-1}). These results were statistically at par with those obtained from the 75% RDF treatment in the pooled analysis (Table 2). Seed and straw yields increased significantly with rising fertilizer levels up to 75% RDF, likely due to the improved nutrient availability in the soil, which enhanced the overall crop nutrition and growth. The enhanced availability and uptake of N, P, and K likely stimulated key physiological processes, thereby improving overall crop growth and development, which culminated in increased seed and straw yields. Since biological yield is the sum of these two components, its significant increase under optimum fertility is a direct consequence of improved seed and straw production. These findings align with previous research on legumes, which similarly report that balanced nutrition enhances biomass partitioning and grain yield in green gram (Mathur et al., 2007; Manoj et al., 2014), groundnut (Meena et al., 2013), and mungbean (Dhakal et al., 2015).

3.2.2. Effect of biofertilizers and stress mitigating chemical

The pooled analysis indicated that the application of biofertilizers and stress-mitigating compounds significantly enhanced mungbean productivity. The treatments increased primary yield components, specifically the number of pods $plant^{-1}$, seeds pod^{-1}, pod length (cm), and test weight (g). This improvement in yield attributes subsequently resulted in elevated seed, straw, and biological yields (kg ha^{-1}), alongside an improved harvest index (HI %) (Table 2). The maximum number of pods $plant^{-1}$ (19.85), seeds pod^{-1} (8.46), length of pod (8.43), test weight (32.49g), seed yield (880 kg ha^{-1}), straw yield (2104 kg ha^{-1}) and biological yield (2939 kg ha^{-1}) were significantly observed after supplementation of *Rhizobium* +PSB+ salicylic acid 200 ppm and found statistically same with the application of *Rhizobium* +PSB+ thiourea 500 ppm in pooled analysis. The increase in branching and improved nutrient availability likely promoted better flower retention and conversion into fertile pods. The dual inoculation of *Rhizobium* and phosphate-solubilizing bacteria (PSB) significantly enhanced root system development, including nodulation, thereby improving nutrient acquisition. This promoted vigorous plant growth and greater dry matter accumulation, which subsequently improved reproductive performance by enhancing flowering, pod set, and final pod yield. Additionally, PSB may have reduced phosphorus fixation and solubilized unavailable phosphorus, increasing nutrient accumulation by crop and ultimately contributing to higher yields (Vanitha, *et al.,* 2014). The same results observed by Rathour et al. (2015) and Singh et al. (2022). Foliar application of salicylic acid (SA) had a significant positive effect on yield attributes and overall yield compared to the control. The influence of SA on physiological processes varies, as it can stimulate certain functions while inhibiting others based on its dose, crop varieties, physiological growth, and ecological factors. The effectiveness of any externally applied plant hormone is often assessed in terms of its impact on biological yield. As a natural signalling molecule, SA plays a key role in regulating multiple physiological phenomenons, including those affecting yield. The observed elevation in crop yield may be attributed to the delayed senescence of plant organs in response to exogenous SA, which extends the duration of photosynthetically active tissues and helps protects untimely loss of flowers and pods. These findings are consistent with the results reported by Singh et al. (2017) for mungbean and Leila et al. (2014) for fenugreek.

