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Effects of Bacteria, Molybdenum and Sulphur Fertilization on Agronomic and Quality Characteristics of Mung Bean

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HIGHLIGHTS

- Bacterial and molybdenum application increases the yield and yield elements, nodule formation and quality characteristics of mung bean.
- The application amount of sulphur fertilization increased, agronomic parameters such as yield, hundred grain weight, protein content, ash content and nodulation activities increased.
- To increase yield and quality in mung bean, 30 kg S ha-1 bacteria and molybdenum should be used.

Abstract

Mung bean is one of the most important edible legumes in the world and although its consumption is increasing day by day, its production is still low. Important cultural practices in mung bean cultivation are inoculation of seeds with symbiotic bacteria and optimum fertilization with nutrients. Therefore, the effects of sulphur (0, 10, 20 and 30 kg ha $^{-1}$) molybdenum (0 and 5 g kg^{-1}) and bacteria application on agronomic and quality characteristics of mung bean and nodule formation were determined in this study. The study was conducted in Isparta University of Applied Sciences, Faculty of Agriculture, Department of Field Crops in 2021. In the study, the differences between plant height, number of grains and pods per plant, plant grain yield, grain yield, harvest index, hundred grain weight, ash content, protein content, number and weight of nodules according to bacteria treatment; all traits except harvest index and hundred grain weight according to molybdenum treatment and all traits according to sulphur doses were found statistically significant. According to the results obtained, it was determined that molybdenum and sulphur treatments together with bacterial inoculation increased the yield, yield components and nodule formation of mung bean. It was determined that the increase in sulphur doses increased agronomic parameters such as yield, hundred grain weight, ash content, protein ratio and nodulation activities. In the study, it was concluded that 30 kg S ha-^{1} should be used together with bacteria and molybdenum to obtain higher yield and quality product in mung bean cultivation.

Keywords: Mung bean; bacteria; molybdenum; sulphur; nodule properties

1. Introduction

Edible legumes are one of the most important crop groups in sustainable agricultural systems. The mung bean (*Vigna radiata* L.), commonly known as green gram in the world and mung bean or mung in Turkey, is one of the traditional legume crops. It is an important legume of Asian origin and is widely cultivated in

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countries in Asia, Australia and Africa (Yang et al. 2008). In Turkey, mung bean production is generally carried out using local varieties for family needs or for local markets. It is also grown locally in the Mediterranean and Southeastern regions of Turkey (Karaman and Türkay 2022). In the world and in our country, mung bean seeds (fresh or dried) can be used whole or processed to make bread, noodles, porridge, soup, snacks and even ice cream (Mogotsi 2006). Mung beans have high nutritional value as they have high and easily digestible proteins (Baraki et al. 2020). It also contains about 61% carbohydrates, 23.8% protein, 1.2% fat, 3.5% ash and 4.5% fiber on a dry weight basis (Dahiya et al. 2015) and is complementary to cereal grains of essential amino acids (lysine, cysteine, methionine, threonine and tryptophan) (Asaduzzaman et al. 2008). In addition, its biological N fixation ability similar to other legumes, short growth period, tasty and highly digestible roughage source, and its inclusion in crop rotations in different regions make mung bean a very advantageous crop (Bell et al. 2015; Taylor et al. 2016; Langworthy et al. 2018; Rawnsley et al. 2019; Karaman et al. 2022). Due to these features, the consumption of mung bean in our country and in the world is increasing day by day. Its popularity is also increasing day by day compared to other edible grain legume species (Karaman and Türkay 2022). However, the grain yield of local mung bean varieties in the world is 400 kg ha^{-1} and the grain yield of new varieties developed can be 2 tons per hectare (Schafleitner et al. 2015; Nair and Schreinemachers 2020). In this direction, in order to meet the expected increase in demand in the coming years, increasing the production and yield of mung bean with appropriate fertilization methods is very important in meeting the global food need.

Mung beans are able to assimilate atmospheric nitrogen through *Rhizobium* bacteria. This improves soil fertility and reduces the need for increasingly expensive synthetic nitrogen fertilizers. Rhizobium bacteria can vary in number and activity, nodulation and nitrogen fixation. Tahir et al. (2011) suggested that Rhizobial populations living in the soil are not sufficient and therefore their efficiency in biological nitrogen fixation is low. To establish an optimum Rhizobial population in the root zone, legume seeds should be inoculated with an effective Rhizobial strain. Indeed, Rhizobium inoculation increased 57% effective nodules, 77% dry matter production, 64% grain yield and 40% hay yield in mung bean compared to control (Hossain et al. 2011).

Nitrogen fixation process is influenced by many factors, sulphur and molybdenum being one of them. Although mung beans require all essential plant nutrients, sulphur plays a very important role in the production and quality of mung beans. Sulphur is also essential for protein and enzyme synthesis and is a component of the amino acids methionine and cysteine (Scherer 2001). Insufficient sulphur supply can negatively affect the yield and quality of mung bean (Scherer et al. 2006). It also increases the formation of nodules in legumes, which results in greater sulphur utilization throughout the vegetative and generative growth phase (Mum et al. 2004). In addition, sulphur application to mung bean can increase plant height, number of main branches and leaves, dry matter, plant seed yield, nodule number and nodule weight (Singh and Yadav 1997). Molybdenum application plays a vital role in enhancing the N fixation process of Rhizobium bacteria. Molybdenum is required for nitrate reductase and nitrogenase enzyme activity (Westermann 2005) and it is also part of the nitrogenase enzyme and *Rhizobium* spp., which fixes nitrogen, requires molybdenum during the fixation process (Vieira et al. 1998). Molybdenum is a highly effective micronutrient especially in nodule formation, increasing N fixation and flowering number, improving pod tying and early flowering (Prasad et al. 1998; Singh et al. 2017). Therefore, it is very important for sustainable agriculture to determine the changes in yield and quality characteristics of Rhizobium inoculation with molybdenum and sulphur application to mung bean. Accordingly, this study was aimed to investigate the effect of sulphur, molybdenum and bacteria application on agronomic and some quality traits of mung bean.

