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Response of mung bean to exogenous applied sulphur and aspartic acid in hot arid region of Rajasthan

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Abstract

Balanced nutrient management is a major concern in the present-day scenario, especially in soils of arid regions, which are low in soil fertility; hence, supplementation of sulphur (S) helps in plant growth and maintenance of soil health. The use of amino acids as biostimulants has gained widespread importance in recent times. L-aspartic acid (ASP) is one of the amino acids, which plays a key role in plant growth and stress management. No studies have reported the use of ASP in mung bean; therefore, the present study investigates the effect of graded levels of S application in soil and foliar application of ASP on growth and yield of mung bean. The field experiment was conducted during kharif 2024 and 2025 at Central Arid Zone Research Institute, Jodhpur in a split plot design containing four main plots (0, 20, 40 and 60 kg sulphur ha^{-1}) and four subplots (0, 40, 80 and 120 mg L^{-1} aspartic acid) with 3 replications. Our research findings revealed that both S and ASP positively improved the growth parameters and yield of mung beans. Relative to the control, the improvement in plant height, leaf area index (LAI), dry matter production, specific leaf weight (SLW), crop growth rate (CGR), net assimilation rate (NAR) and grain yield was 18.3, 15.8, 47.2, 17.1, 52.8, 30.0 and 72.6 %, respectively, by S60 (pooled). Similarly, A120 produced 15.7, 15.1, 34.8, 8.6, 38.2, 19.2 and 25.3 % higher values for the above parameters compared to the control (pooled). The correlation analysis indicated a significantly positive correlation of grain yield with NAR at 25–45 days after sowing (DAS) (0.961 **) and at 45–65 DAS (0.937 **).

Keywords: aspartic acid; crop growth rate; dry matter production; growth; net assimilation rate; sulphur

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Introduction

In recent years, balanced and site-specific nutrient management has gained increasing importance due to disruptions in fertiliser supply chains and rising production costs. Hence, there is a need for adopting balanced and site-specific nutrient management for sustainable crop productivity and profitability (1, 2). In the soils of arid regions, much more emphasis is needed, as the soils are inherently coarse-textured (loamy sand), alkaline in nature, poor in organic matter and soil fertility (3, 4). Hence, proper nutrient management is required. Among the nutrients, sulphur (S) is considered one of the major secondary nutrients, following nitrogen (N), phosphorus (P) and potassium (K) in terms of crop nutrient requirements (5). The low to medium range of S in soils of arid regions is due to poor soil organic matter, the continuous use of high-analysis fertilisers lacking S, conventional agricultural practices and the reduction of S emission by using low-S fuel (6, 7). There is a need to supplement S, particularly in oilseed crops and legumes. In legumes, there is a necessity for S application due to its beneficial role in improving growth and development. It plays a key role in chlorophyll formation, protein synthesis, N metabolism and antioxidant defence mechanisms, which promote photosynthetic efficiency, N fixation, nutrient uptake and dry matter accumulation, thereby enhancing growth and yield of mung bean (*Vigna radiata* L.) (8, 9). One of the major legume crops cultivated in western Rajasthan during kharif is mung bean, covering an area of 23.67 lakh hectare in Rajasthan, which occupies the first place in India (10).

Mung bean (*V. radiata*) is an important pulse crop having good nutritional value, as it contains protein (24–28 %), carbohydrates (59–65 %), fat (1.0–1.5 %) and

fibre (3.5–4.5 %), fulfilling the nutritional requirement (11, 12). The crop is also economically profitable because of its short duration, low input requirement, wider adaptability to adverse climatic conditions and good productivity (13–15). Furthermore, it also has the capacity to improve soil fertility by biological N fixation and reduce the N requirement in the present and immediately sown crop (16). The productivity of the crop is limited by several factors such as abnormal weather conditions, deficiency of soil moisture, low soil fertility and improper nutrient management (17). The nutrient requirement of mung bean mainly includes N, P, K and S. Among these, a major portion of the N requirement is fulfilled by biological N fixation of the crop by nodule formation, as it is a legume crop (18). Phosphorus is supplied through fertiliser and K is highly available in the soil itself, but the use of S is neglected since farmers are unaware of its beneficial role. Therefore, optimising S fertilisation is essential for sustaining mung bean productivity.

Along with the use of fertilisers, biofertilisers and microbial inoculants, the foliar application of amino acids for plant growth improvement and stress mitigation has gained widespread importance in recent times (19–21). L-aspartic acid (ASP) is one of the amino acids which is a component of several biostimulant products. It acts as a precursor of several amino acids, such as lysine, isoleucine, methionine and threonine, which are building blocks of several proteins (22). It also acts as a precursor of metabolites such as glutathione and oxaloacetate, which play a key role in the tricarboxylic acid (TCA) cycle, enhancing the synthesis of adenosine tri phosphates (ATP) and photosynthates (23). L-aspartic acid also enhances plant tolerance to stress conditions such as drought, salinity, temperature and heavy metal stress by stimulating enzymatic and non-enzymatic antioxidant defence mechanisms (24). Several studies have reported enhancements in plant growth parameters such as plant height, leaf area, chlorophyll content and dry matter production by foliar application of ASP (24–26), due to its key role in protein synthesis, photosynthate assimilation and stress mitigation (27). However, information on the response of mung bean to foliar ASP application, particularly under hot-arid conditions and in combination with varying S levels, remains limited.

Therefore, the present study was undertaken to evaluate the effects of soil-applied S levels and foliar-applied ASP levels, individually and in combination, on the growth, yield and productivity of mung bean under the hot-arid conditions of Rajasthan.

Materials and Methods

Study site and weather conditions

A two-year field experiment (kharif 2024 and 2025) was carried out at ICAR-Central Arid Zone Research Institute, Jodhpur, Rajasthan, India, which is located at 26° 24′ N latitude and 73° 00′ E longitude. According to Troll's climatic classification, the experimental site falls under the arid zone and agro-climatic zone IA (Arid Western Plain Zone) among the Rajasthan agroclimatic zones. The soil of the experimental site was loamy sand in texture and slightly alkaline in nature (Table 1). During the crop growth period, rainfall received was 619.2 mm and 526.2 mm for 2024 and 2025, respectively. During the entire crop growth period, average maximum temperature, minimum temperature, pan evaporation and sunshine hours were 34.9 °C, 26.9 °C, 4.6 mm day^{-1} and 5.6 hr day^{-1} respectively, in 2024; the corresponding values for 2025 were 33.7 °C, 26.2 °C, 4.1 mm day^{-1} and 5.9 hr day^{-1} respectively.

Table 1. Chemical properties of experimental field soil at 0–15 cm depth

Sl. No	Properties	Values	Adopted method
1	Soil pH	8.18	(28)
2	Soil EC (dS m^{-1})	0.22	
3	Organic carbon (%)	0.23	(29)
4	Available N (kg ha^{-1})	154.3	(30)
5	Available P_2O_5 (kg ha^{-1})	24.2	(31)
6	Available K_2O (kg ha^{-1})	343.9	(32)
7	Available S (mg kg^{-1})	14.2	(33)

EC: electrical conductivity; N: nitrogen; P_2O_5: potassium pentoxide; K_2O: potassium oxide; S: sulphur.

