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Zinc Induced Variations in Dry Matter Production, Partitioning and Yield of Mungbean (*Vigna radiata* L.) under Water Stress

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Authors' contributions

This work was carried out in collaboration among all authors. Authors BS, KJ and MSR designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author BS managed the analyses of the study. Authors BS and KJ managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted during rabi season of 2017-18 at Agricultural College Farm, Bapatla to study the effect of seed pre - treatment and foliar application of zinc on dry matter production, partitioning and yield of mungbean under water stress. The experiment was laid out in a split plot design with three replications consists of two main treatments viz., no stress i.e. control (M0) and stress from flowering stage (i.e. from 30 DAS) up to harvest (M1) and seven sub-treatments viz., no zinc application (S0), seed treatment with 0.05% and 0.075% ZnSO4 solutions for 5 hrs before sowing (S1 and S2), foliar spray of 300, 400 and 500 ppm ZnSO4 at 30 DAS (S3, S4 and S5) and water spray at 30 DAS (S6). The results showed that leaf, stem, reproductive parts, total dry matter and seed yield was decreased by 23.0, 23.3, 15.3, 18.7 and 33.6 per cent, respectively in the plants that were subjected to stress from flowering stage over control plants. Foliar zinc spray @ 500 ppm at 30 DAS increased the leaf, stem, reproductive parts dry matter, total dry matter and seed yield by 24.6, 24.8, 20.9, 22.5 and 55.2 per cent, respectively, over untreated plants. Normal irrigated plants sprayed with zinc @ 500 ppm (M0S5) recorded the highest mean

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values of above parameters and the lowest mean values were recorded by the stressed plants with no zinc application (M1S0). Under water stress, mungbean plants sprayed with zinc @ 500 ppm at 30 DAS (M1S5) increased the leaf, stem, reproductive parts, total dry matter and seed yield by 17.6, 16.4, 23.9, 21.3 and 42.0 per cent, respectively, over unsprayed plants (M1S0).

Keywords: Water stress; seed pre – treatment; foliar spray; zinc, dry matter and Mungbean.

1. INTRODUCTION

Mungbean is an excellent source of high quality protein in vegetarian diet of Indian population and is particularly preferred for invalids and infants for its easy digestibility and non-flatulence protein. It is cultivated in India since ancient times. The productivity of mungbean is very low, because it is grown in marginal and sub marginal lands with low fertilizer under rainfed conditions. It is frequently grown where soil moisture is a limiting factor for successful crop production. It is cultivated throughout India and occupies an area of about 3.09 million hectares with a production of 1.54 million tonnes and productivity of 499 kg ha^{-1}. In Andhra Pradesh, it is grown in an area of about 0.27 million hectares, with a production of 0.18 million tonnes and with an average productivity of 651 kg ha^{-1} [1].

Zinc is an essential micronutrient which is involved in many physiological functions such as auxin biosynthesis, activation of dehydrogenase enzymes and stabilization of ribosomal fractions [2], protein and carbohydrate synthesis [3]. It is essential for the biosynthesis of the carbonic anhydrase enzyme required for chlorophyll biosynthesis [4] and also as a key constituent of alcohol dehydrogenase and superoxide dismutase [5]. Foliar application of 300 ppm Zn-EDTA recorded higher dry weights of stem, leaves and pods over control in mungbean [6]. Zinc application in maize improves photosynthetic rate, chlorophyll synthesis, nitrogen metabolism and resistance to both biotic and abiotic stresses [7]. The application of zinc under drought conditions would influence crop yield and quality. Therefore, the present investigation was undertaken to study the effect of seed pre-treatment and foliar application of zinc in mitigating the adverse effects of water stress on dry matter production, partitioning and yield of mungbean plants.

