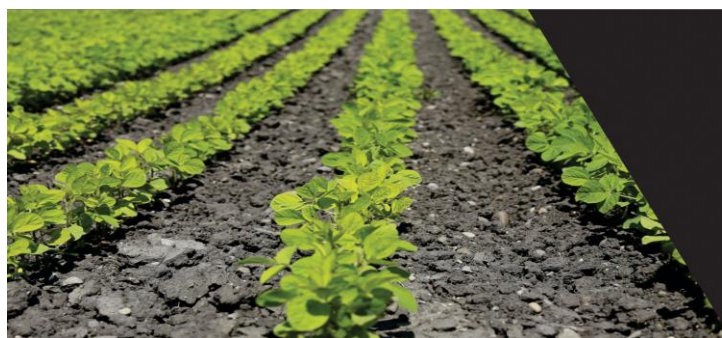




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Effect of Nano Zinc on growth, yield attributes, yield and quality of groundnut (*Arachis hypogaea* L.)

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Abstract

A field experiment was conducted during the *kharif* season of 2024 to evaluate the effect of nano-zinc on growth, nodulation, yield attributes, yield and quality of groundnut (*Arachis hypogaea* L.). The present manuscript focuses on the nano-zinc treatment factor comprising four levels, namely control, 750 ppm, 950 ppm and 1050 ppm. Foliar application of nano-zinc at 950 ppm recorded the highest growth response, with maximum plant height (47.725 cm), number of nodules (43.35/plant), number of branches (10.199/plant), dry weight (29.923 g) and crop growth rate (0.299). The same treatment also produced the best yield expression, registering the highest pods per plant (19.50), seed yield (2769.8 kg/ha), haulm yield (6482.2 kg/ha), shelling (59.231%), harvest index (34.35%), seed index (39.16%) and oil content (39.16%). Compared with the control, nano-zinc at 950 ppm increased seed yield by 19.05% and haulm yield by 17.24%, indicating better vegetative growth, nodulation and assimilate partitioning towards reproductive development. The decline in performance at 1050 ppm suggests that the response of groundnut to nano-zinc was concentration dependent, with 950 ppm emerging as the optimum level under the tested agro-climatic conditions.

Keywords: Groundnut, Nano-Zinc, foliar application, nodulation, seed yield, oil content

Introduction

Groundnut (*Arachis hypogaea* L.) is an important oilseed legume crop cultivated widely for its edible kernels, high-quality oil and nutritious haulm. It occupies a significant position among oilseed crops because it contributes to human nutrition, edible oil production and livestock feeding. The productivity of groundnut is closely associated with healthy vegetative growth, efficient root development, active nodulation, proper peg penetration and successful pod filling. Since the crop produces flowers above the ground but develops pods below the soil surface, balanced nutrient availability during both vegetative and reproductive stages is essential for obtaining higher yield and better kernel quality.

Groundnut is also known for its high nutritional and economic value. The kernels are rich in edible oil, protein, carbohydrates, minerals and vitamins. Generally, groundnut seed contains about 47-50% oil and 25-30% protein, although these values may vary with genotype, season, soil fertility and crop management practices. Groundnut oil is mainly composed of unsaturated fatty acids, particularly oleic and linoleic acids, which contribute to its edible quality, flavour and storage stability. The protein-rich kernels are useful in human diet, while the haulm serves as valuable fodder for livestock. Therefore, improvement in seed yield, oil content, seed index and haulm yield directly enhances both the economic return and nutritional value of the crop.

Among the essential micronutrients, zinc plays an important role in the growth and physiological functioning of crop plants. It is involved in enzyme activation, auxin synthesis, chlorophyll formation, membrane stability, pollen viability and carbohydrate translocation. In leguminous crops like groundnut, adequate zinc nutrition also supports root growth and nodule development, which indirectly improves biological nitrogen fixation and overall plant vigour. Deficiency or poor availability of zinc may reduce plant height, leaf area, dry matter accumulation, flowering efficiency, pod development and seed formation, ultimately resulting in lower yield and quality (Noman *et al.*, 2015; Saleem *et al.*, 2022) [6, 4].

