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Assessing the impact of nano zinc oxide on growth, yield, and nutrient uptake by linseed

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ABSTRACT

This research involved the synthesis of zinc oxide (ZnO) nanoparticles via direct precipitation, followed by their characterization via Fourier Transform Infrared Spectroscopy (FTIR) and Dynamic Light Scattering. The nano ZnO particle size ranged from 45.18 to 48.50 nm, and the mid-range value of the Polydispersity Index (0.224 to 0.250) indicated a consistent dispersion of particles in all samples. The produced nano ZnO particles' zeta potential values were -27.2 ± 7.6 mV, suggesting that they were more stable in aqueous suspension. The results of the experiment revealed several notable findings. When linseed seeds were treated with nano ZnO at a concentration of 1000 ppm, the highest germination rate (88%) and impressive plant attributes were observed. These included a high plant stand per plot (635), an increased number of branches per plant (3.53), abundant capsules per plant (66.87), and a substantial seed yield of 1169 kg/ha, accompanied by a straw yield of 2660 kg/ha and a test weight of 8.23 g. Soil-related parameters were also affected by the treatments. A soil application of ZnSO4 at 15 kg/ha, along with foliar spray of nano ZnO at 0.25% applied at 30 and 45 days after sowing (DAS), resulted in an elevated soil pH (7.40) and increased availability of essential nutrients such as nitrogen (248.83), potassium (326.33), and sulfur (13.83). Additionally, this treatment positively influenced soil electrical conductivity (EC) with a value of 0.22 and enhanced the availability of zinc (0.46) in the soil, contributing to improved soil reaction and fertility. Furthermore, an organic carbon content of 5.9 and increased availability of phosphorus in the soil were recorded with soil application of ZnSO4 at 15 kg/ha, supplemented with foliar application of ZnSO4 at 0.5% at 45 DAS.

Keywords: Nano ZnO, growth, yield, linseed

INTRODUCTION

Linseed (*Linum usitatissimum* L.) is one of the world's oldest crops. It is a member of the Linaceae family and is endemic to the Mediterranean region and Southwest Asia. *Linum usitatissimum* L. is the sole economically important species in the genus Linum, which has approximately 200 species. In other species, it has somatic chromosomal number 2n=30 and ranges from 16 to 86. It is grown in India during the rabi season. There are two farmed species of linseed that are physically distinct, namely flax and linseed. The flax variety is produced commercially for fibre extraction, whilst the linseed variety is farmed for oil extraction from seed. Zinc is an important micronutrient for plants, and zinc deficiency is widespread in many crops. Zinc is required for the activity of several enzymes, including dehydrogenases, aldolases, isomerases, transphosphorylation, RNA, and DNA polymerases, and it is also involved in tryptophan synthesis, cell division, membrane structure maintenance, and photosynthesis, as well as acting as a regulatory cofactor in protein synthesis.

Micronutrient deficits in plants can result in lower yields and, in extreme circumstances, plant mortality (Bhardwaj *et al*., 2022; Kushwaha *et al*., 2021). Zn deficiency is the most damaging micronutrient to crop growth and output of all cereal crops, including wheat (Alloway, 2008, Marschner, 1995). Zn deficiency in Indian and global soils is a well-documented constraint in crop production, and it is now regarded as the fourth most yield-limiting nutrient in India, after N, P, and K (Sillanpaa, 1990; Katyal and Sharma, 1991; Singh, 2009; Shukla *et al.*, 2014).

Nanofertilizers are important tools in agriculture for improving crop growth, yield, and quality characteristics while increasing nutrient usage efficiency, reducing fertiliser waste, and lowering cultivation costs (Fathy *et al.*, 2023). The fundamental reason for the increased interest in nanofertilizers is their great penetration ability, small size, and extremely large surface area, which differs from the identical substance found in bulk form (Bhardwaj *et al.*, 2022; Kashyap *et al.*, 2022). Nanofertilizers are not only environmentally benign, but they also help minimize environmental pollutants. Nanofertilizers are highly effective in precision agriculture for accurate nutrient management by matching the crop growth stage for nutrients and may give nutrients throughout the crop growth cycle (Devi *et al.*, 2023; Jasrotia *et al.*, 2022). Nano-fertilizers promote crop growth up to optimum concentrations, but additional increases in concentration may hinder crop development due to nutrient toxicity. Nanofertilizers were extremely efficient in nutrient uptake. Nanofertilizers have limitations, like synthesis and characterization of nanofertilizers is a difficult job, and these are less available in the market. Nanofertilizers have some disadvantages as they are costlier in the market, and a higher dose of any nanofertilizer leads to a decrease in yield.

