



Interactive Effects of Boron and Molybdenum on Nodulation, Growth and Yield of Cowpea under South Gujarat Condition

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ABSTRACT

Background: Cowpea seeds are nutritious component of human diet and being a legume crop, it also improves the soil fertility by increasing the amount of nitrogen in the soil through symbiotic nitrogen fixation. To study the effect of boron and molybdenum on nodulation, growth and yield of cowpea the field experiment was conducted at the Regional Horticultural Research Station, Navsari Agricultural University, Navsari, Gujarat, India, during summer season of 2019 and 2021.

Methods: The experiment was carried out in a factorial randomized block design with 3 replications. Factor-1 consisted of four levels of seed treatments with molybdenum at 2 mg/l (M_1), 4 mg/l (M_2), 6 mg/l (M_3) for 24 hours prior to sowing including control (M_0), where as the second factor was consisted of four levels of boron (B) spray at 2 mg/l (B_1), 4 mg/l (B_2), 6 mg/l (B_3) and control at 30 DAS, 45 DAS and 60 DAS with control. Boron was applied in the form of Boric acid and Molybdenum as ammonium molybdate.

Result: The treatment combination of seed treatment of molybdenum @ 2 mg/l with foliar spray of boron @ 4 mg/l at 30, 45 and 60 DAS (M_1B_2) has significantly influenced yield parameters and registered maximum number of clusters per plant (6.50), green pod yield per plant (0.153 kg), green pod yield per net plot (3.98 kg), green pod yield per hectare (12.27 tonne). Seed treatment with different levels of molybdenum has significantly influenced nodulation in cowpea and recorded maximum number of nodules per plant (31.69 at final harvest) and fresh nodule weight (0.230 g/plant) in seed treatment of molybdenum @ 2 mg/l (M_2) among all the treatments at final harvest during all the years of study, including pooled analysis.

Key words: Boron, Growth and yield, Molybdenum, Nodulation.

INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp.] is an annual legume crop. Cowpea seeds are a nutritious component in the human diet as well as a nutritious livestock feed. Cowpea is known as *lobiya* or *chowla* in India and used in different cuisines as side dish with staple food. It is grown mainly in semi arid and warm regions. It grows well both during summer and rainy seasons. It also improves the soil fertility by increasing the amount of nitrogen in the soil through symbiotic nitrogen fixation.

Micronutrients play an important role in growth and development of plants. Though, it is required by plants in minute quantity, its unavailability or deficiency in plants may adversely affect metabolic processes and availability of primary and secondary nutrients (Roshni *et al.*, 2022). Legume crops required more amount of boron compared to most field crops as boron plays vital role in proper development of reproductive organs. Its deficiency leads to sterility in plants by malformation of reproductive tissues affecting pollen germination, resulting in increased flower drop and reduced fruit set (Subasinghe *et al.*, 2003). The boron deficiency could hamper the response to applied nitrogen because nitrogen exacerbates the boron demand of the crop. There is a tremendous scope to increase current yield potential of cowpea by enhancing the nutrient availability and better plant growth through inclusion of micronutrients in the production system. Foliar application of nutrients helps the plants to absorb nutrients through the stomatal openings

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in leaves and results in most effective use of fertilizers in a most economical way.

Molybdenum is required by the *Rhizobium* bacteria for proper function of nitrogenase enzyme which are involved in nitrogen fixation. Again molybdenum is the cofactor for the enzyme nitrate reductase, which involved in nitrogen assimilation (Hansch and Mendel, 2009). The application of molybdenum encourages nitrogen fixation and nodule formation (Rahman *et al.*, 2008). Therefore, this study was conducted to study the combined effect of boron and molybdenum on nodulation, growth and yield of cowpea.

MATERIALS AND METHODS

The field experiment was conducted at the Regional Horticultural Research Station, Navasri Agricultural University, Navsari, Gujarat, India, during summer season of 2019, 2020 and 2021 which is geographically situated at 72°54' East longitude and 20°57' North latitude and at an altitude of 11.89 m above the mean sea level. The region is about 12 km away from the Arabian sea coast. The average rainfall of the region is about 1500 mm and is normally received by second fortnight of June and ceases by September end. The soil of experimental site was black, rich in organic matter and potash. The clay content ranges from 60 to 68% predominated by montmorillonitic clay minerals along with pH 6.8 and EC 0.53 dS/m. The experiment was implemented in randomized block design with factorial concept and was replicated thrice. There were two factors in this experiment under study. Factor one consisted of four levels of seed treatments with molybdenum (M) at 2 mg/l (M_1), 4 mg/l (M_2), 6 mg/l (M_3) for 24 hours prior to sowing and control (M_0), where as the second factor was consisted of four levels of boron (B) spray at 2 mg/l (B_1), 4 mg/l (B_2), 6 mg/l (B_3) at 30 DAS, 45 DAS and 60 DAS including control. Thus, overall there were sixteen treatment combinations were studied in this experiment. Boron was applied in the form of boric acid and Molybdenum as ammonium molybdate.

The observations on plant growth parameters such as plant height, numbers of branches per plant, number of clusters per plants were measured following standard procedures from five randomly selected plants. While, the number of nodules per plant and fresh weight of root nodules were recorded at final harvest. Two extra rows per plot were included for destructive characters. The five randomly selected plants were uprooted carefully to avoid unwanted shattering of nodule from each treatment. The number of nodules plant⁻¹ was counted and then the fresh weight of nodules was also measured with the help of electronic weighing balance.