2. MATERIALS AND METHODS

The experiment was conducted during Rabi, 2017-18 at Agricultural college farm, Bapatla. The physical and chemical analyses of the experimental soil are presented in Table 1. The experiment was laid out in a Split Plot Design, replicated thrice with a plot size of 12 square meter and the row spacing of 30 cm and intra row spacing of 10 cm. Sowing was done by dibbling and recommended dose of fertilizers were applied and manual weeding was done to raise a healthy crop. Two main treatments of water stress were applied, i.e., no stress i.e. control (M0) and stress from flowering stage (i.e. from 30 days after sowing) up to harvest (M1). seven sub-treatments regarding zinc, i.e., no zinc application (S0), seed treatment with 0.05% and 0.075% ZnSO4 solutions for 5 hrs before sowing (S1 and S2), foliar spray of 300, 400 and 500 ppm ZnSO4 at 30 DAS (S3, S4 and S5) and water spray at 30 DAS (S6). Prophylactic measures were adopted against pests and diseases. The data on total dry matter accumulation in plants and its partitioning to different plant parts were recorded at 15, 30, 45 and 60 days after sowing (DAS). Five plants were carefully uprooted from each replication for each treatment. The plants were separated into different parts- root, stem, leaves and pods. The plant parts were dried to a constant weight in hot-air oven at 80^{o}C for two days and the dry weights were recorded and expressed in g $plant^{-1}$. Collected data from the experiment were statistically analyzed, using the analysis of variance method. Comparisons among the means of different treatments were done, using least significant differences (L.S.D) test procedure at $p \leq 0.05$ level of probability, as illustrated by Gomez and Gomez [8].

3. RESULTS AND DISCUSSION

3.1 Leaf Dry Matter (g $Plant^{-1}$)

In all the treatments, leaf dry matter has gradually increased upto 45 DAS and then declined. Water stress from flowering stage significantly recorded lesser leaf dry matter mean values (M_1 – 3.55, 3.25 and 2.85 g $plant^{-1}$) compared to irrigated plants (M_0 - 4.62, 4.22 and 3.70 g $plant^{-1}$) at 45, 60 DAS and at harvest, respectively (Table 2). Gupta et al. [9] stated

that, water stress might decrease the translocation of assimilates to the leaf, which lowered the amount of leaf dry weight under stress condition. Among the sub treatments, seed pre - treatment with zinc @ 0.075% before sowing recorded higher leaf dry matter mean values (S_2 – 0.16 and 1.38 g plant^{-1}) compared to seed pre - treatment with zinc @ 0.05% (S_1 – 0.15 and 1.25 g plant^{-1}) at 15 and 30 DAS, respectively. Data presented in Table 2 illustrated that, at 45, 60 DAS and at harvest, foliar spray of zinc @ 500 ppm at 30 DAS recorded the maximum leaf dry matter mean values (S_5 – 4.56, 4.17 and 3.65 g plant^{-1}, respectively), followed by zinc spray @ 400 ppm (S_4 – 4.35, 3.97 and 3.47 g plant^{-1}, respectively), where as the minimum leaf dry matter mean values were recorded by control treatment i.e. no application of zinc (S_0 – 3.66, 3.00 and 2.93 g plant^{-1}, respectively).

In the present study, at 45 DAS, leaf dry matter content was increased by 24.6 per cent with foliar spray of zinc @ 500 ppm at 30 DAS compared to control treatment (i.e. no zinc application), whereas pre - soaking of seeds with zinc solution @ 0.075% before sowing recorded 16.9 percent increase in leaf dry matter content compared to control treatment (Table 2). These results are in agreement with Zarmehri et al. [10], who reported that, zinc application enhanced the leaf area which caused an increase in leaf dry weight. Among the interactions, at 45 DAS, highest leaf dry matter mean value was recorded by unstressed plants (irrigated plants) that were sprayed with zinc @ 500 ppm (M_0S_5 – 5.28 g plant^{-1}), where as the lowest leaf dry matter mean value was recorded by the plants that were stressed from flowering stage with no zinc application (M_1S_0 – 3.29 g plant^{-1}). Foliar spray of zinc @ 500 ppm to the plants that were stressed from flowering stage recorded higher leaf dry matter mean value (M_1S_5 – 3.87 g plant^{-1}) over M_1S_0 (3.29 g plant^{-1}) and it was statistically at par with irrigated mungbean plants with no zinc application, i.e. M_0S_0 (4.03 g plant^{-1}) as shown in Table 2. The same trend was also observed at 60 DAS and at harvest.

3.2 Stem Dry Matter (g Plant^{-1})

The stem dry matter content has gradually increased from 15 DAS to harvest. At 45, 60 DAS and at harvest, water stress from flowering stage significantly reduced the stem dry matter contents (1.23, 2.01 and 2.04 g plant^{-1}, respectively) over control plants (1.59, 2.62 and 2.65 g plant^{-1}, respectively), as illustrated in Table 3. These results were in agreement with those obtained by Hong and Ji-yun [11] in maize and Thalooth et al. [6] in mungbean. Drought stress had a negative effect on current photosynthesis leading to decrease in dry matter accumulation in stems. At 15 and 30 DAS, seed pre - treatment with zinc @ 0.075% before sowing significantly recorded higher stem dry matter mean values (S_2 – 0.065 and 0.50 g plant^{-1}, respectively) than other tested treatments (Table, 3). Foliar spray of zinc @ 500 ppm at 30 DAS recorded the maximum stem dry matter mean values (S_5 – 1.57, 2.58 and 2.62 g plant^{-1}), followed by foliar spray of zinc @ 400 ppm (S_4 – 1.49, 2.46 and 2.49 g plant^{-1}) where as the minimum stem dry matter mean values were recorded by control treatment i.e. no zinc application (S_0 – 1.26, 2.07 and 2.10 g plant^{-1}) at 45, 60 DAS and at harvest, respectively (Table, 3).

