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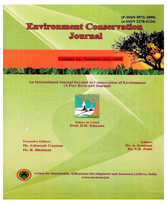

Effect of molybdenum trioxide nanoparticle-mediated seed priming on the productivity of green gram (*Vigna radiata* L.)

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ABSTRACT

A field experiment was undertaken in the post-*Rabi* season of 2019-2020 to reveal the response of greengram (*Vigna radiata* L.) to seed dressing and seed priming with nano molybdenum trioxide (MoO_3). The experiment was laid out in randomized block design (RBD) consisting of 10 different treatments i.e., M_0 (no seed treatment with Mo); M_1 (seed dressing with Sodium molybdate @ 400 ppm); M_2, M_3, M_4, and M_5 (seed dressing with nano Molybdenum trioxide-MoO_3 @ 50, 100, 200 and 400 ppm, respectively); and M_6, M_7, M_8 and M_9 (seed priming with nano MoO_3 @ 50, 100, 200 and 400 ppm, respectively). Inoculation of greengram seeds cv. *Shreya* (IPM 2-14) with *Rhizobium sps.* was undertaken in all treatments as per the recommended practice, except in M_0 (control). The MoO_3 nanoparticles (NPs) synthesized from Ammonium molybdate through calcination at 600 ^{0}C for 5 hours indicated globular-shaped NPs of 68.55 nm in TEM and XRD. Nanopriming with MoO_3 @ 200 ppm (M_8) was most promising in recording significantly superior growth and yield attributing parameters and yield, whereas Mo (control) produced the least. Crop height, number of branches, root length, shoot dry matter, pods/plant and seeds/plant and root nodulation at harvest in M_8 were 39.4% and 22.6%; 39% and 5.6%; 23% and 9.3%; 43.9%, and 16.3%; 28.2% and 5.3%; 28.1% and 0.8%, and 73.3% and 36.5% higher than M_0 (control) and M_1 (farmers' practice), respectively. Superior growth and yield attributing characters in M_8 treatment produced the highest grain and stover yield of 0.88 and 3.74 t/ ha that was 32.53% and 8.37%, and 35.5% and 14.7% higher than M_0 (control) and M_1 (farmers' practice), respectively. Seed priming with nano MoO_3 @ 400 ppm (M_9) and seed dressing with nano MoO_3 @ 400 ppm (M_5) were of second and third order in recording grain and stover yield but M_0 recorded the lowest among all the treatments.

Introduction

Pulses are part of a healthy and balanced diet and have special importance for vegetarians in fulfilling their daily requirements for body proteins. India leads the world in terms of area as well as

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production under pulses with about 35-37% (23.63 m ha) and 27% (14.76 m tons) of global coverage and output, respectively (Movalia *et al.,* 2020). However, pulse productivity is appallingly low (506 kg/ha), resulting in an annual import of about 2-3 m tons. Among the pulses, greengram (*Vigna radiata* L. Wilczek), popularly known as *mung* bean or golden gram, has a special position due to its yielding ability, high nutritive values and wider adaptability to arid and semi-arid agro-ecosystems. It contains 24.3% protein, a good source of riboflavin, thiamine (Awomi *et al.,* 2012) and vitamin C (ascorbic acid). Mung bean contributes 7% (1.7 M tons) of total production from 14% (3.6 M ha) of the area under all pulses in India and the productivity is about 500 kg/ha. It fixes atmospheric N of about 35 kg/ha with the help of symbiotic *Rhizobium*, a soil bacterium (Movalia *et al.,* 2020). The element molybdenum (Mo) is crucial for functions of nitrogenase and nitrate reductase, the two important enzymes that act as a catalyst for N fixation. Plants get Mo from soils and can assimilate in Molybdate (Grant 2018). In low pH, the MoO_4^- adsorbs onto positively charged metal oxides (Fe, Al, and Mn) and the maximum adsorption occurs between pH 4 to 5 (Smith *et al.,* 1997) which leads to its deficiency. Soil application of Mo may require large quantities depending on the crop, soil type and inherent soil contribution. It is subjected to losses through percolation, leaching, runoff and weed uptake. Foliar application is another viable option but is practicable only after crop canopy development; till then, the crop may suffer irreparable loss. Foliar application is prone to weather parameters (Hidayatullah *et al.,* 2016). One more option for supplementing crop requirement for Mo is through seed pelleting and seed dressing but it may impair seed respiration, reduce survival of Rhizobia, plant nodulation and efficiency of N_2 fixation (Almeida *et al.,* 2013; Dwibedi *et al*., 2018). The proportion of applied Mo that enters into the seeds and actively plays a role in plant metabolism is also inadequate. However, no other alternative mode of application of Mo such as the use of nanoparticles of Mo to avert the above-mentioned negative effects of soil, foliar and seed application is traceable. Therefore, the present experiment was conducted to standardize the concentration of hydro priming of nano Mo.

