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Effect of nano zinc application on uptake of major nutrients in *rabi* sorghum (*Sorghum bicolor* L.)

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Abstract
Field experiment was conducted during *rabi* 2019-20 to study the effect of various sources of zinc nanoparticles in sorghum under rainfed conditions. The experiment was laid out in Randomized Block Design (RBD) with 12 treatments and replicated thrice. In this study nitrogen, phosphorus and potassium content and uptake in sorghum grain and stover were evaluated. Results revealed that different treatments had a significant effect on nutrient content and uptake in sorghum. Foliar spray of both green and chemical zinc oxide nanoparticles (ZnO NPs) was superior in results than conventional zinc sulphate heptahydrate ($ZnSO_4.7H_2O$) sources. The nutrient content of phosphorus and potassium in grain and stover at different intervals was superior with foliar spray of chemical ZnO NPs @ 1000 ppm. The total nutrient uptake of nitrogen, phosphorus and potassium in grain and stover was higher with foliar spray of green ZnO NPs @ 1000 ppm with increased biomass production and it was on par with foliar spray of chemical ZnO NPs @ 1000 ppm.

Keywords: ZnO NPs, foliar spray, green, chemical, bulk, nutrient uptake, content

Introduction
Sorghum (*Sorghum bicolor* L.) is the king of millets and the third most important crop in the country after rice and wheat. In India, it is most popularly known as "Jowar" and it is an important source of food, feed, fodder and ration for human, cattle and poultry. Its grains contain about 10-12% protein, 3% fat and 70% carbohydrate. *Rabi* sorghum is an important dry land crop grown in the Deccan Plateau on ~5.0 m ha area in the states of Maharashtra (3.28 m ha), Karnataka (1.40 m ha) and Andhra Pradesh (0.36 m ha) with an annual production of >4.71million tonnes. (Anon., 2021) [3]. In *rabi* sorghum, the fodder yield is more important than *kharif* sorghum. Grain quality is also as much important as the grain yield. For food and fodder quality, the benchmark is the popular landrace, Maldandi (M35-1). Micronutrients are important for maintaining plant health and for increasing the productivity of crops. Among the micronutrients, zinc (Zn) deficiency is the most detrimental to crop growth and yield of all the cereal crops including sorghum. Zinc acts either as the metal component or as a functional, structural or regulatory co-factor of a large number of enzymes. Apart from soil applications, foliar spray of nutrients is a practical means of replenishing the reservoir of nutrients in the leaves. The indiscriminate application of Zn fertilizers to the soil over years will lead to accumulation in soil and toxicity to the plants. At present, with a heavy emphasis on Zn in agriculture, care should be taken not to get overzealous with Zn applications. Gradual increase in Zn uptake could be observed with decreasing granule size. Since granules of 1.5 mm size weigh less than that of 2.0 or 2.5 mm, smaller granules were used resulting in a better distribution of Zn and the higher surface area of contact of Zn fertilizer resulted in better Zn uptake. Hence, the application of Zn fertilizer will give better results compared to bulk materials such as nanoparticles which are atomic or molecular aggregates with at least one dimension between 1 and 100 nm, which can drastically modify their physic-chemical properties compared to the bulk material. Owing to its high surface area to volume ratio, exhibits significantly novel and improved physical, chemical and biological properties, phenomena and its functions.

In recent years, remarkable progress has been made in developing nanotechnology and it also provides the tool and the technological platforms to investigate its effect on biological systems.

Moreover, nanotechnology is currently witnessing impressive advances in various directions such as synthesis of nanoparticles (NPs), understanding their fundamental physical and chemical properties and organization of complex Nano-scale matter using weak non-covalent interactions. (Adhikari *et al.*, 2015) [1].

Green nanotechnology has been described as the development of clean technologies, by minimizing potential environmental and human health risks associated with the manufacture and use of nanotechnology products, which are more environmental friendly with no toxic effects and are safe as compared to chemical Nanoparticles. It includes the synthesis of green Nano-products and using them to support sustainability will be a possible alternative to physical and chemical methods of Nano product synthesis.

Material and Methods

The field experiment was conducted at Gabbur village which is situated in North Eastern Dry Zone (Zone-2) of Karnataka at 16° 30´ N latitude and 77° 20´ E longitude with an altitude of 389 meters above the mean sea level and it is 30 km away from Main Agricultural Research Station, Raichur during *Rabi* 2019-20 in clay loam soil. The sorghum variety M 35-1 with duration of 120 days was sown on 17th October 2019 (*rabi*) with a spacing of 45cm x 15 cm. The design was a Randomized Block Design with 12 treatments and replicated thrice. The treatments consisted of T_1 - Control (pure water); T_2 - Soil application of $ZnSO_4.7H_2O$ @ 15 kg ha^{-1} (RPP); T_3 - FS of chemical ZnO NPs suspension @ 500 ppm; T_4 - FS of chemical ZnO NPs suspension @ 1000 ppm; T_5 - FS of chemical ZnO NPs suspension @ 1500 ppm; T_6- FS of green ZnO NPs suspension @ 500 ppm; T_7 - FS of green ZnO NPs suspension @ 1000 ppm; T_8 - FS of green ZnO NPs suspension @ 1500 ppm; T_9 - FS of bulk ZnO suspension @ 500 ppm; T_{10} - FS of bulk ZnO suspension @ 1000 ppm; T_{11} - FS of bulk ZnO suspension @ 1500ppm; T_{12} - FS of 0.5% $ZnSO_4.7H_2O$.