MATERIALS AND METHODS

In the rabi season of 2019-20, an investigation was conducted at the AICRP Linseed Farm, College of Agriculture, Nagpur (coordinates: 21° 10' N and 79° 4' E, elevation 321.26 meters above sea level). The local climate is characterized as hot and slightly moist. Zinc oxide (ZnO) nanoparticles were synthesized using the direct precipitation method in the laboratory, following the procedure Anonymous described in 2017-18. Various characterization techniques were employed to examine the properties of these nanoparticles, including their particle size (measured in nanometers), polydispersive index (PDI), count rate (Kcps), zeta potential, and morphological features. The determination of particle size, PDI, and Kcps was conducted using Dynamic Light Scattering (Malvern Zetasizer, Nano ZS 90) at a temperature of 25°C. This method relies on laser diffraction and a Multiple Scattering Technique to establish the particle size distribution of the nanoparticles (Figure 1). Fourier-Transform Infrared Spectroscopy (FTIR) was utilized to analyze the functional groups on the surface of the zinc oxide nanoparticles, Fourier-Transform Infrared Spectroscopy (FTIR) was utilized. This analysis was performed using a Perkin Elmer Spectrum II instrument, which applies infrared radiation (IR) to the material samples.

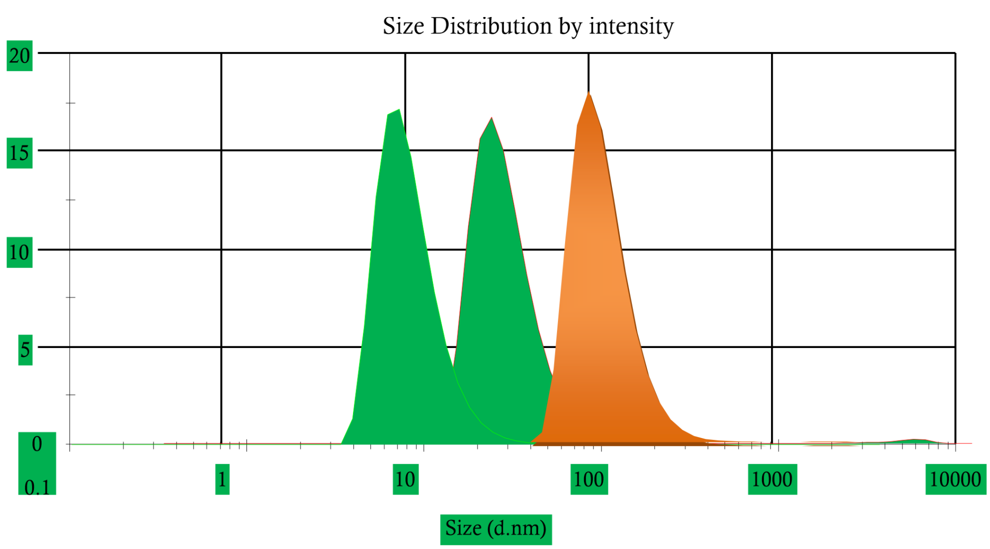

Fig. 1. Particle size distribution of nano ZnO

Table 1. Characterization of ZnO NPs for particle size (nm), PdI and Kcps

Sample details	Particle size (nm)	PdI	Kcps
ZnO NPs (ST)	45.18±1.60	0.224±0.022	225.2±0.2
ZnO NPs (1st spray)	46.8±1.50	0.249±0.024	225.2±0.8
ZnO NPs (2nd spray)	47.33±1.25	0.250±0.016	225.4±0.4