The yield and its attributing characters viz., number of pods per cluster, number of pods per plant, length of pod, diameter of the pod and weight of the pod, green pod yield per plant, green pod yield per plot and harvest index was recorded following standard procedures. In order to test the significance of variation in experimental data obtained for various treatment effects, the data were statistically analysed as described by (Fisher, 1950).

RESULTS AND DISCUSSION

Growth characters

The data in Table 1 represents significant differences among different levels of molybdenum seed treatment for plant height at 60 DAS during all the years of experiment including pooled analysis. M_1 level of molybdenum seed treatment (2 mg/l) has significantly increased plant height (40.77 cm, 70.74 cm and 56.32 cm, respectively) of cowpea during 2nd and 3rd year of experiment including pooled analysis. The studied character was also remained significantly affected by foliar spray of boron during 1st and 2nd year of study including pooled and the cowpea plants sprayed with boron at 2 mg/l registered maximum plant height (59.10 cm, 40.28 cm and 55.74 cm) but during 3rd individual year of study the result was found non-significant for foliar application of boron. Interaction between $M \times B$ was also found significant and the maximum plant height (60.15 cm) recorded in treatment combination of M_1B_1 (Molybdenum seed treatment 2 mg/l + (Boron foliar spray 2 mg/l) in pooled analysis (Fig 1).

As per the data presented in Table 1, different levels of molybdenum seed treatment had significantly affected number of branches per plant at 60 DAS. The trait was significantly affected by molybdenum seed treatment at 60 DAS during all the years of experiment and in pooled analysis. The cowpea seed treated with molybdenum at the rate of 4 mg/l has significantly increased number of branches (7.61, 7.32 and 7.30, respectively) of cowpea during 2nd and 3rd year of experiment including pooled analysis. However, during first individual year of study, the

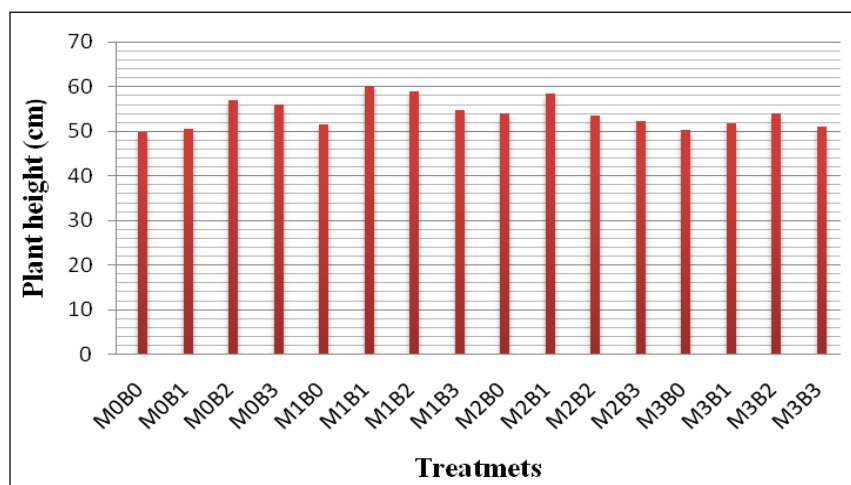


Fig 1: Interaction effects of boron and molybdenum on plant height (cm) (60 DAS) in pooled analysis.

Table 1: Effects of boron and molybdenum on growth characters of cowpea at 60 DAS.