Material and Methods

Experimental site

The experiment was conducted in the Research farm of Odisha University of Agriculture and Technology, Bhubaneswar, India during post-*Rabi*, 2019-20 with a geographical position of 20^0 15’N Latitude and 85^0 52’ E Longitude at an altitude of 25.9 m above sea level, which is about 64 km away from the Bay of Bengal. The total rainfall received at the experimental site during the cropseason was 16.1 mm. The range of monthly average maximum temperatures during the experimental period varied from 27.7 to 34.2 ^{0}C and the monthly average minimum temperatures varied from 16.1 to 22.4 ^{0}C.

Agronomic practices

A short duration (62-65 days) variety, *Shreya* (IPM-2-14) was used as a test variety in this experiment. Sowing was done in lines with a seed rate of 25 kg/ha on a well-pulverised field. The crop was supplied with $N:P_2O_5:K_2O$ @ 20-40-40 kg/ha. The seeds were inoculated with the strains of *Rhizobium spp.*@ 20 g/kg of seeds just before sowing. The plots were irrigated just after sowing with 5 cm of irrigation water for early and uniform germination of the seeds. The weeds thus emerged were effectively managed with the pre-emergence application of herbicide i.e. Pendimethalin @ 0.5 kg a.i./ha. Subsequently, two irrigations were applied at 20 and 40 DAS for mitigating the water requirement of the greengram crop. The harvesting of greengram was done at the physiological maturity stage by cutting just above the ground surface. The harvested crop samples were labelled properly and sun-dried before threshing as per the treatments.

Nanoparticle synthesis and characterization and XRD analysis

The nanoparticles of MoO_3 were synthesized taking commercially available ammonium ortho-molybdate $\{(NH_4)_2MoO_4\}$ in a silica crucible and calcinated at 600 °C in a muffle furnace for 5 hours. The MoO_3 nanoparticles thus formed were kept inside an airtight zipper polythene bag and then stored inside a refrigerator at 4 ^{0}C to prevent agglomeration. The nanoparticles were characterized by Transmission Electron Microscope (TEM) and Power X-ray diffraction (XRD) analyses. The average particle size in the calcined MoO_3 nanoparticles was estimated by the Scherrer equation (Dinesh 2012).

The equation is given by D= kλ / β cosθ, where, D is the crystallite size, k is the shape factor, which usually takes a value of about 0.89, λ is the wavelength of X-ray source used (0.15406 nm for Cu Kα), β is the full width at half-maximum (FWHM) in radians (0.00885231), and θ is the Bragg diffraction angle in radians (0.2259381077) (Figure 1).