In the current study, foliar spray of zinc @ 500 and 400 ppm at 30 DAS increased the stem dry matter content at harvest by 1.25 and 1.19 folds, respectively, whereas seed pre - treatment with zinc @ 0.075% and 0.05% increased the stem dry matter content by 1.17 and 1.10 folds, respectively compared to untreated plants. Sofy [12] reported that, wheat plants treated with zinc resulted in significant increase in shoot length, fresh and dry weight of both shoots and roots as compared with the untreated plants grown in stress condition. Among the interactions, significant differences were noted at 45, 60 DAS and at harvest. At harvest, the highest stem dry matter mean values were recorded by irrigated plants with foliar spray of zinc @ 500 ppm (M_0S_5 – 3.03 g plant^{-1}) and the lowest stem dry matter mean value was recorded by stressed plants which were not treated with zinc (M_1S_0 – 1.89 g plant^{-1}). Under water stress condition, foliar application of zinc @ 500 ppm at 30 DAS recorded higher stem dry matter mean value (M_1S_5 – 2.20 g plant^{-1}) compared to unsprayed plants (M_1S_0 – 1.89 g plant^{-1}) as illustrated in Table 3. Thalooth et al. [6] reported that, treatment of mungbean plants grown under water stress conditions with zinc counteracted the deleterious effects of water stress and resulted in higher stem, leaf and pod dry weights.

3.3 Dry Matter of Reproductive Part (g Plant^{-1})

The data recorded in Table 4 illustrated that, dry matter content of reproductive parts was

gradually increased from 45 DAS to harvest. The plants that were subjected to water stress from flowering stage recorded lesser dry matter mean values of reproductive parts (M_1 – 0.38, 7.16 and 7.30 g plant^{-1}) compared to control treatment at 45, 60 DAS and at harvest, respectively. Reproductive parts dry matter decreased by 15.3 and 14.7 per cent over control treatment (i.e. irrigated) plants at 60 DAS and at harvest, respectively. These results are in agreement with those obtained by Thalooth et al. [6], who stated that, subjecting mungbean plants to water stress at flowering and pod formation stages significantly reduced the number of pods plant^{-1}, pod dry weight, number of seeds pod^{-1}, seed dry weight plant^{-1}, seed index and seed yield. Foliar application of zinc @ 500 ppm at 30 DAS significantly recorded higher dry matter mean value of reproductive parts (S_5 – 0.48 g plant^{-1}) compared to control treatment (S_0 – 0.33 g plant^{-1}) and other treatments, except foliar spray of zinc @ 400 ppm (S_4 – 0.46 g plant^{-1}), which was statistically at par with S_5 treatment at 45 DAS. At 60 DAS and at harvest, the highest reproductive parts dry matter mean values were obtained with foliar spray of zinc @ 500 ppm at 30 DAS (S_5 – 8.58 and 8.72 g plant^{-1}, respectively), followed by seed pre - treatment with zinc @ 0.075% before sowing (S_2 – 8.22 and 8.34g plant^{-1}, respectively), whereas the lowest reproductive parts dry matter mean values were recorded in control treatment i.e. no zinc application (S_0 – 7.11 and 7.21 g plant^{-1}, respectively).

In the present study, foliar spray of zinc @ 500 ppm at 30 DAS and seed pre - treatment with zinc @ 0.075% before sowing increased the reproductive parts dry matter content by 20.9 and 15.7 per cent, over control treatment (i.e. untreated) plants, at harvest (Table 4). Rahman et al. [13] found significant increase in number of pods plant^{-1} and number of seeds pod^{-1} of mungbean due to application of increasing concentration of zinc. Among the interactions, the highest dry matter mean value of reproductive parts was recorded by foliar application of zinc @ 500 ppm at 30 DAS to the irrigated plants (M_0S_5 - 9.24 g plant^{-1}) whereas the lowest reproductive parts dry matter mean value was recorded by the plants that were stressed from flowering stage with no zinc treatment (M_1S_0 – 6.62 g plant^{-1}). The plants that were stressed from flowering stage with zinc spray @ 500 ppm at 30 DAS recorded higher reproductive parts dry matter mean value (M_1S_5 – 8.20 g plant^{-1}) compared to irrigated plants with no zinc application (M_0S_0 – 7.80 g plant^{-1}) at harvest.

