



Improving growth, productivity and energetics of mungbean (*Vigna radiata*) through soil and foliar application of zinc

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ABSTRACT

The present experiment was conducted during rainy (*kharif*) seasons of 2021 and 2022 at Punjab Agricultural University, Ludhiana, Punjab to evaluate the effect of zinc sulphate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) on growth, yield and productivity of mungbean [*Vigna radiata* (L.) Wilczek] under semi-arid and subtropical conditions. The experiment was laid out in a randomized complete block design (RCBD) with four replications. Results revealed that soil applied ZnSO_4 at 20 kg/ha along with foliar spray of Zn (0.5%) at both flower initiation and pod formation phases attributed significant increase in growth and yield attributes of mungbean and was statistically similar with ZnSO_4 application to soil at 20 kg/ha along with 0.5% foliar spray at initiation of flowering alone. The per cent increase in yield was 14.6% and 15.0% with this treatment over control for two years of the study, respectively. The maximum energy output (14448.6 and 14658 MJ/ha) and energy productivity (204.3 and 207.3 g/MJ) was observed with soil Zn application at 20 kg/ha + 0.5% foliar spray at initiation of flowering and pod formation stages during 2021 and 2022, respectively. Thus, zinc sulphate application has greater effect on augmenting growth, productivity and energetics of mungbean.

Keywords: Energy productivity, Foliar spray, Seed yield, Soil application, Zinc

Globally, 30% of the total cultivated land is zinc (Zn) deficient that largely comprises of alkaline soils (Cakmak *et al.* 2017). In India, large-scale analysis of soil samples had revealed that about 39% of Indian soils are Zn deficient (Khokhar *et al.* 2024). Due to less Zn solubility, plants generally utilize only <10% of the total available Zn. High pH, submergence of soil for a prolonged period, higher carbonate content, low organic matter, and interaction with other ions like phosphorus can lead to Zn deficiency (Alloway 2009, Havlin *et al.* 2010). Zn is an important mineral required for various cellular and physiological activities of plants (Sarwar 2011, Rehman *et al.* 2018). Zn deficit plants resulted in reduced activity of enzymes, disturbed ribosomal stabilization and declined protein synthesis (Ullah *et al.* 2019). Furthermore, Zn deficiency enhances flower abortion, reduces pollen formation and increases ovule infertility that resulted in low seed set and ultimately reduced crop yield. Under reproductive stage, Zn demand is high in developing fruiting bodies as compared to vegetative stage. Majority of the Zn element gets transitioned from vegetative to reproductive parts causing shortage of the nutrient in the foliage of the crop (Pathak *et al.* 2012). Consequently, an adequate Zn supply is required throughout the crop period for maximizing the yield.

Mungbean [*Vigna radiata* (L.) Wilczek] is the 3rd most significant pulse crop of India after chickpea and pigeonpea. It is a highly nutritious crop, having 24–25% protein in the grain and also improve soil health through biological nitrogen fixation, besides a cheaper source of human and animal food protein (Haider *et al.* 2018a). Since, the agroclimatic conditions of India favor mungbean cultivation almost throughout the year, thus, there is a plentiful possibility to enhance the yield and quality of green gram with Zn fertilization.

Keeping this in view, the current study was conducted to investigate the effect of ZnSO_4 application as soil and/or foliar spray on growth, and yield of mungbean. The basic hypothesis is to investigate the effect of different Zn application methods on growth, yield and energetics of mungbean, and to ensure Zn availability throughout the crop growing period to facilitate crop yield potential.

MATERIALS AND METHODS

The present experiment was conducted during rainy (*kharif*) seasons of 2021 and 2022 at Punjab Agricultural University, Ludhiana, Punjab. The experimental site is of semi-arid having sub-tropical climatic conditions. Significant variability in the mean minimum and maximum temperature during summer and winter was recorded. The average annual rainfall of this area varies from 500–750 mm, with south-western monsoon contributing to about 75% of the

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precipitation. The meteorological data was obtained Punjab Agricultural University, Ludhiana, Punjab (Fig. 1 and 2). The average minimum and maximum air temperatures were 26.2°C and 32.7°C, whereas the mean relative humidity varied from 66–83% and 67–82% during 2021 and 2022, respectively. During the study period, the amount of rainfall recorded was 455.2 mm and 493.1 mm, respectively.