2. Materials and Methods

2.1. Materials

This study was conducted in Isparta University of Applied Sciences, Faculty of Agriculture, Department of Field Crops 37°45'N and 30°33' E, 997 m) in 2021. Partow mung bean variety was used as seed in the experiment. *Rhizobium leguminosarum* bacteria used in the study were obtained from Ankara Soil and Fertilizer Research Institute Directorate in the form of peat culture, Ammonium heptamolybdate tetrahydrate

$(NH_4)_6Mo_7O_{24}.4H_2O$) (Sigma) chemical as molybdenum source and elemental sulphur (98%) as sulphur source from a private company.

2.2. Methods

2.2.1. Experimental site

When the climatic characteristics of the experimental area are examined, it is seen that there is no significant difference between the average temperatures during the vegetation period in many years. According to the long-term average, the lowest monthly average temperature during the mung bean planting season (May-October) was 10.7°C in May and the highest monthly average temperature was 23.4°C in July. Total rainfall during the vegetation period (291.7 mm) was higher than the long-term average (231.3 mm). Soil samples were taken from different parts of the experimental area at 0-30 cm depths and analyzed. Soil analysis were carried out in 5 different areas of the study area at 0-30 cm depths according to Rowell (1996). The texture of the soils of the test area is clayey-loamy and belongs to the slightly saline (322 $\mu S\ cm^{-1}$) group with a slightly alkaline reaction (pH value 7.7) and a salt content (EC) of 322 $\mu S\ cm^{-1}$. It was found to be rich in lime (28.7%) but poor in organic matter (1.54%).

2.2.2. Experimental design and treatments

The experiment was conducted in 3 replicates according to the split plots experiment design. In the experiment, bacterial inoculation was allotted to main plots (B_0= non inoculated, B_1= inoculated), molybdenum treatment was assigned to sub-plots (Mo_0 = osmopriming without molybdenum, Mo_1= molybdenum at 5 g kg^{-1}) seed (Aslam et al. 2009) and sulphur doses were distributed in sub-sub-plots (S0 = 0 kg ha^{-1} (no sulphur treatment), S_1 = 10 kg ha^{-1}, S_2 = 20 kg ha^{-1}, S_3 = 30 kg ha^{-1}).

In order to prevent contamination of bacteria, molybdenum and sulphur applications from plot to plot, a distance of 2 meters was left between the plots. Sulphur was applied uniformly to the rows opened with sowing. For osmopriming, seeds were kept in molybdenum solution for 6 hours and sowing was done without losing time. The inoculated seeds were moistened with sugar water (10%) just before sowing and inoculated with bacterial culture at the rate of 1 kg bacteria per 100 kg seeds. Inoculation and sowing were carried out in the evening hours when the direct rays of the sun lost their effect. Control plots were sown first to prevent bacterial contamination. The sown seeds were immediately covered and pressed.

The experiment was established in the first week of May. Mung bean seeds were sown in 40 × 10 cm sowing norm with 3 m length and 6 rows in each plot. The area of a plot was 7.2 m^2 (3 m × 2.4 m). Di ammonium phosphate (18:46:0) and urea (46%) fertilizers were applied equally to all plots with the calculation of 40 kg ha^{-1} pure nitrogen and 60 kg ha^{-1} P_2O_5. In the experiment, irrigation was carried out with drip irrigation considering the water requirement of the plants, soil moisture status and climatic conditions. Weed control was done with hand hoe and no chemical control was applied in the experiment. Harvesting was carried out in the first week of October after leaving 50 cm from the outermost rows in the sub-sub-plots and 50 cm from both sides of the plant rows to prevent edge effect.

2.2.3. Determination of agronomic and quality characteristics

In the study, plant height (cm), first pod height (cm), number of pods per plant (number of pods), number of grains per plant (number of grains), plant grain yield (g), harvest index (%) and grain yield (kg ha^{-1}), hundred grain weight (g), number of nodules (g $plant^{-1}$) and nodule weight (g $plant^{-1}$) were examined in 10 randomly selected plants. Yield and yield components were determined according to the methods described by Karaman (2019). During the flowering period, when nodule formation was the highest, the plants from each plot were removed from the soil 30-40 cm deep with the help of a belt and washed carefully to determine the number of nodules and nodule weight. Nitrogen content in mung bean grains was determined according to the Kjeldahl method (Kacar and İnal 2010) and protein content (%) was calculated by multiplying the obtained values with a coefficient of 6.25 (Bremner 1965). The ground mung bean grains were subjected to incineration in a muffle furnace at 550°C for 5 hours and the ash content was obtained by multiplying the obtained value by % (Yılmaz 2005).

2.2.4. Data evaluation

The data obtained were analyzed in the SAS statistical package program according to the split plots experimental design in randomized blocks. The differences of the averages calculated for each treatment were grouped according to the LSD test, some at 1% and some at 5%.

3. Results

In this study, the effects of sulphur, molybdenum and bacteria application on agronomic and some quality traits of mung bean were investigated and the results of analysis of variance are given in Table 1.