Experimental design and treatment application

The experiment was laid out in a split plot design with 3 replications. The main plots consisted of four levels of S (S0: 0 kg ha^{-1}, S20: 20 kg ha^{-1}, S40: 40 kg ha^{-1} and S60: 60 kg ha^{-1}) and the sub plots consisted of four levels of ASP (A0: 0 mg L^{-1}, A40: 40 mg L^{-1}, A80: 80 mg L^{-1} and A120: 120 mg L^{-1}). Gross plot size was 5.0 × 4.5 m. Sulphur was applied in the form of elemental S (90 % S) to each plot according to the treatment level, 15 days before sowing the crop and mixed well into the soil by harrowing. The aspartic acid was applied foliarly twice at 20 days after sowing (DAS) and 40 DAS according to the treatment levels with the help of a knapsack sprayer and control plots received a water spray. About 500 L ha^{-1} spray volume was used with no adjuvants.

Crop management

A well-pulverised seed bed was prepared by discing followed by harrowing of the field. The layout was prepared according to the design, followed by sowing of the mung bean seeds at 20 kg ha^{-1} at adequate soil moisture for germination. The recommended dose of fertilisers, i.e., N : P (18 : 46 kg ha^{-1}), was applied as a basal dose in the form of diammonium phosphate (DAP) to all plots equally. The seed variety selected was MH-421 and sowing was carried out with a tractor-drawn seed drill, maintaining a spacing of 45 cm between rows. To maintain optimum plant population with 10 cm between plants, gap filling was done one week after sowing. Hand weeding was done at 15 and 30 DAS to maintain weed-free conditions. Spraying of quinalphos (25 % EC) and carbendazim 12 % + mancozeb 63 % wettable powder (WP) was carried out

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at the flowering stage to control pests and diseases. Harvest was done manually by picking pods from each plot after attaining maturity and pods were subsequently threshed and cleaned to obtain the grain yield per plot, which was then converted to a hectare basis.

Data collection

Growth parameters

The plant height of the mung bean crop was measured on five randomly selected plants from each plot at specified growth stages using a metre scale. Another five plants from each plot in the sampling row were taken by cutting from the base and used to obtain leaf area by measuring with a leaf area meter (Model LICOR-3100); the same samples were oven-dried at 65 ± 5 °C till a constant weight was obtained to record dry weight per plant at different growth stages (25, 45 and 65 DAS). Leaf area index (LAI) was calculated from the recorded leaf area using the following equation:

$$\text{Leaf area index (LAI)} = \frac{\text{Leafarea plant}^{-1}\ (\text{cm}^2)}{\text{Ground area occupied plant}^{-1}\ (\text{cm}^2)}$$

Several other growth indices are calculated by using oven dry weight of the plants substituted according to the formulas given below:

Specific leaf weight

Specific leaf weight (SLW) is an indicator of leaf thickness, photosynthetic capacity and water relations, calculated using following formulae:

$$\text{SLW (mg/cm}^2) = \frac{\text{Leaf dry weight plant}^{-1}}{\text{Leaf area plant}^{-1}}$$

Crop growth rate

Crop growth rate (CGR) is the rate of dry matter produced per unit ground area per unit time, which is calculated using following formulae (34):

$$\text{CGR (g/m}^2\text{/day)} = \frac{W_2 - W_1}{T_2 - T_1} \text{x } \frac{1}{A}$$

where; W_1 = dry weight of plant at T_1 (g plant^{-1}); W_2 = dry weight of plant at T_2 (g plant^{-1}); T_1=days at first stage; T_2 = days at second stage; A = land area (m^2).

Relative growth rate

Relative growth rate (RGR) is a measure of proportional increase in dry weight per unit dry weight already present over a specific time interval, which is calculated by the formula given below (35).

$$\text{RGR (g/g/day)} = \frac{\ln W_2 - \ln W_1}{T_2 - T_1}$$

Where; W_1 = dry weight of the plant at time T_1; W_2 = dry weight of the plant at time T_2;

T_1 = days at first stage; T_2 = days at second stage.

Net assimilation rate

Net assimilation rate (NAR) is the net gain of assimilated substances by the plant per unit leaf area per unit time, which represent the photosynthetic efficiency of plant, which is estimated by using formula given below (35).

$$\text{NAR (g/m}^2\text{/day)} = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{ln\, L_2 - ln\, L_1}{L_2 - L_1}$$

Where; W_1 = dry weight of plant at T_1 (g plant^{-1}); W_2 = dry weight of plant at T_2 (g plant^{-1}); L_1 = leaf area at T_1 (m^2); L_2 = leaf area at T_2 (m^2); T_1 = days at first stage; T_2 = days at second stage.

Grain yield

After attaining maturity, pod picking was done from each plot separately, sun-dried and threshed manually. After proper cleaning, grain yield per plot was obtained, which was converted to per hectare.

Statistical analysis

Two years' data on all observations were subjected to analysis of variance (ANOVA) technique for a split plot design using the standard procedure (36). The significant difference among the treatments was tested at the 5 % level of probability. For the parameters which exhibited significant difference, least significant difference (LSD) was computed. Bartlett's test confirmed the homogeneity of error variances across years (p > 0.05). Consequently, the data were combined over years and subjected to pooled analysis to assess treatment effects and their interactions.

Results and Discussion

The application of graded levels of S and ASP to the mung bean crop showed a significant impact on growth parameters, growth indices and grain yield of mung bean during both the years of investigation (2024 and 2025). While the interaction between S and ASP showed no significant impact on all the parameters during both the years. Similarly, the interactions between years and years with treatments showed no significant impact.

Plant height

The S and ASP application did not increase plant height significantly at 25 DAS; however, at 45 and 65 DAS, plant height was increased significantly by S and ASP levels (Fig. 1). Pooled analysis showed that plant height at 45 and 65 DAS was significantly higher with S60 (44.03 and 59.60 cm) and lowest with the control (36.80 and 50.36 cm). The improvement in plant height by S20, S40 and S60 was 10.1, 13.5 and 19.7 % over the control at 45 DAS, while at 65 DAS it was 4.1, 11.8 and 18.4 % respectively. Application of S had a significant positive impact on chlorophyll content, amino acid synthesis (cysteine and methionine) and enzyme production, leading to increased cell division and elongation, which improved plant growth (37, 38). Application of S at 40 kg ha^{-1} improved plant height in mung bean compared to lower levels (39).

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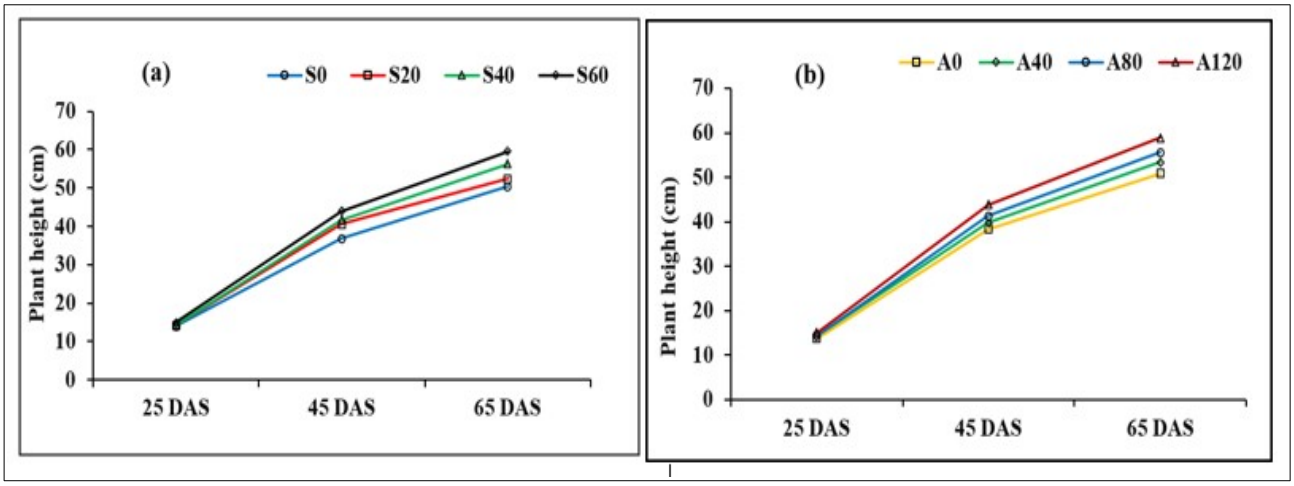


Fig. 1. Plant height of mung bean (pooled) at different growth stages as influenced by graded levels of (a) sulphur and (b) aspartic acid.

