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Response of Pigeonpea to Foliar Spray of Nano-Zinc in An Inceptisol

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Abstract

The present investigation was undertaken to study the "Response of pigeonpea to foliar spray of Nano-Zinc in an Inceptisol". The experiment was conducted at Post Graduate Institute Research Farm, Department of Soil Science, Mahatma Phule Krishi Vidyapeeth, Rahuri, during *kharif* 2023. The experiment was laid out in randomized blockdesign (RBD) with three replications. The experiment consists of ninetreatments *viz*., (T_1) - Absolute control, (T_2) - GRDF (25:50:00 N:P_2O_5:K_2O kg ha^{-1} + Vermicompost @ 1.5 t ha^{-1}), (T_3) - GRDF + Two foliar spray of water, (T_4) - GRDF + Two foliar spray of Nano-ZnO @ 1000 ppm, (T_5) - GRDF + Two foliar spray of Nano-ZnO @ 1500 ppm, (T_6) - GRDF + Two foliar spray of Nano-ZnO @ 2000 ppm, (T_7) - GRDF + Two foliar spray of Chelated-Zn @ 1000 ppm, (T_8) - GRDF + Two foliar spray of Chelated-Zn @ 1500 ppm, (T_9) - GRDF + Two foliar spray of Chelated-Zn @ 2000 ppm. As regards growth and yield attributing characters, the chlorophyll content in fresh leaf tissues at 40 DAS (49.38 SPAD value) and at 65 DAS (52.35 SPAD value), number of pods plant^{-1} (707.33),number of grains pod^{-1} (3.98), grain yield (38.9 q ha^{-1}) and straw yield (123.59q ha^{-1}) were recorded significantly the highest under treatment (T_6) - GRDF + Two foliar spray of Nano-ZnO @ 2000 ppm. As regards quality parameters significantly the highest protein and test weight of pigeonpea was recorded (21.37% and 8.99 g) respectively in treatment of GRDF + Two foliar spray of Nano-Zn @ 2000 ppm. The same trend of total uptake of macronutrients N, P and K (199.32 kg ha^{-1}, 42.16 kg ha^{-1} and 111.40 kg ha^{-1}) , respectively and total uptake of micronutrients *viz*, Fe, Mn, Zn and Cu (2302.53 g ha^{-1}, 1656.01 g ha^{-1} , 232.43 g ha^{-1} and 161.81 g ha^{-1}), respectively were recorded significantly the highest in treatment of GRDF + Two foliar spray of Nano-Zn @ 2000 ppmwiththe highest gross monetary returns (Rs.365651/-), net monetary returns. However, the treatment of GRDF + two foliar spray of chelated Zn (EDTA) @ 2000 ppm at 30 and 55 DAS to pigeonpea was at par and recorded higher B:C ratio as compare to aforesaid treatment.

Key words : Pigeonpea, Foliar spray , Nano-Zinc, Chelated-Zinc,Growth, Yield, Quality, Uptake, Economics.

India is the largest producer of pulses, cultivating number ofvarieties that enhance soil fertility through nitrogen fixation and serve as a vital protein source, especially for vegetarians. Currently, pulses cover 232.56 lakh hectares and yield 18.34 million tonnes, with a productivity of 789 kg per hectare. However, production has stagnated, leading to a per capita availability of only 37 grams daily, significantly below the 80/gram requirement, which contributes to widespread protein malnutrition in the country.

Pigeonpea (*Cajanus cajan* L.) is the second most important pulse crop in India, after chickpea known as red gram, arhar, or tur, it is extensively cultivated for its grains (used as dal), green seeds (as a vegetable), and stalks (for fuelwood). Thriving in tropical and subtropical regions, it is mainly grown during the kharif season, both as a sole and intercrop. Its deep root system allows it to withstand drought, making it suitable for areas with low rainfall. In India, pigeonpea covers 36.3 million hectares and produces 2.76 million tonnes annually, with a productivity of 760.33 kg ha^{-1} (Kailas *et al*., 2019). Zinc (Zn) is commonly the second most

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prevalent transition metal in living organisms after iron and is unique in being involved in all six enzyme classes: oxidoreductases, transferases, hydrolyses, lyases, isomerases, and ligases (Auld, 2001). It is an essential micronutrient for humans, animals, and plants. In higher plants, zinc is usually taken up as a divalent cation (Zn^{2+}) and functions either as a metal component of enzymes or as a structural or regulatory co-factor in numerous enzymes. Several studies have highlighted zinc's critical role in plant growth and yield (Camp and Fudge, 1945; Chapman, 1966). Zinc (Zn) deficiency is widespread across various soils and crops globally (Alloway, 2008). In India, Shukla and Behera (2019) found that 36.5% of agricultural soils exhibit Zn deficiency. This deficiency is particularly prevalent in saline, sodic, calcareous, Vertisols, deeply weathered, sandy, and waterlogged soils (Alloway, 2009). Addressing these issues requires targeted Zn application to ensure sustainable crop production (Behera *et al*., 2020a). Soil Zn deficiency adversely affects crop growth, yield, and the Zn concentration in edible plant parts, as Zn plays a crucial role in several proteins that regulate plant metabolism (Singh *et al*., 2019). Zinc deficiency affects approximately one-third of the global population (Welch and Graham, 2002). Sustainable alleviation of this deficiency can be achieved by enhancing zinc content in food, particularly through zinc-enriched seeds or grains produced in agriculture. Agronomic practices such as adding zinc to soil or applying it to leaves can mitigate zinc deficiency in soil, thereby enhancing plant growth, yield, and the concentration and uptake of micronutrients (Rengel *et al*., 1999). Recently, there has been increasing momentum in agriculture towards using nano-sized fertilizer blends to improve nutrient efficiency and address persistent issues linked with traditional fertilizers. Consequently, studies have been conducted to evaluate the viability of nano micronutrient fertilizers compared to conventional ones in terms of yield and economic outcomes for pigeonpea cultivation. Compared to soil-only applications, foliar application or a combination of soil and foliar zinc application has been found more effective in increasing zinc concentration and uptake in seeds or grains of various crops (Cakmak and Kutman, 2018; Haider *et al*., 2020).Currently, two primary methods are recognized for addressing zinc deficiencies. Foliar spraying with inorganic salts has proven beneficial, although results can be uneven due to limited zinc penetration into leaves. Additionally, multiple applications are often necessary throughout the canopy development phase. Alternatively, soil treatments involving synthetic chelates like Zn-EDTA provide absorbable zinc for plants, contingent upon soil conditions, especially pH and liming status.Foliar application offers benefits such as minimal application rates, even distribution of fertilizer materials, and rapid nutrient response. While there is ongoing discussion regarding its benefits and optimal implementation, applying specific nutrients via foliar spray is widely seen as a superior method to enhance fertilizer efficiency and boost crop yields.