3.4 Total Dry Matter (g Plant^{-1})

Water stress from flowering stage recorded lesser total dry matter mean values (M_1 – 5.18, 12.44 and 12.19 g plant^{-1}, respectively) compared to control treatment i.e. irrigated plants (M_0 – 6.65, 15.30 and 14.92 g plant^{-1}, respectively) at 45, 60 DAS and at harvest (Table, 5). Water stress from flowering stage recorded 22.1 and 18.7 percent reduction in total dry matter compared to control plants at 45 and 60 DAS, respectively. Similar results were also obtained by Thalooth et al. [6] in mungbean. Dry matter accumulation of mungbean plants decreased with increasing soil moisture deficits.

Table 1. Soil sample analysis data of the experimental plot before initiation of the experiment

+	Particulars	Value
A)	**Mechanical analysis**	
1	Sand (%)	15
2	Silt (%)	41
3	Clay (%)	44
4	Textural class	Clay loam
B)	**Chemical analysis**	
1	pH (1:2.5–soil water suspension)	7.21
2	EC (dS m^{-1})	0.63
3	Organic carbon (%)	5.2
4	Available nitrogen (kg ha^{-1})	206.45
5	Available phosphorus (kg P_2O_5 ha^{-1})	86.31
6	Available potassium (kg K_2O ha^{-1})	1247.2

Table 2. Effect of water stress treatments, zinc applications and their interaction on leaf dry matter (g plant^{-1}) during the different tested stages of mungbean growing plants

Treatments	15 DAS			30 DAS			45 DAS			60 DAS			At harvest		
	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean
S_0 : No Zinc application	0.13	0.13	**0.13**	3.68	3.00	**3.34**	3.22	2.63	**2.93**	1.12	1.01	**1.06**	4.03	3.29	**3.66**
S_1 : Seed treatment with Zinc @ 0.05% before sowing	0.15	0.15	**0.15**	4.14	3.25	**3.70**	3.62	2.84	**3.23**	1.26	1.24	**1.25**	4.54	3.55	**4.05**
S_2 : Seed treatment with Zinc @ 0.075% before sowing	0.16	0.16	**0.16**	4.44	3.37	**3.91**	3.88	2.95	**3.42**	1.37	1.38	**1.38**	4.86	3.69	**4.28**
S_3 : Foliar spray of Zinc @ 300 ppm at 30 DAS	0.12	0.13	**0.13**	4.11	3.14	**3.63**	3.63	2.80	**3.22**	1.10	0.98	**1.04**	4.43	3.39	**3.91**
S_4 : Foliar spray of Zinc @ 400 ppm at 30 DAS	0.13	0.13	**0.13**	4.59	3.35	**3.97**	4.02	2.93	**3.47**	1.13	0.94	**1.03**	5.03	3.67	**4.35**
S_5 : Foliar spray of Zinc @ 500 ppm at 30 DAS	0.13	0.14	**0.14**	4.82	3.51	**4.17**	4.22	3.07	**3.65**	1.09	1.05	**1.07**	5.28	3.87	**4.56**
S_6 : Foliar spray of water at 30 DAS	0.14	0.14	**0.14**	3.78	3.10	**3.44**	3.31	2.72	**3.02**	1.10	1.05	**1.08**	4.14	3.40	**3.77**
Mean	**0.14**	**0.14**		**4.22**	**3.25**		**3.70**	**2.85**		**1.16**	**1.09**		**4.62**	**3.55**	
	SEm±	**CD**	**CV (%)**	**SEm ±**	**CD**	**CV (%)**	**SEm ±**	**CD**	**CV (%)**	**SEm±**	**CD**	**CV (%)**	**SEm±**	**CD**	**CV (%)**
Main	0.001	NS	4.42	0.01	0.04	4.88	0.01	0.02	5.28	0.02	NS	9.89	0.01	0.05	5.68
Sub	0.002	0.01	4.37	0.02	0.06	5.77	0.01	0.03	6.54	0.02	0.06	4.77	0.04	0.12	4.89
Interactions	0.003	NS		0.03	0.09		0.02	0.04		0.03	NS		0.06	0.16	