Among the ASP levels, significantly superior plant height was recorded with A120 (43.78 and 58.83 cm) and lowest with the control (38.34 and 50.84 cm) at 45 and 65 DAS, respectively. The improvement over the control by A40, A80 and A120 was 3.6, 7.7 and 14.2 % at 45 DAS and 5.1, 9.3 and 15.8 % at 65 DAS (pooled means). This positive impact of aspartic acid on plant height, as it plays a key role in the synthesis of amino acids, proteins and hormonal conjugates, promotes cell division and elongation. In tobacco, a 14.1 % increase in plant height was recorded with foliar application of ASP (10 mM) over the control (40); similarly, the plant height increment observed in paddy was 9 % with 20 mg L^{-1} (25) and 40 % in peanut with 100 mg L^{-1} concentration (20).

Leaf area index

Analysis of the results indicated a significant difference in LAI with the application of S and ASP (Table 2). The plants receiving S60 exhibited significantly higher LAI (1.44 and 1.98), which was at par with S40 (1.39 and 1.90) and lowest with control (1.24 and 1.71) at 45 and 65 DAS, respectively (pooled means). Relative to the control, the increase in LAI was 6.4, 12.1 and 16.1 % by S20, S40 and S60, respectively, at 45 DAS; similarly, at 65 DAS it was 5.3, 11.1 and 15.8 % (pooled means). Higher leaf area and canopy spread result in a higher LAI, as S has a prominent role in the synthesis of several enzymes and chlorophyll in the leaf, which improves assimilation of photosynthates, leading to tissue formation and also increasing the number of leaves, as similarly recorded in mung bean with 40 kg ha^{-1} S (41). Likewise, S at 45 kg ha^{-1} improved LAI by 10.1 % in mung bean (42) and 44.3 % in groundnut (43).

Among the levels of ASP, higher LAI was obtained with A120 (1.44 and 1.98) at 45 and 65 DAS, respectively. The lowest values were recorded with no ASP application (1.25 and 1.72) at 45 and 65 DAS, respectively. The sequential level increase resulted in an increase in LAI by 5.6, 10.4 and 15.2 % at 45 DAS and 4.6, 9.9 and 15.1 % at 65 DAS relative to the control (pooled means). Aspartic acid, being a source of N, improves the growth of the plant, enhancing photosynthetic pigments, which increase the levels of growth hormones such as indole acetic acid, leading to cell division and enlargement (20). In faba bean, 7.1 and 7.8 % increase in LAI was recorded with ASP acid at 150 mg L^{-1} relative to the control in a two-season study (27).

Dry matter production

Dry matter production (g $plant^{-1}$) of mung bean was significantly influenced by both S and ASP levels at different growth stages during both the years (Table 3 and Fig. 2). It clearly showed a positive increase in dry matter production by 3.1, 10.6 and 13.6 % by S20, S40 and S60 relative to the control at 25 DAS; at 45 DAS, it was 14.1, 29.9 and 39.0 % and at 65 DAS, it was 16.2, 34.0 and 47.1 % respectively (pooled means). As S has a synergistic relation with N, an increase in S leads to an increase in N uptake and use efficiency. In addition to protein synthesis and chlorophyll formation, S also plays a significant role in N fixation in legumes by promoting root nodule formation and improving enzyme activity of nitrogenase because it is a constituent of Fe-S protein, which is a component of the nitrogenase enzyme (37, 39). Iron–sulphur (Fe-S) protein is also involved in the electron transport chain of photophosphorylation, which produces ATP and NADPH (9). Hence, these processes altogether enhance biomass production. Sulphur improved dry matter production by 25.1 % in mung bean (44), with an 8.5 % increase in groundnut (45) and a 37.1 % increase in black gram (46).

Conversely, increasing aspartic acid levels enhanced the dry matter production at all the growth stages. Relative to the control, the improvement was 9.7, 19.3 and 25.8 % at 25 DAS, 11.1, 21.1 and 30.1 % at 45 DAS and 13.2, 24.5 and 34.8 % at 65 DAS by A40, A80 and A120, respectively (pooled means). As ASP acid is a source of N and carbon, which helps in the production of enzymes, co-enzymes, energy and other metabolites for plant metabolism, thus supplying the requirements of the cell for growth, this was reflected in plant growth and consequently in biomass production (20, 47).

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Table 2. Effect of sulphur and aspartic acid on leaf area index and specific leaf weight of mung bean at different growth stages

Treatment	LAI			SLW (mg cm^{-2})			LAI			SLW (mg cm^{-2})			LAI			SLW (mg cm^{-2})		
	25 DAS						45 DAS						65 DAS					
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	pooled	2024	2025	Pooled	2024	2025	Pooled
Sulphur levels (kg ha^{-1})																		
S_0 (control)	0.170	0.222	0.196	5.63	4.83	5.23	1.13	1.35	1.24	6.76	6.43	6.59	1.65	1.77	1.71	9.25	10.69	9.97
S_{20}	0.173	0.224	0.199	5.81	4.99	5.40	1.20	1.45	1.32	7.50	6.94	7.22	1.73	1.87	1.80	9.87	11.29	10.58
S_{40}	0.178	0.227	0.202	6.21	5.10	5.65	1.25	1.53	1.39	7.58	7.32	7.45	1.82	1.98	1.90	10.36	11.79	11.07
S_{60}	0.181	0.230	0.205	6.52	5.09	5.80	1.30	1.59	1.44	7.76	7.44	7.60	1.90	2.07	1.98	11.01	12.32	11.67
S.Em.±	0.006	0.008	0.005	0.28	0.13	0.15	0.04	0.07	0.04	0.40	0.23	0.23	0.04	0.06	0.04	0.29	0.31	0.21
LSD (p = 0.05)	NS	NS	NS	NS	NS	0.33	0.09	0.16	0.08	NS	0.56	0.51	0.10	0.16	0.08	0.70	0.77	0.46
C.V.	8.458	8.187	8.355	11.19	6.45	9.59	7.36	10.92	9.68	13.40	8.04	11.18	5.46	8.20	7.08	6.96	6.65	6.80
Aspartic acid (mg L^{-1})																		
A_0 (control)	0.169	0.219	0.194	5.51	4.58	5.04	1.13	1.37	1.25	6.93	6.78	6.85	1.67	1.78	1.72	9.63	11.07	10.35
A_{40}	0.172	0.223	0.197	5.77	4.91	5.34	1.20	1.45	1.32	7.34	6.88	7.11	1.72	1.88	1.80	10.01	11.49	10.75
A_{80}	0.178	0.227	0.202	6.31	5.18	5.75	1.25	1.51	1.38	7.49	7.13	7.31	1.82	1.96	1.89	10.20	11.69	10.94
A_{120}	0.183	0.233	0.208	6.58	5.33	5.96	1.30	1.59	1.44	7.84	7.34	7.59	1.89	2.07	1.98	10.65	11.83	11.24
S.Em.±	0.004	0.008	0.005	0.32	0.25	0.20	0.03	0.04	0.03	0.28	0.41	0.25	0.04	0.04	0.03	0.33	0.49	0.30
LSD (p = 0.05)	0.009	NS	0.009	0.65	0.53	0.41	0.07	0.09	0.05	0.59	NS	0.50	0.09	0.09	0.06	0.68	NS	0.60
C.V.	5.881	8.982	8.018	12.84	12.47	12.75	6.41	6.88	6.73	9.43	14.26	11.97	6.14	5.56	5.84	7.99	10.49	9.50
Interaction																		
S.Em.±	0.008	0.017	0.009	0.63	0.51	0.41	0.06	0.08	0.05	0.57	0.82	0.50	0.09	0.09	0.06	0.66	0.99	0.59
LSD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

S: sulphur; ASP: aspartic acid; LAI: leaf area index; SLW: specific leaf weight.