Table 1. Analysis of variance results for the effects of bacteria, molybdenum and sulphur treatments on yield and yield components in mung bean

SD	DF	Plant Height	First Pod Height	Pods per Plant	Grains per Plant[1]
Replication	2	0.19	6.25	1.93	170.04
Bacteria (B)	1	195.62*	72.40 ns	1429.76**	99748.19**
Error-1	2	5.77	7.72	1.04	92.17
Molybdenum (Mo)	1	166.18**	26.78*	124.90**	6441.96**
B x Mo Interaction	1	1.80 ns	0.17 ns	1.93 ns	1000.37 ns
Error-2	4	4.62	2.93	1.91	206.73
Sulphur (S)	3	47.00**	19.03**	64.31**	4185.73**
B x S Interaction	3	1.83 ns	0.76 ns	17.74**	577.05**
Mo x S Interaction	3	9.17 ns	2.33 ns	6.44**	854.47**
B x Mo x S Interaction	3	1.34 ns	2.81 ns	5.83**	268.41*
Error-3	24	5.58	2.61	1.14	67.43
SD	**DF**	**Plant Grain Yield**	**Grain Yield**	**Harvest Index**	**Protein Content**
Replication	2	1.29	12962.0	5.24	0,15
Bacteria (B)	1	239.77**	7925954.3**	315.70**	119,39**
Error-1	2	0.03	36967.4	2.98	0,13
Molybdenum (Mo)	1	13.06**	988060.7**	10.03 ns	8,02**
B x Mo Interaction	1	0.99 ns	168189.6 ns	1.15 ns	0,08 ns
Error-2	4	0.21	41949.2	1.91	0,16
Sulphur (S)	3	12.50**	399170.7**	22.98**	9,36**
B x S Interaction	3	1.69*	148434.4*	29.10**	0,94 ns
Mo x S Interaction	3	0.31 ns	208011.8**	1.86 ns	0,55 ns
B x Mo x S Interaction	3	0.30 ns	78062.3 ns	1.64 ns	0,41 ns
Error-3	24	0.52	38194.7	3.94	0,55
SD	**DF**	**Hundred Grain Weight**	**Ash Content**	**Number of Nodules**	**Nodule weight**
Replication	2	0.12	0.01	0.83	0.00
Bacteria (B)	1	4.24*	0.89 **	418.07**	20.66**
Error-1	2	0.13	0.01	0.96	0.01
Molybdenum (Mo)	1	1.08 ns	0.22**	54.70**	1.18**
B x Mo Interaction	1	0.01 ns	0.01 ns	12.77**	0.00 ns
Error-2	4	0.16	0.01	0.25	0.02
Sulphur (S)	3	1.42**	0.23**	29.03**	1.93**
B x S Interaction	3	0.11 ns	0.01**	7.94**	0.41**
Mo x S Interaction	3	0.01 ns	0.01**	0.58 ns	0.03 ns
B x Mo x S Interaction	3	0.11 ns	0.02**	0.05 ns	0.06 ns
Error-3	24	0.21	0.01	0.23	0.02

*: P<0.05; **: P<0.01; [1]: Mean squared values of traits; SD: Sources of variation; DF: Degrees of freedom

According to the variance analysis results of Rhizobium bacteria, molybdenum and sulphur (S) doses applied to mung bean on yield and yield components; the differences between plant height, number of grains and pods per plant, plant grain yield, grain yield, harvest index, hundred grain weight, protein content, ash content, number and weight of nodules were found statistically significant different level (P<0.01 and P<0.05). Differences between all traits except harvest index and hundred grain weight according to osmopriming treatment with molybdenum and differences between all traits according to sulphur doses were statistically significant. On the other hand, bacteria (B) x molybdenum (Mo) interaction for biological yield and nodule number; B x S interaction for number of pods per plant, number of grains per plant, plant grain yield, grain yield, harvest index, ash content, number of nodules and nodule weight; Mo x S interaction for number of pods per plant, number of grains per plant, ash content and grain yield; B x Mo x S interaction for number of pods per plant, ash content and number of grains per plant were statistically significant (Table 1).

3.1. Plant Height

The mean plant height of mung bean plants varied between 62.03-66.06 cm and 62.18-65.91 cm according to bacteria and molybdenum treatments, respectively, and the plant height of the plants in the plots treated with bacteria and molybdenum was higher than the plots not treated with bacteria and molybdenum. Plant height averages varied between 61.75 cm and 66.42 cm according to sulphur doses. The lowest plant height was determined at 0 kg ha^{-1} S dose and the highest plant height was determined at 30 kg ha^{-1} S dose, and there was no statistical difference between them and 20 kg ha^{-1} S application. However, plant height values of mung bean increased with increasing sulphur doses (Table 2).

Table 2. Mean values of plant height and first pod height traits of mung bean according to bacteria, molybdenum and sulphur treatments

Boron Appl.	Mo Appl.	Plant Height (cm)					First Pod Height (cm)				
		S (kg ha^{-1})					S (kg ha^{-1})				
		0	10	20	30	Mean	0	10	20	30	Mean
B_0	Mo_0	59.07	59.20	60.00	61.60	**59.97**	29.67	29.60	30.40	32.80	**30.62**
	Mo_1	60.67	63.13	64.40	68.13	**64.08**	30.00	32.67	32.40	32.90	**31.99**
Mean		**59.87**	**61.17**	**62.20**	**64.87**	***62.03^{B*}***	**29.83**	**31.13**	**31.40**	**32.85**	***31.30***
B_1	Mo_0	62.53	64.73	64.90	65.40	**64.39**	32.05	32.70	33.20	33.87	**32.95**
	Mo_1	64.73	66.33	69.33	70.53	**67.73**	32.40	33.53	35.93	36.40	**34.57**
Mean		**63.63**	**65.53**	**67.12**	**67.96**	***66.06^{A}***	32.23	33.12	34.57	35.13	***33.76***
Mo x S	Mo_0	60.80	61.97	62.45	63.50	**62.18^{b}**	30.86	31.15	31.80	33.33	**31.79^{b}**
	Mo_1	62.70	64.73	66.87	69.33	**65.91^{a}**	31.20	33.10	34.17	34.65	**33.28^{a}**
Mean		**61.75^{C}**	**63.35^{BC}**	**64.66^{AB}**	**66.42^{A}**		**31.03^{C}**	**32.13^{BC}**	**32.98^{AB}**	**33.99^{A}**	

*: There is no statistical difference between averages with the same letters.