The experimental plot soil exhibited characteristics of clayey texture and had low levels of available nitrogen (239.5 kg/ha), medium levels of available phosphorus (12.70 kg/ha), high levels of available potassium (314.60 kg/ha), and available sulfur (8 kg/ha). The soil contained a slight alkaline reaction with a pH of 7.25, an electrical conductivity (EC) of 0.16 dS/m, and an organic carbon content of 5.3 g/kg. The study was designed to investigate the impact of nano zinc oxide on the growth, yield, and soil fertility status after the linseed (Variety: PKVNL-260) harvest, using a Randomized Block Design with three replications. The various treatment groups included 30 and 45 DAS and RDF common to all (60: 30: 00 NPK kg ha^{-1}). In all treatments, a common recommended dose of nitrogen (60:30:00 NPK kg/ha) was applied, with 60 kg of nitrogen per hectare divided into two equal splits, i.e., 30 kg as a basal dose and 30 kg applied as top dressing after 30 DAS. Full phosphorus dose was applied at the time of sowing.

RESULT AND DISCUSSION

Characterization of nano ZnO

The produced ZnO nanoparticles had a particle size of 45.18-47.33 nm, according to the data in Table 1. In all of the samples, the Poly-dispersity (PdI) Index scale ranges from 0.224 to 0.250, indicating that it is in the mid-range and the particles remain dispersed. Because the particle size of the synthesized ZnO nanoparticles is less than 100 nm, it may be deemed an excellent result (Hasnidawani *et al.*, 2016).

Effect of nano ZnO on growth attributes

Table 2 shows data on germination (%) and plant stand at 30 days as influenced by different treatments. The treatment of linseed seeds with micro ZnO resulted in a small increase in germination (%). The treatment of seeds with nano ZnO 1000 ppm resulted in enhanced germination (%) (88). However, the results were determined to be insignificant. Prasad *et al.* (2012) reported similar findings. The treatment with the highest plant stand (635) was seed treatment with nano ZnO (T5). Boonyanitipong *et al.*, (2011) discovered that ZnO-NPs at various doses had no negative impact on germination.

Table 2. Effect of nano ZnO on germination (%) and plant stand at 30 days per plot of linseed

Treatments	Germination (%)	Plant stand per plot
T1	84	628
T2	85	629
T3	86	628
T4	86	627
T5	88	635
T6	87	633
T7	87	630
F-Test	NS	NS
SE(m) ±	1.63	12.72

Effect of nano ZnO on yield parameters

Table 3 presents data concerning the number of branches per plant, and the results show the influence of different treatments. At the time of harvest, the seed treatment with nano ZnO (T_5) yielded the highest number of branches per plant, recorded at 3.53. These results were statistically similar to treatments T_6 (3.40) and T_7 (3.37). These findings align with those reported by Jayarambabu *et al.* in 2014. Furthermore, the seed treatment with nano ZnO (T_5) also resulted in the highest number of capsules per plant, with a value of 66.87. This outcome was statistically on par with treatment T_6 (62.53). These results are consistent with the findings reported by Arya and Singh in 2000, Kumar *et al.* in 2017, and Prasad *et al.* in 2012.

The highest test weight, measuring 8.23, was significantly observed in the treatment involving seed treatment with nano ZnO at a concentration of 1000 ppm (T_5). These results were statistically consistent with treatments T_6 (8.12) and T_7 (8.07). This outcome aligns with the findings of Prasad *et al.* in 2012 and Laware and Raskar in 2014. Moving on to seed yield per hectare, the data in Table 2 show that the maximum seed yield per hectare, totaling 1169 kg/ha, was achieved with the treatment of seed treatment with nano ZnO at 1000 ppm (T_5). This result was statistically similar to treatment T_6, which yielded 1115 kg/ha. Regarding straw yield (in kg/ha) of linseed, the data displayed in Table 3 indicate

Table 3. Effect of nano ZnO on yield parameter

Treatment	Number of branches plant^{-1}	Number of capsule plant^{-1}	Test weight (g) (1000 seed)	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T1	2.18	46.20	7.70	830	2037
T2	2.40	54.40	7.81	978	2203
T3	2.33	51.53	7.90	933	2129
T4	3.17	60.40	7.99	1063	2317
T5	3.53	66.87	8.23	1169	2660
T6	3.40	62.53	8.12	1115	2515
T7	3.37	61.00	8.07	1082	2419
F-Test	Sig.	Sig.	Sig.	Sig.	Sig.
SE(m) ±	0.11	1.44	0.10	22.19	39.55
CD at 5%	0.35	4.44	0.32	68.38	121.88