Treatments	2019 (60 DAS)					2020 (60 DAS)					2021 (60 DAS)					Pooled (60 DAS)				
	M ₀	M ₁	M ₂	M ₃	Mean (B)	M ₀	M ₁	M ₂	M ₃	Mean (B)	M ₀	M ₁	M ₂	M ₃	Mean (B)	M ₀	M ₁	M ₂	M ₃	Mean (B)
Plant height (cm)																				
B ₀	52.40	51.60	55.20	48.73	51.98	35.80	35.60	40.33	36.93	37.17	60.91	67.19	66.49	65.48	65.02	49.70	51.46	54.01	50.38	51.39
B ₁	51.87	65.60	68.73	51.40	59.40	38.07	42.80	36.80	42.00	39.92	61.74	72.04	69.44	61.67	66.22	50.56	60.15	58.32	51.69	55.18
B ₂	65.87	60.47	53.80	56.27	59.10	39.63	43.20	37.67	40.60	40.28	65.13	72.93	68.60	64.68	67.84	56.88	58.86	53.36	53.85	55.74
B ₃	62.80	52.13	50.33	51.33	54.15	38.80	41.47	39.47	37.07	39.20	65.97	70.83	67.24	64.59	67.16	55.86	54.81	52.35	51.00	53.50
Mean(M)	58.23	57.45	57.02	51.93		38.08	40.77	38.57	39.15		63.44	70.74	67.94	64.11		53.25	56.32	54.51	51.73	
	M	B	M × B			M	B	M × B			M	B	M × B			M	B	M × B		
S.E.m.±	1.55	1.55	3.11			0.68	0.68	1.36			1.49	1.49	2.98			0.87	0.87	1.74		
C.D. at 5%	4.48	4.48	8.97			1.97	1.97	3.94			4.30	NS	NS			2.46	2.46	4.91		
C.V. %			9.58					6.03					7.76					9.69		
Numbers of branches/plant																				
B ₀	6.20	6.87	7.27	7.40	6.93	7.20	7.00	7.87	7.53	7.40	6.00	6.67	7.27	6.60	6.63	6.47	6.84	7.47	7.18	6.99
B ₁	6.40	6.87	7.33	7.33	6.98	7.20	7.77	7.80	7.47	7.56	6.13	6.87	7.53	6.73	6.82	6.58	7.17	7.56	7.18	7.12
B ₂	6.93	7.90	6.47	7.33	7.16	7.10	7.03	7.73	7.33	7.30	6.20	7.20	7.13	6.53	6.77	6.74	7.38	7.11	7.07	7.08
B ₃	6.33	7.67	6.80	6.60	6.85	7.03	7.53	7.03	7.33	7.23	6.40	7.00	7.33	6.47	6.80	6.59	7.40	7.06	6.80	6.96
Mean (M)	6.47	7.33	6.97	7.17		7.13	7.33	7.61	7.42		6.18	6.93	7.32	6.58		6.59	7.20	7.30	7.06	
	M	B	M × B			M	B	M × B			M	B	M × B			M	B	M × B		B
S.E.m.±	0.17	0.17	0.35			0.11	0.11	0.22			0.13	0.13	0.26			0.11	0.11	0.22		
C.D. at 5%	0.50	NS	NS			0.32	NS	NS			0.38	NS	NS			0.31	NS	NS		
C.V. %			8.62					5.27					6.71					9.39		
Number of clusters/plant																				
B ₀	4.90	5.57	5.53	4.77	5.19	4.70	5.33	6.00	5.40	5.36	5.80	6.20	6.13	6.07	6.05	5.13	5.70	5.89	5.41	5.53
B ₁	4.87	5.80	5.63	5.63	5.48	5.73	5.27	5.40	5.47	5.47	6.00	6.60	6.40	6.33	6.33	5.53	5.89	5.81	5.81	5.76
B ₂	5.60	6.63	6.17	5.40	5.95	5.27	5.80	5.33	5.73	5.53	6.20	7.07	6.60	6.33	6.55	5.69	6.50	6.03	5.82	6.01
B ₃	5.00	6.07	6.13	5.10	5.58	4.60	5.53	5.00	5.07	5.05	5.53	6.53	6.33	6.00	6.10	5.04	6.04	5.82	5.39	5.58
Mean (M)	5.09	6.02	5.87	5.23		5.08	5.48	5.43	5.42		5.88	6.60	6.37	6.18		5.35	6.03	5.89	5.61	
	M	B	M × B			M	B	M × B			M	B	M × B			M	B	M × B	Y × M	Y × B
S.E.m.±	0.08	0.08	0.16			0.09	0.09	0.18			0.10	0.10	0.21			0.06	0.06	0.12	0.10	0.10
C.D. at 5%	0.24	0.24	0.48			0.26	0.26	0.53			0.30	0.30	NS			0.17	0.17	0.34	0.30	0.30
C.V. %			5.13					5.92					5.75					6.36		

seed exposed to molybdenum seed treatment at 2 mg/l registered maximum number of branches per plant (7.33) at 60 DAS. While, in case of foliar application of boron, it failed to show significant influence on the studied trait during

all the individual year of study including pooled analysis. All possible interaction among foliar application of boron and seed treatment of molybdenum on number of branches per plant at 60 DAS were found non-significant

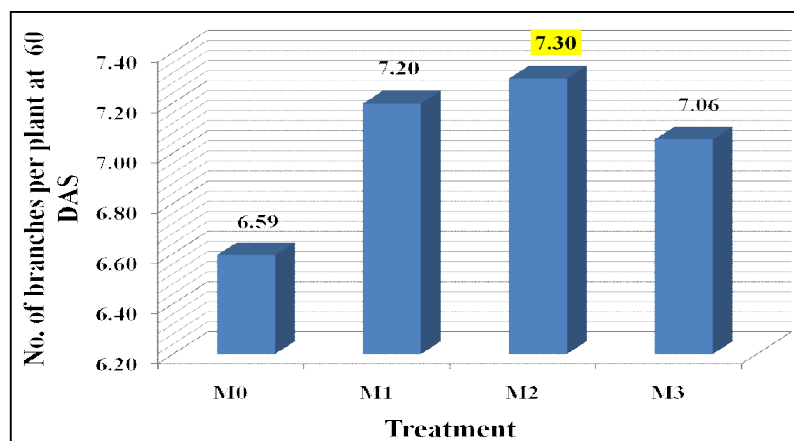


Fig 2: Effects of molybdenum on number of branches per plant (60 DAS) in pooled analysis.

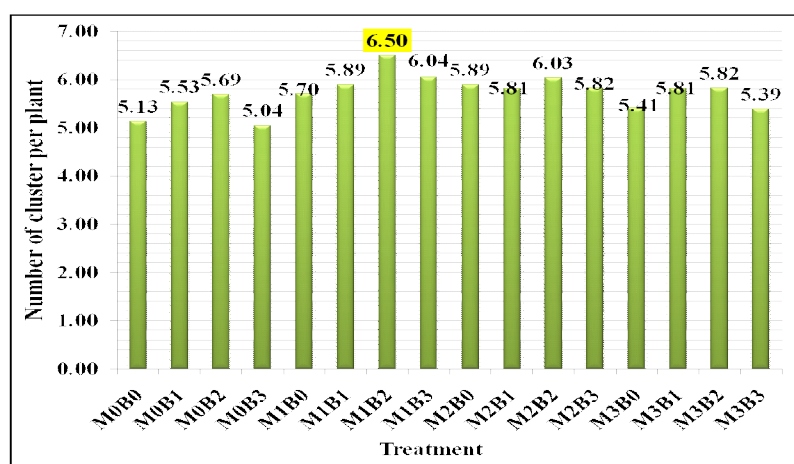


Fig 3: Interaction effects of boron and molybdenum on number of clusters per plant (60 DAS) in pooled analysis.