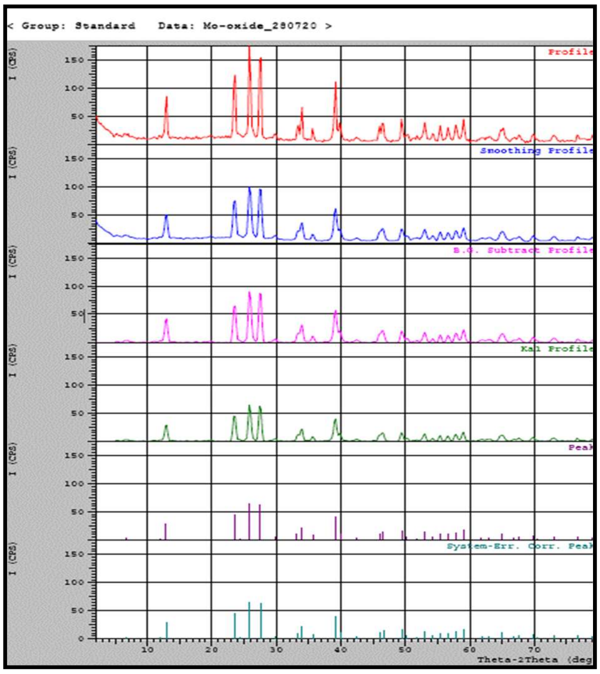

Figure 1: X-ray diffraction (XRD) analysis of Molybdenum trioxide nanoparticles

Treatments details

The treatments consisted of 10 different seed treatment methods *i.e.* control (without seed dressing or priming of Mo); farmers' practice (seed dressing with sodium molybdate @ 400 ppm by weight of seeds); seed dressing with Mo-NPs @ 50, 100, 200 and 400 ppm and seed priming with Mo-NPs @ 50, 100, 200 and 400 ppm. The fieldexperiment was carried out in a randomized block design with 10 different treatments (*i.e.* M_0, M_1, M_2, M_3, M_4, M_5, M_6, M_7, M_8 and M_9) and 3 replications, giving rise to 30 experimental units. The details of the treatments used in the experiment are given in Table 1. The plant height at 15, 30, and 45 days after sowing (DAS) and at harvest was measured from the base of the plant up to the tip by using a meter scale and was expressed in cm.

Table 1: Details of treatments and symbols used (field experiment)

Treatments	**Symbols used**
Control (noseed treatment with Mo or seed inoculation with *Rhizobium*)	M_0
Farmers' practice (seed dressing with sodium molybdate @ 400 ppm + seed inoculationwith *Rhizobium*)	M_1
Seed dressing with MoO_3-NPs @ 50 ppm + seed inoculationwith *Rhizobium*	M_2
Seed dressing with MoO_3-NPs @ 100 ppm + seed inoculationwith *Rhizobium*	M_3
Seed dressing with MoO_3-NPs @ 200 ppm + seed inoculationwith *Rhizobium*	M_4
Seed dressing with MoO_3-NPs @ 400 ppm + seed inoculationwith *Rhizobium*	M_5
Seed priming with MoO_3-NPs @ 50 ppm + seed inoculationwith *Rhizobium*	M_6
Seed priming with MoO_3-NPs @ 100 ppm + seed inoculationwith *Rhizobium*	M_7
Seed priming with MoO_3-NPs @ 200 ppm + seed inoculationwith *Rhizobium*	M_8
Seed priming with MoO_3-NPs @ 400 ppm + seed inoculationwith *Rhizobium*	M_9