Experimental details: The texture of experimental soil was loamy sand with low available N and Zn and medium available P and K. The pH (7.5) was recorded normal with 0.45 dS/m electrical conductivity. The present experiment was conducted in randomized complete block design (RCBD) with 12 treatments, comprised of foliar and soil application of zinc as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ (21%) and their combinations, replicated four times. Crop was applied fertilizers @12.5 kg N and 40 kg P_2O_5 /ha through urea and single superphosphate @27.5 and 250 kg/ha, respectively. Soil application of Zn was applied as basal at the time of sowing, whereas foliar sprays were done at flower initiation and/or pod formation stages during evening time on clean day with calm winds.

Crop management practices: After seedbed preparation, sowing of mungbean cultivar ‘ML-1808’ was done on 26th July, 2021 and 18th July 2022 @20 kg seed/ha with wheat bed planter on the raised beds which was 67.5 cm apart consisted of bed of 37.5 cm and furrow of 30 cm. Paired rows were sown on each bed at 20 cm spacing. Harvesting after maturing 80% pods was done on 8th October 2021 and 2nd October 2022. The seed yield of mungbean of every plot replication wise was calculated from the net plot area in kg/ha.

Observations: For recording growth attributes, viz. plant height, leaf area index (LAI), dry matter accumulation (DMA), and number of branches per plants were taken from randomly selected five plants from each treatment plot (at harvest) and then average was calculated. Plant height was recorded from soil surface to the base of fully opened top leaf in centimetres. For LAI, three leaves of different sizes i.e. large, medium and small were selected and their area was measured and expressed as total leaf area in relation to ground area on which the crop was grown as explained in the following formula:

$$\text{Leaf area index} = \frac{\text{Leaf area of the plant}}{\text{Ground area occupied by the plant}}$$

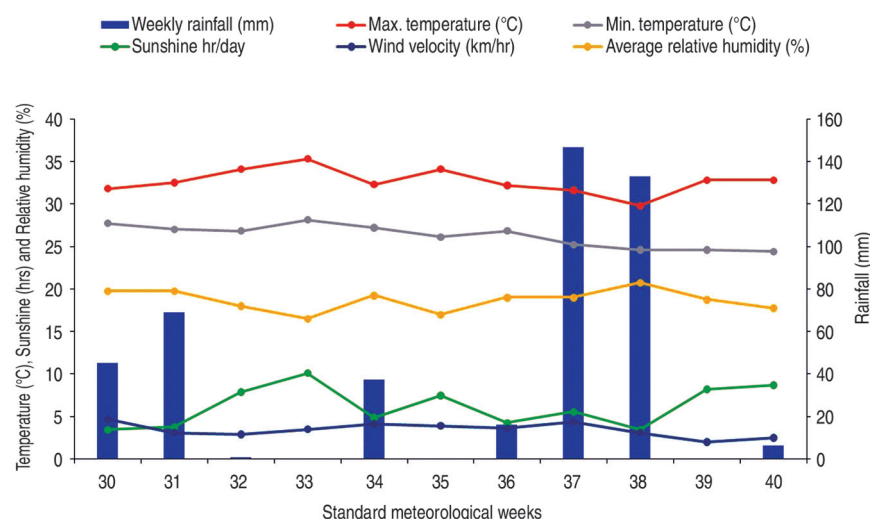


Fig. 1 Mean weekly meteorological data recorded during *kharif* 2021.

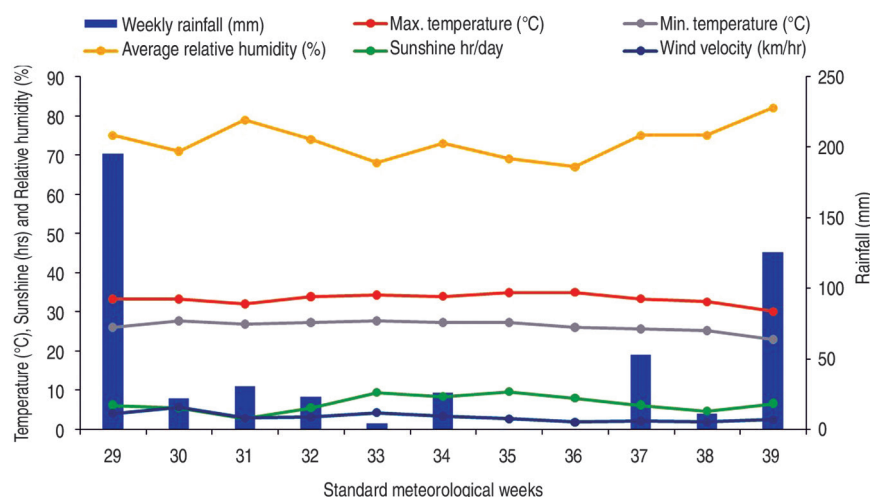


Fig. 2 Mean weekly meteorological data recorded during *kharif* 2022.