3.2. First Pod Height

The height of the first pod is an important trait affecting harvest losses in machine harvesting and it is one of the most important agronomic traits for mung bean. In the study, the first pod height of mung bean increased with the increase in S doses. However, there was no statistical difference between 20 and 30 kg ha^{-1} S treatments. According to molybdenum treatments, the first pod height was higher in the plots where Mo was applied compared to the plots where Mo was not applied. The first pod height increased with bacteria application, but this increase was not statistically different (Table 2).

3.3. Number of Pods per Plant

Bacteria, Mo and S fertilizer applications had a significant effect on the number of pods in mung bean plants. It was determined that the number of pods in the plants in the plots where bacteria and molybdenum were applied (30.75 and 26.90 pcs, respectively) was higher. However, the number of pods in the plant increased with the increase in S doses, the highest number of pods was determined in 30 kg ha^{-1} S application and the lowest number of pods was determined in 10 kg ha^{-1} S application and control (0 kg ha^{-1} S) application. The number of pods per plant varied between 18.27-34.90 (S_0R_0-S_3R_1) according to S doses and bacteria application, and it was determined that the number of pods of the plants in the plots inoculated with bacteria was higher with increasing S doses. When the Mo x S interaction was examined, the highest number of pods was determined in 30 kg S fertilization per hectare with Mo application (29.69), followed by 20 kg S fertilization per hectare with Mo application (28.05). The lowest number of pods was determined in plots without Mo and S application (22.93). In the B x Mo x S combination, the highest number of pods was obtained in plots with 3 kg S application and molybdenum and bacteria inoculation (35.80) and the lowest number of pods was obtained in plots without molybdenum and bacteria inoculation with 0 and 10 kg S application (17.27 and 17.33 pcs, respectively) (Table 3).

Table 3. Mean values of number of pods per plant and number of grains per plant according to bacteria, molybdenum and sulphur treatments to mung bean

Boron Appl.	Mo Appl.	Number of Pods per Plant (pcs)					Number of Grains per Plant (pcs)				
		S (kg ha^{-1})					S (kg ha^{-1})				
		0	10	20	30	Mean	0	10	20	30	Mean
B_0	Mo_0	17.27^{g}	17.33^{g}	19.27^{fg}	18.20^{fg}	**18.02**	165.60^{j}	171.33^{ij}	172.53^{h-j}	217.33^{ef}	**181.70**
	Mo_1	19.27^{fg}	20.73^{ef}	23.00^{e}	23.58^{e}	**21.64**	183.87^{g-j}	195.47^{f-1}	201.00^{f-h}	202.62^{e-g}	**195.74**
Mean		**18.27^{f}**	**19.03^{ef}**	**21.13^{d}**	**20.89^{de}**	***19.83^{B}***	**174.73^{d}**	**183.40^{d}**	**186.77^{d}**	**209.98^{c}**	***188.72^{B*}***
B_1	Mo_0	28.60^{d}	23.87^{e}	30.87^{b-d}	34.00^{ab}	**29.33**	252.80^{cd}	230.53^{de}	276.33^{bc}	295.30^{ab}	**263.74**
	Mo_1	29.40^{d}	30.33^{cd}	33.10^{a-c}	35.80^{a}	**32.16**	267.47^{bc}	287.67^{ab}	313.33^{a}	315.70^{a}	**296.04**
Mean		**29.00^{c}**	**27.10^{c}**	**31.98^{b}**	**34.90^{a}**	***30.75^{A}***	**260.13^{b}**	**259.10^{b}**	**294.83^{a}**	**305.50^{a}**	***279.89^{A}***
MoxS	Mo_0	22.93^{d}	20.60^{e}	25.07^{c}	26.10^{bc}	**23.68^{b}**	209.20^{de}	200.93^{e}	224.43^{cd}	256.32^{ab}	**222.72^{b}**
	Mo_1	24.33^{cd}	25.53^{c}	28.05^{ab}	29.69^{a}	**26.90^{a}**	225.67^{cd}	241.57^{bc}	257.17^{ab}	259.16^{a}	**245.89^{a}**
Mean		**23.63^{C}**	**23.07^{C}**	**26.56^{B}**	**27.89^{A}**		**217.43^{C}**	**221.25^{C}**	**240.80^{B}**	**257.74^{A}**	

*: There is no statistical difference between averages with the same letters.

3.4. Number of Grains per Plant

Number of grains per plant, which is effective on seed yield in mung bean, varied significantly according to sulphur, molybdenum and bacteria treatments. It was determined that the average number of grains per plant in the plots treated with bacteria and molybdenum (279.89 and 245.89 plants, respectively) was higher than the plots without treatment (188.72 and 222.72 plants, respectively). According to S doses, the number of grains per plant varied between 217.43-257.74 and the highest number of grains per plant was determined at 30 kg ha^{-1} S dose, while the lowest number of grains per plant was determined in control (0 kg ha^{-1}) and 10 kg ha^{-1} S treatments. However, the number of grains per plant increased with increasing S doses and 30 kg ha^{-1} S dose increased the number of grains per plant by 19% compared to the control treatment. On the other hand, when the S x B interaction was examined, the number of grains per plant varied between 174.73- 305.50, the highest number of grains per plant was determined in the plots where 30 kg ha^{-1} S application and bacteria were applied and there was no statistical difference between the number of grains per plant in the plots where 20 kg ha^{-1} S application and bacteria were applied together. Again, the lowest number of grains per plant was determined in the plots without S and bacteria application, while they were in the same statistical group with 10 and 20 kg ha^{-1} S and non-bacteria inoculated treatments. According to the Mo x S treatment, the highest number of grains per plant was determined in the Mo treatment with 30 kg ha^{-1} S and the lowest number of grains per plant was determined in the plants without Mo treatment with 10 kg ha^{-1} S application. When the S x Mo x B interaction was examined, the highest number of grains per plant was determined in plots with 3 kg S application and Mo and bacteria inoculation (315.70 pieces), while the lowest number was obtained from plants without molybdenum and bacteria inoculation with 0 kg ha^{-1} S application (165.6 pieces). It was determined that S, bacteria and Mo applications and their co-applications significantly increased the number of grains per plant of mung bean (Table 3).