The length of the longest root at 15, 30, and 45 DAS and at harvest was measured from the base of the plant up to the tip of the longest root by using a meter scale and was expressed in cm. The total shoot and root dry weight at 15, 30, and 45 DAS and at harvest was weighed after drying the plant samples in a hot air oven at 70 ^{0}C for 48 hours and expressed in grams (g). The total number of leaves/plant at 15, 30, and 45 DAS and at harvest was recorded by counting the number of healthy leaves with less than 30% non-green area. The number of nodules/plant at 15, 30, and 45 DAS and at harvest was recorded by counting the number of healthy nodules present on the root irrespective of their size. The number of pods of 10 randomly selected plants of greengram from each plot was counted and harvested at the maturity stage and an average number of pods/plant was produced. Randomly selected 10 pods from each plot were used to count the number of seeds produced in each pod. For comparison, the average number of seeds/pod was considered. The sun-dried 1,000 well-filled seeds per plot were counted at random from the composite seed sample of each treatment which was then cooled in the shade for recording their weight (g) to find out the test weight. The seed weights derived from the harvest area of 5 m X 1 m selected at random within each plot were collected and recorded accurately after threshing, cleaning and sun-drying. The weights of seeds thus recorded were then converted into t/ha. Standard error of means i.e., S.Em. (±) were used in all cases. The significance of variance was tested by the 'Error mean square" method of Fisher Snedecor's F-test at the probability level of 0.05 for appropriate degrees of freedom. Statistical analyses were done by using R-studio version 4.2.1 to elucidate the treatment effects.

Results and Discussion

Characterization of molybdenum trioxide nanoparticles

Figure 2 illustrates the TEM image of MoO_3-NP. From the image it is observed that a small amount of agglomeration is present in the synthesized ash sample. The MoO_3 particles are nearly monodisperse oblong-shaped crystalline with the average size seen in the micrograph below 100 nm at least in one dimension. Upon calcination of Ammonium molybdenum, the particles were transformed into orthorhombic (α) MoO_3. The XRD pattern of the MoO_3 sample, calcined at 600 ^{0}C for 5 hr indicated an average particle size of 68.55 nm (Figure 1). Such a low-cost nanoformulation technology, as characterized by TEM and XRD, could produce oblong shaped crystalline nano MoO_3 with concurrent results in TEM and XRD. However, the presence of a small amount of metallic agglomeration in the submitted sample as observed from the TEM image could possibily be due to the absorbance of moisture during storage and characterization. Similar results were also obtained by Muthamizh *et al.* (2015).

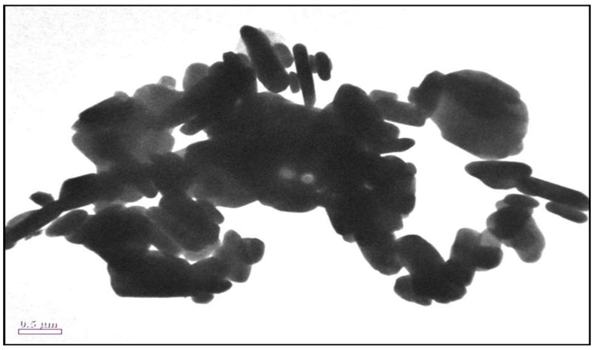

Figure 2: TEM image of Molybdenum trioxide nanoparticles

Growth traits

Seed treatment with molybdenum had no significant effect on the crop height at 15 DAS, but at subsequent growth stages, the impact was significant and positive. Seed priming with MoO_3 @ 200 ppm + seed inoculation with Rhizobium spp. (M_8) resulted in the tallest plants with a height advantage of 39.4% and 22.6% over the control (M_0) and farmers' practice (M_1), respectively (Table 2). The influence of seed dressing on crop height was positive but the increments were lower than priming at all four levels of MoO_3. No significant difference in crop height at 15 DAS was observed but at subsequent growth stages, the treatments with Mo supplementation gained an advantage in recording taller plants. An increase in crop height might be because Mo increases the biosynthesis of chlorophyll and the stability of photosynthetic apparatus, which results in increased biomass and crop height. Similar results were obtained by Singh *et al.* (2014) who studied the effect of seed priming with molybdenum on the performance of rainfed chickpea and observed that with the increase in level of seed priming with molybdenum up to 500 ppm, there was increased plant height. This corroborated the earlier findings by Srinivasan *et al.* (2007) and Arpit *et al.* (2016) researching foliar Mo application on greengram and soybean, respectively.