Materials and Methods

Experimental Details : The research on Response of pigeonpea to foliar spray of nano-zinc in an Inceptisol was conducted at the field of Post Graduate Institute research farm, Department of Soil Science, Mahatma Phule Krishi Vidyapeeth, Rahuri, during *kharif* 2023. The experiment was laid out during *kharif* 2023, at Post Graduate Institute Research Farm of Department of Soil Science, M.P.K.V., Rahuri, Dist. Ahmednagar, Maharashtra (India). The location of the experimental farm lies between 19° 47' N to 19° 57' N latitude and 74° 18' E to 74° 19' E longitude. The elevation above mean sea level is 512 m. The tract lies on the eastern side of western ghat and falls under scarcity zone. The experiment was laid out in randomized block design(RBD) with three replications. The experiment consists of ninetreatments *viz*., (T_1) - Absolute control, (T_2) - GRDF (25:50:00 N:P_2O_5:K_2O kg ha^{-1} + Vermicompost @ 1.5 t ha^{-1}), (T_3) - GRDF + Two foliar spray of water, (T_4) - GRDF + Two foliar spray of Nano-ZnO @ 1000 ppm, (T_5) - GRDF + Two foliar spray of Nano-ZnO @ 1500 ppm, (T_6) - GRDF + Two foliar spray of Nano-ZnO @ 2000 ppm, (T_7) - GRDF + Two foliar spray of Chelated-Zn @ 1000 ppm, (T_8) - GRDF + Two foliar spray of Chelated-Zn @ 1500 ppm, (T_9) - GRDF + Two foliar spray of Chelated-Zn @ 2000 ppm.

Table 1. Initial properties of field experiment soil

Parameters	Value
pH (1:2.5)	8.31
EC (dSm^{-1})	0.26
Organic carbon (%)	0.45
Available N (kg ha^{-1})	208.70
Available P (kg ha^{-1})	15.34
Available K (kg ha^{-1})	326.40
Available Fe (mg kg^{-1})	5.192
Available Zn (mg kg^{-1})	0.52
Available Mn (mg kg^{-1})	9.24
Available Cu (mg kg^{-1})	2.14

Soil and plant analysis : Soil samples were processed and analyzed for pH and electrical conductivity (1:2.5) using glass electrode pH meter and EC meter, respectively. Organic carbon (g kg^{-1}) was estimated by Wet oxidation method (Nelson and Sommer, 1982), available N by alkaline permanganate method (Subbiah and Asija, 1956) , available P by Olsen method (Watanabe and Olsen, 1965) and available K by Neutral normal ammonium acetate method (Jackson, 1973). For DTPA micronutrients (Fe, Mn, Zn and Cu), soil samples extracted by 0.005 M DTPA method (pH7.3) (Lindsay and Norvell, 1978). Finely ground grain and straw samples were digested with di-acid mixture (H_2O_2:H_2SO_4 1:1) for total N by Kjeldahl method and total micronutrients (Fe, Mn, Zn and Cu) atomic absorption spectro-photometry (AAS) and for total P and K digested with (HNO_3:$HClO_4$ 9:4) and analyzed by Vanado-Molybdate yellow colour in HNO_3 and Flame photometer, respectively.

Statistical analysis : The data obtained was analyzed as per the methods described by Panse and Sukhatme (1985).

Results and Discussion

1. Growth Characters : Data regarding to growth and yield contributing charactersof pigeonpea as influenced by foliar spray of Nano-Zinc and Chelated-Zincare presented in Table 2 viz.,chlorophyll content of fresh leaf tissues of pigeonpea at 40 and 65 DAS (SPAD Value), number of pods plant^{-1}, number of grains pod $^{-1}$, grain yield and straw yield.

1.1 Chlorophyll Content of Fresh Leaf Tissues of Pigeonpea at 40 and 65 DAS (SPAD Value) : Table 2 illustrated the influence of foliar spray of Nano-Zinc and Chelated-Zinc on total chlorophyll content (SPAD value) in fresh leaf tissues of pigeonpea at 40 and 65 DAS. At 40 DAS, the treatment T_6 (GRDF + Two foliar sprays of Nano-ZnO @ 2000 ppm) showed significantly higher total chlorophyll content (49.38 SPAD value) in fresh leaf tissues of pigeonpeaover treatments T_1, T_2, T_3, T_4, T_5, T_7 and T_8 (with SPAD values of 38.98, 41.40, 42.58, 45.28, 46.32, 45.84 and 46.36, respectively), however, the treatment T_9 (47.68 SPAD value) was at par with T6. Same trend of increased chlorophyll content of fresh leaf tissues of pigeonpea found at 65 DAS, treatment T_6 (GRDF + Two foliar sprays of Nano-ZnO @ 2000 ppm) exhibited significantly higher total chlorophyll content (42.40 SPAD value) over all the treatments except treatment T_9 (52.14 SPAD value) which was at par with treatment T6.

Table 2. Effect of foliar spray of Nano-Zinc and Chelated-Zinc on chlorophyll content of fresh leaf tissues of pigeonpea

Treatments	**Total chlorophyll content of leaf tissues (SPAD value)**	
	40 DAS	**65 DAS**
T_1 - Absolute control	38.98	41.79
T_2 - GRDF (25:50:00 N:P_2O_5:K_2O kg ha^{-1} + Vermicompost @ 1.5 t ha^{-1})	41.40	41.93
T_3 - GRDF + Two foliar spray of water	42.58	44.73
T_4 - GRDF + Two foliar spray of Nano-ZnO @ 1000 ppm	45.28	48.11
T_5 - GRDF + Two foliar spray of Nano-ZnO @ 1500 ppm	46.32	49.48
T_6 - GRDF + Two foliar spray of Nano-ZnO @ 2000 ppm	49.38	52.35
T_7 - GRDF + Two foliar spray of Chelated-Zn @ 1000 ppm	45.84	49.44
T_8 - GRDF + Two foliar spray of Chelated-Zn @ 1500 ppm	46.36	49.62
T_9 - GRDF + Two foliar spray of Chelated-Zn @ 2000 ppm	47.68	51.14
SE m(±)	0.58	0.6
C.D. at 5%	1.73	1.87

The increase in chlorophyll content in pigeonpea plants can be attributed to the role of zinc in stimulating the process of photosynthesis. It is essential for the development of photosynthetic tissues and the activation of carbonic enzymes, such as carbonic anhydrase. Zinc also contributes to chlorophyll formation, which is critical for food synthesis and essential for cell division and elongation. These factors collectively promote better vegetative growth, leading to increased food production and higher crop yields.These results were consistent with the findings reportedin chickpea by Boonyanitipong *et al*., (2011), in rice by Prasad *et al*., (2012), in soyabean by Sedghi *et al*., (2013),in mungbean by Jayarambabu *et al*., (2014) and in maize and rice by Yang *et al*., (2015). The use of nano fertilizers enriched with micronutrients further improves leaf count and total leaf area, boosting chlorophyll levels through enhanced biological and enzymatic activities. This increased chlorophyll production intensifies enzyme activity, which helps inhibit ethylene production and its adverse effects. Ethylene usually triggers chlorophyllase, causing chloroplast degradation, but nano fertilizers help to preserve chloroplasts longer, thereby delaying the aging process. These results were also consistent with the findings of Al-Toki *et al*. (2021), Kumar *et al*. (2021), Tondey *et al*. (2021).