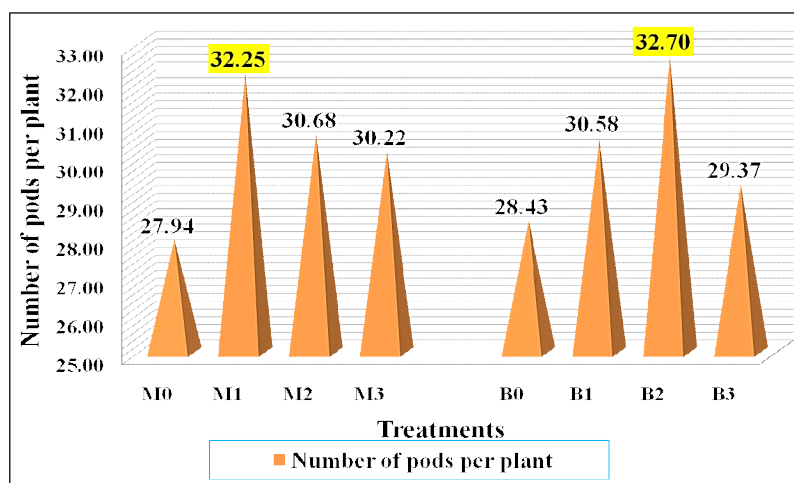


Fig 4: Individual effects of boron and molybdenum on number of pods per plant in pooled analysis.

during all the three years as well as in pooled analysis (Fig 2).

While, as per the data presented in Table 1, during 1st years of experimentation as well as in pooled analysis, the treatment combination of M_1B_2 i.e., Molybdenum seed treatment at 2 mg/l + Boron foliar spray at 4 mg/l recorded maximum number of clusters per plant (6.63 and 6.50) at 60 DAS (Fig 3). Combination of seed treatment with molybdenum along with foliar spray of boron periodically at 30 DAS, 45 DAS and 60 DAS showed synergistic effect and resulted in improvement of growth parameters such as plant height, numbers of branches per plant, number of clusters per plants that triggered more flowering, better pod setting and higher pod yield. The results showed that management of micronutrient in the form of seed treatment with molybdenum and foliar application of boron periodically at 30 DAS, 45 DAS and 60 DAS both had prominent effect on availability of major nutrients in the

soil, which might have promoted the nodule bacteria for nitrogen fixation as well as enhanced the availability of nitrogen, phosphorous and potassium in the soil (Srivastava and Varma, 1995).

Green pod characters

The individual effect of molybdenum seed treatment as well as foliar application of boron failed to exert any significant influence on pod characters viz., pod length, pod diameter and average pod weight. In addition to this, all the possible interactions between $M \times B$ were found non-significant during all the three individual years including pooled analysis. Despite of having non-significant result, the highest pod length (14.27 cm) and pod diameter (0.53 cm) were recorded in treatment combination of M_2B_2 i.e., Molybdenum seed treatment at 4 mg/l + Boron foliar spray at 4 mg/l in pooled analysis. While, the average pod weight (4.76 g) was registered maximum in M_1B_2 i.e.,

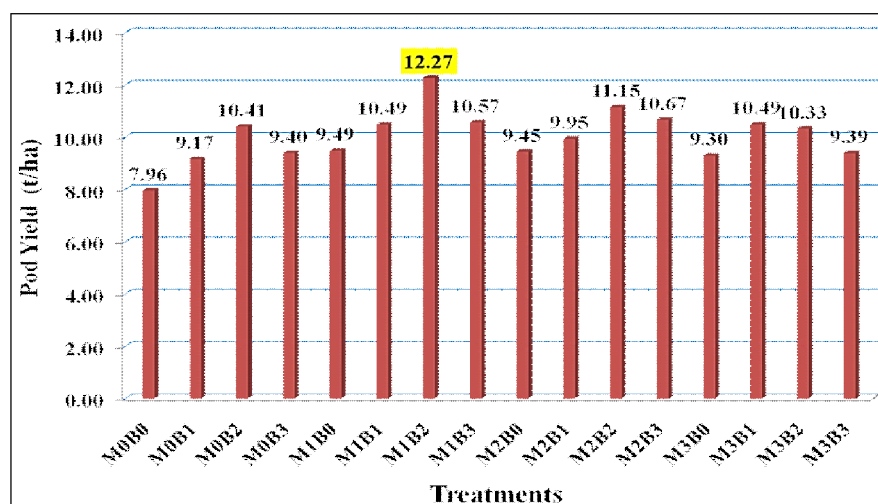


Fig 5: Interaction effect of boron and molybdenum on green pod yield per hectare (t/ha) in pooled analysis.