In recent years, nano-fertilizers have gained attention as a promising approach for improving nutrient-use efficiency in crop production. Due to their smaller particle size, larger surface area and better contact with plant surfaces, nano forms of nutrients may improve absorption and utilization at comparatively lower concentrations. Foliar application of nano-zinc can be particularly useful because it supplies zinc directly to the growing plant tissues and may reduce nutrient losses caused by soil fixation or limited root-zone availability. This makes nano-zinc important for improving physiological activity, nodulation, dry matter production and reproductive growth in groundnut. Previous studies have indicated that nanoscale zinc oxide can improve germination, seedling vigour, growth and yield of peanut when applied at suitable concentrations (Prasad *et al.*, 2012)^[9]. However, the response of nano-fertilizers is generally concentration dependent. An optimum concentration may enhance crop growth, nodulation, assimilate production and pod filling, whereas an excessive concentration may not provide additional benefit and may even reduce performance due to nutrient imbalance or physiological stress. Therefore, identifying the suitable dose of nano-zinc is important for its effective use in groundnut production.

Keeping these points in view, the present field experiment was conducted during *kharif* 2024 to evaluate the effect of different concentrations of nano-zinc on growth, nodulation, yield attributes, yield and quality of groundnut. The study was aimed at identifying the most effective nano-zinc concentration for improving groundnut productivity and quality under the tested field conditions.

Materials and methods: The field experiment was conducted during the *kharif* season of 2024 at the Crop Research Farm, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj, Uttar Pradesh, India. The groundnut (*Arachis hypogaea* L.) variety RG-559-3 was used as the test crop. Although the original field trial comprised phosphogypsum and nano-zinc as treatment factors, the present manuscript is confined specifically to the main-effect response of nano-zinc during 2024.

The nano-zinc treatment factor included four levels, namely control, nano-zinc at 750 ppm, nano-zinc at 950 ppm and nano-zinc at 1050 ppm. Foliar application of nano-zinc was carried out according to the treatment schedule adopted in the field experiment. All other agronomic and plant-protection practices were followed uniformly in accordance with the recommended package of practices for groundnut, so that the observed variation could be attributed mainly to the imposed nano-zinc treatments. Growth observations, including plant height, number of nodules per plant, number of branches per plant, dry weight and crop growth rate, were recorded before harvest as per standard procedures. Yield attributes and yield-related parameters, such as number of pods per plant, seed yield, haulm yield, shelling percentage, harvest index, seed index and oil content, were recorded at harvest. The data were compiled treatment-wise to assess the comparative performance of different nano-zinc concentrations.

The experimental data were subjected to statistical analysis using the standard analysis of variance procedure appropriate for the design of the study. Treatment means were compared with the help of standard error of mean [SEm ($\pm$)] and critical difference (CD) at 5% level of probability wherever the treatment effect was found significant. Since the objective of the present article is limited to the nano-zinc component of the experiment, only the nano-zinc main-effect data of 2024 have been presented and discussed.

Results and discussion: Growth response: The growth parameters of groundnut responded clearly to foliar application of

nano-zinc during *kharif* 2024 (Table 1). Among the four treatment levels, nano-zinc at 950 ppm consistently recorded the highest numerical values for plant height, nodulation, branching, dry matter accumulation and crop growth rate. The response declined at 1050 ppm, indicating that the beneficial effect of nano-zinc was concentration dependent and that 950 ppm was the most effective level under the tested field conditions.

Plant height: The effect of nano-zinc on plant height was marked. Foliar application of nano-zinc at 950 ppm recorded the maximum plant height (47.725 cm) and was significantly higher than the control (38.775 cm), nano-zinc at 750 ppm (40.668 cm) and nano-zinc at 1050 ppm (41.277 cm). Nano-zinc at 1050 ppm was significantly higher than the control but remained statistically at par with 750 ppm, while 750 ppm was statistically at par with the control. The increase in plant height at 950 ppm may be ascribed to optimum zinc availability, which supports enzyme activation, auxin biosynthesis and cell elongation, thereby improving vegetative growth in groundnut (Prasad *et al.*, 2012; Saleem *et al.*, 2022)^[4,9].