Table 4. Effect of nano zinc oxide on available nutrient status of soil

Treatment	pH	EC (dS m^{-1})	OC (g kg^{-1})	N	P_2O_5	K_2O	S	Zn
				(kg ha^{-1})			(mg kg^{-1})	
T1	7.28	0.18	5.5	245.50	14.27	318.33	10.00	0.40
T2	7.30	0.19	5.8	246.00	16.55	319.00	11.17	0.41
T3	7.29	0.19	5.5	246.68	16.57	322.33	11.50	0.41
T4	7.36	0.21	5.9	246.90	17.00	324.00	14.17	0.42
T5	7.38	0.22	5.7	247.33	16.33	324.67	12.33	0.46
T6	7.40	0.20	5.5	248.83	14.83	326.33	13.83	0.45
T7	7.38	0.21	5.6	247.17	15.00	324.00	11.67	0.44
F-Test	NS	NS	NS	NS	NS	NS	Sig.	Sig.
SE(m)±	0.04	0.013	0.16	2.44	0.72	3.56	0.43	0.006
CD at 5%	-	-	-	-	-	-	1.34	0.018

that different nutrient management treatments had a significant impact. The highest straw yield, reaching 2660 kg/ha, was observed in the treatment involving seed treatment with nano ZnO at 1000 ppm (T_5). This result was statistically comparable to the yield of treatment T_6, which was 2515 kg/ha.

Effect of nano ZnO on fertility status of soil after harvest of linseed

Data showed in Table 4 about the soil pH across different treatments ranged from 7.28 (T_1) to 7.40 (T_5). The highest pH value (7.40) was observed in the treatment involving soil application of $ZnSO_4$ at 15 kg/ha, combined with a foliar spray of nano ZnO at a concentration of 0.25% at 30 and 45 days after sowing (T_6). The highest electrical conductivity (EC) reading, measuring 0.22, was recorded in the treatment that included seed treatment with nano ZnO at 1000 ppm (T5). It was noted that the highest organic carbon content, which reached 5.9, was recorded in the treatment involving soil application of ZnSO4 at 15 kg/ha, combined with a foliar application of $ZnSO_4$ at 0.5% at 45 days after sowing (T_4). This increase was attributed to the enhanced biomass of the plant and related plant characteristics. These results are consistent with the findings of Du *et al*. in 2011. Regarding available nutrients in the soil, the available nitrogen (N) ranged from 245.50 to 248.33 kg/ha, with the highest N content (248.33) found in the treatment involving soil application of $ZnSO_4$ at 15 kg/ha, along with a foliar spray of nano ZnO at 0.25% at 30 and 45 days after sowing (T_6). The available phosphorus (P) in the soil varied from 14.27 to 17.00, with the highest P content (17.00) recorded in the treatment involving soil application of $ZnSO_4$ at 25 kg/ha, combined with a foliar application of ZnSO4 at 0.5% at 45 days after sowing (T_4). This result is in line with the findings of Reetu *et al*. in 2019. Similarly, the available potassium (K) in the soil ranged from 318.33 to 326.33, with the highest K content (326.33) observed in the treatment involving soil application of $ZnSO_4$ at 15 kg/ha, along with a foliar spray of nano ZnO at 0.25% at 30 and 45 days after sowing (T_6). These results align with those found by Lonergan *et al*. in 2009. The highest sulfur (S) content in the soil (14.17) was recorded in the treatment that included soil application of $ZnSO_4$ at 25 kg/ha, combined with a

Table 5. Effect of nano zinc oxide on uptake of nutrient by seed and straw of linseed

Treatments	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})		Zn uptake (g ha^{-1})	
	Seed	Straw	Seed	Straw	Seed	Straw	Seed	Straw
T1	21.86	11.13	6.06	3.32	9.97	5.36	18.27	51.59
T2	26.26	12.26	7.09	3.81	11.90	6.23	22.47	58.01
T3	24.51	12.06	7.03	3.47	11.67	6.24	22.09	58.20
T4	29.09	13.35	8.09	4.01	13.32	7.10	25.48	67.95
T5	33.32	16.32	9.35	5.32	15.39	9.14	30.40	90.46
T6	31.31	14.92	8.76	4.77	14.41	8.38	27.86	82.16
T7	29.94	14.27	8.54	4.43	13.85	7.73	26.15	78.23
F-Test	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.
SE(m) ±	0.58	0.23	0.19	0.09	0.44	0.30	0.63	1.19
CD at 5%	1.81	0.72	0.60	0.30	1.35	0.93	1.95	3.67

