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Biofortification and Enhancement in Nutrient Uptake in Maize (*Zea mays* L.) through the Foliar Application of Nanofertilizers

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ABSTRACT

Nanotechnology based biofortification may be the most sustainable solution to combat the nutrient deficiency in humans. Nanofertilizers due to their unique properties, serve as potential sources of nutrients for the biofortification of crops. A field experiment study was conducted during June- October in *kharif* 2020 with the aim to examine the effect of foliar application of nanofertilizers (N, Zn and Cu) on nutrient content and uptake by grain and stover of maize (*Zea mays* L.) crop at Instructional Farm, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan. The present investigation was carried out in Randomized Block Design having 12 treatments which were replicated three times. The maize crop was treated either with conventional fertilizers or with the combination of nanofertilizers (N+Zn or N+Zn+Cu) or with both 50 % conventional plus nanofertilizers. The significantly highest nutrient (N, K, Zn and Cu) content and uptake by maize grain and stover was recorded under the combined application of 50% conventional plus nanofertilizers i.e.,T_{12} (100% PK + 50% NZn + two sprays of nano N + nano Zn + nano Cu) over control. However, the application of 100% PK + 50% NZn + two sprays of nano N + nano Zn + nano Cu (T_{12}) remained statistically at par with 100% PK + 50% NZn + two sprays of nano N + nano Zn (T_{11}) in N, K and Zn content and uptake by maize grain and stover. Whereas, the highest P content was found under control and highest P uptake was recorded with application of 100% NPK (T_3). Thus, foliar application of 100% PK + 50% NZn + two sprays of nano N + nano Zn + nano Cu (T_{12}) may be a viable option to increase the N, K, Zn and Cu content and uptake of by grain and stover of maize.

Keywords Biofortification, Conventional fertilizers, Maize, Nanofertilizers, Nanotechnology.

INTRODUCTION

Maize is important cereal crop grown in more than 170 countries globally. It is third leading staple food crop after rice and wheat. It is known as queen of cereals due to its high yield potential. In India, maize ranks fourth in terms of area and seventh in terms of output, accounting for around 4% of global maize area and 2% of total production. In India, the

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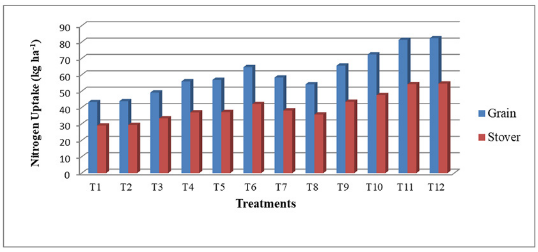
maize covers an area of 9.2 million hectares with a production of 27.8 million metric tonnes and having average productivity of 2965 kg ha^{-1}, during 2018-19 (FAI 2020). It is a nutritional staple food crop for more than 200 million people. India's most dominant rice–wheat cropping system has encountered various problems, viz. low input-use efficiency, nutrients imbalances, more groundwater depletion and irrigation water shortages, high energy and labor demands, high emissions of greenhouse gases, weed resistance. Therefore maize can take place of rice in rice–wheat cropping system (Ladha *et al.* 2009).

The process of nutrient enrichment in the edible sections of crops through the exogenous delivery of nutrients in the form of fertilizers is referred to as "biofortification." The crucial goal of the fortification strategy is to reduce nutrients deficiency in humans that leads to malnutrition. Nanotechnology has great potential in precision agriculture to improve the quality and quantity of staple crops via biofortification. Nanofertilizers due to their unique properties, serve as potential sources of nutrients for the biofortification of crops. Engineered nanoparticles have many unique features, high surface area to volume ratio and tuneable dissolution profiles can be a safer alternative to promote biofortification of food crops (Elemike *et al.* 2019).

MATERIALS AND METHODS

Experimental area : This study was conducted at the Instructional Farm of Agronomy, Rajasthan College of Agriculture, MPUAT Udaipur, Rajasthan in India during June-October in *kharif* 2020. The experimental location was located at 24°35' north latitude, 72°42' east longitude and 579.5 meters above mean sea level. The area is part of Rajasthan's agro-climatic zone IVa (Sub-Humid Southern Plain and Aravalli Hills).