Number of nodules per plant: The number of nodules per plant also showed a significant response to nano-zinc application. Nano-zinc at 950 ppm recorded the highest nodules per plant (43.35) and was significantly superior to the control (35.27), nano-zinc at 750 ppm (36.98) and nano-zinc at 1050 ppm (37.49). Nano-zinc at 1050 ppm was significantly higher than the control and statistically at par with 750 ppm, whereas 750 ppm remained statistically at par with the control. The higher nodulation at 950 ppm may be attributed to better root growth and zinc-supported nodule development, which favour biological nitrogen fixation and overall plant vigour in legumes (Noman *et al.*, 2015; León-Mediavilla *et al.*, 2018)^[6].

Number of branches per plant: The maximum number of branches per plant was recorded with nano-zinc at 950 ppm (10.199). This treatment was significantly higher than the control (9.148) and nano-zinc at 750 ppm (9.263), while it remained statistically at par with nano-zinc at 1050 ppm (9.703). The 1050 ppm treatment was also statistically at par with 750 ppm and the control. The improvement in branching at 950 ppm may be due to adequate zinc nutrition, which enhances chlorophyll formation, metabolic activity and auxin-regulated shoot development (Saleem *et al.*, 2022)^[4].

Dry weight: Dry matter accumulation was significantly influenced by nano-zinc treatments. Nano-zinc at 950 ppm recorded the highest dry weight (29.923 g), which was significantly higher than the control (24.312 g), nano-zinc at 750 ppm (25.498 g) and nano-zinc at 1050 ppm (25.879 g). Nano-zinc at 1050 ppm was significantly higher than the control and statistically at par with 750 ppm, whereas 750 ppm remained statistically at par with the control. The greater dry matter accumulation at 950 ppm may be explained by improved photosynthetic efficiency, enzyme activity and translocation of assimilates towards actively growing plant parts under optimum zinc supply (Prasad *et al.*, 2012; Saleem *et al.*, 2022)^[9,4].

Crop growth rate: Crop growth rate followed a similar trend. Nano-zinc at 950 ppm recorded the highest CGR value (0.299) and was significantly higher than the control (0.243), nano-zinc at 750 ppm (0.255) and nano-zinc at 1050 ppm (0.258). The control, 750 ppm and 1050 ppm treatments were statistically at par with each other. The higher CGR at 950 ppm may be due to

greater leaf activity, improved nutrient uptake and increased biomass production under an optimum nano-zinc concentration (Prasad *et al.*, 2012; Noman *et al.*, 2015) ^[9, 6].

Overall interpretation: Overall, the growth data clearly indicated that nano-zinc at 950 ppm was the most effective treatment for improving pre-harvest growth characters of groundnut during 2024. The superiority of 950 ppm over the

control and other nano-zinc levels suggests that adequate nano-zinc supply improved plant vigour, nodulation and biomass accumulation. However, the reduced performance at 1050 ppm shows that increasing the concentration beyond the optimum level did not provide additional benefit. Thus, nano-zinc at 950 ppm may be considered the optimum concentration among the tested levels for improving growth performance of groundnut under the present experimental conditions.

Table 1: Treatment response summary based on CD at 5% probability

Parameter	Best treatment	Statistical interpretation
Plant height	Nano-zinc at 950 ppm (47.725 cm)	Significantly higher than control, 750 ppm and 1050 ppm.
Nodules/plant	Nano-zinc at 950 ppm (43.35)	Significantly higher than control, 750 ppm and 1050 ppm.
Branches/plant	Nano-zinc at 950 ppm (10.199)	Significantly higher than control and 750 ppm; statistically at par with 1050 ppm.
Dry weight	Nano-zinc at 950 ppm (29.923 g)	Significantly higher than control, 750 ppm and 1050 ppm.
CGR	Nano-zinc at 950 ppm (0.299)	Significantly higher than control, 750 ppm and 1050 ppm.