1.2 Number of pods plant^{-1} and number of grains pod^{-1} : The number of pods per plant and number of grains per plant as influenced by foliar spray of Nano-Zinc and Chelated Zinc are reported in Table 3. Treatment of GRDF+ Two foliar spray of Nano-Zn @ 2000 ppm) recorded (702.33) the highestnumber of pods per plant which was significantly higher over all the treatments except Treatment T_9 (which was at par with treatment T_6. However, the minimum (436.40) number of pods per plant was noticed in T_1 - Absolute control. The treatments applied in the study did not significantly affect the data concerning the number of grains per pod of pigeonpea. Nonetheless, the treatment T_6 (GRDF + Two foliar spray of Nano-Zn @ 2000 ppm) showed numerically higher number of grains per pod (3.98) compared to all other treatments. Zinc plays a crucial role in increasing the number of pods in pigeonpea plants. It enhances various physiological and biochemical processes that are essential for pod

Table 3. Effect of foliar spray of Nano-Zinc and Chelated-Zinc on growth parameter of pigeonpea

Treatment	No. of pods plant^{-1}	No. of grains pod^{-1}
T_1 - Absolute control	436.40	3.53
T_2 - GRDF (25:50:00 N:P_2O_5:K_2O kg ha^{-1} + Vermicompost @ 1.5 t ha^{-1})	519.26	3.64
T_3 - GRDF + Two foliar spray of water	578.66	3.73
T_4 - GRDF + Two foliar spray of Nano-ZnO @ 1000 ppm	680.26	3.80
T_5 - GRDF + Two foliar spray of Nano-ZnO @ 1500 ppm	621.26	3.86
T_6 - GRDF + Two foliar spray of Nano-ZnO @ 2000 ppm	707.33	3.98
T_7 - GRDF + Two foliar spray of Chelated-Zn @ 1000 ppm	665.45	3.82
T_8 - GRDF + Two foliar spray of Chelated-Zn @ 1500 ppm	697.88	3.89
T_9 - GRDF + Two foliar spray of Chelated-Zn @ 2000 ppm	702.33	3.93
S.E.(m)±	2.46	0.31
C.D at 5 %	7.36	NS

development. Zinc is vital for the synthesis of plant hormones and enzymes that regulate growth and reproduction. It also improves overall plant health and nutrient uptake, which supports better flower and pod formation. By promoting these factors, zinc directly contributes to a higher number of pods per plant, ultimately boosting crop yield. The study by Prasad *et al.*, (2012) suggested that nanoscale ZnO is absorbed by plants were more effectively than bulk chelated ZnSO4. These nanoparticles have been shown to significantly enhance plant growth and pod yield.

2 Yield Parameter

2.1 Grain yield : The grain yieldof pigeonpea was significantly influenced by the foliar spray of Nano-Zinc and Chelated Zinc on pigeonpea are reported in table 4. Significantly the highest grain yield (38.98 q ha^{-1}) was observed in treatment T6 (GRDF + Two foliar spray of Nano-Zn @ 2000 ppm) over all the treatment except treatments T_8 (37.74 q ha^{-1}) and T_9 (38.69 q ha^{-1}) which were at par with treatment T_6. The enhanced grain yield of pigeonpea was observed at higher concentration of foliar spray of Nano ZnOtreatments can be attributed due to increase inplant growth parameters. Notably, in treatment T_6 (GRDF + Two foliar spray of Nano-Zn @ 2000 ppm) resulted significantly the higher grain yield in pigeonpea. Nano zinc plays a pivotal role in boosting grain yield in pigeonpea. It enhances nutrient absorption and utilization, which improves overall plant health and growth.Nano zinc promotes efficient photosynthesis, strengthens metabolic processes, and supports better flower and pod development. By optimizing these factors, nano zinc contributes to a higher number of grains per pod and increases the total grain yield. A study by Poornima and Koti (2019) found that grain yield increased by 9.5 percent with a 500 ppm Nano ZnO foliar spray compared to a 1000 ppm bulk $ZnSO_4$ foliar spray.

2.2 Straw yield : The straw yieldof pigeonpea was significantly influenced by the foliar spray of Nano-Zinc and Chelated Zinc on pigeonpea are reported in Table 4. The highest straw yield (123.59 q ha^{-1}) of pigeonpea was observed in treatment T_6 (GRDF + Two foliar spray of Nano-Zn @ 2000 ppm), which was significantly higher than all other treatments except treatment T_9 (121.35 q ha^{-1}) which was at par with treatment T_6. Zinc is known to activate several enzymes and improve the metabolic activity thereby biomass. Nano zinc

Table 4. Effect of foliar spray of Nano-Zinc and Chelated-Zinc on yield of pigeonpea

Treatment	Yield (q ha^{-1})	
	Grain	Straw
T_1 - Absolute control	28.27	99.92
T_2 - GRDF (25:50:00 N:P_2O_5:K_2O kg ha^{-1} + Vermicompost @ 1.5 t ha^{-1})	34.25	110.09
T_3 - GRDF + Two foliar spray of water	34.79	113.83
T_4 - GRDF + Two foliar spray of Nano-ZnO @ 1000 ppm	35.16	114.63
T_5 - GRDF + Two foliar spray of Nano-ZnO @ 1500 ppm	36.59	118.79
T_6 - GRDF + Two foliar spray of Nano-ZnO @ 2000 ppm	38.98	123.59
T_7 - GRDF + Two foliar spray of Chelated-Zn @ 1000 ppm	36.12	115.48
T_8 - GRDF + Two foliar spray of Chelated-Zn @ 1500 ppm	37.74	119.43
T_9 - GRDF + Two foliar spray of Chelated-Zn @ 2000 ppm	38.69	121.35
SE m(±)	0.77	1.20
C.D. at 5%	2.32	3.58

plays a significant role in increasing straw yield in pigeonpea. By enhancing nutrient uptake and improving overall plant health, nano zinc supports robust vegetative growth and stronger plant structures. It boosts photosynthesis and stimulates the development of stems and leaves, leading to a greater biomass accumulation. As a result, the plant produces more straw, contributing to a higher overall straw yield. The similar conclusions are also reported by Uma *et al*. (2019), Satdev*et al*. (2020), Rajesh *et al*. (2021), Choudhary *et al*. (2022) and Vijay (2022).

3. Quality Parameter

3.1 Protien Content : The results revealed that significantly the highest protein content (21.37%) was observed in the treatment T_6 - GRDF + Two foliar spray of Nano-Zn @ 2000 ppm, over all treatments except treatment T_9 - GRDF + Two foliar spray of Chelated Zn @ 2000 ppm (21.31%) which was at par with treatment T_6. The foliar spray of nano zinc positively affect protein content inpigeonpea. Nano zinc plays a crucial role in increase protein content in pigeonpea. Zn is a crucial cofactor necessary for the activity and regulation of various enzymes involved in transcription, translation, and signal transduction. Increased levels of Zn ions spray through nano ZnO may have stimulated the production of Zn-dependent proteins (Kisan *et al*., 2015).Zn plays a role in protein synthesis, membrane function, cell elongation, and the ability to tolerate environmental stresses (Cakmak, 2000). By boosting enzyme activity and promoting efficient photosynthesis, nano zinc contributes to the synthesis of amino acids and proteins. It was also noted that nano ZnO at a concentration of 1.0 mg L^{-1} led to increased protein levels in spinach Patra *et al*. (2013).This effect was attributed to Zn enhancing cation exchange in plant roots, which improved the absorption of essential nutrients like nitrogen, thereby boosting protein content. similarly in this study found that nano ZnO @ 1000, 1500 and 2000 ppm increased protein content in pigeonpea.