3.5. Plant Grain Yield

Plant grain yield is one of the important agronomic traits that directly affect grain yield. In the study, average plant grain yield varied between 10.65-15.12 g and 12.36-13.41 g according to bacteria and Mo treatments, respectively. Especially the grain yields of the plants treated with bacteria and Mo were found to be higher. According to S doses, average plant grain yield varied between 11.56 (S_0)-14.02 (S_3) g. It was determined that plant grain yield of mung bean increased with the increase in S doses. While the S x B interaction significantly changed the plant grain yield of mung bean, the highest plant grain yield was determined in plants inoculated with bacteria with 30 kg ha^{-1} S application, followed by plants inoculated with bacteria with 10 and 20 kg ha^{-1} S application. However, the lowest plant grain yield was detected in plants that were not inoculated (B_0) with 0 kg ha^{-1} (control) S dose (Table 4).

Table 4. Mean values of plant grain yield and grain yield traits of mung bean according to bacteria, molybdenum and sulphur treatments

Boron Appl.	Mo Appl.	Plant Grain Yield (g)					Grain Yield (kg ha^{-1})				
		S (kg ha^{-1})					S (kg ha^{-1})				
		0	10	20	30	Mean	0	10	20	30	Mean
B_0	Mo_0	8.94	9.85	10.27	12.02	**10.27**	1867.0	1947.7	2031.7	2136.4	**1995.7**
	Mo_1	14.05	16.44	16.22	16.43	**11.03**	2202.6	2554.7	2200.6	2646.1	**2401.0**
Mean		**9.56^{d}**	**10.27^{d}**	**10.58^{d}**	**12.19^{c}**	***10.65^{B}***	**2034.8^{d}**	**2251.3^{d}**	**2116.1^{d}**	**2391.2^{cd}**	***2198.4^{B*}***
B_1	Mo_0	13.05	14.35	15.12	15.29	**14.45**	2868.8	2665.5	3165.4	3007.5	**2926.8**
	Mo_1	10.18	10.68	10.89	12.35	**15.78**	2494.5	3199.8	3334.5	3352.7	**3095.4**
Mean		**13.55^{b}**	**15.40^{a}**	**15.67^{a}**	**15.86^{a}**	***15.12^{A}***	**2681.6^{bc}**	**2932.7^{ab}**	**3249.9^{a}**	**3180.1^{a}**	***3011.1^{A}***
Mo x S	Mo_0	11.00	12.10	12.70	13.66	**12.36^{b}**	2367.9^{c}	2306.6^{c}	2598.5^{bc}	2571.9^{bc}	**2461.2^{b}**
	Mo_1	12.12	13.56	13.55	14.39	**13.41^{a}**	2348.5^{c}	2877.4^{ab}	2767.5^{ab}	2999.4^{a}	**2748.2^{a}**
Mean		**11.56^{C}**	**12.83^{B}**	**13.12^{B}**	**14.02^{A}**		**2358.2^{C}**	**2592.0^{B}**	**2683.0^{AB}**	**2785.7^{A}**	

*: There is no statistical difference between averages with the same letters.

3.6. Grain Yield

Increasing grain yield in mung bean is one of the most important breeding objectives. In this direction, it was determined that S, Mo and bacteria applied to mung bean were highly effective on grain yield. Grain yield varied between 2358.2- 2785.7 kg ha^{-1} according to S doses. The highest average grain yield was determined at 30 kg ha^{-1} S dose and this dose was statistically in the same group with 20 kg ha^{-1} S dose. The lowest grain yield was determined at 0 kg ha^{-1} (control) S treatment. However, it was determined that 30 kg ha^{-1} S application increased grain yield by 18% compared to the control application. On the other hand, average grain yield varied between 2198.4 (B_0)-3011.1(B_1) kg ha^{-1} and 2461.2 (Mo_0)-2748.2(Mo_1) kg ha^{-1} according to bacteria and Mo treatments, respectively. It was determined that the grain yields of the plants treated with bacteria and molybdenum were higher than the untreated plots. When S x Mo was analysed, the highest grain yield was determined in plots inoculated with bacteria with 3 kg ha^{-1} S application (3180.1 kg ha^{-1}), followed by plots inoculated with bacteria with 20 and 10 kg ha^{-1} S application (3249.9 kg ha^{-1} and 2932.7 kg ha^{-1}, respectively). The lowest grain yield was recorded at 0, 10 and 20 kg ha^{-1} (control) S doses and in plots without bacteria inoculation (2034.8 kg ha^{-1}, 2251.3 kg $ha^{-1}$and 2116.1 kg ha^{-1}, respectively) (Table 4).