Table 2: Effect of nano zinc on growth parameters of groundnut during 2024

Treatment	Plant height (cm)	Nodules/plant	Branches/plant	Dry weight (g)	CGR
Control	38.775	35.27	9.148	24.312	0.243
Nano zinc at 750 ppm	40.668	36.98	9.263	25.498	0.255
Nano zinc at 950 ppm	47.725	43.35	10.199	29.923	0.299
Nano zinc at 1050 ppm	41.277	37.49	9.703	25.879	0.258
SEm (±)	1.123	1.007	0.321	0.704	0.0071
CD (P=0.05)	2.332	2.09	0.666	1.462	0.0154

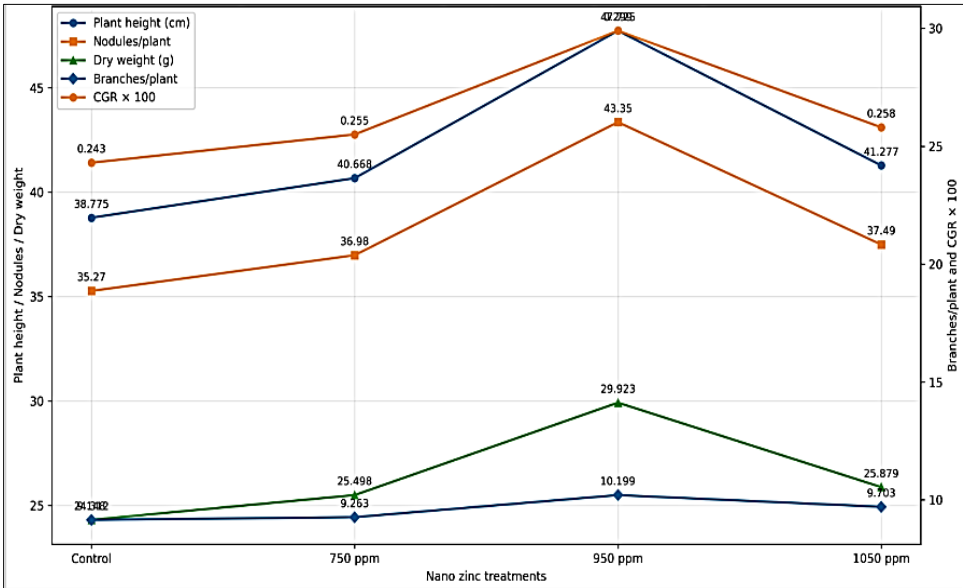


Fig 1: Shows that nano-zinc at 950 ppm recorded the highest values for plant height, nodules, branches, dry weight and CGR in groundnut. The decline at 1050 ppm indicates that nano-zinc response was concentration dependent, and 950 ppm was the most effective level.

Yield attributes, yield and quality response

The data on yield attributes, yield and quality characters of groundnut showed a clear response to foliar application of nano-zinc during *kharif* 2024. Among the evaluated concentrations, nano-zinc at 950 ppm recorded the highest values for pods per plant, seed yield, haulm yield, shelling percentage, harvest index, seed index and oil content. The response declined at 1050 ppm, indicating that the beneficial effect of nano-zinc was concentration dependent and that 950 ppm was the most effective concentration under the tested field conditions. The data on yield attributes, yield and quality characters of groundnut showed a clear response to foliar application of nano-zinc during *kharif* 2024. Among the evaluated concentrations, nano-zinc at 950 ppm recorded the highest values for pods per plant, seed yield, haulm yield, shelling percentage, harvest index,

seed index and oil content. The response declined at 1050 ppm, indicating that the beneficial effect of nano-zinc was concentration dependent and that 950 ppm was the most effective concentration under the tested field conditions.

Number of pods per plant: Nano-zinc at 950 ppm recorded the maximum number of pods per plant (19.50) and was significantly higher than control (16.63), nano-zinc at 750 ppm (17.45) and nano-zinc at 1050 ppm (17.71). Nano-zinc at 1050 ppm was significantly superior to control and statistically at par with 750 ppm, while 750 ppm remained statistically at par with control. The higher pod number under nano-zinc at 950 ppm may be due to improved vegetative growth, better nodulation and greater assimilate supply towards peg development and pod formation (Prasad *et al.*, 2012; Noman *et al.*, 2015) ^[9, 6].