Table 3. Effect of water stress treatments, zinc applications and their interaction on stem dry matter (g plant^{-1}) during the different tested stages of Mungbean growing plants

Treatments	15 DAS			30 DAS			45 DAS			60 DAS			At harvest		
	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean
S_0 : No Zinc application	0.050	0.049	**0.050**	2.28	1.86	**2.07**	2.31	1.89	**2.10**	0.41	0.36	**0.39**	1.39	1.13	**1.26**
S_1 : Seed treatment with Zinc @ 0.05% before sowing	0.062	0.061	**0.061**	2.55	1.98	**2.26**	2.58	2.02	**2.30**	0.46	0.45	**0.46**	1.55	1.21	**1.38**
S_2 : Seed treatment with Zinc @ 0.075% before sowing	0.065	0.065	**0.065**	2.75	2.09	**2.42**	2.79	2.12	**2.45**	0.49	0.50	**0.50**	1.67	1.27	**1.47**
S_3 : Foliar spray of Zinc @ 300 ppm at 30 DAS	0.054	0.055	**0.055**	2.58	1.99	**2.29**	2.62	2.02	**2.32**	0.43	0.39	**0.41**	1.57	1.21	**1.39**
S_4 : Foliar spray of Zinc @ 400 ppm at 30 DAS	0.050	0.054	**0.052**	2.84	2.07	**2.46**	2.88	2.10	**2.49**	0.43	0.41	**0.42**	1.73	1.26	**1.49**
S_5 : Foliar spray of Zinc @ 500 ppm at 30 DAS	0.052	0.051	**0.052**	2.98	2.17	**2.58**	3.03	2.20	**2.62**	0.41	0.38	**0.40**	1.82	1.32	**1.57**
S_6 : Foliar spray of water at 30 DAS	0.055	0.051	**0.053**	2.34	1.92	**2.13**	2.37	1.95	**2.16**	0.43	0.40	**0.41**	1.42	1.17	**1.30**
Mean	**0.056**	**0.055**		**2.62**	**2.01**		**2.65**	**2.04**		**0.43**	**0.41**		**1.59**	**1.23**	
	SEm±	**CD**	**CV (%)**	**SEm±**	**CD**	**CV (%)**	**SEm±**	**CD**	**CV (%)**	**SEm±**	**CD**	**CV (%)**	**SEm±**	**CD**	**CV (%)**
Main	0.000	NS	2.28	0.004	0.02	6.32	0.004	0.03	5.89	0.01	NS	7.69	0.003	0.02	4.87
Sub	0.001	0.003	5.14	0.010	0.03	5.14	0.008	0.02	5.64	0.01	0.03	5.08	0.005	0.01	4.23
Interactions	0.002	NS		0.014	0.04		0.011	0.03		0.01	NS		0.007	0.02	

Table 4. Effect of water stress treatments, zinc applications and their interaction on reproductive parts dry matter (g plant^{-1}) during the different tested stages of mungbean growing plants

Treatments	45 DAS			60 DAS			At Harvest		
	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean
S_0 : No Zinc application	0.34	0.31	**0.33**	7.73	6.48	**7.11**	7.80	6.62	**7.21**
S_1 : Seed treatment with Zinc @ 0.05% before sowing	0.42	0.39	**0.40**	8.47	7.05	**7.76**	8.57	7.19	**7.88**
S_2 : Seed treatment with Zinc @ 0.075% before sowing	0.46	0.42	**0.44**	8.84	7.59	**8.22**	8.95	7.74	**8.34**
S_3 : Foliar spray of Zinc @ 300 ppm at 30 DAS	0.40	0.37	**0.39**	8.18	6.82	**7.50**	8.32	6.98	**7.65**
S_4 : Foliar spray of Zinc @ 400 ppm at 30 DAS	0.48	0.44	**0.46**	8.65	7.40	**8.03**	8.80	7.51	**8.16**
S_5 : Foliar spray of Zinc @ 500 ppm at 30 DAS	0.51	0.45	**0.48**	9.10	8.06	**8.58**	9.24	8.20	**8.72**
S_6 : Foliar spray of water at 30 DAS	0.34	0.30	**0.32**	8.15	6.75	**7.45**	8.24	6.88	**7.56**
Mean	**0.42**	**0.38**		**8.45**	**7.16**		**8.56**	**7.30**	
	SEm±	**CD**	**CV (%)**	**SEm±**	**CD**	**CV (%)**	**SEm±**	**CD**	**CV (%)**
Main	0.004	0.02	4.66	0.02	0.10	6.89	0.02	0.13	8.25
Sub	0.007	0.02	4.54	0.03	0.09	5.96	0.04	0.11	7.14
Interactions	0.011	NS		0.04	0.13		0.05	0.15	