3.7. Harvest index

Harvest index is calculated by the ratio of grain yield to biological yield and increasing the harvest index value of mung bean is among the important breeding objectives. In this study, harvest index values varied between 24.08-27.45% according to S doses. While the highest harvest index value was found at 30 kg ha^{-1} S dose, it was in the same statistical group with 10 and 20 kg ha^{-1} S doses. However, the lowest harvest index value was found at 0 kg ha^{-1} S dose. On the other hand, according to the bacterial treatments, the highest harvest index value was found in the plots with bacterial treatment (B_1). Although molybdenum application was not statistically effective on harvest index, it was determined that the harvest index value (26.35%) of the plants in molybdenum treated plots (Mo_1) was higher. When the S x B interaction was analysed, harvest index values varied between 20.99% (S_0B_0) and 30.44% (S_1B_1). There was no statistical difference between 10 kg ha^{-1} S dose and bacteria treatment, 20 and 30 kg ha^{-1} S dose and bacteria treatments (Table 5).

3.8. Hundred Grain Weight

Hundred grain weight, which is important for marketing, is an important quality criterion for determining large grains in mung bean. Bacteria treatments significantly changed the hundred grain weight of mung bean and the highest hundred grain weight was determined in bacterial inoculation (6.39 g). In molybdenum treatment, the highest hundred grain weight was determined in seeds osmoprimed with molybdenum, while there was no statistical difference between molybdenum treatments. On the other hand, according to the sulphur treatments, facial grain weight varied between 5.64-6.43 g. The highest facial grain weight was determined at 30 kg ha^{-1} S dose, followed by 20 (6.27 g) and 30 (6.04 g) kg ha^{-1} S dose, respectively. In the study, it was determined that especially bacteria and sulphur treatments significantly increased the hundred grain weight. However, facial grain weight increased according to molybdenum treatment and interactions (Mo x S, B x Mo, B x S, B x Mo x S, B x Mo x S), but there was no statistical difference (Table 5).

Table 5. Mean values for harvest index and hundred grain weight traits of mung bean according to bacteria, molybdenum and sulphur treatments

Boron Appl.	Mo Appl.	Harvest Index (%)					Hundred Grain Weight (g)				
		S (kg ha⁻¹)					S (kg ha⁻¹)				
		0	10	20	30	Mean	0	10	20	30	Mean
B_0	Mo_0	19.09	21.59	23.94	26.24	**22.72**	5.28	5.35	5.81	6.12	**5.64**
	Mo_1	22.88	21.96	23.54	27.39	**23.94**	5.33	5.90	6.20	6.36	**5.95**
Mean		**20.99^d**	**21.77^d**	**23.74^{cd}**	**26.82^{bc}**	***23.33^B***	**5.31**	**5.62**	**6.01**	**6.24**	***5.79^{B*}***
B_1	Mo_0	27.08	30.51	27.09	27.94	**28.16**	5.68	6.34	6.44	6.51	**6.24**
	Mo_1	27.28	30.37	29.17	28.22	**28.76**	6.25	6.56	6.63	6.71	**6.54**
Mean		**27.18^{a-c}**	**30.44^a**	**28.13^{ab}**	**28.08^{ab}**	***28.46^A***	**5.97**	**6.45**	**6.53**	**6.61**	***6.39^A***
Mo x S	Mo_0	23.09	26.05	25.52	27.09	**25.44**	5.48	5.85	6.12	6.31	**5.94**
	Mo_1	25.08	26.16	26.36	27.80	**26.35**	5.79	6.23	6.42	6.53	**6.24**
Mean		**24.08^B**	**26.11^{AB}**	**25.94^{AB}**	**27.45^A**		**5.64^B**	**6.04^{AB}**	**6.27^A**	**6.43^A**	

*: There is no statistical difference between averages with the same letters.

3.9. Protein Content

In the study, bacteria, molybdenum and S fertilizer applications had significant effect on the protein content of mung bean. It was determined that the protein ratio was higher in the plots where bacteria and molybdenum were applied (20.70% and 17.54%, respectively). In addition, the protein content also increased with the increase in S doses, the highest protein content was determined in 20 and 30 kg ha^{-1} S treatments and the lowest protein content was determined in the control (0 kg ha^{-1} S) treatment. On the other hand, it was determined that the mung bean grains obtained from the plots where S doses increased and bacteria and molybdenum treatments were applied had higher protein content (Table 6).

Table 6. Mean values of protein and ash content traits of mung bean according to bacteria, molybdenum and sulphur treatments

Boron Appl.	Mo Appl.	Protein Content (%)					Ash Content (%)				
		S (kg ha⁻¹)					S (kg ha⁻¹)				
		0	10	20	30	Mean	0	10	20	30	Mean
B_0	Mo_0	16.45	17.05	17.50	17.72	**17.18**	4.47^h	4.54^g	4.64^f	4.86^d	**4.63**
	Mo_1	16.98	17.93	18.22	18.53	**17.92**	4.53^{gh}	4.77^e	4.86^d	4.89^{cd}	**4.76**
Mean		**16.71**	**17.49**	**17.85**	**18.13**	***17.54^{B*}***	**4.50^g**	**4.65^f**	**4.75^e**	**4.87^{cd}**	***4.69^{B*}***
B_1	Mo_0	18.84	19.29	21.23	21.65	**20.25**	4.75^e	4.85^d	4.95^c	5.03^b	**5.03**
	Mo_1	19.67	21.32	21.61	22.00	**21.15**	4.94^c	4.95^c	5.04^b	5.20^a	**4.89**
Mean		**19.26**	**20.31**	**21.42**	**21.82**	***20.70^A***	**4.84^d**	**4.90^c**	**5.00^b**	**5.12^a**	***4.96^A***
Mo x S	Mo_0	17.64	18.17	19.37	19.69	**18.71^b**	4.61^g	4.69^f	4.79^d	4.95^b	**4.76^b**
	Mo_1	18.33	19.63	19.92	20.27	**19.53^a**	4.74^e	4.86^c	4.95^b	5.04^a	**4.90^a**
Mean		**17.99^C**	**18.90^B**	**19.64^{AB}**	**19.98^A**		**4.67^D**	**4.78^C**	**4.87^B**	**4.99^A**	

*: There is no statistical difference between averages with the same letters.