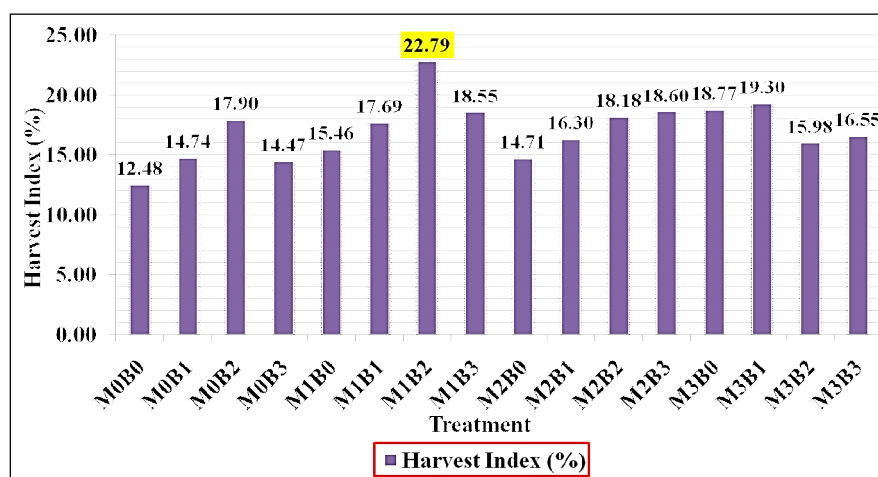


Fig 6: Interaction effect of boron and molybdenum on harvest Index (%) in pooled analysis.

Table 2: Effects of boron and molybdenum on green pod characters of cowpea.

Treatments	Pod length (cm)				Pod diameter (cm)				Weight of pod (g)			
	2019	2020	2021	Pooled	2019	2020	2021	Pooled	2019	2020	2021	Pooled
T ₁ - M ₀ B ₀ (Control)	14.22	13.29	12.32	13.28	0.43	0.56	0.45	0.48	4.10	4.26	4.77	4.37
T ₂ - M ₀ B ₁ (Boron foliar spray 2 mg/l (At 30, 45 and 60 DAS)	14.64	13.48	12.56	13.56	0.43	0.55	0.46	0.48	4.17	4.65	4.80	4.54
T ₃ - M ₀ B ₂ (Boron foliar spray 4 mg/l (At 30, 45 and 60 DAS)	14.83	13.45	12.69	13.66	0.39	0.56	0.47	0.47	4.43	4.60	4.83	4.62
T ₄ - M ₀ B ₃ (Boron foliar spray 6 mg/l (At 30, 45 and 60 DAS)	13.64	14.02	12.37	13.34	0.39	0.59	0.48	0.49	3.90	4.77	4.97	4.54
T ₅ - M ₁ B ₀ (Molybdenum seed treatment 2 mg/l)	14.41	13.60	12.61	13.54	0.46	0.57	0.48	0.49	3.87	4.70	5.00	4.52
T ₆ - M ₁ B ₁ (Molybdenum seed treatment 2 mg/l + (Boron foliar spray 2 mg/l (At 30, 45 and 60 DAS)	13.97	13.36	13.10	13.48	0.39	0.56	0.51	0.48	3.83	4.72	5.10	4.55
T ₇ - M ₁ B ₂ (Molybdenum seed treatment 2 mg/l + (Boron foliar spray 4 mg/l (At 30, 45 and 60 DAS)	14.00	14.38	13.33	13.90	0.44	0.59	0.53	0.52	4.07	4.97	5.23	4.76
T ₈ - M ₁ B ₃ (Molybdenum seed treatment 2 mg/l + (Boron foliar spray 6 mg/l (At 30, 45 and 60 DAS)	14.47	13.74	13.07	13.76	0.42	0.62	0.49	0.51	3.90	4.80	5.10	4.60
T ₉ - M ₂ B ₀ (Molybdenum seed treatment 4 mg/l)	14.62	13.86	13.45	13.97	0.44	0.56	0.47	0.49	4.00	4.88	4.87	4.58
T ₁₀ - M ₂ B ₁ (Molybdenum seed treatment 4 mg/l + (Boron foliar spray 2 mg/l (At 30, 45 and 60 DAS)	14.49	13.92	13.33	13.91	0.47	0.60	0.49	0.52	4.00	4.71	4.83	4.51
T ₁₁ - M ₂ B ₂ (Molybdenum seed treatment 4 mg/l + (Boron foliar spray 4 mg/l (At 30, 45 and 60 DAS)	14.81	14.20	13.80	14.27	0.44	0.62	0.50	0.53	4.10	4.78	5.10	4.66
T ₁₂ - M ₂ B ₃ (Molybdenum seed treatment 4 mg/l + (Boron foliar spray 6 mg/l (At 30, 45 and 60 DAS)	14.58	13.94	12.85	13.79	0.42	0.57	0.47	0.50	4.43	4.69	4.80	4.64
T ₁₃ - M ₃ B ₀ (Molybdenum seed treatment 6 mg/l)	14.85	13.70	13.19	13.91	0.47	0.55	0.47	0.50	4.13	4.87	4.87	4.62
T ₁₄ - M ₃ B ₁ (Molybdenum seed treatment 6 mg/l + (Boron foliar spray 2 mg/l (At 30,45 and 60 DAS)	15.44	14.05	13.09	14.19	0.45	0.56	0.49	0.50	4.37	4.72	4.80	4.63
T ₁₅ - M ₃ B ₂ (Molybdenum seed treatment 6 mg/l + (Boron foliar spray 4 mg/l (At 30,45 and 60 DAS)	15.81	13.41	13.56	14.26	0.47	0.60	0.48	0.52	4.03	4.62	4.77	4.47
T ₁₆ - M ₃ B ₃ (Molybdenum seed treatment 6 mg/l + (Boron foliar spray 6 mg/l (At 30,45 and 60 DAS)	14.43	13.41	12.62	13.49	0.39	0.54	0.49	0.47	4.03	4.58	4.77	4.46
M × B	M × B	M × B	M × B	M × B	M × B	M × B	M × B	M × B	M × B	M × B	M × B	M × B
SEm [±]	0.50	0.49	0.58	0.34	0.02	0.02	0.02	0.013	0.16	0.15	0.17	0.11
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	5.92	6.12	7.70	7.43	9.68	5.21	6.62	8.05	6.89	5.65	5.82	6.86