Table 3. Effect of sulphur and aspartic acid on dry matter production (g plant^{-1}) of mung bean at different growth stages

Treatment	Dry matter production (g plant^{-1})								
	25 DAS			45 DAS			65 DAS		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
Sulphur levels (kg ha^{-1})									
S_0 (control)	0.60	0.72	0.66	5.97	7.01	6.49	13.44	18.03	15.73
S_{20}	0.61	0.75	0.68	6.87	7.93	7.40	15.63	20.92	18.28
S_{40}	0.68	0.77	0.73	7.91	8.95	8.43	18.04	24.12	21.08
S_{60}	0.70	0.80	0.75	8.33	9.70	9.02	19.71	26.58	23.15
S.Em.±	0.02	0.02	0.02	0.20	0.25	0.16	0.32	0.53	0.31
LSD (p = 0.05)	0.05	0.05	0.03	0.49	0.61	0.35	0.77	1.30	0.67
C.V.	8.12	7.01	7.52	6.68	7.23	7.02	4.63	5.79	5.46

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Aspartic acid (kg L^{-1})									
A_0 (control)	0.56	0.69	0.62	6.10	7.45	6.78	13.87	19.25	16.56
A_{40}	0.62	0.74	0.68	6.96	8.11	7.53	15.96	21.51	18.74
A_{80}	0.69	0.79	0.74	7.72	8.71	8.21	17.81	23.41	20.61
A_{120}	0.72	0.83	0.78	8.30	9.34	8.82	19.18	25.49	22.33
S.Em.±	0.03	0.02	0.02	0.24	0.22	0.16	0.51	0.54	0.37
LSD (p = 0.05)	0.06	0.05	0.04	0.50	0.45	0.33	1.05	1.12	0.75
C.V.	10.77	7.99	9.30	8.13	6.30	7.16	7.45	5.92	6.57
Interaction									
S.Em.±	0.06	0.05	0.04	0.48	0.43	0.32	1.02	1.08	0.74
LSD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

S: sulphur; ASP: aspartic acid

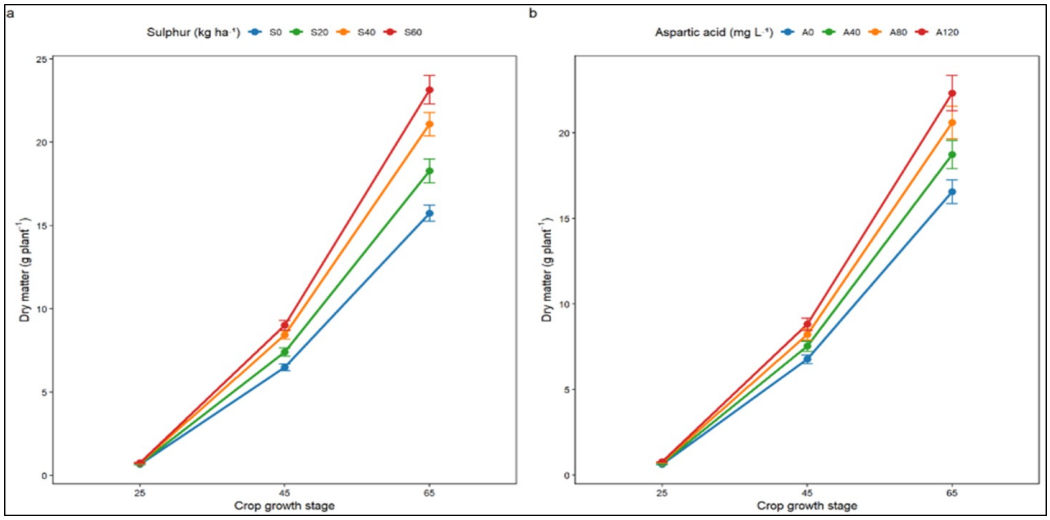


Fig. 2. Dry matter production (g $plant^{-1}$) of mung bean (pooled) at different growth stages as influenced by graded levels of (a) sulphur and (b) aspartic acid.

Branches per plant

Branches per plant at harvest were significantly influenced by levels of S, with the highest value recorded with S60 (2.60), which was at par with S40 (2.48) and lowest with the control (1.93) (Fig. 3). All the S levels were significantly higher than the control and S40 was superior to S20 on a pooled basis. It showed 11.4, 28.5 and 34.7 % improvement by S20, S40 and S60, respectively, relative to the control. Similarly, an increase in the number of branches per plant by S through enhanced photosynthate accumulation and biomass production was observed in mung bean (42) and in black gram (48). It also reflects improved assimilate availability and hormonal balance, facilitating more extensive canopy development and greater potential for reproductive structures.

Similarly, aspartic acid levels increased the number of branches per plant with an increase in levels (Fig. 3). The lowest was recorded with the control (2.07) and the value was significantly superior with A120 (2.55). All the aspartic acid levels were significantly higher than the control by 6.3, 13.1 and 23.2 % with A40, A80 and A120, respectively. Similarly, a 36.2 % improvement in branches per plant was recorded in peanut with aspartic acid (100 mg L^{-1}), by enhancing photosynthetic efficiency (20).

Specific leaf weight (mg cm^{-2})

Among the S levels, the lowest SLW was recorded with the control at all the growth stages and at 45 DAS the highest was recorded with S60 (7.60 mg cm^{-2}), which was statistically equivalent to S20 (7.22 mg cm^{-2}) and S40 (7.45 mg cm^{-2}) (Table 2). However, at 65 DAS, the significantly highest value was recorded with S60 (11.67 mg cm^{-2}) over all the lower levels. All S levels were also significantly higher than the control by 6.1, 11.1 and 17.1 % with S20, S40 and S60, respectively (pooled means). This shows that the increase in leaf weight was more compared to the leaf area, indicating an increase in leaf thickness with an increase in S levels. As S boosts chloroplast formation, increasing sucrose synthesis that feeds leaf thickening (49).

Among the ASP levels, the lowest SLW was recorded with the control (5.04, 6.85 and 10.35 mg cm^{-2}) and the highest with A120 (5.96, 7.59 and 11.24 mg cm^{-2}) at 25, 45 and 65 DAS, respectively. At 45 DAS and 65 DAS, the highest values were recorded with

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A120, which was statistically equivalent to A80 and A40 and significantly higher than the control by 10.8 and 8.6 %, respectively (pooled basis). Similarly, in faba bean, 20.1 % higher SLW was recorded with 150 mg L^{-1} ASP acid due to an increase in leaf thickness by a higher photosynthetic rate (27).