foliar application of $ZnSO_4$ at 0.5% at 45 days after sowing (T_4), and this was statistically similar to treatment T6 (13.83). These results correspond to those reported by Liu *et al*. in 2015. In terms of zinc (Zn) content in the soil, the highest Zn content (0.46) was found in the treatment involving seed treatment with nano ZnO at 1000 ppm (T_5) and was statistically on par with treatment T_6. These findings are consistent with those reported by Subbaiah in 2016.

The results further demonstrated that the uptake (Table 5) of nitrogen (N) by the linseed seed (33.32 kg/ha) and straw (16.32 kg/ha) was significantly higher in the treatment of seed treatment with nano ZnO at 1000 ppm (T_5). This outcome was also supported by the findings of Fan *et al*. in 2012 and Van *et al*. in 2013. Regarding phosphorus (P) uptake, the data revealed that the treatment involving seed treatment with nano ZnO at 1000 ppm (T_5) exhibited significantly higher P uptake by the seed (9.35 kg/ha), which was statistically similar to treatment T_6 (8.76). In the case of P uptake by linseed straw, the seed treatment with nano ZnO at 1000 ppm (T_5) also recorded significantly higher straw P uptake (5.32 kg/ha), which was statistically comparable to treatment T_6 (4.77). These results are in line with the findings of Liang *et al*. in 2013. In terms of potassium (K) uptake, the treatment involving seed treatment with nano ZnO at 1000 ppm (T_5) demonstrated significantly higher K uptake by the seed (15.39 kg/ha), which was statistically on par with T6 (14.41). Similarly, the seed treatment with nano ZnO at 1000 ppm (T_5) resulted in significantly higher K uptake by the straw (9.14 kg/ha), which was statistically comparable to T6 (8.38). These findings correspond to those reported by Ladan *et al*. in 2012. Finally, the uptake of zinc (Zn) by the linseed seed (30.40 g/ha) and straw (90.46 g/ha) was significantly higher in the treatment involving seed treatment with nano ZnO at 1000 ppm (T_5). These results are consistent with those reported by Prasad *et al*. in 2012, Subbaiah *et al*. in 2016, and Adhikari *et al*., in 2016.

CONCLUSION

In conclusion, the utilization of nano ZnO has proven to enhance both the yield and nutrient uptake of linseed. Furthermore, the application of nano ZnO has demonstrated a marginal improvement in soil fertility, post-harvest. However, a combined application of $ZnSO_4$ and nano ZnO notably improved the soil's sulfur (S) and zinc (Zn) content.

REFERENCES

Adhikari, T., Kundu, S., and Subba Rao, A., (2016). Zinc delivery to plants through seed coating with nano-zinc oxide particles. *Journal of Plant Nutrition*, *39*(1),136-146.

Alloway, B.J., (2008). Zinc in soils and crop nutrition (2nd edition). Brussels, Belgium: International Zinc Association; and Paris, France: *International Fertilizer Industry Association*, 135.

Arya, K.C., and Singh, S.N., (2000). Effect of different levels of phosphorus and zinc on yield and nutrient uptake of maize (Zea mays L.) with and without irrigation. *Indian Journal of Agronomy*, *45*(4),717-721.

Bhardwaj, A.K., Arya, G., Kumar, R., Hamed, L., Pirasteh-Anosheh, H., Jasrotia, P., and Singh, G.P., (2022). Switching to nanonutrients for sustaining agroecosystems and environment: The challenges and benefits in moving up from ionic to particle feeding. Journal of Nanobiotechnology, 20(1), 19.

Bhardwaj, A.K., Chejara, S., Malik, K., Kumar, R., Kumar, A., and Yadav, R.K., (2022). Agronomic biofortification of food crops: An emerging opportunity for global food and nutritional security. Frontiers in Plant Science, 13, 1055278.

Boonyanitipong, P., Kositsup, B., Kumar, P., Baruah, B., and Dutta, J., (2011). Toxicity of ZnO and TiO_2 nanoparticles on germinating rice seed *Oryza sativa* L. *International Journal of Bioscience, Biochemistry and Bioinformatics*, *1*(4), 282-285.