Soil condition of experimental area : The soil of experimental area was clay loam (38.82%, silt 26.58% and clay 34.60 %) in texture, saline in reaction (8.40), normal in electrical conductivity (0.81 dSm^{-1}), medium in soil organic carbon (0.55%), low in soil available nitrogen (260.20 kg ha^{-1}), phosphorus 16.09 kg ha^{-1}, high in potassium (350.47 kg ha^{-1}), high in zinc



Graph 1. Effect of different treatments of nanofertilizers on nitrogen uptake.

(1.99 mg kg^{-1}) and copper (1.58 mg kg^{-1}).

Experimental design and treatments : The experiment was laid out in Randomized Block Design with three replication and twelve treatments (Table 1). The total number of plots was 36 and gross size of each plot was 21 m^2 (5 m × 4.2 m). The seeds of the Pratap Makka 9 (PM-9) maize variety was used for this experiment.

Application of nanofertilizers : The foliar application of nanofertilizer was given twice 1st at 21 days after sowing and 2nd at 42 days after sowing as per treatments with the help of a knapsack sprayer with flat fan nozzle. Foliar spray of nano N was applied @ 4 ml l^{-1} water while a double dose of nitrogen @ 8 ml l^{-1} water was applied in T_5. Nano Zn @ 2 ml l^{-1} water was given in all zinc treatments except T_{10}, T_{11} and T_{12} in which nano zinc applied @ 1.25 ml l^{-1} water. Nano Cu was given @2 ml l^{-1} water as per the scheduled treatments.

Table 1. Treatments details.

Treatments		
T_1	:	100% PK (Control)
T_2	:	100% PKZn
T_3	:	100% NPK
T_4	:	100% PKZn + two sprays of nano N
T_5	:	100% PKZn + two sprays of nano N (2X)
T_6	:	100% NPK + two sprays of nano Zn
T_7	:	100% PK + two sprays of nano N + nano Zn
T_8	:	100% RDF (NPKZn)
T_9	:	100% PKZn + 50% N + two sprays of nano N
T_{10}	:	100% NPK + 50% Zn + two sprays of nano Zn
T_{11}	:	100% PK + 50% NZn + two sprays of nano N + nano Zn
T_{12}	:	100% PK + 50% NZn + two sprays of nano N + nano Zn + nano Cu

Table 2. Response of foliar application of nanofertilizers on N, P, K, Zn and Cu content in grain and stover of maize.

	Treatment	Nitrogen content (%)		Phosphorus content (%)		Potassium content (%)		Zinc content (mg kg^{-1})		Copper content (mg kg^{-1})	
		Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
T_1	100% PK (Control)	1.44	0.53	0.40	0.20	0.44	1.31	26.11	17.10	7.20	4.14
T_2	100% PKZn	1.45	0.53	0.37	0.18	0.44	1.31	27.30	17.27	7.20	4.14
T_3	100% NPK	1.51	0.56	0.42	0.21	0.46	1.34	28.64	18.83	7.35	4.22
T_4	100% PKZn + two sprays of nano N	1.57	0.57	0.38	0.19	0.48	1.36	30.35	19.97	7.48	4.31
T_5	100% PKZn + two sprays of nano N (2X)	1.59	0.57	0.38	0.19	0.48	1.36	30.45	19.99	7.49	4.31
T_6	100% NPK + two sprays of nano Zn	1.66	0.61	0.33	0.16	0.50	1.40	32.96	20.75	7.56	4.37
T_7	100% PK+ two sprays of nano N + nano Zn	1.60	0.58	0.35	0.17	0.48	1.36	31.57	20.04	7.49	4.33
T_8	100% RDF (NPKZn)	1.55	0.56	0.35	0.17	0.47	1.35	30.01	19.56	7.41	4.28
T_9	100% PKZn + 50% N + two sprays of nano N	1.68	0.63	0.33	0.16	0.50	1.40	33.13	20.80	7.59	4.39
T_{10}	100% NPK + 50% Zn + two sprays of nano Zn	1.73	0.64	0.31	0.16	0.52	1.43	34.53	21.88	7.63	4.42
T_{11}	100% PK + 50% NZn + two sprays of nano N + nano Zn	1.81	0.68	0.28	0.14	0.53	1.45	36.23	23.57	7.89	4.50
T_{12}	100% PK +50% N Zn + two sprays of nano N + nano Zn + nano Cu	1.84	0.68	0.28	0.14	0.53	1.45	36.24	23.59	8.43	4.85
SEm±		0.01	0.00	0.004	0.006	0.005	0.007	0.45	0.23	0.11	0.09
CD (p= 0.05)		0.04	0.02	0.01	0.01	0.01	0.02	1.32	0.69	0.32	0.26