Crop growth rate, relative growth rate and net assimilation rate

The CGR, RGR and NAR of mung bean at different stages significantly varied with both S and ASP levels (Table 4). Crop growth rate of mung bean at all growth stages was higher with S60 and lower with the control. Between 25–45 and 45–65 DAS, the CGR was significantly higher with S60 (9.18 and 15.70 g m^{-2} day^{-1}) and lower with the control (6.48 and 10.27 g m^{-2} day^{-1}). All the S levels were significantly higher than the control by 15.3, 32.1 and 41.7 % between 25–45 DAS and 17.6, 36.8 and 52.9 % between 45–65 DAS with S20, S40 and S60, respectively (pooled means). Similarly, NAR between 25–45 and 45–65 DAS was also lowest with the control (1.15 and 0.70 mg cm^{-2} day^{-1}) and significantly higher with S60 (1.45 and 0.91 mg cm^{-2} day^{-1}), which was at par with S40 (1.40 and 0.86 mg cm^{-2} day^{-1}) from pooled means. However, RGR was only significantly affected at 25–45 DAS, with the highest value with S60 (124.2 mg g^{-1} day^{-1}) and lowest with the control (114.3 mg g^{-1} day^{-1}); all S levels were higher than the control (pooled means). The increase in CGR, RGR and NAR were attributed to the key role of S in enhancing leaf area and greater interception of solar radiation, leading to the synthesis and efficient translocation of photosynthates from source to sink (50). It also promotes nitrate assimilation by converting absorbed N to protein by enhancing the activity of the enzyme nitrate reductase. However, RGR at 45–65 DAS was not significantly varied due to less assimilation at the final growth stage, as similarly reported in mung bean with different S levels (44).

Among the ASP levels, significantly higher CGR was recorded with A120 (8.93 and 15.02 g m^{-2} day^{-1}) and lower with the control (6.84 and 10.87 g m^{-2} day^{-1}) at 25–45 and 45–65 DAS, respectively (pooled values). All the ASP levels were significantly higher than the control by 11.3, 21.5 and 30.7 % at 25–45 DAS and 14.5, 26.7 and 38.2 % at 45–65 DAS with A40, A80 and A120, respectively (pooled means). Similarly, NAR was also significantly higher with A120 (1.41 and 0.87 mg cm^{-2} day^{-1}), which was at par with A80 (1.36 and 0.84 mg cm^{-2} day^{-1}) and lowest with the control (1.20 and 0.73 mg cm^{-2} day^{-1}) at 25–45 and 45–65 DAS, respectively. However, RGR was not significantly influenced by ASP levels. Aspartic acid, being the precursor of metabolites such as glutathione and oxaloacetate, enhances the TCA cycle and energy production, promoting the synthesis of photosynthates and their translocation (23). Furthermore, it is a source of N, promoting the synthesis of proteins and enzymes required for biomass production (27).

Grain yield

The grain yield of mung bean was positively increased with an increase in levels of both S and ASP (Fig. 4). Significantly higher grain yield among the S levels was recorded with S60 (1162.7 kg ha^{-1}), which was at par with S40 (1128.0 kg ha^{-1}) and lowest with the control (673.6 kg ha^{-1}). Relative to the control, the percentage improvement in yield of S20, S40 and S60 was 40.5, 67.5 and 72.6 %, respectively (pooled means). Increase in grain yield is a combination of several factors, such as an increase in chlorophyll content by enhancing enzymes such as glutamate-1-semialdehyde aminotransferase and porphobilinogen synthase, which are helpful in the synthesis of chlorophyll precursors, i.e., 5-aminolevulinic acid and porphobilinogen (51). Along with the role of S in protein synthesis, it also stabilises protein structure by forming S-S bonds, which promote grain formation and development.

Table 4. Effect of sulphur (S) and aspartic acid (ASP) on crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) of mung bean at different growth stages

Treatment	CGR (g m^{-2} day^{-1})			RGR (mg g^{-1} day^{-1})			NAR (mg cm^{-2} day^{-1})			CGR (g m^{-2} day^{-1})			RGR (mg g^{-1} day^{-1})			NAR (mg cm^{-2} day^{-1})		
	25-45 DAS									45-65 DAS								
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
Sulphur levels (kg ha^{-1})																		
S_0 (control)	5.97	6.99	6.48	114.7	114.0	114.3	1.18	1.12	1.15	8.29	12.25	10.27	40.6	47.2	43.9	0.60	0.79	0.70
S_{20}	6.95	7.98	7.47	120.9	118.2	119.5	1.31	1.22	1.27	9.74	14.43	12.08	41.1	48.4	44.8	0.67	0.87	0.77
S_{40}	8.04	9.08	8.56	122.9	122.3	122.6	1.46	1.33	1.40	11.26	16.85	14.05	41.1	49.5	45.3	0.74	0.97	0.86
S_{60}	8.47	9.90	9.18	123.4	124.9	124.2	1.49	1.41	1.45	12.65	18.75	15.70	43.1	50.3	46.7	0.80	1.03	0.91
S.Em.±	0.23	0.28	0.18	2.1	2.2	1.5	0.05	0.07	0.04	0.49	0.49	0.35	1.8	1.3	1.12	0.04	0.03	0.03
LSD (p = 0.05)	0.55	0.68	0.39	5.2	5.3	3.3	0.13	0.16	0.09	1.21	1.19	0.75	NS	NS	NS	0.10	0.08	0.06
C.V.	7.49	8.07	7.85	4.3	4.4	4.3	9.66	12.53	11.10	11.51	7.67	9.21	10.7	6.6	8.59	14.8	8.9	11.5

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Aspartic acid (mg L^{-1})																		
A_0 (control)	6.16	7.52	6.84	119.3	119.1	119.2	1.22	1.19	1.20	8.63	13.11	10.87	41.0	47.3	44.2	0.62	0.84	0.73
A_{40}	7.04	8.19	7.61	120.3	119.6	119.9	1.32	1.25	1.29	10.00	14.89	12.45	41.5	48.6	45.1	0.69	0.90	0.79
A_{80}	7.81	8.80	8.31	120.6	119.9	120.3	1.42	1.30	1.36	11.22	16.33	13.77	41.6	49.3	45.5	0.74	0.94	0.84
A_{120}	8.42	9.45	8.93	121.7	120.8	121.2	1.48	1.34	1.41	12.08	17.95	15.02	41.8	50.1	45.9	0.76	0.98	0.87
S.Em.±	0.27	0.23	0.18	2.7	1.9	1.6	0.06	0.05	0.04	0.58	0.56	0.40	2.0	1.5	1.24	0.04	0.04	0.03
LSD (p = 0.05)	0.55	0.48	0.36	NS	NS	NS	0.12	0.10	0.08	1.20	1.16	0.81	NS	NS	NS	0.09	0.08	0.06
C.V.	8.93	6.76	7.78	5.5	3.8	4.8	10.18	9.58	9.91	13.59	8.87	10.77	11.7	7.4	9.51	15.2	10.6	12.6
Interaction																		
S.Em.±	0.536	0.47	0.36	5.5	3.7	3.3	0.11	0.10	0.08	1.163	1.13	0.81	4.0	3.0	2.48	0.09	0.08	0.06
LSD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

S: sulphur; ASP: aspartic acid; CGR: crop growth rate; RGR: relative growth rate; NAR: net assimilation rate.