3.10. Ash Content

Crude ash content, which is an indicator of inorganic matter content of seeds, varied between 4.69% (B_0)-4.96% (B_1) and 4.76% (Mo_0)-4.90% (Mo_1) according to bacteria and molybdenum treatments, while bacteria and molybdenum treatments increased ash content. As the application amount of S doses increased, ash content also increased. The highest ash content was determined at 30 kg ha^{-1} S dose and the lowest at 0 kg ha^{-1} (control) S dose. On the other hand, when the S x B interaction was analysed, the highest ash content was determined in S_2B_1(5.12%) and the lowest in S_0B_0 (4.50%). According to Mo x S interaction, the highest ash content was determined in Mo_1S_3(5.04%) and the lowest in Mo0S0 (4.61%). In the B x Mo x S combination, the highest ash rate was obtained in molybdenum and bacterial inoculation ($B_1Mo_1S_3$, 5.20%) with 30 kg S application per hectare, and the lowest ash rate was obtained in molybdenum and bacterial inoculation ($B_0Mo_0S_0$, 4.47%) with

0 S application per hectare. Rhizobium bacteria, molybdenum and sulphur applications to mung bean increased the ash content (Table 6).

3.11. Number of Nodules

In the study, it was determined that *Rhizobium* bacteria inoculated to mung bean seeds before sowing (9.12 pieces plant^{-1}) increased the number of nodules compared to the plants in the plots without inoculation (3.21 pieces plant^{-1}). Molybdenum application also encouraged nodule formation and the number of nodules was higher in the treated plots (7.24 pieces plant^{-1}). According to S doses, the number of nodules in plants varied between 4.23 (S_0)-7.74 (S_3) pieces plant^{-1} and the number of nodules in plants increased in parallel with the increase in S doses. When the S x B interaction was analysed, the number of nodules varied between 2.32 (S_0B_0)-11.08 (S_3B_1) pieces plant^{-1}. However, S_0B_0 and S_1B_0 treatments with the lowest nodule number and S_3B_1 and S_2B_1 treatments with the highest nodule number were in the same statistical group. It was found that increasing S doses and inoculation with bacteria increased the number of nodules (Table 7).

3.12. Nodule Weight

In the study, average nodule weight values varied between 0.79 (R_0)- 2.10 (R_1) g plant^{-1} and 1.28 (Mo_0)-1.60 (Mo_1) g plant^{-1} according to bacteria and molybdenum treatments, respectively, while bacteria and molybdenum treatments increased nodule weight values. According to S doses, the average nodule weight varied between 0.90 (S_0) g plant^{-1} and 1.82 (S_3) g plant^{-1}. However, it was determined that the nodule weight of mung bean increased with increasing S doses. When the S x B interaction was analysed, nodule weight varied between 0.50 (S_0B_0)- 2.51 (S_3B_1) g plant^{-1}. S_2B_1 and S_3B_1 treatments, which had the highest nodule weight, were in the same statistical group. Similar to the nodule number, especially the increase in S doses and bacterial inoculation were effective in increasing the nodule weight of the plants (Table 7).

Table 7. Mean values for nodule number and nodule weight traits of mung bean according to bacteria, molybdenum and sulphur treatments

Boron Appl.	Mo Appl.	Number of Nodules (pcs plant^{-1})					Nodule Weight (g plant^{-1})				
		S (kg ha^{-1})					S (kg ha^{-1})				
		0	10	20	30	Mean	0	10	20	30	Mean
B_0	Mo_0	2.14	2.36	2.60	3.57	**2.67^d**	0.33	0.58	0.64	0.94	**0.62**
	Mo_1	2.50	3.45	3.90	5.23	**3.77^c**	0.66	0.82	0.97	1.33	**0.95**
Mean		**2.32^e**	**2.90^e**	**3.25^e**	**4.40^d**	***3.21^B***	**0.50^e**	**0.70^{de}**	**0.81^d**	**1.14^c**	***0.79^{B*}***
B_1	Mo_0	4.80	6.78	9.20	9.37	**7.54^b**	1.07	1.80	2.48	2.43	**1.94**
	Mo_1	7.47	10.08	12.47	12.80	**10.70^a**	1.55	2.33	2.55	2.57	**2.25**
Mean		**6.13^c**	**8.43^b**	**10.83^a**	**11.08^a**	***9.12^A***	**1.31^c**	**2.06^b**	**2.51^a**	**2.50^a**	***2.10^A***
Mo x S	Mo_0	3.47	4.57	5.90	6.47	**5.10^b**	0.70	1.19	1.56	1.69	**1.28^b**
	Mo_1	4.98	6.77	8.18	9.02	**7.24^a**	1.11	1.58	1.76	1.95	**1.60^a**
Mean		**4.23^D**	**5.67^C**	**7.04^B**	**7.74^A**		**0.90^D**	**1.38^C**	**1.66^B**	**1.82^A**	

*: There is no statistical difference between averages with the same letters.