Table 2: Physicochemical properties of the soil of the experimental site

Physicochemical traits	Values
Bulk density (g/cm^3)	1.67
Particle density (g/cm^3)	2.65
Sand (%)	80.2
Silt (%)	7.4
Clay (%)	12.4
pH	5.3
Organic Carbon (%)	0.64
EC (ds/m)	0.16
Available N (kg/ha)	290.5
Available P_2O_5 (kg/ha)	10.24
Available K_2O (kg/ha)	143.52
Available Mo (ppm)	0.017

In all four stages, M_8 (seed priming with nano MoO_3 @ 200 ppm + seed inoculation with *Rhizobiumsps*.) recorded the highest number of leaves but plants under M_0 (control) had fewer leaves (Table 3). This could be due to increased nitrogen availability in M_8. Moreover increased chlorophyll content due to Mo seed priming resulted in higher photosynthetic activity and higher biomass production, which might have produced more leaves in the plant. This corroborated the earlier results of Khan *et al.* (2019) who evaluated different priming methods and molybdenum applications on various cultivars of mung bean and similar positive effects of conventional Mo application in greengram by Srinivasan *et al*. (2007), and Anwarulla and Shivashankar (1987) corroborated the present result. The branching of greengram did not start up to 15 DAS, but subsequently started and continued up to 45 DAS faster (Table 3). But the rate of increase was very slow during maturity due to ageing. Among the treatments, M_8 and M_5 produced the maximum number of branches/plant whereas untreated control produced the least at 45 DAS and harvest. More branches might be due to the availability of growth factors in adequate quantity and in suitable proportions. Research results of Anwarulla and Shivashankar (1987), and Srinivasan *et al*. (2007) on the application of conventional Mo on greengram also corroborated the positive influence of Mo in the present investigation. At harvest, nano-priming with MoO_3 at 50, 100, 200 and 400 ppm significantly affected shoot dry matter accumulation with 26.7%, 36.4%, 43.9%, and 40.0% increments over the unprimed control, respectively. But only seed dressing with nano MoO_3 @ 400 ppm (M_5) was significantly superior to the control (M_0) and all other levels of seed dressing were at par with the unprimed seeds in recording shoot dry biomass. Nano priming was also reported to produce more branches and higher shoot biomass accumulation which could be due to better availability of Mo in plants that might have supported nutrient metabolisms such as N, P, K, S, and Fe as suggested by Awomi *et al*. (2012), Kumar *et al*. (2015), and Kumar *et al*. (2018). The root length recorded from 15 DAS till harvest increased up to the harvest but the rate of increment was higher from 30 to 45 DAS but beyond that, the rate slowed down (Table 4). The longest roots were recorded under M_8 but the shortest ones were recorded in M_0 (control) at all four observations. The increase in the concentration of nanopriming from 200 to 400 ppm resulted in the shortening of roots but remained at par with the other priming levels. Roots are dynamic and their growth is strongly affected by the environmental conditions in the root zone. Microbial association and non-toxic soil chemistry results in longer roots in plants. Mo plays a crucial role in the symbiotic association between the root of legume plants and the Rhizobium bacteria. This might be the reason for the longer roots produced in M_8. Increase in concentration of nano priming from 200 to 400 ppm resulted in shortening of roots. The rate of root biomass accumulation was faster up to 45 DAS but the rate slowed down towards the harvest. At harvest, M_8 accumulated 53.1% and 22.8% more root biomass than M_0 and M_1. Nanopriming at 200 ppm (M_8) and 400 ppm (M_9) levels did not differ significantly throughout the crop growth despite higher root biomass accumulation in M_8. The reason might be that with increased level of Mo, there is an increased shoot uptake than root uptake, resulting in higher shoot growth than root growth (Zakikhani *et al*., 2014). This corroborated the earlier findings of Kailash et al. (2019) and Gewehr et al. (2019) by applying nano Mo in pigeon pea and conventional Mo in soybean, respectively. Root nodule count increased from 15 DAS up to 45 DAS but it declined at harvest. Higher rate of increment in nodulation between 30 to 45 DAS matched with the active growth stage of the crop. Irrespective of growth stages, nano priming with MoO_3 showed positive results and the highest nodule counts/plant were recorded under M_8. At 45 DAS, M_8 could produce 78.1% and 36.8% higher nodules in plant roots over the control (M_0) and farmers' practice (M_6), respectively. As nodulation in greengram usually begins at around two weeks after sowing no significant difference in the treatment effects was recorded at 15 DAS but at subsequent growth stages, the treatment effects on nodule count were significant due to Mo application. Nano priming with MoO_3 positively influenced nodule number possibility because of the higher accumulation of Mo in seeds that favoured nodulation compared to other modes of Mo application. Seed priming with MoO_3 significantly impacts the root nodule count irrespective of the growth stage and the highest nodule count per plant was recorded in M_8. Root nodules are formed in leguminous plants due to symbiotic association with N-fixing bacteria Rhizobium. As Mo plays a key role in this symbiotic nitrogen fixation, its application might