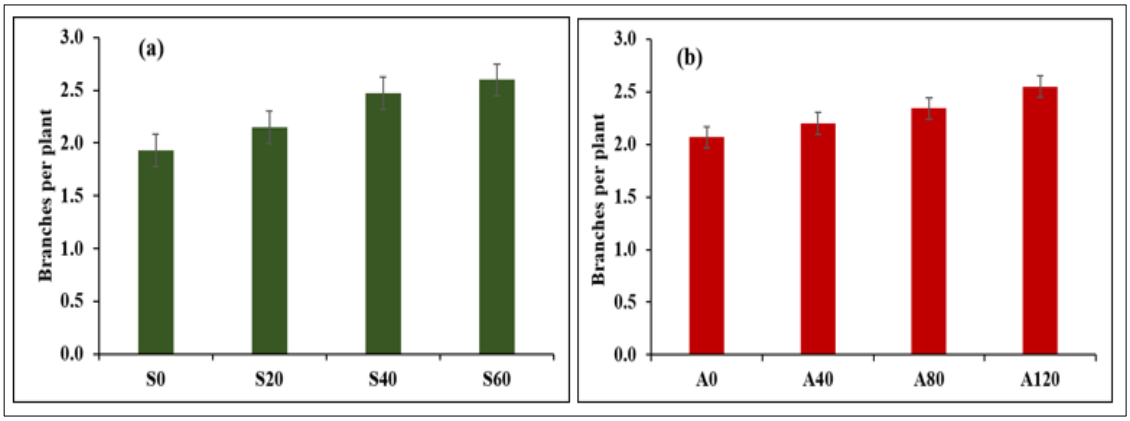


Fig. 3. Number of branches of mung bean (pooled) at harvest as influenced by graded levels of (a) sulphur and (b) aspartic acid. With standard error of the mean (Sem) and least significant difference (LSD) values are 0.06 and 0.14 for sulphur levels and 0.05 and 0.11 for aspartic acid levels.

Similarly, an increasing trend was recorded with an increase in aspartic acid levels, with A120 (1059.1 kg ha^{-1}) showing significantly higher grain yield, which was at par with A80 (1033.5 kg ha^{-1}) and lower with the control (845.5 kg ha^{-1}) from the pooled data of two years. All the ASP levels were significantly higher than the control by 15.0, 22.2 and 25.3 % with A40, A80 and A120, respectively (pooled means). Aspartic acid, being the precursor of proteins, enzymes and other secondary metabolites, plays a key role in N metabolism, carbon assimilation and the photosynthesis process, leading to photosynthate formation and assimilation. Altogether, these processes enhance biomass production and grain formation, as similarly reported in groundnut (20), faba bean (27) and tobacco (40).

Correlation

Correlation analysis between growth parameters and grain yield of mung bean (pooled means), as shown in Fig. 5, depicted a significant positive correlation between growth parameters at different growth stages and grain yield. Grain yield was strongly positively correlated with NAR at 25–45 DAS (0.961 **) and at 45–65 DAS (0.937 **), indicating the significant role of NAR in enhancing grain yield. Similarly, positive correlation was observed with dry matter production at 45 DAS (0.932 **) and 65 DAS (0.929 **). Dry matter production at 65 DAS in turn showed a positive correlation with LAI at 65 DAS (0.987 **) and 45 DAS (0.986 **), indicating the key role of leaf area in capturing sunlight and transforming it into biomass. However, grain yield showed a positive but statistically non-significant correlation with LAI at 25 DAS (0.424 NS). Overall, correlation analysis demonstrated that grain yield of mung bean was governed by all the growth parameters such as NAR, CGR, LAI and dry matter production; hence, improvement in growth parameters by sulphur and aspartic acid application led to grain yield improvement by increasing canopy spread, photosynthetic efficiency and biomass production. Similar findings were reported in chickpea (52) and mung bean (53), stating the key role of growth parameters in enhancing grain yield.

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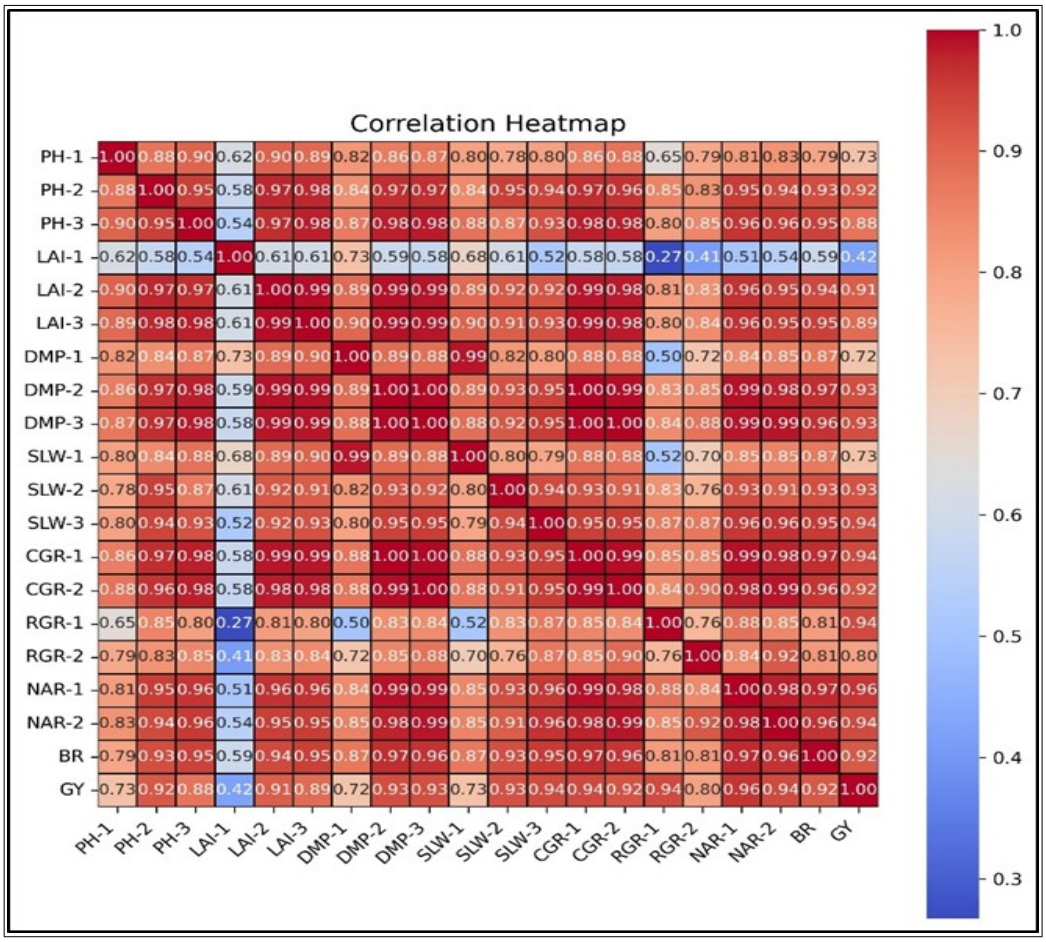


Fig. 5. Heatmap based on correlation matrix of growth parameters and grain yield with different sulphur and aspartic acid levels. *Significant at $p \leq 0.05$; ** Significant at $p \leq 0.01$. PH^{-1}, 2, 3: plant height at 25, 45 and 65 DAS; LAI^{-1}, 2, 3: leaf area index at 25, 45 and 65 DAS; DMP^{-1}, 2, 3: dry matter production at 25, 45 and 65 DAS; SLW^{-1}, 2, 3: specific leaf weight at 25, 45 and 65 DAS; CGR^{-1}, 2: crop growth rate at 25-45, 45–65 DAS; RGR^{-1}, 2: relative growth rate at 25-45, 45-65 DAS; NAR^{-1}, 2: net assimilation rate at 25-45, 45–65 DAS; BR: branches per plant; GY: grain yield.