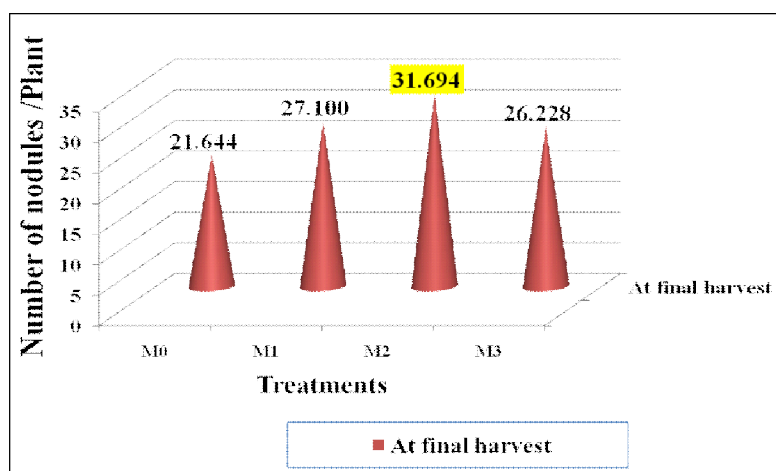


Fig 7: Individual effect of molybdenum on number of nodule per plant (At Final Harvest) in pooled analysis.

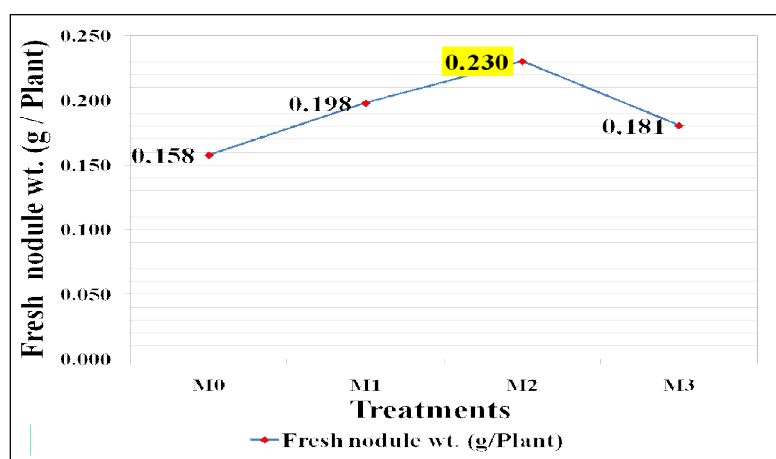


Fig 8: Individual effect of molybdenum on fresh nodule weight (g/plant) in pooled analysis.

Molybdenum seed treatment at 2 mg/l + Boron foliar spray at 4 mg/l treatment combination in pooled data (Table 2).

Green pod yield and its contributing characters

Table 3 presents the results on the effect of different levels of molybdenum seed treatment and foliar application of boron on number of pods per plant and it is clear from the data that the trait on number of pods per plant remained unaffected by combinations of both the factors during all the individual years including pooled. Individual effects of molybdenum level M_1 (2 mg/l) and boron level B_2 (4 mg/l) was found to exhibit maximum number of pod per plant in cowpea during all the years of study and in pooled analysis (Fig 4). In case of green pod yield per hectare and harvest index (%), different levels of molybdenum seed treatment and foliar application of boron and its combinations has significantly influenced both the characters. The treatment combination of M_1B_2 (Molybdenum seed treatment at 2 mg/l + Boron foliar spray at 4 mg/l) registered maximum green pod yield per hectare (12.88, 11.62, 12.31 and 12.27 t/ha,

respectively) and harvest index (25.38, 22.50, 20.48 and 22.79%, respectively) during all the individual years of experimentation as well as in pooled analysis (Fig 5 and 6).

Boron plays an important role in cell wall formation and strengthens fast growing tissues. Being one of the essential micronutrient, its deficiency during flowering prevents pollen tube growth and leads to flower abortion and poor pod setting. Many researchers have reported the positive effects of boric acid on pollen germination and tube growth. Boric acid is essential for pollen germination, pollen tube growth and pollen tube guidance (Di Giorgio *et al.*, 2016). Therefore, at reproductive phase its continuous supply is must. Foliar application of boron (in the form of boric acid), periodically at 30 DAS, 45 DAS and 60 DAS coincides with the onset of the reproductive phase that might resulted in increased number of pod setting per plant and ultimately increases total green pod yield per hectare. The results are inconformity with the findings of Chatterjee and Bandyopadhyay (2017). In case of harvest index, positive result was registered up to

Table 3: Effects of boron and molybdenum on green pod yield and its contributing characters of cowpea.