For DMA, five plants were cut just above the soil surface per plot. Samples were sun-dried and after that the samples were put in oven at temperature 60°C for further drying till obtaining a constant dry weight. Resulting data was expressed in g/plant. Branches per plant were counted from randomly selected plants and average were expressed on per plant basis.

To determine the average nodules per plant, five randomly selected plants per plot were sensibly uprooted from the soil at harvest and set on a sieve. The nodules were gently detached from the roots using forceps and numbered; their average was used to express the number of nodules/plant. After that roots were properly rinsed in flowing water. The collected nodules were put in oven at 60°C for drying, where they were dried and their dry weight could be measured and expressed as dry weight (DW) of nodules per plant.

Total number of fully matured pods were counted from five plants selected randomly treatment wise and average pods/plant was calculated. To count number of seeds/pod, 10 pods were selected randomly per plot and average was

worked out. Subsequently threshing/cleaning the bulk produce, the sample of seeds were taken and 100 seed weight (g) was recorded with a digital top pan balance.

Seed yield and biological yield: After crop harvest, bundles from net plot area were sun-dried and weighed and represented in kg/ha as biological yield. However, seed yield was noted from net plot area, after threshing and cleaning of the final crop produce. Harvest index (HI) indicates the ability of a crop to move metabolites from the vegetative portions to the commercial significant sections or reproductive parts. The following formula was used to determine the harvest index:

$$HI = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

Energetics: Energetics is used to evaluate the relationship among input and output energies to enhance energy use efficiency (EUE) and eventually productivity of specific crop. The energy input/ha was determined by summing up of partial energies of farm labour hours, fuel (diesel/petrol), machinery, irrigation, agrochemicals etc., whereas the energy output is the energy obtained from final commercial produce and was measured through their energy equivalents and expressed as MJ/ha (Hansda *et al.* 2023).

Energy productivity (EP) was also calculated by the formula given by Demircan *et al.* (2006) and expressed as g/MJ:

$$EP = \frac{\text{Seed yield (g/ha)}}{\text{Energy input (MJ/ha)}}$$

Statistical analysis: Analysis of variance (ANOVA) was done to get the effects of Zn application on mungbean in terms of symbiotic parameters, growth and productivity. The variance was analyzed using software CPCS1 (Cheema and Singh 1991). Differences between treatment means were compared with Fisher's LSD @5% significance level.

RESULTS AND DISCUSSION

Growth and symbiotic attributes: The Zn application significantly influenced the growth components of mungbean (Table 1) such as plant height, LAI and DMA except numbers of branches per plant over the control. Combination of both foliar and soil Zn application showed better results than its sole application either as foliar or soil. Soil Zn application @20 kg/ha followed by 0.5% foliar spray at initiation of flowering and formation of pods (T_{12}), exhibited the highest plant height, LAI and DMA, that was statistically *at par* with 20 kg/ha soil application along with 0.5% foliar spray at flower initiation (T_{10}) but significantly higher than the control. Increase in growth attributes with Zn application might be attributed due to the ability of Zn to produce plant growth regulators like auxins, which actively contribute to the expansion and plant cell elongation and eventually the height of plants (Ehsanullah *et al.* 2015). Zn also plays a significant role in the formation, partitioning and utilization of photosynthates and their translocation from source to sink, which leads to increased dry matter of crop plants

and thus supports to enhancing the plant growth attributes (Kosesakal and Unal 2009), nitrogen fixation (Weisany *et al.* 2013) and photosynthesis (Samreen *et al.* 2017) which ultimately contributed for increasing crop yield. Haider *et al.* (2018a) also revealed that Zn application improved the root and shoot characteristics with increased leaf area and dry weight/plant of mungbean.