Table 5. Effect of water stress treatments, zinc applications and their interaction on total dry matter (g plant $^{-1}$) during the different tested stages of mungbean growing plants

Treatments	15 DAS			30 DAS			45 DAS			60 DAS			At harvest		
	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean
S_0 : No Zinc application	0.173	0.177	**0.175**	13.69	11.34	**12.51**	13.32	11.13	**12.23**	1.53	1.37	**1.45**	5.75	4.73	**5.24**
S_1 : Seed treatment with Zinc @ 0.05% before sowing	0.206	0.209	**0.208**	15.18	12.31	**13.74**	14.79	12.06	**13.43**	1.70	1.68	**1.69**	6.51	5.16	**5.84**
S_2 : Seed treatment with Zinc @ 0.075% before sowing	0.217	0.219	**0.218**	16.03	13.05	**14.54**	15.62	12.80	**14.21**	1.85	1.88	**1.86**	7.00	5.38	**6.19**
S_3 : Foliar spray of Zinc @ 300 ppm at 30 DAS	0.187	0.193	**0.190**	14.94	12.02	**13.48**	14.59	11.81	**13.20**	1.53	1.37	**1.45**	6.54	5.10	**5.82**
S_4 : Foliar spray of Zinc @ 400 ppm at 30 DAS	0.180	0.191	**0.186**	16.08	12.82	**14.45**	15.70	12.54	**14.12**	1.48	1.32	**1.40**	7.23	5.36	**6.30**
S_5 : Foliar spray of Zinc @ 500 ppm at 30 DAS	0.186	0.189	**0.188**	16.90	13.75	**15.33**	16.48	13.47	**14.98**	1.50	1.43	**1.47**	7.61	5.62	**6.62**
S_6 : Foliar spray of water at 30 DAS	0.191	0.190	**0.190**	14.27	11.77	**13.02**	13.92	11.54	**12.73**	1.53	1.45	**1.49**	5.91	4.87	**5.39**
Mean	**0.192**	**0.195**		**15.30**	**12.44**		**14.92**	**12.19**		**1.59**	**1.50**		**6.65**	**5.18**	
	SEm ±	**CD**	**CV (%)**	**SEm ±**	**CD**	**CV (%)**	**SEm±**	**CD**	**CV (%)**	**SEm ±**	**CD**	**CV (%)**	**SEm ±**	**CD**	**CV (%)**
Main	0.001	NS	5.89	0.02	0.10	8.28	0.02	0.12	8.94	0.03	NS	9.21	0.01	0.07	8.87
Sub	0.003	0.01	4.27	0.04	0.11	7.14	0.04	0.12	7.23	0.02	0.06	7.99	0.02	0.05	7.27
Interactions	0.004	NS		0.06	0.16		0.06	0.17		0.03	0.08		0.03	0.08	