Application of conventional fertilizers : According to the packages of practices of maize in Udaipur, the recommended dose of N (90 kg ha^{-1}), P (40 kg ha^{-1}), K (30 kg ha^{-1}) and Zn (25 kg ha^{-1}) through urea, diammonium phosphate, murate of potash and zinc sulphate heptadydrate, respectively.

Nutrient uptake : Uptake of N, P and K were calculated using following formula :

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{Nutrient content in grain /stover (\%)} \times \text{Yield of grain/stover (kg ha}^{-1})}{100}$$

Uptake of Zn and Cu were calculated using following formula :

$$\text{Nutrient uptake (g ha}^{-1}) = \frac{\text{Nutrient content in grain /stover (mg kg}^{-1}) \times \text{Yield of grain/stover (kg ha}^{-1})}{1000}$$

Statistical analysis : The obtained data were statistically analyzed with the techniques of analysis of varianceas described by Steel and Torrie (1960). The comparison in the treatment mean was tested by critical difference (CD) at 5% level of significance.

RESULTS AND DISCUSSION

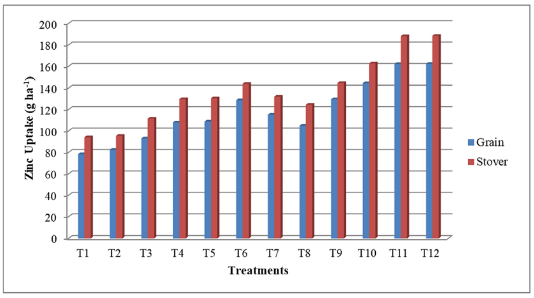
Nutrient content

The foliar application of nanofertilizers (N, Zn and Cu), separately and combinedly resulted in significantly higher nutrient (N, K, Zn and Cu) content in maize grain and stover over control (Table 2). The significantly highest N, K, Zn and Cu content in maize grain (1.84%, 0.53%, 36.24 mg kg^{-1} and 8.43 mg kg^{-1}, respectively) and stover (0.68%, 1.45%, 23.59 mg kg^{-1} and 4.85 mg kg^{-1}, respectively) was recorded with application of 100% PK + 50% NZn + two sprays of nano N + nano Zn + nano Cu (T_{12}) followed by 100% PK + 50% NZn + two sprays of nano N + nano Zn (T_{11}), 100% NPK + 50% Zn + two sprays of nano Zn (T_{10}), 100% PKZn + 50% N + two sprays of nano N (T_9) and 100% NPK + two sprays of nano Zn (T_6) over control. However, there was no

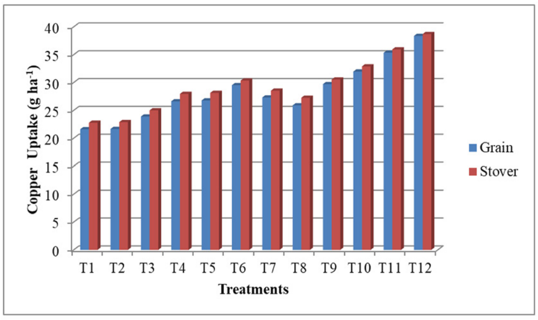
Table 3. Response of foliar application of nanofertilizers on N, P, K, Zn and Cu uptake by maize grain and stover of maize.