Similarly, symbiotic parameters, viz. nodule numbers and their dry weight/plant (Table 1) revealed that Zn application gave statistically a greater number of nodules and their dry weight than control treatment. Soil Zn application exhibited higher nodule number and their dry weight than its foliar spray and no Zn treatment. Among soil application treatments, 20 kg/ha was more effective than 10 kg/ha (Table 1). Further, soil + foliar application performed better than soil or foliar application alone. The maximum nodule number and their dry weight were observed with soil Zn application @20 kg/ha + its foliar spray (0.5%) at flowering initiation and pod formation stages which was considerably higher than the control treatment. This increase could be attributed to the significant role of Zn in nodule regulation in pulses (Pal *et al.* 2019). Zn is also needed for tryptophan (amino acid) synthesis that is accountable for the formation of indole acetic acid and further important for the formation and development of nodules in the roots. Singh *et al.* (2018) also revealed that Zn promotes nodule formation and stimulates effective and proper functioning of bacteria present in the nodules for fixing atmospheric nitrogen, resulted in increased mungbean productivity.

Yield and yield attributes: Application of Zn significantly influenced mungbean yield and yield contributing traits, viz. pods/plant, seeds/pod, 100-seed weight over the control (Table 2). Although Zn application in the soil at 20 kg/ha (T_3) recorded higher yield over control (T_1) and foliar spray (T_4 and T_5) but combined soil Zn + foliar application was significantly better than their sole applications. The highest seed yield was elicited with 20 kg/ha Zn application in the soil along with 0.5% foliar application at initiation of flowering and pod formation stages, i.e. T_{12} (1,035 and 1,050 kg/ha) that is statistically similar with soil Zn application at 20 kg/ha along with 0.5% foliar application at initiation of flowering only i.e. T_{10} (1,025 and 1,034 kg/ha), however, statistically more than control (903 and 913 kg/ha) during 2021 and 2022, respectively. The per cent increase was 14.6 and 15.0 over control during the two respective years. The higher seed yield obtained with the application of Zn was owing to elevated yield contributing traits such as number of pods per plant, seeds per pod and 100-seed weight which in turn was the result of higher LAI and DMA/plant (Table 1). Additionally, combined Zn application at sowing followed by its foliar spray at flower initiation and pod formation led to greater influence on seeds/pod and 100-seed weight, that ultimately contributed to increased seed yield than their sole applications (soil or foliar). This could be attributed to continuous availability of Zn throughout the growth and developmental stages, which might improve the crop growth and development compared

Table 1 Effect of soil and foliar application of zinc on growth attributes and symbiotic parameters of mungbean at harvest

Treatment	Plant height (cm)		Leaf area index		Dry matter accumulation (g/plant)		No. of branches/plant		No. of nodules (per plant)		Dry weight of nodules (mg/plant)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
T ₁ , Control (No Zn)	68.0	70.0	2.60	2.70	20.53	20.97	8.0	8.2	24.0	24.9	47.0	48.4
T ₂ , Soil application of Zn (10 kg/ha)	71.0	72.0	2.80	2.80	21.00	22.30	8.3	8.4	25.7	26.7	48.3	49.7
T ₃ , Soil application of Zn (20 kg/ha)	73.5	75.5	3.20	3.20	21.86	22.87	8.4	8.4	28.0	28.9	50.0	51.4
T ₄ , Foliar application of Zn (0.5%) at flower initiation	69.5	71.6	2.70	2.70	21.00	22.32	8.2	8.3	25.0	25.9	48.0	49.5
T ₅ , Foliar application of Zn (0.5%) at pod formation	68.0	70.0	2.80	2.85	20.45	21.97	8.2	8.3	24.5	25.5	47.4	48.9
T ₆ , Foliar application of Zn (0.5%) at flower initiation and pod formation	69.0	71.1	2.73	2.76	21.40	22.82	8.3	8.4	25.0	25.9	48.1	49.5
T ₇ , Soil (10 kg/ha) + foliar application of Zn (0.5%) at flower initiation	72.5	73.5	2.80	3.00	22.00	23.40	8.5	8.6	25.5	26.4	48.2	49.7
T ₈ , Soil (10 kg/ha) + foliar application of Zn (0.5%) at pod formation	72.0	74.5	2.80	2.90	21.95	23.52	8.5	8.5	26.0	26.9	48.5	50.1
T ₉ , Soil (10 kg/ha) + foliar application of Zn (0.5%) at flower initiation and pod formation	72.5	72.5	2.90	2.90	22.50	23.82	8.6	8.7	25.9	26.8	48.5	50.0
T ₁₀ , Soil (20 kg/ha) + foliar application of Zn (0.5%) at flower initiation	74.0	76.0	3.40	3.60	23.75	25.07	8.6	8.7	28.5	29.5	50.4	51.8
T ₁₁ , Soil (20 kg/ha) + foliar application of Zn (0.5%) at pod formation	72.4	75.0	3.40	3.50	23.45	24.97	8.6	8.7	28.7	29.7	50.7	52.3
T ₁₂ , Soil (20 kg/ha) + foliar application of Zn (0.5%) at flower initiation and pod formation	74.8	77.0	3.50	3.75	24.00	25.57	8.7	8.8	28.9	29.9	50.9	52.4
LSD ($P=0.05$)	2.4	1.8	0.10	0.12	0.38	0.51	NS	NS	0.8	0.7	1.5	1.4