Treatments	2019					2020					2021					Pooled				
	M ₀	M ₁	M ₂	M ₃	Mean (B)	M ₀	M ₁	M ₂	M ₃	Mean (B)	M ₀	M ₁	M ₂	M ₃	Mean (B)	M ₀	M ₁	M ₂	M ₃	Mean (B)
Number of pods per plant																				
B ₀	23.95	30.80	29.53	27.65	27.98	25.60	29.27	30.67	29.80	28.82	26.60	28.60	29.60	29.13	28.48	25.38	29.56	29.91	28.86	28.43
B ₁	27.65	33.45	29.15	30.95	30.30	30.20	32.80	32.80	32.20	31.47	28.00	31.87	30.13	29.93	29.98	28.62	32.71	29.98	31.03	30.58
B ₂	30.77	38.35	34.30	33.57	34.25	31.33	33.87	32.20	30.67	32.02	29.27	34.87	32.40	30.87	31.85	30.46	35.69	32.97	31.70	32.70
B ₃	27.37	30.82	29.38	28.03	28.90	27.87	31.67	30.47	29.60	29.90	26.67	30.67	29.67	30.27	29.32	27.30	31.05	29.84	29.30	29.37
Mean (M)	27.43	33.35	30.59	30.05		28.75	31.90	30.98	30.57		27.63	31.50	30.45	30.05		27.94	32.25	30.68	30.22	
	M	B	M × B			M	B	M × B			M	B	M × B			M	B	M × B	Y × M	Y × B
S.E.m.±	0.50	0.50	1.01			0.57	0.57	1.14			0.80	0.80	1.60			0.42	0.42	0.84		
C.D. at 5%	1.46	1.46	NS			1.65	1.65	NS			2.31	2.31	NS			1.18	1.18	NS		
C.V. %	5.75	6.48	9.26	8.28																
Green pod yield (t/ha)																				
B ₀	8.08	10.08	9.76	9.43	9.34	7.47	9.39	9.87	9.80	9.13	8.32	9.01	8.72	8.66	8.68	7.96	9.49	9.45	9.30	9.05
B ₁	9.50	10.53	9.60	11.42	10.26	9.47	10.33	9.79	10.11	9.92	8.52	10.61	10.45	9.94	9.88	9.17	10.49	9.95	10.49	10.02
B ₂	11.52	12.88	11.59	11.15	11.78	10.98	11.62	10.43	9.62	10.66	8.74	12.31	11.43	10.21	10.67	10.41	12.27	11.15	10.33	11.04
B ₃	9.32	9.92	11.28	9.34	9.97	10.26	10.89	10.10	8.73	9.99	8.64	10.90	10.63	10.11	10.07	9.40	10.57	10.67	9.39	10.01
Mean (M)	9.61	10.85	10.56	10.34		9.55	10.56	10.05	9.56		8.56	10.71	10.31	9.73		9.24	10.71	10.30	9.88	
	M	B	M × B			M	B	M × B			M	B	M × B			M	B	M × B		
S.E.m.±	0.26	0.26	0.53			0.24	0.24	0.47			0.18	0.18	0.36			0.15	0.15	0.31		
C.D. at 5%	0.76	0.76	1.53			0.68	0.68	1.36			0.52	0.52	1.05			0.44	0.44	0.87		
C.V. %	8.85	8.21	6.41	9.25																
Harvest index (%)																				
B ₀	13.18	16.10	14.99	21.88	16.54	12.01	15.01	14.76	21.14	15.73	12.24	15.27	14.38	13.29	13.80	12.48	15.46	14.71	18.77	15.36
B ₁	15.58	18.93	15.79	22.00	18.08	14.72	17.90	16.44	19.98	17.26	13.93	16.23	16.66	15.90	15.68	14.74	17.69	16.30	19.30	17.01
B ₂	19.36	25.38	18.84	17.25	20.21	18.31	22.50	17.17	14.84	18.20	16.03	20.48	18.53	15.86	17.72	17.90	22.79	18.18	15.98	18.71
B ₃	14.46	19.21	21.23	19.41	18.58	15.65	21.02	18.59	15.75	17.75	13.30	15.42	15.99	14.49	14.80	14.47	18.55	18.60	16.55	17.04
Mean (M)	15.65	19.91	17.71	20.14		15.17	19.11	16.74	17.93		13.88	16.85	16.39	14.88		14.90	18.62	16.95	17.65	
	M	B	M × B			M	B	M × B			M	B	M × B			M	B	M × B		
S.E.m.±	0.59	0.59	1.18			0.52	0.52	1.04			0.49	0.49	0.97			0.36	0.36	0.71		
C.D. at 5%	1.71	1.71	3.41			1.50	1.50	3.00			1.40	1.40	NS			1.01	1.01	2.01		
C.V. %	11.16	10.43	10.87	12.59																

Table 4: Effects of boron and molybdenum on nodulation of cowpea at final harvest.