Seed yield

The highest seed yield was recorded with nano-zinc at 950 ppm (2769.8 kg/ha), which was significantly higher than control (2362.6 kg/ha), 750 ppm (2478.0 kg/ha) and 1050 ppm (2514.7 kg/ha). Nano-zinc at 1050 ppm was significantly higher than control and statistically at par with 750 ppm, whereas 750 ppm was statistically at par with control. In comparison with control, nano-zinc at 950 ppm increased seed yield by about 17.24%. The improvement in seed yield may be attributed to zinc-mediated enhancement in enzyme activity, photosynthesis, pollen function and translocation of carbohydrates from source to sink, resulting in better pod filling and kernel development (Saleem *et al.*, 2022; Prasad *et al.*, 2012)^[4, 9].

Haulm yield

Nano-zinc at 950 ppm produced the highest haulm yield (6482.2 kg/ha) and was significantly superior to control (5529.1 kg/ha), 750 ppm (5799.1 kg/ha) and 1050 ppm (5885.0 kg/ha). Nano-zinc at 1050 ppm was significantly higher than control but remained statistically at par with 750 ppm; 750 ppm was statistically at par with control. The increase in haulm yield at 950 ppm over control was about 17.24%. Higher haulm yield may be due to better canopy development, increased dry matter accumulation and improved nutrient-use efficiency under optimum nano-zinc application (Prasad *et al.*, 2012; Saleem *et al.*, 2022).

Shelling percentage

The effect of nano-zinc on shelling percentage was non-significant. However, the highest numerical shelling percentage was recorded with nano-zinc at 950 ppm (59.231%), followed by 1050 ppm (57.318%), 750 ppm (57.308%) and control (55.623%). All nano-zinc treatments were statistically at par with each other for this character. The numerical improvement in shelling percentage may be associated with better seed filling and kernel development due to improved zinc nutrition, although the variation was not large enough to become statistically distinct (Noman *et al.*, 2020; Saleem *et al.*, 2022)^[8, 4].

Harvest index: Harvest index was not significantly influenced by nano-zinc levels. Numerically, nano-zinc at 950 ppm recorded the

highest harvest index (34.35%), followed by 750 ppm (33.40%), 1050 ppm (33.24%) and control (32.42%). The treatments remained statistically at par, indicating that nano-zinc improved economic yield and biological yield in a relatively proportional manner. The non-significant variation in harvest index suggests that the yield increase was mainly due to overall biomass improvement and pod development rather than a marked shift in dry matter partitioning (Saleem *et al.*, 2022)^[4].

Seed index

The seed index was also not significantly affected by nano-zinc application. The highest numerical seed index was observed with nano-zinc at 950 ppm (39.16%), while nano-zinc at 1050 ppm (37.90%), 750 ppm (37.89%) and control (36.78%) were statistically at par. The slight improvement in seed index may be due to better assimilate translocation and seed filling under adequate zinc availability, as zinc supports carbohydrate metabolism and reproductive growth (Prasad *et al.*, 2012; Saleem *et al.*, 2022)^[9, 4].

Oil content

Oil content followed a trend similar to seed index. Nano-zinc at 950 ppm recorded the highest numerical oil content (39.16%), followed by 1050 ppm (37.90%), 750 ppm (37.89%) and control (36.78%). However, the differences among treatments were statistically at par, showing that nano-zinc did not significantly alter oil content in the present season. The marginal improvement in oil content may be related to better seed metabolic activity and improved seed development under zinc nutrition, but the effect on oil accumulation remained statistically non-significant under the supplied 2024 data (Noman *et al.*, 2020; Saleem *et al.*, 2022)^[8, 4]. Overall, nano-zinc at 950 ppm was the most effective treatment for improving yield attributes, seed yield and haulm yield of groundnut during 2024. The lower performance at 1050 ppm indicates that increasing the concentration beyond the optimum level did not provide additional advantage. Therefore, the response pattern confirms that nano-zinc application in groundnut is dose dependent, with 950 ppm emerging as the best concentration among the tested levels.