4. Discussion

In this study, the changes in some agronomic and quality characteristics of mung bean as a result of sulphur, molybdenum and bacteria application were determined. It was observed that sulphur, molybdenum and bacteria treatments were highly effective on plant height and first pod height of mung bean and the treatments increased plant height and first pod height. However, plant height and first pod height increased with the increase in sulphur doses, and the highest plant height was determined in 20 and 30 kg ha^{-1} sulphur application (Table 2). Rhizobium bacteria are well known to affect plant growth and development through a wide variety of mechanisms such as N_2 fixation, production of plant growth regulators, mineral uptake and suppression of plant diseases (Kennedy et al. 2004; Ahmad et al. 2013). Sulphur fertilization improves nitrogen uptake efficiency of plants and prevents nitrogen loss from the soil (Brown et al. 2000). Therefore, the development of plants increases. In this study, it was determined that sulphur, bacteria and molybdenum applications increased plant height and first pod height of mung bean (Table 2). As a matter of fact, other studies have also reported significant increases in plant growth with sulphur, Rhizobium inoculation and molybdenum application (Iqbal et al. 2012; Togay et al. 2008; Bahadur and Tiwari 2014).

In the study, changes in yield and yield components according to sulphur, molybdenum and bacteria applications applied to mung beans were examined. Especially the application of sulphur, molybdenum and bacterial inoculation alone and in combination had a significant effect on the number of pods and grains in the plant, plant grain yield, grain yield and harvest index, especially of mung bean. Rhizobium bacteria and molybdenum application applied to mung bean increased the number of pods and grains in the plant, plant grain yield, grain yield, harvest index and hundred grain weight compared to the control application. However, with the increase in S doses, it was determined that the number of pods and grains per plant, plant grain yield, grain yield, harvest index and hundred grain weight of mung bean increased, and 30 kg S application per hectare gave the highest values (Tables 3; 4; 5). The beneficial effect of this increase in S, Mo and bacterial application on yield and parameters contributing to yield can be attributed to the vital role of enzymes in the function of biological processes that lead to an increase in yield components in plants. Molybdate, the dominant form present in plants, is included in enzymes by participating directly or indirectly in nitrogen metabolism, especially in plants, as a part of the protein complex molybdenum cofactor (Kaiser et al. 2005). Along with these, the findings in the study are similar to Rabbani et al. (2005) who found that the number of pods and grain yield of the plant increased with *Rhizobium* inoculation in combination with micronutrients is consistent with the findings.

In the study, protein and ash content of mung bean showed significant changes according to the treatments. Especially protein and ash content of mung bean grains increased with increasing S doses. However, protein and ash content increased according to bacteria and molybdenum treatments (Table 5). In this context, the importance of sulphur in pulse nutrition has been well understood in recent years. It is involved in various metabolic and enzymatic processes, including protein formation, photosynthetic activity, and symbiotic nitrogen fixation between legume and *Rhizobium* (Becana et al. 2018). In addition, sulphur plays an important role in the synthesis of coenzyme A (CoA), biotin, thiamine (vitamin B_1) and glutathione (Kahraman et al. (2016) found a significant negative relationship between protein content and nitrogen-free substances and a significant positive relationship between sulphur content. In this respect, they stated that nitrogen-free substances and sulphur content should be emphasized in order to increase the protein content in legumes. They stated that environmental conditions and genotypes are effective on the protein and ash content of mung bean grains (Baraki et al. 2020; Karaman 2019; Yadav et al. 2023); and that the protein content may vary according to various nutrients such as sulphur, bacteria and molybdenum (Ahmad et al. 2021; Ahmad et al. 2022; Junaid et al. 2022). In this context, the findings obtained in this study are in agreement with the data obtained by the researchers.

In the abscence of *Rhizobium* bacteria, mung beans are not able to assimilate atmospheric nitrogen, which increases soil fertility and minimizes the need for nitrogen fertilizers. Weisany et al. (2013) observed that biological nitrogen fixation provides an economic advantage by improving the quality and quantity of the product by reducing nitrogen input as fertilizer. In this context, inoculation of Rhizobium bacteria increased the nodule number and weight of mung bean. In addition, S and Mo treatments were also found to be effective in increasing the nodule number and weight of mung bean (Table 6). The increase in nodule formation and weight is due to bacterial inoculation, sulphur and molybdenum, which are required by *Rhizobium* bacteria to fix atmospheric nitrogen in legumes. Indeed, Rhizobium inoculation was found to increase the number of effective nodules in mung bean by 57% compared to the control (Hossain et al. 2011). In particular, molybdenum is an important element that helps protein synthesis and the fixation of atmospheric nitrogen by nodule bacteria in the roots of legumes. In addition, since Mo has low mobility, it is present at higher levels in the root zone of the plant than in the stem and leaves. The Mo element nitrogenase enzyme acts as a key enzyme in the functions of nitrogen fixing microorganisms, while nitrate reductase enzyme acts as a key enzyme in the reduction of nitrate to nitrite in plants. Nicoloso and Dos Santos (1990) determined the effects of different nitrogen doses, Rhizobium inoculation and molybdenum applications on bean plants and found that molybdenum did not increase nodule weight in nitrogen-free applications, while inoculation and molybdenum increased dry matter content, total nitrogen accumulation and grain yield. It was also found that

S and Mo application can increase nodule formation in legume plants (Vieira et al. 1998; Yadav, 2004; Singh et al. 2017).

5. Conclusions

In this study, some agronomic and quality traits and changes in nodule development were determined as a result of sulphur, molybdenum and bacteria treatments applied to mung bean. In the study, significant differences were found in terms of the traits examined according to sulphur, molybdenum and bacteria treatments. It was determined that bacteria and molybdenum application increased the yield, yield components and nodule formation of mung bean. It was determined that agronomic parameters such as yield, hundred grain weight, protein content, ash content and nodulation activities increased as the application amount of sulphur fertilization increased. As a result, it can be recommended to use 30 kg S ha^{-1} with bacteria and molybdenum for higher yield and quality in mung bean cultivation. Encouraging the use of S and Mo-containing fertilizers and bacterial inoculation and providing the necessary support in this regard will make significant contributions to the development of mung bean cultivation.

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