Table 3: Plant height, number of leaves and number of branches/plant of greengram at different stages as influenced by seed treatments with molybdenum

Treatments	Plant height (cm)				Number of leaves/plant				Number of branches/plant			
	15 DAS	30 DAS	45 DAS	Harvest	15 DAS	30 DAS	45 DAS	Harvest	15 DAS	30 DAS	45 DAS	Harvest
M_0	7.0	21.4	29.0	31.5	4.3	11.5	16.2	12.1	1.1	1.2	3.9	4.1
M_1	7.4	24.3	32.9	35.8	4.6	14.6	20.8	15.4	1.0	1.5	5.1	5.4
M_2	7.2	22.2	30.1	33.4	4.4	11.7	17.5	14.4	1.1	1.4	4.6	5.0
M_3	7.3	22.9	31.1	34.1	4.5	12.1	18.1	14.5	1.0	1.5	4.7	5.2
M_4	7.5	25.3	34.4	37.5	4.9	12.9	19.2	15.8	1.1	1.7	4.7	5.4
M_5	7.7	26.5	35.7	39.3	4.9	14.2	22.4	15.8	1.1	1.8	5.3	5.7
M_6	7.6	26.7	36.3	39.6	5.1	13.5	18.5	16.5	1.0	1.6	4.7	5.1
M_7	7.8	28.0	37.8	41.5	5.4	15.4	20.4	18.4	1.0	1.8	5.1	5.4
M_8	8.0	29.8	40.4	43.9	5.8	16.7	23.4	19.8	1.1	1.9	5.3	5.7
M_9	7.9	27.3	37.1	40.8	5.6	16.4	21.4	18.3	1.0	1.9	5.2	5.5
S.Em. (±)	0.48	0.24	0.36	0.27	0.19	0.81	1.55	1.01	0.00	0.06	0.22	0.26
CD (0.05)	NS	0.7	1.1	0.8	0.6	2.4	4.6	3.0	NS	0.2	0.7	0.8

Table 4: Dry matter of shoot, longest root length and root dry matter of greengram at different stages as influenced by seed treatments with molybdenum