Treatment		Nitrogen uptake ($kg\ ha^{-1}$)		Phosphorus uptake ($kg\ ha^{-1}$)		Potassium uptake ($kg\ ha^{-1}$)		Zinc uptake ($g\ ha^{-1}$)		Copper uptake ($g\ ha^{-1}$)	
		Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
T_1	100% PK (Control)	43.32	29.01	12.00	11.19	13.26	72.38	78.32	94.11	21.60	22.77
T_2	100% PKZn	43.86	29.38	11.19	10.14	13.34	72.75	82.40	95.41	21.65	22.88
T_3	100% NPK	49.19	33.39	13.75	12.64	15.11	79.50	93.11	111.46	23.88	24.99
T_4	100% PKZn + two sprays of nano N	55.95	37.03	13.65	12.31	17.27	88.28	107.92	129.69	26.61	27.94
T_5	100% PKZn + two sprays of nano N (2X)	56.91	37.22	13.60	12.44	17.36	88.92	108.78	130.48	26.77	28.13
T_6	100% NPK + two sprays of nano Zn	64.67	42.10	13.02	11.57	19.59	97.48	128.70	143.97	29.51	30.34
T_7	100% PK+ two sprays of nano N + nano Zn	58.33	38.18	12.89	11.64	17.77	90.11	115.17	131.94	27.30	28.53
T_8	100% RDF (NPKZn)	54.17	35.74	12.25	11.24	16.45	86.05	104.89	124.45	25.89	27.25
T_9	100% PKZn + 50% N + two sprays of nano N	65.60	43.53	12.93	11.14	19.67	98.03	129.63	144.75	29.70	30.53
T_{10}	100% NPK + 50% Zn + two sprays of nano Zn	72.42	47.57	13.00	11.90	21.87	106.89	144.56	162.66	31.95	32.88
T_{11}	100% PK + 50% NZn + two sprays of nano N + nano Zn	81.31	54.26	12.82	11.21	24.26	117.76	162.13	188.11	35.34	35.93
T_{12}	100% PK +50% N Zn + two sprays of nano N + nano Zn + nano Cu	82.30	54.65	12.58	11.27	24.43	118.01	162.30	188.49	38.36	38.69
SEm±		1.53	0.89	0.35	0.47	0.45	1.70	3.17	2.65	0.75	0.51
CD (p= 0.05)		4.51	2.62	1.05	1.40	1.33	4.98	9.32	7.79	2.22	1.52

statistical difference between T_{12} (100% PK + 50% NZn + two sprays of nano N + nano Zn + nano Cu) and T_{11} (100% PK + 50% NZn + two sprays of nano N + nano Zn) in terms of N, K and Zn content in maize grain and stover (Table 2). The higher nutrient (N, K, Zn and Cu) content under T_{12} might be due to the foliar application which causes immediate availability of the nutrients. This might also associated with the application of nanofertilizers which avoid structural barriers and allow easily penetration of nutrient through cell wall and reach to the plasma membrane due to small size less than the pore size of plant cell (5 to 20 nm) over conventional fertilizers (Fleischer *et al.*1998). The unique features of nanofertilizers like high charge density, reactivity and high surface to volume ratio may promote targeted and slow delivery of nutrients, which resulted in efficient absorption of nutrients and ultimately increasing the nutrient concentration in food crop (Verma and Kapoor 2020). The result of present study showed that combined application of conventional and nanofertilizers resulted in highest nutrient content in maize grain and stover. Similar result was also found by Rani *et al.* (2019). The increase in N, Zn and Cu content with the combined application of three nutrients (nano N + nano Zn + nano Cu) could be associated with the increased bioavailability of these nutrients, which is confirmed by the (Prasad *et al.* 2012). The present study showed that K content increases with nano Zn and nano N application might be due to synergistic interaction of K with N and Zn, resulted in higher photosynthetic activity in leaves indirectly led to the efficient utilization of potassium by crop and translocate to grain (Charishma *et al.* 2022). Data (Table 2) showed that Cu application showed no significant increase in N, P, K and Zn content. The present study showed that applying zinc and nitrogen as a foliar fertilizer is a successful way to raise grain zinc content in grain might be due to role of N (in the form of protein) to transfer the micronutrients from leaves to grain (Distelfeld *et al.* 2007). Previous study indicated the higher nutrient content (N, P and K) in grain and stover with application of nano urea (Sharma *et al.* 2022). Apoorva *et al.* (2017) found that the application of



Graph 2. Effect of different treatments of nano fertilizers on zinc uptake.



Graph 3. Effect of different treatments of nano fertilizers on copper uptake.

nano Zn increased the N, K and Zn content in grain and stover. Wang *et al*. (2019) found that application of nano CuO enhanced Cu concentration in wheat grain by over control.