Depar, N., Rajpar, I., Memon, M.Y., Imtiyaz, M., and Hassan, Z., (2011). Mineral nutrient densities in some domestis and exotic rice genotypes. *Pakistan Journal of Agricultural Engineering and Veterinary Science*, *27*,134-142.

Devi, S., Kumar, N., Kumar, A., Dhansu, P., Pazhany, A. S., Mann, A., and Sheoran, P., (2023). Potential Use of Nanofertilizers in Alleviating Stresses in Plants. In: Salinity and Drought Tolerance in Plants: Physiological Perspectives Singapore: Springer Nature Singapore, pp. 521-535.

Du, W.C., Sun, Y.Y., Ji, R., Zhu, J.G., Wu, J.C., and Guo, H.Y., (2011). TiO_2 and ZnO nanoparticles negatively affect wheat growth and soil enzyme activities in agricultural soil. *Journal of Environmental Monitoring*, *13*, 822-828.

Fan, L., Wang, W., Shao, X., Geng, Y., Wang, Z., and Ma, Y., (2012). Effects of combined nitrogen fertilizer and nano-carbon application on yield and nitrogen use of rice grown on saline-alkali soil. *Journal of Food, Agriculture & Environment*, *10*(1), 558-562.

Fathy, M.A., Abdellatif, A.A., Emara, E.I., Malik, K., Bhardwaj, A.K., and Hamed, L.M., (2023). Synthesis, Characterization, and Uses of Nanofertilizers and Nano-Agrochemicals for Sustainable Agriculture. In Nanofertilizers for Sustainable Agroecosystems: Recent Advances and Future Trends, Springer Nature Switzerland, pp. 181-203.

Garcia, A.B., Cuesta, A., Montes-Moran, M.A., Martinez-Alonso, A., and Tascon, J.M.D., (1997). Zeta potential as a tool to characterize plasma oxidation of carbon fibres. *Journal of colloid and interface science*, *19*, 363-367.

Hasnidawani, J.N., Azlina, H.N., Norita, H., Bonnia, N.N., Ratim, S., and Ali, E.S., (2016). Synthesis of ZnO nanostructures using sol-gel method. *Procedia Chemistry*, *19*, 211-216.

Hunter, R.J., (1981). Zeta Potential in Colloid Science: Principles and Applications. *Academic Press*, London.

Jasrotia, P., Nagpal, M., Mishra, C.N., Sharma, A.K., Kumar, S., Kamble, U., and Singh, G. P., (2022). Nanomaterials for postharvest management of insect pests: Current state and future perspectives. Frontiers in Nanotechnology, 3.

Jayarambabu, M., Sivakumari, B., Rao, K.V., and Prabhu, Y.T., (2014). Germination and growth characteristics of mungbean seeds affected by synthesized ZnO nanoparticles. *International Journal of Current Engineering and Technology*, *4*, 3411-3416.

Kashyap, P.L., Kumar, S., Kaul, N., Aggarwal, S.K., Jasrotia, P., Bhardwaj, A.K., and Singh, G.P., (2022). Nanotechnology for Wheat and Barley Health Management: Current Scenario and Future Prospectus. In: New Horizons in Wheat and Barley Research: Crop Protection and Resource Management Singapore: Springer Nature Singapore, pp. 337-363.

Katyal, J.C., and Sharma, B.D., (1991). DTPA-extractable and total Zn, Cu, Mn and Fein Indian soils and their association with some soil properties. *Geoderma*, *49*,165-179.

Kumar, J.U., Bahadur, V., Prasad, V.M., Mishra, S., and Shukla, P.K., (2017). Effect of Different Concentrations of Iron Oxide and Zinc Oxide Nanoparticles on Growth and Yield of Strawberry (*Fragariaxananassa duch*) cv. Chandler. *International Journal of Current Microbiology and Applied Sciences*, 6(8), 2440-2445.

Kushwaha, P., Srivastava, R., Pandiyan, K., Singh, A., Chakdar, H., Kashyap, P.L., Bhardwaj, A.K., and Saxena, A.K., (2021). Enhancement in plant growth and zinc biofortification of chickpea (Cicer arietinum L.) by Bacillus altitudinis. Journal of Soil Science and Plant Nutrition, 21, 922-935.