Conclusion

The results of the current study clearly show the potential beneficial effect of both sulphur (S) and aspartic acid (ASP) on growth parameters of mung bean at various growth stages of the crop. Among the growth parameters, the leaf area index (LAI) of the plant has a prominent role in biomass production and net assimilation rate (NAR), which boosted yield by the transformation of photosynthates from source to sink. Among the S levels, maximum growth parameters and yield were recorded with 60 kg ha^{-1}, which was statistically at par with 40 kg ha^{-1}, making it a viable dose for mung bean cultivated under hot-arid conditions of Rajasthan. While ASP showed greater improvement in growth indices with increasing levels, showing that 120 mg L^{-1} is highly beneficial for crop growth. Further research is required regarding the optimal growth stages and frequency of ASP foliar application in mung bean under hot-arid conditions.

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Authors' contributions

RNK and AS were involved in the conceptualisation and field experimentation. SPST and MS were involved in the conceptualisation of the work. MK^1 and MK^2 conducted the laboratory analysis. VK, K and RG performed the data analysis. RNK, SPST, AS, MS and MK^1 wrote the paper and edited the manuscript. All authors have read and approved the final manuscript [MK^1 stands for Mahesh Kumar and MK^2 stands for Mahesh Kumar].

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Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

None

References

1. Khambalkar PA, Agrawal S, Dhaliwal SS, Yadav SS, Sadawarti MJ, Singh A, et al. Sustainable nutrient management balancing soil health and food security for future generations. Appl Food Res. 2025;5(2):101087. http://doi.org/10.1016/j.afres.2025.101087
2. Malviya A, Singh P, Singh RK, Solanki P. Comparative evaluation of urea and integrated PGPR with nitrogen-fixing microbes: and their effects on maize (*Zea mays*). In: Diazotrophic plant growth-promoting microorganisms and green energy. Singapore: Springer Nature Singapore; 2026. p. 71–90. http://doi.org/10.1007/978-981-95-9682-9_4
3. Kumar M, Panwar NR, Kumawat RN, Santra P. Influence of different land use systems on soil properties in hot arid Rajasthan. J Indian Soc Soil Sci. 2020;68(2):121–7. http://doi.org/10.5958/0974-0228.2020.00014.6
4. Kumar M, Raina P, Singh SK. Soil fertility appraisal for hot arid regions of Thar Desert, Rajasthan, India. Ann Arid Zone. 2020;59(1-2):1–6. http://doi.org/10.56093/aaz.v59i1-2.103051
5. Zhao FJ, Tausz M, De Kok LJ. Role of sulfur for plant production in agricultural and natural ecosystems. In: Sulfur metabolism in phototrophic organisms. Dordrecht: Springer Netherlands; 2008. p. 417–35. http://doi.org/10.1007/978-1-4020-6863-8_21
6. Sharma RK, Cox MS, Oglesby C, Dhillon JS. Revisiting the role of sulfur in crop production: a narrative review. J Agric Food Res. 2024;15:101013. http://doi.org/10.1016/j.jafr.2024.101013
7. Islam S, Kaur S, Solah V, Motesharezadeh B, Ma W. Declining soil sulphur: a hidden threat to cereal yield and protein quality. Agriculture. 2026;16(7):756. http://doi.org/10.3390/agriculture16070756
8. Bhatla SC, Kathpalia R. Essential and functional mineral elements. In: Plant physiology, development and metabolism. Singapore: Springer Nature Singapore; 2023. p. 25–49. http://doi.org/10.1007/978-981-99-5736-1_2
9. Narayan OP, Kumar P, Yadav B, Dua M, Johri AK. Sulfur nutrition and its role in plant growth and development. Plant Signal Behav. 2023;18(1):2030082. http://doi.org/10.1080/15592324.2022.2030082
10. Directorate of Economics and Statistics. Agricultural statistics at a glance 2024-25 [statistical report]. New Delhi: Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India; 2025. http://agriwelfare.gov.in/Documents/CWWGDATA/Agricultural_Statisitcs_at_a_Glance_2024_25_En.pdf
11. Kemal M, Teka TA, Dibaba K, Urugo MM. Effects of processing methods on nutrient and antinutrient composition, techno-functional and antioxidant properties of mungbean (*Vigna radiata* (L.) R. Wilczek) varieties. LWT. 2025;222:117663. http://doi.org/10.1016/j.lwt.2025.117663
12. Elobuike CS, Idowu MA, Adeola AA, Bakare HA. Nutritional and functional attributes of mungbean (*Vigna radiata* [L.] Wilczek) flour as affected by sprouting time. Legume Sci. 2021;3(4). http://doi.org/10.1002/leg3.100
13. Mbeyagala EK, Karimi Rael, Binagwa PH, Amuge ES, Vemula A Kumar, Nair RM. Yield and mineral composition among mungbean [*Vigna radiata* (L.) R. Wilczek] genotypes grown in different agroecologies in East Africa. Int J Agron. 2023;2023:1–17. http://doi.org/10.1155/2023/5534650
14. Hou D, Yousaf L, Xue Y, Hu J, Wu J, Hu X, et al. Mung bean (*Vigna radiata* L.): bioactive polyphenols, polysaccharides, peptides and health benefits. Nutrients. 2019;11(6):1238. http://doi.org/10.3390/nu11061238
15. Assefa ZB, Dinku AM, Jemal AM. Value chain analysis of mung bean (*Vigna radiata* L. Wilczek thrive) in Kalu Woreda, Ethiopia. Agric Food Secur. 2022;11(1):54. http://doi.org/10.1186/s40066-022-00393-2
16. Wang X, Chang L, Yang J, Jiang Y, Zhang W, Zhang Y, et al. Reduced nitrogen input enhances proso millet nitrogen acquisition advantage in proso millet/mung bean intercropping. Farming Syst. 2026:100258. http://doi.org/10.1016/j.farsys.2026.100258
17. Singh D, Gaur MK. Sustainability farming in rainfed areas: constraints and strategies. In: Geo-environment of the Thar Desert. Cham: Springer Nature Switzerland; 2026. p. 315–33. http://doi.org/10.1007/978-3-032-16742-2_16
18. Zahoor A, Asim M, Ahmed U, Saeed MF, Jamal A, Dewir YH, et al. Sustainable nitrogen optimization in mung bean production: evaluating nitrogen-fixing bacteria and nitrogen dosages for yield and soil health. J Plant Nutr. 2026;49(9):1513–24.http://doi.org/10.1080/01904167.2026.2645756
19. Li T, Chen X, Cao S, Liu Z, Tian L, Gao Z, et al. Integrated physiological and transcriptome analyses of the effects of water-soluble amino acid fertiliser on plant growth. J King Saud Univ Sci. 2024;36(11):103504. http://doi.org/10.1016/j.jksus.2024.103504
20. Sadak MS, Bakry BA, Abdel-Razik TM, Hanafy RS. Amino acids foliar application for maximizing growth, productivity and quality of peanut grown under sandy soil. Braz J Biol. 2023;83. http://doi.org/10.1590/1519-6984.256338
21. Abdelhamid MT, Sh Sadak M, Schmidhalter U. Effect of foliar application of amino acids on plant yield and physiological parameters in bean plants irrigated with seawater. Acta Biol Colomb.2014;20(1):140–52. http://doi.org/10.15446/abc.v20n1.42865
22. Trovato M, Funck D, Forlani G, Okumoto S, Amir R. Editorial: amino acids in plants: regulation and functions in development and stress defense. Front Plant Sci. 2021;12:772810. http://doi.org/10.3389/fpls.2021.772810
23. Yan P, Dong X, Lu L, Fang M, Ma Z, Du J, et al. Wheat yield and nitrogen use efficiency enhancement through poly(aspartic acid)-coated urea in clay loam soil based on a 5-year field trial. Front Plant Sci. 2022;13:953728. http://doi.org/10.3389/fpls.2022.953728
24. Han M, Sun S, Feng J, Wang S, Liu X, Si Y, et al. Investigation of stimulated growth effect by application of L-aspartic acid on poplar. Ind Crops Prod. 2024;209:118023. http://doi.org/10.1016/j.indcrop.2024.118023
25. Rizwan M, Ali S, Zaheer Akbar M, Shakoor MB, Mahmood A, Ishaque W, et al. Foliar application of aspartic acid lowers cadmium uptake and Cd-induced oxidative stress in rice under Cd stress. Environ Sci Pollut Res. 2017;24(27):21938–47. http://doi.org/10.1007/s11356-017-9860-1
26. Sadak MS, Sekara A, Al-ashkar I, Habib-ur-Rahman M, Skalicky M, Brestic M, et al. Exogenous aspartic acid alleviates salt stress-induced decline in growth by enhancing antioxidants and compatible solutes while reducing reactive