3.2 Test Weight (100 seeds) : Table 5 shows that foliar application of Nano-Zinc and Chelated Zinc significantly influenced test weight among the treatments. The highest test weight (8.99 g) was obtained in treatment T6 (GRDF + Two foliar spray of Nano-Zn @ 2000 ppm), which was statistically significant with all the other treatments except treatments T_9 - (GRDF + Two foliar spray of Chelated Zn @2000 ppm) which showed (8.97 g), test weight which was at par with treatment T_6. Nano zinc significantly impacts on the test weight of pigeonpea seeds. It improves nutrient uptake and plant health, leading to enhanced growth and development. By boosting photosynthesis and optimizing metabolic processes, nano zinc promotes better seed filling and maturation. This results in heavier, more robust seeds, thereby increasing the test weight and overall quality of the crop. A study by Poornima and Koti (2019) found that test weight increased with a 500 ppm nano ZnO foliar spray (NFS) compared to 1000 ppm bulk $ZnSO_4$ and foliar spray (BFS). These observations can be linked to the role of nano fertilizers as slow-release options, which help minimize fertilizer losses, enhance nutrient utilization efficiency, and support balanced nutrition for crops. Nano fertilizers are designed to release nutrients gradually over a longer duration throughout the growth cycle, potentially improving crop yields without negative repercussions. These results are consistent with studies by Gerdini (2016), and Gomma *et al*. (2017). This improvement may be attributed to the increased uptake of zinc, which facilitates the movement of sugars and boosts carbohydrate levels in grains, as supported by findings from Jaberzadeh *et al*. (2013) and Raezaei *et al*. (2014).

4. Nutrient Uptake

4.1 Macronutrients Uptake : The effect of foliar spray of Nano-Zinc and Chelated Zinc on macronutrient uptake in both grain and straw by pigeonpea reported in Table 6.

4.1.1 Nitrogen : The effect of foliar spray of Nano-Zinc and Chelated Zinc on total nitrogen uptake by pigeonpea given in Table 6 which revealed that the foliar spray of Nano-Zinc and Chelated Zinc turned into increase in total nitrogen uptake by pigeonpea which found significantly, the highest (199.32 kg ha^{-1}) in treatment T_6 (GRDF + Two foliar spray of Nano-Zn @ 2000 ppm), over all treatments except treatment T_8 (190.04 kg ha^{-1}) and T_9 (196.88 kg ha^{-1}) which were at par with treatment T_6. The lowest total uptake of N by pigeonpea (130.24 kg ha^{-1}) was observed in treatment T_1 which was (Absolute control).Foliar spraying with nano zinc and chelated zinc enhances total nitrogen uptake in pigeonpea enhance nitrogen absorption in plants by

Table 5. Effect of foliar spray of Nano-Zinc and Chelated-Zinc on quality of pigeonpea

Treatment	Quality parameter	
	Protein content (%)	Test weight (100 seeds) (g)
T_1 - Absolute control	20.25	8.56
T_2 - GRDF (25:50:00 N:P_2O_5:K_2O kg ha^{-1} + Vermicompost @ 1.5 t ha^{-1})	20.43	8.63
T_3 - GRDF + Two foliar spray of water	20.56	8.75
T_4 - GRDF + Two foliar spray of Nano-ZnO @ 1000 ppm	20.75	8.86
T_5 - GRDF + Two foliar spray of Nano-ZnO @ 1500 ppm	21.06	8.89
T_6 - GRDF + Two foliar spray of Nano-ZnO @ 2000 ppm	21.37	8.99
T_7 - GRDF + Two foliar spray of Chelated-Zn @ 1000 ppm	20.87	8.86
T_8 - GRDF + Two foliar spray of Chelated-Zn @ 1500 ppm	21.18	8.96
T_9 - GRDF + Two foliar spray of Chelated-Zn @ 2000 ppm	21.31	8.97
SE m(±)	0.04	0.02
C.D. at 5%	0.13	0.07

activating cells, promoting chlorophyll formation, and improving nitrogen uptake, which benefits seed development. This aligns with findings from White *et al*. (2017). Nano zinc improves immediate nutrient absorption, while chelated zinc ensures stable availability, both contributing to better nitrogen uptake and utilization. This effect may be attributed to the use of zinc in its nano form, which improves nutrient uptake by plants. The tiny size of nanoparticles allows them to quickly penetrate the plant cell membrane. The increased nutrient uptake seen with foliar application of ZnO nano fertilizer is due to its higher nutrient content, leading to better yields in both grains and stover. This results are supported by the research of Rashmi *et al*. (2022).

4.1.2 Phosphorus : The effect of foliar spray of Nano-Zinc and Chelated Zinc on total phosphorus uptake by pigeonpea given in table 6 which revealed thatthe foliar spray of Nano-Zinc and Chelated Zinc turned into increase in total phosphorus uptake by pigeonpea which was found significantly the highest (42.16 kg ha^{-1}) in treatment T_6 (GRDF + Two foliar spray of Nano-Zn @ 2000 ppm), over all treatments except treatment T_9 (40.83 kg ha^{-1}) which was at par with treatment T_6. Nano zinc enhances rapid phosphorus uptake, while chelated zinc ensures stable and prolonged availability, both contributing to better phosphorus nutrition in plants. Nano fertilizers effectively sustain phosphorus availability through gradual release (Joseph *et al*., 2019) without negative interactions with zinc. This may be due to the unique properties of nanoparticles, which reduce the metabolic issues typically seen with simultaneous zinc and phosphorus applications. Using chargeless nano zinc could enhance phosphorus uptake as supported by Subramanian and Gopalswamy (2012), with low zinc concentrations promoting this effect Liang *et al*. (2013).

4.1.3 Potassium : The Effect of foliar spray of Nano-Zinc and Chelated Zinc on total potassium uptake by pigeonpea given in table 6 which revealed that the foliar spray of Nano-Zinc and Chelated Zinc turned into increase in total potassium uptake by pigeonpen was found significantly the highest (111.40 kg ha^{-1}) in treatment T_6 (GRDF + Two foliar spray of Nano-Zn at 2000 ppm), over all other treatments except treatment T_9 (108.19 kg ha^{-1}) which was at par with treatment T_6. The synergistic effect of zinc enhances K uptake and crop yield, supported by Ladan *et al*. (2012) and Chen *et al*. (2016).