Treatments	2019 (At final harvest)					2020 (At final harvest)					2021 (At final harvest)					Pooled (At final harvest)				
	M ₀	M ₁	M ₂	M ₃	Mean (B)	M ₀	M ₁	M ₂	M ₃	Mean (B)	M ₀	M ₁	M ₂	M ₃	Mean (B)	M ₀	M ₁	M ₂	M ₃	Mean (B)
Number of nodules per plant																				
B ₀	20.40	26.27	31.47	24.53	25.67	21.87	26.93	28.53	26.47	25.95	23.87	27.73	33.60	28.00	28.30	22.04	26.98	31.20	26.33	26.64
B ₁	19.60	27.13	29.53	27.87	26.03	20.73	28.33	29.80	25.67	26.13	24.80	28.73	36.27	26.67	29.12	21.71	28.07	31.87	26.73	27.09
B ₂	19.13	22.87	28.67	25.93	24.15	20.07	27.33	30.27	27.53	26.30	25.40	28.60	33.40	26.53	28.48	21.53	26.27	30.78	26.667	26.31
B ₃	19.67	25.53	32.60	23.67	25.37	20.00	26.60	32.13	25.53	26.07	24.20	29.13	34.07	26.33	28.43	21.29	27.09	32.93	25.18	26.62
Mean (M)	19.70	25.45	30.57	25.50			27.30	30.18	26.30			28.55	34.33	26.88		21.64	27.10	31.69	26.23	
	M	B	M × B			M	B	M × B			M	B	M × B			M	B	M × B		
S.E.m.±	0.64	0.64	1.27			0.65	0.65	1.30			0.56	0.56	1.12			0.41	0.41	0.83		
C.D. at 5 %	1.84	NS	NS			1.87	NS	NS			1.62	NS	NS			1.17	NS	NS		
C.V.%			8.71					8.59					6.81					9.33		
Fresh weight of nodules/Plant																				
B ₀	0.17	0.20	0.26	0.18	0.20	0.160	0.196	0.260	0.188	0.201	0.167	0.205	0.252	0.186	0.203	0.165	0.199	0.256	0.184	0.201
B ₁	0.14	0.21	0.23	0.18	0.19	0.156	0.205	0.226	0.184	0.193	0.172	0.211	0.224	0.178	0.196	0.156	0.209	0.225	0.182	0.193
B ₂	0.14	0.20	0.21	0.18	0.18	0.160	0.175	0.221	0.187	0.186	0.168	0.185	0.232	0.175	0.190	0.157	0.187	0.220	0.182	0.187
B ₃	0.14	0.20	0.22	0.17	0.19	0.154	0.196	0.220	0.175	0.186	0.163	0.197	0.216	0.173	0.187	0.153	0.198	0.220	0.174	0.186
Mean (M)	0.15	0.20	0.23	0.18			0.193	0.232	0.183			0.200	0.231	0.178		0.158	0.198	0.230	0.181	
	M	B	M × B			M	B	M × B			M	B	M × B			M	B	M × B		
S.E.m.±	0.01	0.01	0.02			0.006	0.006	0.012			0.004	0.004	0.009			0.004	0.004	0.008		
C.D. at 5 %	0.02	NS	NS			0.02	NS	NS			0.01	NS	NS			0.012	NS	NS		
C.V. %			13.89					11.22					7.77					13.19		

4 ppm boron concentration (B_2) but was found negative with further increase in boron concentration which is in agreement with Subasinghe *et al.* (2003).

Number of nodule per plant (30 DAS and at last picking) and fresh nodule weight (g/plant)

The result on effects of boron and molybdenum on number of nodule per plant and fresh nodule weight are presented in Table 4. Seed treatment with different levels of molybdenum has significantly influenced number of nodules and fresh nodule weight in cowpea at final harvest. However, different levels of boron did not showed any significant influence on both the traits during all the years of study including pooled analysis. Cowpea seeds treated with at 2 mg/l molybdenum (M_2) has recorded maximum number of nodules per plant (30.57, 30.18, 34.33 and 31.69, respectively) and fresh nodule weight per plant (0.230, 0.232, 0.231 and 0.230 g, respectively) among all the treatments during all the three years of study as well as pooled analysis (Fig 7 and 8). Molybdenum plays a vital role in synthesis and activity of molybdoenzymes such as nitrogen assimilation enzyme like, nitrate reductase and the nitrogen fixing enzyme *i.e.*, nitrogenase, which are the key regulatory components for initiation of nodulation and maintenance of nitrogen fixation in legumes. Seed treatment with molybdenum, effectively redeem the activity of molybdoenzymes by fulfilling the internal molybdenum demand (Kothari, 2002). The increase in the rhizobia activity in the rhizosphere due to increased nutrients availability resulted in the formation of active and a greater number of root nodules. Absence of molybdenum in soil, leads to break down of plant molybdoenzymes, which ultimately hampers the nitrogen fixation by soil bacteria (Kaiser *et al.*, 2005).

CONCLUSION

The data of three consecutive years of experimentation revealed that seed treatment of molybdenum @ 2 mg/l with foliar spray of boron @ 4 mg/l at 30, 45 and 60 DAS (M_1B_2) resulted in maximum number of clusters per plant and green pod yield per hectare. In addition to this, seed treatment with different levels of molybdenum has significantly influenced number of nodules and fresh nodule weight in cowpea at final harvest. Thus, cowpea productivity under south Gujarat region can be enhanced by supplementing micronutrients periodically at various growth stages. Adoption of seed treatment with molybdenum along with foliar spray of boron periodically at 30 DAS, 45 DAS and 60 DAS following recommended package of practices can improve cowpea production in south Gujarat region. Looking

to its productive, remunerative and beneficial for soil health, the practice will encourage farmers of south Gujarat to include cowpea in crop sequence.

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Conflict of interest

All authors declare that they have no conflicts of interest.

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