Ladan, M.A., Vattani, H., Baghaei, N., and Keshavarz, N., (2012). Effect of different levels of fertilizer nano iron chelates on growth and yield characteristics of two varieties of spinach (*Spinaciaoleracea* L.): varamin 88 and viroflay. *Research Journal of Applied Sciences, Engineering and Technology*, *4*(12), 4813-4818.

Laware, S.L., and Raskar, S., (2014). Influence of zinc oxide nanoparticles on growth, flowering, and seed productivity in onion. *International Journal of Current Microbiology and Applied Sciences*, *3*(7), 874-881.

Liang, T.B., Yin, Q.S., Zhang, Y.L., Wang, B.L., Guo, W.M., and Wang, J.W., (2013). Effects of carbon nanoparticles application on the growth, physiological characteristics and nutrient accumulation in tobacco plants. *Journal of Food, Agriculture and Environment*, *11*, 954-958.

Liscano, J.F., Wilson, C.E., Norman, Jr. R.J., and Slaton, N.A., (2000). Zinc availability to rice from seven granular fertilizers. *AAES Research Bulletin* 963,1-31.

Liu, X., Wang, F., Shi, Z., Tong, R., and Shi, X., (2015). Bioavailability of Zn in ZnO nanoparticle-spiked soil and the implications to maize plants. *The Journal of Nanoparticle Research*, *17*,175-185.

Lonergan, P.F., Pallota, M.A., Lorimer, M., Paull, J.G., Barker, S.J., and Graham, R.D. (2009). Multiple genetic loci for Zn uptake and distribution in barley (*HordeumVulgare*). *New Phytol*, *184*,168-179.

Marschner, H., (1995). Mineral Nutrition of Higher Plants (2nd Ed.) *Academic Press*, London, 889.

Pandey, A.C., Sanjay, S.S., and Yadav, R.S. (2010). Application of ZnO nanoparticles in influencing the growth rate of Cicerarietinum. *Journal of Experimental Nanoscience*, *5*(6), 488-497.

Prasad, T.N.V.K.V., Sudhakar, P., Sreenivasulu,Y., Latha. P., Munaswamy, Y., and Raja Reddy, K., (2012). Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. *Journal of Plant Nutrition*, *35*(6), 905- 927.

Reetu, B., Anu, K., and Salwinder, S.S. (2019). Evaluation of efficacy of ZnO nanoparticles as remedial zinc nanofertilizer for rice. *Journal of Soil Science and Plant Nutrition*, *19*, 379-389.

Shukla, A.K., Tiwari, P.K., and Prakash, C., (2014). Micronutrients deficiencies vis-a-vis food and nutritional security of India. *Indian Journal of Fertilisers*, *10*, 94-112.

Sillanpaa, M., (1990). Micronutrient assessment at the country level: an international study. FAO Soils Bulletin 63.FAO/Finnish *International Development Agency*, Rome, Italy.

Singh, M.V., (2009). Micronutrient nutritional problems in soils of India and improvement for human and animal's health. *Indian Journal of Fertilizers*, *5*(4),11-26.

Subbaiah, L.V., Prasad, TNVKV, Krishna, T.G., Sudhakar, P., Reddy, B.R., and Pradeep, T., (2016). Novel effects of nanoparticulate delivery of zinc on growth, productivity, and zinc biofortification in maize (*Zea mays* L.). Journal of Agricultural and Food Chemistry, *64*(19), 3778- 3788.

Van, N.S., Minh, H.D., Dzung, N.A., (2013). Study on chitosan nanoparticles on biophysical characteristics and growth of Robusta coffee in green house. *Biocatalysis and Agricultural Biotechnology*, *2*, 289-294.

Yang, Z., Chen, J., Dou, R., Gao, X., Mao, C., and Wang, L., (2015). Assessment of the phytotoxicity of metal oxide nanoparticles on two crop plants, maize (Zea mays L.) and rice (Oryza sativa L.). *International Journal of Environmental Research and Public Health*, *12*,15100-15109.

Zak, A.K., Razali, R., Majid, W., and Darroundi, M., (2011). Synthesis and characterization of a narrow size distribution of ZnO nanoparticles. *International Journal of Nanomedicine*, *6*,1399-1403.