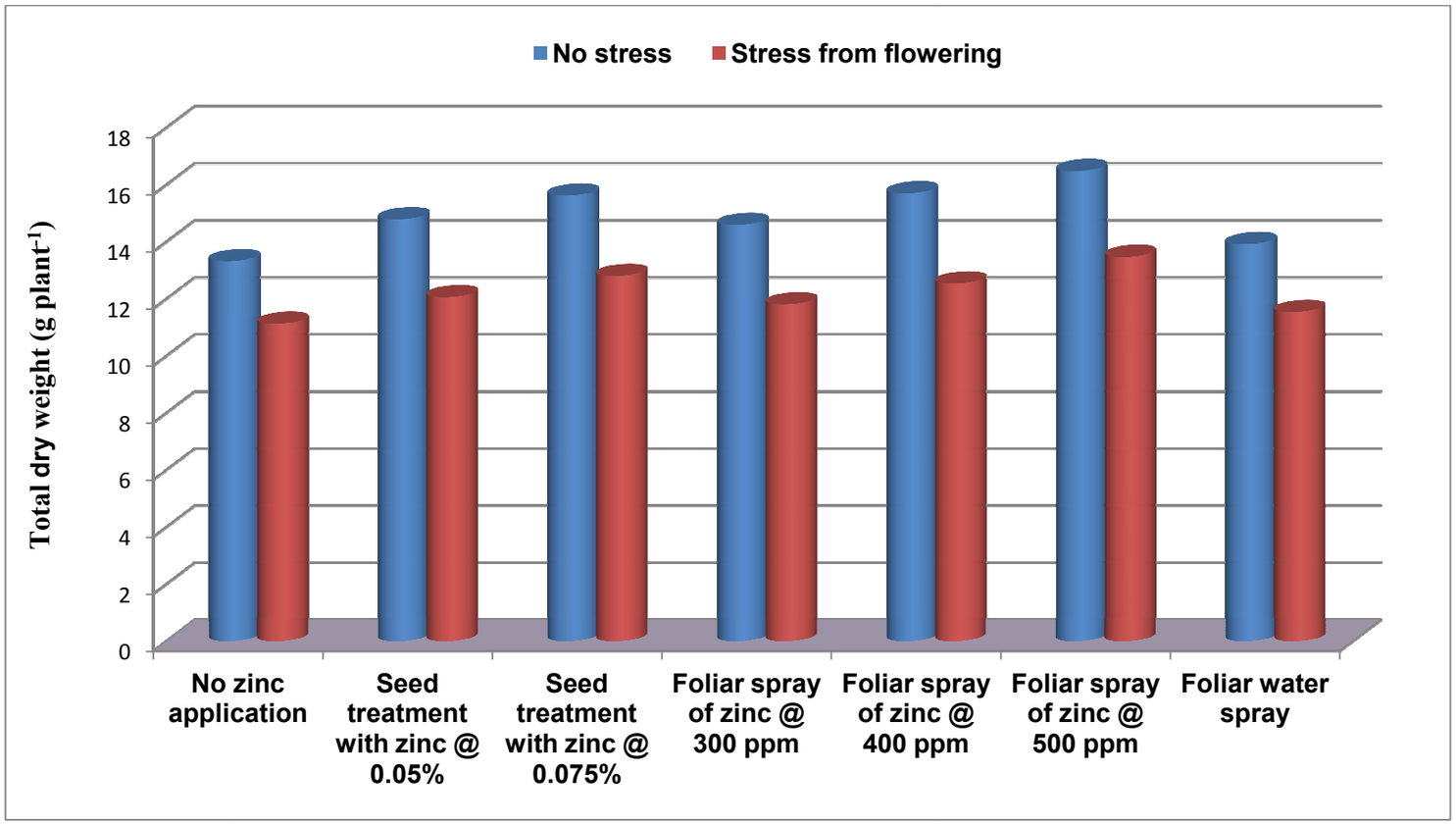

Fig. 1. Effect of the interaction between water stress treatments and zinc application treatments on total dry matter weight (g plant $^{-1}$)

Table 6. Effect of water stress treatments, zinc applications and their interaction on mungbean seed yield (Kg ha^{-1})

Treatments	Seed yield (Kg ha^{-1})		
	M_0	M_1	Mean
S_0 : No Zinc application	1476.67	1069.69	**1273.18**
S_1 : Seed treatment with Zinc @ 0.05% before sowing	1769.77	1237.91	**1503.84**
S_2 : Seed treatment with Zinc @ 0.075% before sowing	2111.76	1366.91	**1739.33**
S_3 : Foliar spray of Zinc @ 300 ppm at 30 DAS	1881.25	1228.51	**1554.88**
S_4 : Foliar spray of Zinc @ 400 ppm at 30 DAS	2194.61	1363.02	**1778.81**
S_5 : Foliar spray of Zinc @ 500 ppm at 30 DAS	2435.67	1517.31	**1976.49**
S_6 : Foliar spray of water at 30 DAS	1521.40	1111.68	**1316.54**
Mean	**1913.02**	**1270.72**	
	SEm±	**CD**	**CV (%)**
Main	49.41	300.63	14.22
Sub	59.71	174.27	9.19
Interactions	84.44	246.46	

Seed pre - treatment with zinc @ 0.075% before sowing significantly recorded higher total dry matter mean values (S_2 – 0.218 and 1.86 g plant^{-1}) compared to other treatments at 15 and 30 DAS, respectively. At 45, 60 DAS and at harvest, foliar spray of zinc @ 500 ppm at 30 DAS recorded the highest total dry matter mean values (S_5 – 6.62 g plant^{-1}, 15.33 and 14.98 g plant^{-1}, respectively), whereas the lowest total dry matter mean values were recorded by untreated plants (i.e. control, S_0 – 5.24 g plant^{-1}, 12.51 and 12.23 g plant^{-1}, respectively) as illustrated in Table 5.