Table 6. Effect of foliar spray of Nano-Zinc and Chelated-Zinc on total uptake of macronutrients by pigeonpea

Treatment	Total macronutrients uptake (kg ha^{-1})		
	N	P	K
T_1 - Absolute control	130.24	22.47	65.50
T_2 - GRDF (25:50:00 $N:P_2O_5:K_2O$ kg ha^{-1} + Vermicompost @ 1.5 t ha^{-1})	160.44	28.74	81.05
T_3 - GRDF + Two foliar spray of water	164.72	31.14	85.82
T_4 - GRDF + Two foliar spray of Nano-ZnO @ 1000 ppm	169.80	33.37	90.02
T_5 - GRDF + Two foliar spray of Nano-ZnO @ 1500 ppm	179.21	35.90	98.06
T_6 - GRDF + Two foliar spray of Nano-ZnO @ 2000 ppm	199.32	42.16	111.40
T_7 - GRDF + Two foliar spray of Chelated-Zn @ 1000 ppm	176.11	34.72	95.98
T_8 - GRDF + Two foliar spray of Chelated-Zn @ 1500 ppm	190.04	38.82	102.82
T_9 - GRDF + Two foliar spray of Chelated-Zn @ 2000 ppm	196.88	40.83	108.19
SE m(±)	3.30	0.71	1.84
C.D. at 5%	9.89	2.13	5.51

4.2 Micronutrients Uptake : The effect of foliar spray of Nano-Zinc and Chelated Zinc on micronutrient uptake in both grain and straw by pigeonpea reported in Table 7.

4.2.1 Iron : The effect of foliar spray of Nano-Zinc and Chelated Zinc on total iron uptake by pigeonpea given in Table 7 which revealed thatthe foliar spray of Nano-Zinc and Chelated Zinc turned into increase in total iron uptake by pigeonpea which found significantly, the highest (2302g ha^{-1}) in treatment T_6 (GRDF + Two foliar spray of Nano-Zn @ 2000 ppm), over all treatments except treatment T_8 (2182 g ha^{-1}) and T_9 (2242g ha^{-1}) which were at par with treatment T_6. Nano fertilizers with particle sizes under 100 nanometers improve plant fertilizer utilization, reduce pollution and are environmentally friendly. Their enhanced water solubility boosts metabolic activities and trace element uptake (Joseph and Morrison, 2006). Additionally, research indicates that zinc enhances iron absorption in plants (Kheyri *et al*., 2018).The increasing Fe uptake may also be attributed to concentration of Fe in plant and seed. The concluded results are in agreement with the findings noticed by Balpande *et al*. (2016).

4.2.2 Mangnese : The effect of foliar spray of Nano-Zinc and Chelated Zinc on total mangnese uptake by pigeonpea given in table 4.12 which revealed thatthe foliar spray of Nano-Zinc and Chelated Zinc turned into increase in total mangnese uptake by pigeonpea which found significantly, the highest (1656g ha^{-1}) in treatment T_6 (GRDF + Two foliar spray of Nano-Zn @ 2000 ppm), over all treatments except treatment T_8 (1587g ha^{-1}) and T_9 (1626g ha^{-1}) which were at par with treatment T_6. The large surface area and small particle size of nano fertilizers, smaller than plant leaf pores, enable better penetration and uptake (Kumar *et al*., 2014). Additionally, zinc application enhances positive interactions and distribution of mangnese within the plant (Arunachalam *et al*., 2013).

4.2.3 Zinc : The effect of foliar spray of nano-zinc and chelated zinc on total zinc uptake by pigeonpea given in table 4.12 which revealed thatthe foliar spray of nano-zinc and chelated zinc turned into increase in total zinc uptake by pigeonpea which found significantly, the highest (232 g ha^{-1}) in treatment T_6 (GRDF + Two foliar spray of Nano-Zn @ 2000 ppm), over all treatments except treatment T_8 (218 g ha^{-1}) and T_9 (228g ha^{-1}) which were at par with treatment T_6. Foliar spraying with nano zinc and chelated

Table 7. Effect of foliar spray of Nano-Zinc and Chelated Zinc quality ontotal uptake of micronutrients by pigeonpea

Treatment	Total micronutrient uptake (g ha^{-1})			
	Fe	**Mn**	**Zn**	**Cu**
T_1 - Absolute control	1439	1080	141	93
T_2 - GRDF (25:50:00 N:P_2O_5:K_2O kg ha^{-1} + Vermicompost at 1.5 t ha^{-1})	1801	1346	181	126
T_3 - GRDF + Two foliar spray of water	1860	1363	185	129
T_4 - GRDF + Two foliar spray of Nano-ZnO @ 1000 ppm	1955	1398	198	134
T_5 - GRDF + Two foliar spray of Nano-ZnO @ 1500 ppm	2062	1479	207	143
T_6 - GRDF + Two foliar spray of Nano-ZnO @ 2000 ppm	2303	1656	232	162
T_7 - GRDF + Two foliar spray of Chelated-Zn @ 1000 ppm	2033	1471	205	140
T_8 - GRDF + Two foliar spray of Chelated-Zn @ 1500 ppm	2182	1587	218	152
T_9 - GRDF + Two foliar spray of Chelated-Zn @ 2000 ppm	2242	1626	228	158
SE m(±)	41.88	28.48	4.23	2.82
C.D. at 5%	125.56	85.37	12.69	8.46

zinc enhances zinc concentration in grains and straw by improving direct absorption, optimizing nutrient uptake, boosting photosynthesis, supporting enzyme activity, mitigating stress, and providing both rapid and sustained nutrient benefits. Nano zinc facilitates immediate increases in zinc uptake, while chelated zinc ensures stable, prolonged availability, both contributing to improved zinc nutrition in plants. Through foliar application, zinc is readily absorbed by the leaves and transported to developing grains via the phloem (Curie *et al.*, 2009). Also Prasad *et al.* (2012) found in their study that foliar application of nanoscale ZnO resulted in notably higher zinc uptake by both leaves and kernels compared to chelated zinc sulphate similar findingsreported by various studies on wheat (Yang *et al.* 2011; Saha *et al.* 2017; Zhao *et al.* 2020; Wang *et al.* 2020) and mungbean (Haider *et al.* 2020) with foliar application.

4.2.4 Copper : The effect of foliar spray of nano-zinc and chelated zinc on total copper uptake by pigeonpea given in table 4.12 which revealed thatthe foliar spray of nano-zinc and chelated zinc turned into increase in total copper uptake by pigeonpea which found significantly, the highest (162 g ha^{-1}) in treatment T6 (GRDF + Two foliar spray of Nano-Zn @ 2000 ppm), over all treatments except treatment T_9 (158 g ha^{-1}) which was at par with treatment T6. The lowest total uptake of Cu by pigeonpea (93 g ha^{-1}) was observed in treatment T_1 which was (Absolute control). Nano zinc facilitates rapid increases in copper concentration, while chelated zinc ensures consistent and long-lasting availability, contributing to better copper nutrition in plants. This can be attributed to the beneficial effect of split nitrogen application, which has been observed to enhance the uptake of micronutrients, particularly copper. The heavy metal uptake is influenced by nanoparticle-induced additive interactions, which also identify pathways for pollution movement in plants, Similar results also reported by Skiba *et al.* (2020).