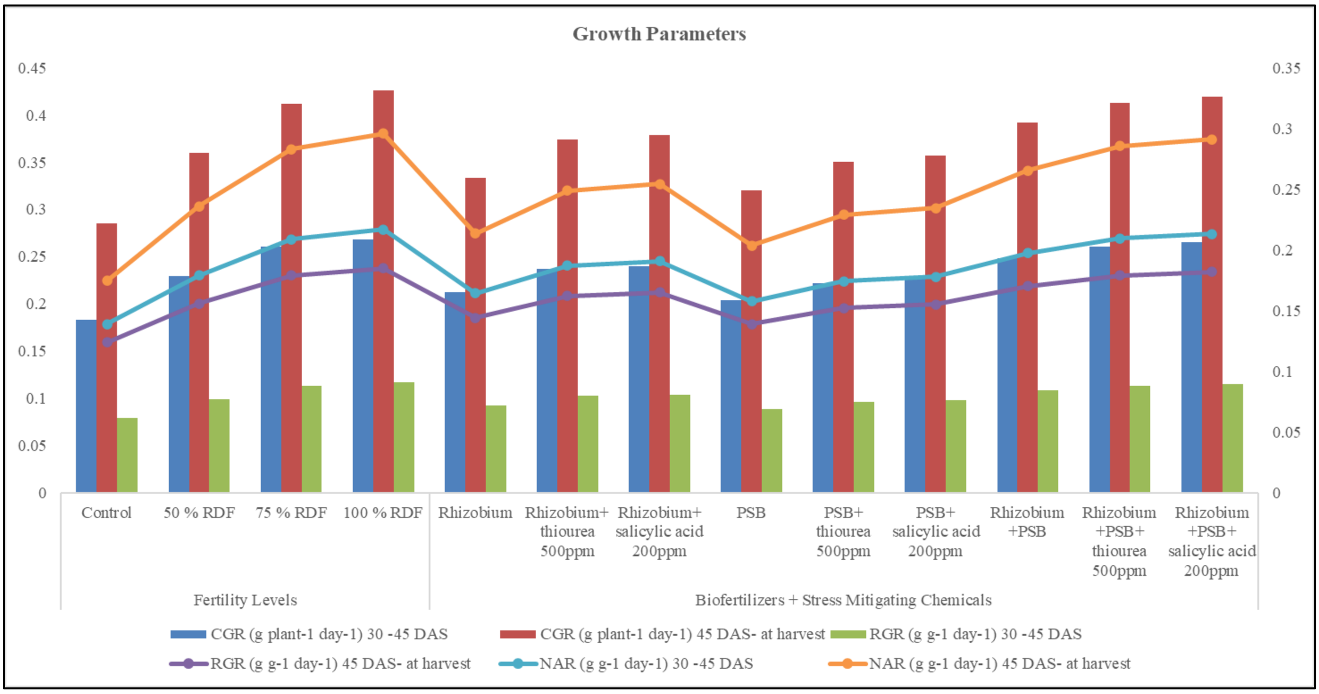

Figure 1 Effect of fertility levels, biofertilizers and stress mitigating chemicals on growth parameters of mungbean at successive growth stages (Pooled)

Table 2 Effect of fertility levels, biofertilizers and stress mitigating chemicals on yield attributes of mungbean (pooled)

Treatment	Yield attributes				Yield			Harvest index (%)
	Number of pods plant^{-1}	Number of seeds pod^{-1}	Length of pod (cm)	Test weight (g)	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	
Fertility Levels								
Control	13.70	5.83	5.81	22.36	554	1678	2233	24.69
50 % RDF	17.14	7.30	7.28	28.04	737	1922	2658	27.63
75 % RDF	19.55	8.33	8.30	31.99	864	2068	2930	29.43
100 % RDF	20.13	8.58	8.55	32.95	895	2104	2997	29.74
SEm±	0.15	0.07	0.06	0.25	6.76	17.48	24.01	0.10
CD (P=0.05)	0.47	0.20	0.20	0.76	20.82	53.87	73.99	0.31
Biofertilizers + Stress Mitigating Chemicals								
Rhizobium	15.90	6.76	6.73	25.95	669	1849	2519	26.28
Rhizobium+ thiourea 500ppm	17.76	7.57	7.54	29.06	770	1949	2719	28.11
Rhizobium+ salicylic acid 200ppm	18.02	7.68	7.65	29.49	783	1963	2747	28.32
PSB	15.30	6.52	6.49	25.02	640	1819	2459	25.69
PSB+ thiourea 500ppm	16.65	7.10	7.07	27.24	711	1895	2602	27.05

PSB+ salicylic acid 200ppm	16.98	7.24	7.21	27.79	729	1908	2637	27.40
Rhizobium +PSB	18.60	7.92	7.90	30.43	814	1993	2807	28.81
Rhizobium +PSB+ thiourea 500ppm	19.59	8.34	8.32	32.06	866	2050	2911	29.49
Rhizobium +PSB+ salicylic acid 200ppm	19.85	8.46	8.43	32.49	880	2060	2939	29.71
SEm±	0.10	0.05	0.04	0.16	4.94	7.41	9.22	0.08
CD (P=0.05)	0.28	0.13	0.12	0.44	13.81	20.74	25.79	0.23

4. Conclusion

Based on a two-year field study, it is concluded that the application of 100% of the Recommended Dose of Fertilizers (RDF) with a combined treatment of *Rhizobium* + Phosphate Solubilizing Bacteria (PSB) + salicylic acid (200 ppm) constitutes the optimal agronomic practice for mungbean cultivation under semi-arid conditions. This integrated approach significantly enhanced vegetative growth, physiological efficiency, and key yield components, culminating in superior seed yield and harvest index. The performance of 100% RDF was statistically equivalent to 75% RDF, indicating a flexible fertility range. Furthermore, the efficacy of the *Rhizobium* + PSB + salicylic acid combination was statistically comparable to *Rhizobium* + PSB + thiourea, offering a choice of effective stress-mitigating agents for sustainable productivity enhancement.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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