Table 2 Effect of soil and foliar application of zinc on yield and yield attributes of mungbean

Treatment	No. of pods/ plant		No. of seeds/ pod		100-seed weight (g)		Seed yield (kg/ha)		Biological yield (kg/ha)		Harvest index (%)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
T ₁ , Control (No Zn)	30.0	31.0	9.0	9.4	3.70	3.71	903	913	4,430	4,485	20.38	20.36
T ₂ , Soil application of Zn (10 kg/ha)	31.5	32.1	10.0	10.0	3.79	3.80	930	938	4,506	4,566	20.64	20.54
T ₃ , Soil application of Zn (20 kg/ha)	32.0	32.7	10.1	10.2	3.80	3.82	948	957	4,560	4,614	20.79	20.74
T ₄ , Foliar application of Zn (0.5%) at flower initiation	31.4	32.0	10.0	10.1	3.75	3.78	920	931	4,465	4,535	20.60	20.53
T ₅ , Foliar application of Zn (0.5%) at pod formation	31.0	31.7	10.0	10.0	3.74	3.75	916	926	4,450	4,520	20.58	20.49
T ₆ , Foliar application of Zn (0.5%) at flower initiation and pod formation	32.0	32.4	10.1	10.1	3.75	3.77	941	951	4,540	4,600	20.73	20.67
T ₇ , Soil (10 kg/ha) + foliar application of Zn (0.5%) at flower initiation	33.3	33.5	10.1	10.2	3.77	3.80	969	980	4,635	4,690	20.91	20.90
T ₈ , Soil (10 kg/ha) + foliar application of Zn (0.5%) at pod formation	33.0	33.3	10.0	10.0	3.76	3.79	956	968	4,584	4,654	20.86	20.80
T ₉ , Soil (10 kg/ha) + foliar application of Zn (0.5%) at flower initiation and pod formation	34.2	34.6	10.3	10.3	3.80	3.83	990	1000	4,688	4,750	21.12	21.05
T ₁₀ , Soil (20 kg/ha) + foliar application of Zn (0.5%) at flower initiation	35.0	35.3	10.5	10.4	3.83	3.85	1025	1034	4,790	4,857	21.40	21.29
T ₁₁ , Soil (20 kg/ha) + foliar application of Zn (0.5%) at pod formation	34.5	35.0	10.0	10.2	3.82	3.84	993	1015	4,700	4,830	21.13	21.01
T ₁₂ , Soil (20 kg/ha) + foliar application of Zn (0.5%) at flower initiation and pod formation	36.0	36.4	10.6	10.6	3.86	3.90	1035	1050	4,825	4,925	21.45	21.32
LSD ($P=0.05$)	1.0	0.6	0.3	0.3	0.10	0.12	26.0	31.0	113.0	110.0	0.62	0.54

to control. As per the observation recorded by Pal *et al.* (2019), the soil and/or foliar Zn application enhanced the conversion of flowers into pods along with increased sink size that attributed to greater mobilization of photosynthates to the growing grain and led to more pods/plant and ultimately increased the seed weight and seed yield.