5. Economic studies : The effect of foliar spray of nano-zinc and chelated zinc on economics of pigeonpea given in Table 8. The lowest cost of cultivation Rs. 66208 /- was observed in T_1 i.e., absolute control followed by treatment T_2 (Rs. 82064/-). The higher gross monetary return (Rs. 365651/-) was recorded higher in T_6 - (GRDF+ Two foliar spray of

Table 8. Effect of foliar spray of Nano-Zinc and Chelated-Zinc on economics of pigeonpea

Treatment	Gross monetary return (Rs. ha^{-1})	Cost of cultiva-tion (Rs. ha^{-1})	Net monetary return (Rs. ha^{-1})	B:C ratio
T_1 - Absolute control	266421	66208	200213	4.02
T_2 - GRDF (25:50:00 $N:P_2O_5:K_2O$ kg ha^{-1} + Vermicompost @ 1.5 t ha^{-1})	321461	82064	239397	3.92
T_3 - GRDF + Two foliar spray of water	326770	84064	242706	3.89
T_4 - GRDF + Two foliar spray of Nano-ZnO @ 1000 ppm	330197	85154	245043	3.88
T_5 - GRDF + Two foliar spray of Nano-ZnO @ 1500 ppm	343565	85699	257866	4.01
T_6 - GRDF + Two foliar spray of Nano-ZnO @ 2000 ppm	365651	86244	279407	4.24
T_7 - GRDF + Two foliar spray of Chelated-Zn @ 1000 ppm	338938	85064	253874	3.98
T_8 - GRDF + Two foliar spray of Chelated-Zn @ 1500 ppm	353992	84814	269178	4.17
T_9 - GRDF + Two foliar spray of Chelated-Zn @ 2000 ppm	362772	84564	278208	4.29

(Note : Vermicompost - 8 Rs. kg^{-1}, N- 11.73 Rs. kg^{-1}, P- 71.25 Rs. kg^{-1}, K- 56.66 Rs.kg^{-1}, Chelated Zinc EDTA - 1000 Rs. kg^{-1}, Nano-Zinc - 2180 Rs. kg^{-1}, Grain - 90 Rs. kg^{-1}, Stalk - 1.20 Rs. kg^{-1}, Spraying charge- 40 Rs./pump(10L).

Nano-Zn @ 2000 ppm) followed by treatment T_9 - (GRDF + Two foliar spray of Chelated Zn @ 2000 ppm (Rs. 362772/-). The net monetary return (Rs. 279407/-) was also recorded higher in T_6 (GRDF+ Two foliar spray of Nano-Zn @ 2000 ppm) followed by treatment T_9 - (GRDF + Two foliar spray of Chelated Zn @ 2000 ppm (Rs. 278208/-). The B:C ratio (4.29) was recorded higher in treatment T_9 - (GRDF + Two foliar spray of Chelated Zn @ 2000 ppm) followed by treatment T_6 - (GRDF + Two foliar spray of Nano-Zn at 2000 ppm (4.24). There was very slight difference in net returns and B:C ratio in treatment T_6 over T_9. Kumar *et al*. (2020) highlighted that nano fertilizers can boost crop yields, decrease fertilizer wastage, and lower overall cultivation costs. Comparable findings were also reported by Mahdi *et al*. (2012) and Kumar *et al*. (2014).This outcome was made possible by the noteworthy increase in grain yield and the associated fertilizer costs across various treatments. This increase in grain yield at these levels is attributed to higher levels of productivity, resulting in elevated gross returns, net returns, and an improved benefit-cost ratio. According to Kumar *et al*. (2020), nano fertilizers have the capacity to enhance crop yields while concurrently reducing fertilizer wastage and minimizing the overall cost of cultivation. Similar results were also observed by Mahdi *et al*. (2012) and Kumar *et al*. (2014). Foliar spraying with nano zinc and chelated zinc positively impacts the economics of pigeonpea crops by increasing yields, improving produce quality, enhancing nutrient use efficiency, reducing input costs, supporting pest and disease management, optimizing resource use, and promoting long-term soil health.

Conclusion

From the one year experimental results, it can be concluded that the application of general recommended dose of nutrients (25:50:00 kg ha^{-1} $N:P_2O_5:K_2O$ + Vermicompost @ 1.5 t ha^{-1}) as a basal dose and two foliar spray of Nano-ZnO @ 2000ppm at 30 and 55 DAS of pigeonpea was found beneficial for increase in yield attributes , total uptake of macro and micro nutrients, yield and quality of pigeonpea grown on medium deep black soil. However, the treatment of GRDF + two foliar spray of chelated Zn (EDTA) @ 2000 ppm at 30 and 55 DAS to pigeonpea was at par and recorded higher B:C ratio as compare to aforesaid treatment.

References

Ajithkumar, K., Kumar, Y., Savitha, A. S., Ajayakumar, M. Y., Narayanaswamy, C. and Bhat, S. N. 2021. Effect of IFFCO nanofertilizer on growth, grain yield and managing triticum leaf blight disease in maize. International Journal of Plant and Soil Science 33(16): 19-28.

Alloway, B. J. 2009. Soil factors associated with zinc deficiency in crops and humans. Environ Geochem Health.

Alloway, B. J. ed., 2008. Micronutrient deficiencies in global crop production. Springer Science & Business Media.

Al-Toki, M. A. M. and Halloul, R. 2021. Effect of chelated zinc and nano - zinc and interaction on growth traits of wheat (*Triticum aestivum* L.). In IOP Conference Series: Earth and Environ. Science 923: 012072.

Alzreejawi, S. A. and Al-Juthery, H. W. 2021. Effect of foliar application of nano nutrients and amino acids as a complementary nutrition on quantity and quality of maize grains. In Iop Conference Series : Earth and Environmental Science 735: 012060.

Anjum, S. A., Saleem, M. F., Shahid, M., Shakoor, A., Safeer, M., Khan, I. and Nazir, U. 2017. Dynamics of soil and foliar applied boron and zinc to improve maize productivity and profitability. Pakistan Journal of Agricultural Research 30(3): 35-37.

Arunachalam, P., Kannan, P., Prabukumar, G. and Govindaraj, M. 2013. Zinc deficiency in Indian soils with special focus to enrich zinc in peanut. African Journal of Agricultural Research 8(50): 6681-6688.

Auld, D. S. 2001. Zinc coordination sphere in biochemical zinc sites. Biometals 14: 271-313.

Balpande, S.S., Sarap, P.A. and Ghodpage, R.M. (2016) Effect of potassium and sulphur on nutrient uptake, yield and quality of pigeon pea (*Cajanus cajan*). Agricultural Science Digest Journal 36(4), 323-325.

Behera, S. K., Shukla, A. K., Tiwari, P. K., Tripathi, A., Singh, P., Trivedi, V., Patra, A. K., Das, S. 2020a. Classification of pigeonpea *Cajanus cajan* L. Millsp genotypes zinc efficiency. Plants 9(952): 1-14

Behera, S. K., Shukla, A. K., Singh, P., Trivedi, V., Patra, A. K., Rao, A. S. and Singh, A. K. 2021. Zinc application enhances yield and alters micronutrients concentration in pigeonpea (*Cajanus cajan L. Millsp.).* Nutrient Cycling in Agroecosystems, 119, 423-443.

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 Bioinformatics 1(4), 282-285.

Cakmak, I. and Kutman, U. B. 2018. Agronomic biofortification of cereals with zinc: a review. European Journal of Soil Science 69, 172-180.

Cakmak, I. and Kutman, U. B. 2018. Agronomic biofortification of cereals with zinc: a review. European Journal of Soil Science 69, 172-180.