Treatments	Dry matter of shoot (g)/plant				Longest root length (cm)				Root dry matter (g)			
	15 DAS	30 DAS	45 DAS	Harvest	15 DAS	30 DAS	45 DAS	Harvest	15 DAS	30 DAS	45 DAS	Harvest
M0	1.56	3.59	7.16	10.15	4.8	9.8	26.2	29.5	0.102	0.191	0.423	0.622
M1	1.69	3.96	8.39	11.89	5.6	10.9	31.2	33.2	0.123	0.223	0.505	0.775
M2	1.62	3.75	7.71	10.92	4.9	10.6	28.2	32.1	0.107	0.204	0.455	0.699
M3	1.69	3.84	7.98	11.31	5.2	10.7	28.3	32.5	0.110	0.208	0.505	0.776
M4	1.68	4.04	8.67	12.28	5.9	10.9	30.3	33.3	0.113	0.232	0.505	0.776
M5	1.75	4.13	8.94	12.67	6.0	11.4	31.3	34.1	0.127	0.234	0.555	0.853
M6	1.68	4.17	9.08	12.86	5.0	10.2	29.8	34.2	0.110	0.196	0.504	0.721
M7	1.76	4.37	9.76	13.84	5.2	10.5	30.5	36.1	0.107	0.223	0.604	0.865
M8	1.85	4.54	10.31	14.61	6.3	12.0	33.3	36.3	0.130	0.235	0.632	0.952
M9	1.84	4.41	10.13	14.21	6.0	11.0	30.6	35.9	0.130	0.221	0.613	0.914
S.Em. (±)	0.043	0.166	0.370	0.859	0.27	0.39	1.17	0.97	0.0078	0.0076	0.0177	0.0151
CD (0.05)	0.13	0.49	1.10	2.55	0.8	1.1	3.5	2.9	NS	0.022	0.053	0.045

Table 5: Number of root nodules/plant, yield and yield attributing charactersof greengram at different stages as influenced by seed treatments with molybdenum

Treatments	Number of root nodules/plant				Pod/ plant	Seeds/ pod	Test weight (g)	Grain yield (t/ha)	Stover yield (t/ha)
	15 DAS	30 DAS	45 DAS	Harvest					
M_0	0.6	5.1	9.6	8.1	12.4	9.6	31.32	0.654	2.76
M_1	0.7	7.2	12.5	10.4	14.5	12.4	32.01	0.812	3.26
M_2	0.7	6.7	11.4	9.5	13.8	10.2	31.28	0.710	3.06
M_3	0.7	7.1	12.1	10.1	14.2	11.3	31.42	0.752	3.09
M_4	0.8	7.5	13.0	10.6	14.8	11.7	31.54	0.788	3.25
M_5	0.8	8.0	14.8	11.0	15.3	11.6	32.42	0.829	3.35
M_6	0.7	8.3	14.3	11.0	14.3	11.4	31.45	0.769	3.45
M_7	0.8	9.1	15.9	12.3	14.8	11.9	31.86	0.826	3.65
M_8	0.8	9.5	17.1	14.2	15.9	12.5	32.42	0.880	3.74
M_9	0.9	9.4	16.3	13.8	15.8	12.3	32.24	0.854	3.57
S.Em. ($\pm$)	0.11	0.34	1.28	0.99	0.55	0.60	0.77	0.0325	0.13
CD (0.05)	NS	1.0	3.8	2.9	1.6	1.8	NS	0.096	0.39

have resulted in increased nodule count. Evidence of enhanced nodulation due to elevated Mo concentration has also been reported by Kumar *et al*. (2015), Velmurugan and Mahendra (2015), and Kumar *et al*. (2018) which corroborated the present investigation.

Yield and yield attributing characters

Seed priming with MoO_3 at all four levels had significantly increased the number of pods/plant over M_0 but M_1 (farmers' practice) remained at par with both treatment effects of nano priming and dressing. Seed priming with MoO_3 @ 200 (M_8) and 400 ppm (M_9), and seed dressing @ 400 ppm (M_5) were of first, second and third order in pod count. Seeds/pod significantly showed positive (30.2%) effects of Mo seed treatment over control (Table 5). But no significant difference in seed number was recorded between farmers' practice (M_1) and seed dressing or priming with nano MoO_3, except under M_3 i.e. seed dressing at 50 ppm which recorded a significantly lower number of seeds. Similar results were obtained in the case of test weight as well. Yield attributing characters like pod number, seeds/pod and test weight are influenced by Mo seed treatment, either seed dressing or seed priming. This result might be due to the availability of Mo in adequate amounts towards the crop maturity stage irrespective of the sources. Seed treatment with Mo could be attributed to the adequate availability of plant growth elements in appropriate proportions. The above results on pods/plant, seeds/pod, and seed weight confirmed the earlier findings from the research conducted by Manjili *et al*. (2014), Gad *et al*. (2013), Heidarzade *et al*. (2016), Kumar *et al*. (2018), studied greengram and other pulses by using conventional and nano Mo.