Similarly, the highest biological yield (4,825 and 4,925 kg/ha) and harvest index was determined with 20 kg/ha soil Zn application along with 0.5% Zn foliar spray at flower initiation and pod formation stages during both the years, respectively. However, other treatments also recorded better results as compared to the control. Ram and Katiyar (2018) also observed increased grain yield with Zn application in mungbean, led to a higher buildup of dry matter, which all contributed to the higher biological yield. These outcomes are consistent with those Haider *et al.* (2018b). They found that Zn application improved the biological yield and harvest index of mungbean (MN-2006). The crop was given a balanced ratio and sufficient amounts of plant nutrients during the growth phase, which encouraged the development of yield-enhancing traits and as a result, increased seed and biological yield (Devi *et al.* 2011).

Energetics: Among different Zn application treatments, the current study revealed that the energy use efficiency (EUE) and productivity in different treatments could be augmented by input optimization which intern increases the

crop productivity (Table 3). The maximum energy input was attained from soil application of Zn at the rate of 20 kg/ha along with 0.5% foliar spray at initiation of flowers and pod formation stages (T_{12}). Soil Zn application at 20 kg/ha along with foliar application of 0.5% at flower initiation (T_{10}) and pod formation (T_{11}) displayed similar levels of energy input (5,030.4 MJ/ha) due to one soil application and one foliar spray (flower initiation/pod formation). However, the lowest energy input was recorded in control.

Significant increase in energy output was observed with Zn application treatments over control except soil application at 10 kg/ha (T_3) and single foliar sprays either at initiation of flowering (T_4) or pod formation stages (T_5). Although combination of both soil+ foliar application had higher energy output and energy productivity than sole applications and no application. Maximum energy output (14,448.6 and 14,658.0 MJ/ha) and energy productivity (204.3 and 207.3 g/MJ) was observed with soil Zn application at 20 kg/ha + 0.5% foliar spray at initiation of flowering and pod formation stages (T_{12}) during two-years of field study and was statistically higher than no Zn treatment (control).

The current field study exhibited the influence of Zn fertilization on the various parameters of mungbean and helped in optimizing the time and method of application of $ZnSO_4$ on increasing the growth, yield attributes, yield and energetics of mungbean. Zn application at 20 kg/ha at

Table 3 Effect of soil and foliar application of zinc on energetics of mungbean

Treatment	Energy input (MJ/ha)		Energy output (MJ/ha)		Energy productivity (g/MJ)	
	2021	2022	2021	2022	2021	2022
T_1 , Control (No Zn)	4,581.2	4,581.2	12,605.9	12,745.5	197.1	199.3
T_2 , Soil application of Zn (10 kg/ha)	4,788.2	4,788.2	12,982.8	13,094.5	194.2	195.9
T_3 , Soil application of Zn (20 kg/ha)	4,995.2	4,995.2	13,234.1	13,359.7	189.8	191.6
T_4 , Foliar application of Zn (0.5%) at flower initiation	4,616.4	4,616.4	12,843.2	12,996.7	199.3	201.7
T_5 , Foliar application of Zn (0.5%) at pod formation	4,616.4	4,616.4	12,787.4	12,926.9	198.4	200.6
T_6 , Foliar application of Zn (0.5%) at flower initiation and pod formation	4,651.6	4,651.6	13,136.4	13,275.9	202.3	204.4
T_7 , Soil (10 kg/ha) + foliar application of Zn (0.5%) at flower initiation	4,823.4	4,823.4	13,527.2	13,680.8	200.9	203.2
T_8 , Soil (10 kg/ha) + foliar application of Zn (0.5%) at pod formation	4,823.4	4,823.4	13,345.8	13,513.3	198.2	200.7
T_9 , Soil (10 kg/ha) + foliar application of Zn (0.5%) at flower initiation and pod formation	4,858.6	4,858.6	13,820.4	13,960.0	203.8	205.8
T_{10} , Soil (20 kg/ha) + foliar application of Zn (0.5%) at flower initiation	5,030.4	5,030.4	14,309.0	14,434.6	203.8	205.6
T_{11} , Soil (20 kg/ha) + foliar application of Zn (0.5%) at pod formation	5,030.4	5,030.4	13,862.3	14,169.4	197.4	201.8
T_{12} , Soil (20 kg/ha) + foliar application of Zn (0.5%) at flower initiation and pod formation	5,065.6	5,065.6	14,448.6	14,658.0	204.3	207.3
LSD ($P=0.05$)	---	---	414.5	391.8	7.1	6.6

sowing along with foliar application of 0.5% Zn at flowering and pod formation stage evolved as the best treatment in terms of augmented productivity and energetics.

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