Camp, A. F., and B. R. Fudge. 1945. Zinc as a nutrient in plant growth. Soil Science 60: 157-164.

Chapman, H. D. 1966. Zinc. In: Diagnostic Criteria for Plant and Soils, ed. H. D. Chapman, pp. 484-499. Riverside, CA: University of California.

Chen, S., Liu, Y., Hu, J., Zhang, Z., Hou, Z., Huang, F. and Yu, H., 2016. Zinc isotopic compositions of NIST SRM 683 and whole rock reference materials. Geostandards and Geoanalytical Research, 40(3), pp.417-432.

Choudhary, P., Singh, D., Kaushik, M. K., Sharma, S. S., Jain, H. K., Saharan, V. and Chouhan, D. 2022. Production, productivity and quality of maize (*Zea mays* L.) as affected by foliar application of zinc-based nano-fertilizer and different fertility levels. Journal of Pharmaceutical Innovation 11(2): 1878-1882.

Curie, C., Cassin, G., Couch, D., Divol, F., Higuchi, K., Jean, M. L., Misson, J., Schikora, A., Czernic, P., Mari, S. 2009. Metal movement within the plant: Contribution of nicotianamine and yellow stripe 1-like transporters. Ann Bot 103: 1-11.

Du, W., Sun, Y., Ji, R., Zhu, J., Wu, J. and Guo, H. (2011) TiO_2 and ZnO nano-particles negatively affect wheat growth and soil enzyme activities in agricultural soil. Journal of Environmental Monitoring13: 822-828.

Gerdini, F. S. 2016. Effect of nano potassium fertilizer on some parchment pumpkin (*Cucurbita pepo*) morphological and physiological characteristics under drought conditions. International Journal of Farming and Allied Sciences 5(5): 367-371.

Gomma, M. A., Kandil, E. E. and Amera, M. M. Ibrahim 2020. Response of maize to organic fertilization and some nano-micronutrients. Egyptian Academic Journal of Biological Sciences 11(1): 13-21.

Haider, M. U., Hussain, M., Farooq, M. and Nawaz, A. 2020. Zinc nutrition for improving the productivity and grain biofortification of mungbean. Journal of Soil Science and Plant Nutrition 3(2): 26-30.

Harsini, M. G., Habibi, H. and Talaei, G. H. 2014. Effect of nano iron foliar application on quantitative characteristics of new line of wheat. Science Journal of Crop Science 3(4), 37-42.

Jaberzadeh, A., Moaveni, P., Moghadam, H. R. T. and Zahedi, H. 2013. Influence of bulk and nanoparticles titanium foliar application on some agronomic traits, seed gluten and starch contents of wheat subjected to water deficit stress. Notulae Botanicae Horti Agro botanici Cluj-Napoca 41(1): 201-207.

Jackson, M. L. 1973. Soil chemical analysis. Prentice-Hall of India Pvt. Ltd., New Delhi, India. pp. 111-204.

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

Joseph, J., Ganga, W. J. and Hettiarachchi, M. 2019. A review of the latest in phosphorus fertilizer technology: possibilities and pragmatism. Journal of Environmental Quality 48: 1300-1313.

Kailas, Veeresh, H., Narayana Rao, K., Balanagoudar, S.R. and Sharanagouda, H. 2019. Effect of conventional and nanomicronutrient fertilizers on yield and economics of pigeonpea [*Cajanuscajan* (L.) Mill sp.]. International Journal of Current Microbiology and Applied Sciences 8(09), 185-193.

Kheyri, N., 2022. Effect of silicon and nanosilicon application on rice yield and quality. In Silicon and Nano-silicon in Environmental Stress Management and Crop Quality Improvement (pp. 297-307). Academic Press.

Kisan, B., Shruthi, H., Sharanagouda, H., Revanappa, S. B., Pramod, N.K. Effect of nano-zinc oxide on the leaf physical and nutritional quality of spinach. Agrotechnology 2015,5, 135.

Kumar, G. P., Lalitha, B. S., Murthy, K. K. and Bhavya, V. 2018. Foliar nutrition: a novel technology to increase growth and yield in baby corn (*Zea mays* L.). International Journal of Current Microbiology and Applied Sciences 7(4): 1136-1148.

Kumar, K. H., Adithya, S. and Savalgi, V. P. 2021. Evaluation of foliar application of zinc nanoparticles on growth and yield parameters of maize (*Zea mays* L.) grown under greenhouse conditions. International Journal of Conservation Science 9(1): 1464-1467.

Kumar, S., Patra, A. K., Datta, S. C., Rosin, K. G. and Purakayastha, T. J. 2015. Phytotoxicity of nanoparticles to seed germination of plants. International Journal of Advanced Research 3(3), 854-865.

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.

Li, M., Tian, X., Li, X. and Wang, S. 2017. Effect of Zn application methods on Zn distribution and bioavailability in wheat pearling fractions of two wheat genotypes. Journal of Integrative Agriculture 16(7), 1617-1623.

Liang, T., Yin, Q., Zhang, Y., Wang, B., Guo, W., Wang, J. and Xie, L. 2013. Effects of carbon nano-particles application on the growth, physiological characteristics and nutrient accumulation in tobacco plants. Journal of Food, Agriculture and Environment 11(3 and 4): 954-958.

Lindsay, W. L. and Norwell, W. A. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. Soil Science Society of America Journal 42: 421-428.

Lyngdoh, B., Krishnamurthy, N., Jayadeva, H. M., Gowda, J. and Seenappa, C. 2019. Influence of foliar nutrition on the performance of soybean [*Glycine max* (L.) Merrill]. Mysore Journal of Agricultural Sciences 53(2).

Mahdi, S. S., Hasan, B. and Singh, L. 2012. Influence of seed rate, nitrogen and zinc on fodder maize (*Zea mays*) in temperate conditions of western Himalayas. Indian Journal of Agronomy, 57(1), 85-88.

Mahesh, R. H., Dayal, A., Nasakar, J. and Sharan, E. A. 2022. Effect of particle size and concentration of zinc oxide nanoparticles on growth, yield and yield attributing traits of maize (*Zea mays* L.) International Journal of Noval Research and Development.

Moghaddam, H. T. and Madani, A. 2016. Influence of titanium foliar application on antioxidant enzyme activity and some biochemical attributes of corn. Maydica 61(3).

Moghaddasi, S., Fotovat, A., Khoshgoftarmanesh, A. H., Karimzadeh, F., Khazaei, H.R. and Khorassani, R., 2017. Bioavailability of coated and uncoated ZnO nanoparticles to cucumber in soil with or without organic matter. Ecotoxicology and environmental safety, 144, pp.543-551.

Naik, S. K. and Das, D. P. 2007. Effect of split application of zinc on yield of rice (*Oryza sativa* L.) in an Inceptisol. Archives of Agronomy and Soil Science 53(3): 305-313.

Nelson, D. W. and Sommers, L. E. 1982. Total carbon, organic carbon and organic matter. In: Methods of Soil Analysis, Part-II, Page, A.L. (Ed.). American Society of Agronomy. Inc. Soil Science Society of America Inc. Madison, Wisconsin, USA. pp. 539-579.