Table 3: Effect of nano-zinc on yield attributes, yield and quality of groundnut during 2024

Treatment	Pods/plant	Seed yield (kg/ha)	Haulm yield (kg/ha)	Shelling (%)	Harvest index (%)	Seed index (%)	Oil content (%)
Control	16.63	2362.6	5529.1	55.623	32.42	36.78	36.78
Nano zinc at 750 ppm	17.45	2478.0	5799.1	57.308	33.40	37.89	37.89
Nano zinc at 950 ppm	19.50	2769.8	6482.2	59.231	34.35	39.16	39.16
Nano zinc at 1050 ppm	17.71	2514.7	5885.0	57.318	33.24	37.90	37.90
SEm (±)	0.411	58.42	136.73	1.281	0.688	0.847	16.13
CD (P=0.05)	0.854	121.29	283.87	NS	NS	NS	33.49

Note: NS = non-significant. Treatment means are interpreted on the basis of SEm and CD values supplied in the data table.

Overall interpretation

The 2024 data clearly indicated that nano zinc at 950 ppm was the most effective level among the tested treatments. The treatment improved growth, nodulation, dry matter production, pods per plant, seed yield and haulm yield. The 1050 ppm treatment did not maintain the same level of response, which shows that higher

concentration alone is not always beneficial. From a practical agronomic view, 950 ppm may be considered the optimum nano-zinc concentration under the tested field conditions. However, because this manuscript uses only one year of nano-zinc data, multi-season validation and economic analysis would be useful before making a wider recommendation.

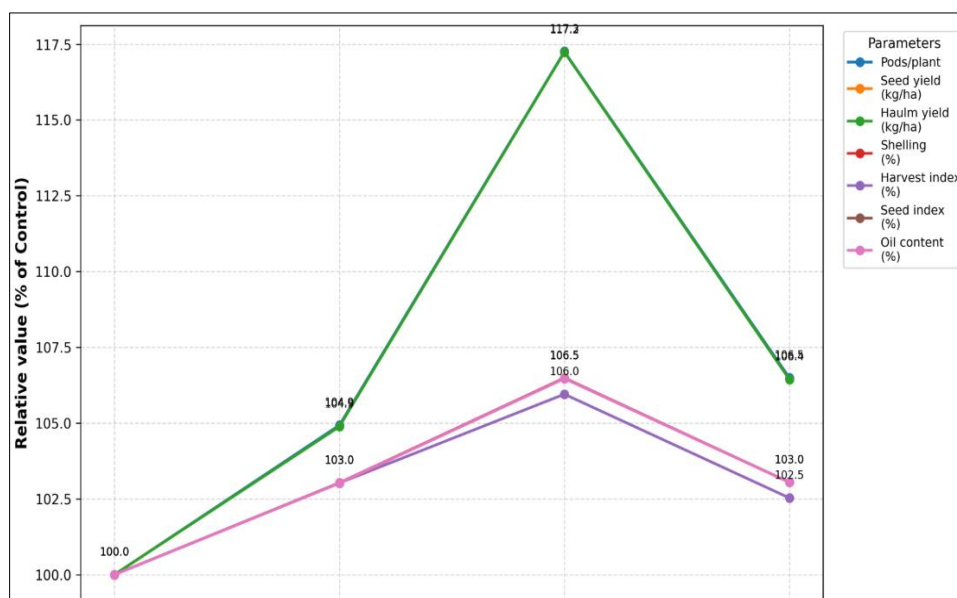


Fig 2: Effect of Nano-Zinc on Yield Attributes, Yield and Quality of Groundnut during 2024

Conclusion

Nano zinc at 950 ppm recorded the best performance in groundnut during 2024. It produced the highest plant height, nodules per plant, branches per plant, dry weight, CGR, pods per plant, seed yield and haulm yield. The yield advantage was mainly associated with improved vegetative growth and better sink development. The response declined at 1050 ppm, indicating that 950 ppm was the optimum concentration among the tested nano-zinc levels. Therefore, nano zinc at 950 ppm can be considered a promising treatment for improving groundnut productivity under the experimental conditions of Prayagraj, Uttar Pradesh.

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