In the present study, zinc spray @ 500 ppm, seed pre - treatment with zinc @ 0.075% before sowing and zinc spray @ 400 ppm at 30 DAS increased the total dry matter content by1.22, 1.16 and 1.16 folds, respectively, over untreated plants, at 60 DAS. Shahri et al. [14] reported that, zinc foliar application tended to increase total biological yield of sunflower compared to control (without zinc), and maximum biological yield was obtained by spraying 1% zinc concentration. Significant differences were found among the interactions at 30, 45, 60 DAS and at harvest. At 60 DAS, the highest total dry matter mean value was obtained with foliar spray of zinc @ 500 ppm at 30 DAS to the irrigated plants i.e. no stress (M_0S_5 – 16.90 g plant^{-1}), whereas the lowest total dry matter mean value was recorded with the plants that were stressed from flowering stage with no zinc application (M_1S_0 – 11.34 g plant^{-1}). The plants that were subjected to water stress from flowering stage with zinc spray @ 500 ppm at 30 DAS recorded the total dry matter mean value (M_1S_5 – 13.75 g plant^{-1}), which was statistically at par with the irrigated plants with no zinc application (M_0S_0 – 13.69 g plant^{-1}). In the present study, both under irrigated as well as water stress conditions, zinc spray @ 500 ppm at 30 DAS exhibited superior performance by increasing the total dry matter accumulation in mungbean plants compared to other tested zinc treatments (Table, 5 and Fig. 1).

3.5 Seed Yield (kg ha^{-1})

Significant differences were observed among the main, sub treatments and their interactions for seed yield. Among the main treatments, water stress from flowering stage significantly decreased the seed yield of mungbean (M_1 – 1270.72 kg ha^{-1}) compared to control treatment i.e. irrigated plants (M_0 – 1913.02 kg ha^{-1}). Water stress from flowering decreased the seed yield by 33.6 per cent over control treatment. Thalooth et al. [6] stated that irrigation is critical during flowering and pod filling stages in mungbean plants mainly because of higher leaf area index during these periods and consequently, greater demand for water. The authors reported that, subjecting mungbean plants to water stress at pod formation stage caused the highest reduction in number of pods plant^{-1}, pod dry weight, number of seeds pod^{-1}, seed dry weight plant^{-1} and seed yield, whereas stress at flowering came in the second order with respect to above parameters, while early stress at vegetative stage has more detrimental effect on straw and biological yield.

The seed yield of mungbean among the sub treatments ranged from 1273.18 to 1976.49 kg ha^{-1}. Foliar spray of zinc @ 500 ppm at 30 DAS recorded the highest seed yield mean value (S_5 – 1976.49 kg ha^{-1}), and the lowest seed yield was recorded by untreated treatment (S_0 – 1273.18

kg ha^{-1}). Foliar spray of zinc @ 400 ppm at 30 DAS (S_4 – 1778.81 kg ha^{-1}) is at par with seed pre - treatment with zinc @ 0.075% before sowing (S_2 – 1739.33 kg ha^{-1}), which came in the second order with respect to seed yield of mungbean. Foliar spray of water at 30 DAS (S_6 – 1316.54 kg ha^{-1}) is also at par with untreated treatment. As for the interaction effect of water stress and zinc treatments, Table 6 revealed that the highest seed yield mean value was recorded by the plants irrigated regularly (control) and sprayed with zinc @ 500 ppm at 30 DAS (M_0S_5 – 2435.67 kg ha^{-1}), whereas the lowest seed yield mean value was recorded by the plants that were stressed from flowering stage with no zinc application (M_1S_0 – 1069.69 kg ha^{-1}). In the present study, foliar spray of zinc @ 500 ppm at 30 DAS to the plants that were subjected to water stress from flowering stage (M_1S_5 – 1517.31 kg ha^{-1}) recorded the seed yield which was at par with irrigated plants with no zinc application (M_0S_0 – 1476.67 kg ha^{-1}).

4. CONCLUSION

Foliar zinc spray @ 500 ppm at 30 DAS increased leaf, stem, reproductive parts dry matter and total dry matter content and seed yield (kg ha^{-1}) by 24.6, 24.8, 20.9, 22.5 and 55.2 per cent, respectively, over untreated plants. Foliar spray of zinc @ 500 ppm at 30 DAS have shown better results compared to other tested treatments in mitigating the deleterious effects of water stress on mungbean from flowering stage.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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