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https://doi.org/10.14719/pst.17670

oxygen species in wheat. Front Plant Sci. 2022;13:987641. http://doi.org/10.3389/fpls.2022.987641

27. Amin A. Improving growth and productivity of faba bean plants by foliar application of thiourea and aspartic acid. Int J Plant Soil Sci. 2014;3(6):724–36. http://doi.org/10.9734/IJPSS/2014/8227
28. Jackson ML. Soil chemical analysis. New Delhi: Prentice Hall of India Pvt Ltd; 1973. 498 p.
29. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 1934;37(1):29–38. http://doi.org/10.1097/00010694-193401000-00003
30. Subbiah BV, Asija GL. Rapid procedure for estimation of available nitrogen in soils. Curr Sci. 1956;25:259–60.
31. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular No. 939. USDA; 1954.
32. Standford G, English L. Use of the flame photometer in rapid soil tests for K and Ca. Agron J. 1949;41(9):446–7. http://doi.org/10.2134/agronj1949.00021962004100090012x
33. Cheisen L, Yien CH. Turbidometric determination of available sulphates. Soil Sci Soc Am Proc. 1956;15:149–51.
34. Watson DJ. The physiological basis of variation in yield. In: Advances in Agronomy. Elsevier; 1952. p. 101–45. http://doi.org/10.1016/S0065-2113(08)60307-7
35. Radford PJ. Growth analysis formulae – their use and abuse. Crop Sci. 1967;7(3):171–5. http://doi.org/10.2135/cropsci1967.0011183X000700030001x
36. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York: John Wiley & Sons; 1984. 680 p.
37. Mishra A, Gupta H, Mishra US, Sirothia P, Darwai P. Interaction effect of sulphur and NPK on growth parameters and yield of mustard. Int J Plant Soil Sci. 2023;35(15):138–44.http://doi.org/10.9734/ijpss/2023/v35i153089
38. Dawar R, Karan S, Bhardwaj S, Meena DK, Padhan SR, Reddy KS, et al. Role of sulphur fertilization in legume crops: a comprehensive review. Int J Plant Soil Sci. 2023;35(21):718–27.http://doi.org/10.9734/ijpss/2023/v35i214033
39. Karaman R, Türkay C. Effects of bacteria, molybdenum and sulphur fertilization on agronomic and quality characteristics of mung bean. Selcuk J Agric Food Sci. 2024;38(2):274–87.http://doi.org/10.15316/SJAFS.2024.026
40. Kurt D. Responses of tobacco plants after the exogenous application of L-aspartic acid. J Plant Nutr. 2026;49(5):938–49. http://doi.org/10.1080/01904167.2025.2591186
41. Meena KK, Meena RS, Kumawat SM. Effect of sulphur and iron fertilization on yield attributes, yield and nutrient uptake of mung bean (*Vigna radiata*). Indian J Agric Sci. 2013;83(4):472–6.
42. Sahu S, Shankar T, Maitra S, Adhikary R, Mondal T, Duvvada SK. Impact of phosphorus and sulphur on the growth and productivity of green gram (*Vigna radiata*). Res Crops. 2021;22(4):785–91. http://doi.org/10.31830/2348-7542.2021.131
43. Balagangathar B, Kalaiyarasan C, Kandasamy S, Madhavan S, Jawahar S. Impact of nitrogen and sulphur application on the growth and yield of groundnut (*Arachis hypogaea* L.). Crop Res. 2024;59(3):138–42. http://doi.org/10.31830/2454-1761.2024.CR-972
44. Bijarnia KK, Shukla UN, Kumari K, Khippal AK, Dhayal BC, Choudhary MS. Influence of stress mitigating chemicals and sulphur on growth and yield of green gram. J Agri Search. 2023;10(3):163–7. http://doi.org/10.21921/jas.v10i03.13767
45. Gautam P, Bhunia SR, Sahoo A, Sawal RK, Rakshit S, Yadav VK, et al. Drip irrigation and sulphur fertilization influenced fodder yield, quality and water use efficiency of groundnut in arid region. PLoS One. 2023;18(8). http://doi.org/10.1371/journal.pone.0288090
46. Sastry YS, Dawson J. Influence of sulphur and molybdenum on growth and yield of black gram (*Vigna mungo* L.). Int J Environ Clim Change. 2023;13(9):2714–20. http://doi.org/10.9734/ijecc/2023/v13i92557
47. Ramdan AA, Mahmoud YO Ramdan, Bakry BA, El-Bassiou HMS. Biochemical and yield of flax in responses to some natural antioxidant substances under sandy soil conditions. Asian J Plant Sci. 2020;19(3):261–72. http://doi.org/10.3923/ajps.2020.261.272
48. Parashar A, Jain M, Tripathi DL. Effect of phosphorus and sulphur on the growth and yield of black gram (*Vigna mungo* L.). J Pharmacogn Phytochem. 2020;9(5):2585–8.
49. Park JC, SP N, Kim HD, Kang DY, Kim IH, Bae SW, et al. The exogenous application of non-toxic sulfur contributes to the growth-promoting effects of leaf lettuce (*Lactuca sativa* L. var. crispa). Agriculture. 2021;11(8):769. http://doi.org/10.3390/agriculture11080769
50. Raj VSA, Debbarma V, Nikhitha K. Impact of sulphur and boron levels on growth, yield and economics of summer green gram (*Vigna radiata* L.). Int J Environ Clim Change. 2023;13(6):56–63.http://doi.org/10.9734/ijecc/2023/v13i61797
51. Shah SH, Islam S, Mohammad F. Sulphur as a dynamic mineral element for plants: a review. J Soil Sci Plant Nutr. 2022;22(2):2118–43. http://doi.org/10.1007/s42729-022-00798-9
52. Panda D, Sen A, Dhakre DS, Mondal S. Correlation analysis of some growth, physiological parameters, yield and yield attributes of chickpea (*Cicer arietinum* L.). Int J Bio-res Env Agril Sci. 2015;1(3):90–5.
53. Mondal MMA, Puteh AB, Malek MA, Ismail MR, Rafii MY, Latif MA. Seed yield of mung bean (*Vigna radiata* (L.) Wilczek) in relation to growth and developmental aspects. Sci World J. 2012;2012:1–7. http://doi.org/10.1100/2012/425168

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