Noufal, E., Farid, I., Attia, M. A., Ahmed, R. and Abbas, M. 2021. Effect of traditional sources of Zn and ZnO-nano-particles foliar application on productivity and P-uptake of maize plants grown on sandy and clay loam soils. Environment, Biodiversity and Soil Security 5: 59-72.

Olsen, S. R., Cole, C. V., Watanbe, F. S. and Dean, L. A. 1965. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United States Department of Agriculture Circular No. 939

Panse, V. G. and Sukhatme, P. V. 1985. Statistical Method of Agricultural Workers. 4th Ed.

Patra, P., Choudhury, S. R., Mandal, S., Basu, A., Goswami, A., Gogoi, R., Gopal, M. 2013. Effect of sulfur and ZnO nanoparticles on stress physiology and plan t (*Vigna radiata*) nutrition. In Advanced Nanomaterials and Nanotechnology; Springer: Berlin/Heidelberg, Germany, 301-309.

Poornima, R. and Koti, R. V. 2019. Effect of nano zinc oxide on growth, yield and grain zinc content of sorghum (Sorghum bicolor). Journal of Pharmacognosy and Phytochemistry 8(4): 727-731.

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

Racuciu, M., Creanga, D. and Amoraritei, C., 2007. Biochemical changes induced by low frequency magnetic field exposure of vegetal organisms. Rom. J. Phys, 52(5-7), pp. 645-651.

Ramesh Raddy, Pavithra, G. J., Rajashekar Reddy, B. H., Salimath, M., Geetha, K. N. and Shankar, A. G. 2017. Zinc oxide nano particles increases Zn uptake, translocation in rice with positive effect on growth, yield and moisture stress tolerance. Indian Journal of Plant Physiology 22: 287-294.

Rashmi, C. M., Prakash, S. S., Basavaraj, P. K., Krishnamurthy, R., Yogananda, S. B., Bhavani, P. and Giridhar, B. N. 2022. Effect of nano phosphorus fertilizers on uptake of nitrogen, phosphorus and potassium by maize. Journal of pharmaceutical innovation. 11(11): 2172-2175.

Reazaei, M. and Abbasi, H. 2014. Foliar application of nano chelate and non nano chelate of zinc on plant resistance physiological processes in cotton (*Gossipium* *hirsutum* L.). Iranian Journal of Plant Physiology 4(4): 1137-1144.

Rengel, Z., Batten, G. D., Crowley, D. E. 1999. Agronomic approaches for improving the micronutrient density in edible portion of field crops. Field Crop Res 60: 27-40.

Saha, S., Chakraborty, M., Padhan, D., Saha, B., Murmu, S., Batabyal, K., Seth, A., Hazra, G. C., Mandal, B. and Bell, R. W., 2017. Agronomic biofortification of zinc in rice: Influence of cultivars and zinc application methods on grain yield and zinc bioavailability. Field Crops Research, 210, pp. 52-60.

Satdev, V. J., Chavda, B. N. and Saini, L. K. 202.) Effect of nano ZnO on growth and yield of sweet corn under South Gujarat condition. International Journal of Conservation Science 8(1): 63-65.

Sedghi, M., Hadi, M., Toluie, S. G. Effect of nano zinc oxide on the germination parameters of soybean seeds under drought stress. Ann. West Univ. Timişoara, Ser. Biol. 2013; 16(2):73-78.

Shukla, A. K., Behera, S. K. 2019. All India research project on micro- and secondary nutrients and pollutant elements in soils and plants: research achievements and future thrusts. Indian Journal of Fertilisersb 15(5):b 522-543

Singh, P., Shukla, A. K., Behera, S. K. and Tiwari, P. K. 2019. Zinc application enhances super oxide dismutase and carbonic anhydrase activities in zinc efficient and inefficient wheatgenotypes. Journal of Soil Science and Plant Nutrition 19(3), 477-487.

Skiba, E., Michlewska, S., Pietrzak, M. and Wolf, W. M. 2020. Additive interactions of nanoparticulate ZnO with copper, manganese and iron in pea (*Pisum sativum* L.) A hydroponic study. Science Report 10(1): 31-47.

Subbiah, B. V. and Asija, G. L. 1965. A rapid procedure for estimation of available nitrogen in soil. Current Science 5: 259-260.

Subramanian, S. and Gopalswamy, A. 2012. Effect of moisture, organic matter, phosphate and silicate on availability of silicon and phosphorus in rice soils. Journal of Indian Society of Soil Science 39: 99-103.

Tondey, M., Kalia, A., Singh, A., Dheri, G. S., Taggar, M. S., Nepovimova, E. and Kuca, K. 2021. Seed priming and coating by nano-scale zinc oxide particles improved vegetative growth, yield and quality of fodder maize (*Zea mays*). Agronomy 11(4), 729.

Tondey, M., Kalia, A., Singh, A., Dheri, G. S., Taggar, M. S., Nepovimova, E. and Kuca, K. 2021. Seed priming and coating by nano-scale zinc oxide particles improved vegetative growth, yield and quality of fodder maize (*Zea mays*). Agronomy 11(4), 729.

Uma, V., Jayadeva, H. M., Rehaman, H. A., Kadalli, G. G. and Umashankar, N. 2019. Influence of nano zinc oxide on yield and economics of maize (*Zea mays* L.). Mysore Journal of Agricultural Science 53(4): 44-8.

Uma, V., Jayadeva, H. M., Rehaman, H. A., Kadalli, G. G. and Umashankar, N. 2019. Influence of nano zinc oxide on yield and economics of maize (*Zea mays* L.). Mysore Journal of Agricultural Science 53(4): 44-8.

Vijay, F. V. 2022. Effect of zinc oxide nanoparticles (ZnONPs) on yield attributes and yield of hybrid maize (*Zea mays* L.). Journal of Pharmaceutical Innovation 11(8): 225-228.

Wang S, Li M, Tian X, Li J, Li H, Ni Y, Zhao J, Chen Y, Guo C, Zhao A. 2015. Foliar zinc, nitrogen, and phosphorus application effects on micronutrient concentrations in winter wheat. Agronomy Journal 107: 61-70

Welch, R. M. and Graham, R. D. 2002. Breeding crops for enhanced micronutrient content. Plant Soil 245, 205-214.

White, B., Tubana, B. S., Babu, T., Mascagni, H., Agostinho, F., Datnoff, L. E. and Harrison, S. 2017. Effect of silicate slag application on wheat grown under two nitrogen rates. Plants Annuals Agriculture Science 6(4): 1-14.

White, B., Tubana, B. S., Babu, T., Mascagni, H., Agostinho, F., Datnoff, L. E. and Harrison, S. 2017. Effect of silicate slag application on wheat grown under two nitrogen rates. Plants Annuals Agriculture Science 6(4): 1-14.

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 (*Oryza sativa* L.). International Journal of Environmental Research and Public Health 12, 15100-15109.

Zhao, A, Wang, B, Tian, X., Yang, X. 2020. Combined soil and foliar $ZnSO_4$ application improves wheat grain Zn concentration and Zn fractions in a calcareous soil. European Journal of Soil Science 71(4): 681-694.