Whereas, the highest P content in grain (0.42 %) and stover (0.21 %) were recorder with application of 100% NPK (T_3). The lowest P content in grain and stover with use of 100% PK + 50% NZn + two sprays of nano N + nano Zn + nano Cu (T_{12}) may be due the Zn application. This may be due to the antagonistic effect of P and Zn, reduces the grain P concentration by forming P and Zn precipitate in the spray solution reducing Zn entry into plant tissues (Bostick *et al.* 2001).

Nutrient uptake

The each treatment with foliar application of nano-fertilizers resulted in higher uptake by maize grain and stover over control (Table 3). The significantly highest N, K, Zn and Cu uptake by maize grain (82.30 kg ha^{-1}, 24.43 kg ha^{-1}, 162.3 g ha^{-1} and 38.36 g ha^{-1}, respectively) and stover (54.65 kg ha^{-1}, 118.01 kg ha^{-1}, 188.49 g ha^{-1} and 38.69 g ha^{-1}, respectively) were found with application of 100% PK + 50% NZn + two sprays of nano N + nano Zn + nano Cu (T_{12}), compared to control as shown in Table 3, Graph 1, Graph 2 and Graph 3. However, T_{12} (100% PK + 50% NZn + two sprays of nano N + nano Zn + nano Cu) and T_{11} (100% PK + 50% NZn + two sprays of nano N + nano Zn) were found statistically at par in terms of N, K and Zn content in maize grain and stover (Table 3). The higher nutrient uptake might be due to the application of micronutrient (Zn and Cu) which enhance the chlorophyll synthesis, photosynthesis, root and respiration cell growth and the efficiency of enzymes involved in primary and secondary metabolism which result in better root and shoot development (Ali *et al.* 2019). This will give positive response on N, K, Zn and Cu uptake by maize crops. Nanofertilizers prevent fixation, denitrification, volatization, especially NO_3-N and NH_4-N and increased absorption and uptake through different plant parts (Qureshi *et al.* 2018). The combined effect of increased dry matter yield and N, P, K, Zn and Cu concentration in grain and stover may be the possible reason to higher N, P, K, Zn and Cu uptake, which is confirmed by Meena *et al.* (2021). Elshayb *et al.* (2021) concluded that foliar application of ZnO NPs led to an enhanced the total N, P and K uptake by rice compared to the control. Hemdan *et al.* (2020) also found that foliar application of nano NPK increased the Zn and Cu uptake by lupine plant. Previous study showed that application of nano N + nano Zn + nano Cu enhance the microbial population, dehydrogenase and acid phosphatase activity in soil which is responsible for nutrients transformation and mineralization which ultimately resulted in nutrients availability and facilitate more nutrient uptake by plants (Khardia *et al.* 2022).

However, the highest P uptake by grain (13.75 kg ha^{-1}) and stover (12.64 kg ha^{-1}) were recorder with application of 100% NPK (T_3). The lowest P uptake recorded with use of 100% PK + 50% NZn + two sprays of nano N + nano Zn + nano Cu (T_{12}) might be due the Zn application. This is due to antagonistic interaction between Zn and P as discussed above.

From the foregoing results, it is concluded that the foliar application of 100% PK + 50% NZn + two sprays of nano N + nano Zn + nano Cu can be a better way to enhance N, K, Zn and Cu content and uptake by grain and stover of maize crop. The 50% recommended dose of conventional fertilizers reduced by two sprays of nanofertilizers. Therefore, nanofertilizers can be the most sustainable option for biofortification of maize crop in Sub-Humid Southern Plain and Aravalli Hills Region of Rajasthan.

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REFERENCES

Ali S, Rizwan M, Noureen S, Anwar S, Ali B, Naveed M, Allah EF, Alqarawi AA, Ahmad P (2019) Combined use of biocharand zinc oxide nanoparticle foliar spray improved the plant growth and decreased the cadmium accumulation in rice (*Oryza sativa* L.) plant. *Environ Sci Pollut Res* 26 : 11288—11299.

Apoorva MR, Rao PC, Padmaja G (2017) Effect of zinc with special reference to nano zinc carrier on yield, nutrient content and uptake by rice (*Oryza sativa* L.). *Int J Curr Microbiol Appl Sci* 6 : 1057—1063.