The grain yield of greengram was influenced significantly due to the difference in molybdenum seed treatment. Seed priming with nano MoO_3 @ 200 ppm along with *Rhizobium* seed inoculation (M_8) was the most promising in recording significantly the highest grain yield of 0.88 t/ha that provided an additional yield of 0.068 t/ha (8.37% more) over farmers' practice (M_1 i.e. seed dressing with sodium molybdate @ 400 ppm and seed inoculation with *Rhizobium*) and 0.226 t/ha (32.53% more) over the control (M_0 i.e. no Mo seed treatment or *Rhizobium* seed inoculation). Seed priming with nano MoO_3 @ 400 ppm and *Rhizobium* seed inoculation (M_9) resulted in second highest grain yield of 0.854 t/hathat produced an additional yield of 0.042 t/ha(5.17% more) over farmers' practice (M_1) and 0.2 t/ha(30.58% more) over the control (M_0). Seed dressing with nano MoO_3 @ 400 ppm along with *Rhizobium* seed inoculation (M_5) resulted in third highest grain yield of 0.829 t/ha. The grain yield/plant followed a similar trend as grain yield in the field. The stover yield of greengram was influenced significantly due to the difference in seed treatment with molybdenum. Seed priming with nano MoO_3 @

200 ppm along with *Rhizobium* seed inoculation (M_8) recorded significantly the highest stover yield of 3.74 t/ha which provided an additional yield of 0.48 t/ha (14.7% more) over farmers' practice (M_1) and 0.98 t/ha (35.5% more) over control (M_0). Seed priming with nano MoO_3 @ 100 (M_7) and 400 ppm (M_9) occupied the second and third ranks in recording stover yield of 3.65 and 3.57 t/ha, respectively.
Priming treatment with MoO_3 results in rapid seedling emergence and crop establishment with increased growth and yield attributing characters, and ultimately higher yield. Moreover, Mo plays a crucial role in symbiotic nitrogen fixation in leguminous crops, increasing the availability of nitrogen. This might be the reason for the treatment M_8 has attributed to the maximum grain and stover yield (Maroufi *et al*., 2011). Higher grain yield in treatments over control except M_2 and M_3 could be due to the synergistic effects of all yield attributes such as pods/plant, seeds/pod, and test weight so also the effect of *Rhizobium* inoculation that might have supported nutrient metabolisms such as N, P, K, S, and Fe as suggested by Awomi *et al*. (2012). The present result was in line with earlier reports by Manjili *et al*. (2014), Velmurugan and Mahendra (2015), Arpit *et al*. (2016), Heidarzade *et al*. (2016), Hossain *et al*. (2018) and Kumar *et al*. (2018). The highest stover yield in the case of M_8 might be due to its higher growth attributing characters like plant height, number of branches, number of leaves etc. Research findings of Arpit *et al*. (2016), Kumar *et al*. (2018), and Movalia *et al*. (2020) in greengram and other pulse crops also corroborate the above results.

Conclusion

From the analysis of the observations recorded in the present experiment, it can be concluded that molybdenum seed treatment, irrespective of mode and level of application, positively influenced the growth, development, and productivity of the greengram crop. The overall performance of seed priming with Molybdenum trioxide nanoparticles (MoO_3-NPs) was better than either seed dressing with MoO_3-NPs or Sodium molybdate. Preconditioning of greengram seeds by nanopriming with MoO_3 @ 200 ppm + Rhizobium inoculation was the best option for achieving higher grain yield, and productivity under the present investigation.

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Conflict of interest

The authors declare that they have no conflict of interest.

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