Bostick BC, Hansel CM, la Force MJ, Fendorf S (2001) Seasonal fluctuations in zinc speciation within a contaminated wet-land. *Environm Sci Technol* 35 : 3823—3829.

Charishma DS, Ravi MV, Balanagoudar SR, Veeresh H, Hiregoudar S (2022) Effect of nano zinc application on uptake of major nutrients in *rabi* sorghum (*Sorghum bicolor* L.). *The Pharma Innov J* 11 (7) : 1608—1611.

Distelfeld A, Cakmak I, Peleg Z, Ozturk L, Yazici AM, Budak H, Saranga Y, Fahima T (2007) Multiple QTL-effects of wheat Gpc-B_1 locus on grain protein and micronutrient con centrations. *Physiologia Plantarum* 129 (3) : 635—643.

Elemike EE, Uzoh IM, Onwudiwe DC, Babalola OO (2019) The role of nanotechnology in the fortification of plant nutrients and improvement of crop production. *Appl Sci* 9 (3) : 499.

Elshayb OM, Farroh KY, Amin HE, Atta AM (2021) Green synthesis of zinc oxide nanoparticles: Fortification for rice grain yield and nutrients uptake enhancement. *Molecules* 26 (3) : 584.

FAI (2020) Fertiliser Statistics. The Fertilizer Association of India, New Delhi.

Fleischer A, Titel C, Ehwald R (1998) The boron requirement and cell wall properties of growing- and station ary-phase suspension-cultured *Chenopodium album* L. cells. *Pl Physiol* 117 : 1401—1410.

Hemdan NA, Hussein MM, El-Ashry S (2020) Conventional and nano fertilizers and its effect on growth and nutrient status of lupine plants. *Curr Sci Int* 9 (4) : 698—705.

Khardia N, Meena RH, Jat G, Sharma S, Kumawat H, Dhayal S, Meena AK, Sharma K (2022) Soil properties influenced by the foliar application of nano fertilizers in maize (*Zea mays* L.) crop. *Int J Pl Soil Sci* 34 (14) : 99—111.

Ladha JK, Kumar V, Alam MM, Sharma S, Gathala MK, Chandna P, Saharawat YS, Balasubramanian V (2009) Integrating crop and resource management technologies forenhanced productivity, profitability and sustainability of the rice–wheat system in South Asia. (In) Integrated Crop and Resource Management in the Rice–Wheat System of South Asia. IRRI, Los Banos, Philippines, pp 69—108.

Meena RH, Jat G, Jain D (2021) Impact of foliar application of different nano-fertilizers on soil microbial properties and yield of wheat. *J Environm Biol* 42 (2) : 302—308.

Prasad TNVKV, Sudhakar P, Sreenivasulu Y, Latha P, Munaswamy V, Reddy KR, Sreeprasad TS, Sajanlal PR, Pradeep T (2012) Effects of nanoscale zinc oxide particles on the germination, growth and yield of peanut. *J Pl Nutrition* 35 (6) : 905—927.

Qureshi A, Singh DK, Dwivedi S (2018) Nanofertilizers : A novel way for enhancing nutrient use efficiency and crop productivity. *Int J Curr Microbiol Appl Sci* 7(2) : 3325—3335.

Rani B, Zalawadia NM, Buha D, Rushang K (2019) Effect of different levels of chemical and nano nitrogenous fertilizers on content and uptake of NPK by sorghum crop cv Gundari. *J Pharmacog Phytochem* 8 (5) : 454—458.

Sharma SK, Sharma PK, Mandeewal RL, Sharma V, Chaudhary R, Pandey R, Gupta S (2022) Effect of foliar application of nano-urea under different nitrogen levels on growth and nutrient content of pearl millet (*Pennisetum glaucum* L.). *Int J Pl Soil Sci* 34 (20) : 149—155.

Steel RGD, Torrie JH (1960) Principles and procedures of statistics with special reference to the biological sciences, McGraw Hill, New York.

Verma H, Kapoor A (2020) Agronanotechnology: An agricultural paradigm. *(In) New Perspectives in Agricult* pp. 1—24.

Wang Y, Jiang F, Ma C, Rui Y, Tsang DC, Xing B (2019) Effect of metal oxide nanoparticles on amino acids in wheat grains (*Triticum aestivum*) in a life cycle study. *J Environm Manag* 241 : 319—327.