Soil application of NPK (50:25:0 kg ha^{-1}), FYM @ 2.5 t $ha^{-1,}$ and *Azospirullum* @ 500 g ha^{-1} is common for all the treatments except T_1. Foliar spray of ZnO NPs suspension at 20 and 40 DAS for all the treatments except T_1 and T_2.

ZnO nanoparticles were synthesized through a biological approach by using spinach leaf extract (Sagili *et al*., 2017) [12]. Commercial Nano ZnO procured from HI media Pvt. Ltd. company and $ZnSO_4$ were procured from SRL laboratory used as reference. The required concentration of zinc Nano-powder was dissolved in distilled water and kept for ultra-sonication @ 60 °C for 30 min to avoid aggregation before spraying. (Prasad *et al*., 2012) [10].

Results and Discussion

Nitrogen content and uptake in stover and grain of sorghum

The data pertaining to nitrogen content and its uptake by grain and straw are summarized in Table 1. Foliar spray of chemical ZnO NPs @ 1000 ppm recorded higher nitrogen content in stover (1.45%) and grain (1.49%) which was found to be significantly similar with FS of green ZnO NPs @ 1000 ppm in stover (1.43%) and grain (1.38%) followed by FS of bulk ZnO NPs @ 500 ppm. The higher nitrogen accumulation may be due to the positive relation between zinc and nitrogen content in stover. These results were in line with the views of Amin and Omidi (2015) [2] in maize by the application of ZnO NPs. The higher nitrogen content in grain could be due to zinc application since; zinc is essential for the synthesis of DNA and RNA and metabolisms for the production of carbohydrates, lipids, and proteins reported by Apoorva *et al.* (2017) [4] in rice grain.

Foliar spray of green ZnO NPs @ 1000 ppm recorded significantly higher nitrogen uptake in sorghum stover (327.73 kg ha^{-1}) which was followed by FS of chemical ZnO NPs @ 1000 ppm (322.68 kg ha^{-1}) and FS of bulk ZnO NPs @ 500 ppm (270.07 kg ha^{-1}). The positive correlation between zinc and nitrogen enhanced the uptake in stover by the foliar application of ZnO NPs. The application of zinc has a significant effect on chlorophyll synthesis which eventually resulted in the production of higher biomass yield and nutrient uptake (Ravi *et al.*, 2008) [11]. The data revealed that FS of chemical ZnO NPs @ 1000 ppm significantly increased the nitrogen uptake by grain (38.35 kg ha^{-1}) and was on par with FS of green ZnO NPs @ 1000 ppm (36.67 kg ha^{-1}). It appears that nitrogen uptake was enhanced with the application of zinc at higher concentrations through foliar spray which gave a positive response in grain N uptake as there is a synergistic interaction between nitrogen, zinc and sulphur (Patel *et al.*, 2019) [9].

Table 1: Effect of different nano zinc treatments on nitrogen content and uptake by sorghum

	Content (%)		Uptake (kg ha^{-1})		
Treatments	**Grain**	**Stover**	**Grain**	**Stover**	**Total**
T_1	1.07	0.86	18.32	156.49	174.81
T_2	1.30	1.04	27.92	212.14	240.06
T_3	1.23	1.00	25.85	197.94	223.79
T_4	1.49	1.45	38.35	322.68	361.03
T_5	1.24	0.96	27.97	185.13	213.10
T_6	1.25	1.04	29.06	198.99	228.05
T_7	1.38	1.43	36.67	327.73	364.40
T_8	1.24	1.06	29.98	205.36	235.34
T_9	1.30	1.24	32.02	270.07	302.09
T_{10}	1.28	0.94	25.67	182.45	208.12
T_{11}	1.24	1.18	24.71	223.66	248.37
T_{12}	1.33	1.23	29.44	258.23	287.67
S.Em±	0.06	0.04	1.25	10.22	11.73
CD @ 5%	0.18	0.24	3.66	29.98	34.71

Phosphorus content and uptake in stover and grain of sorghum

The data pertaining to phosphorus content and its uptake by grain and straw are summarized in Table 2. Phosphorus content in sorghum was found to be significantly superior with FS of green ZnO NPs @ 1000 ppm in stover (0.40%) and grain (0.70%) respectively and it was found to be on par with FS of chemical ZnO NPs @ 1000 ppm in stover (0.39%) and grain (0.67%) followed by bulk ZnO @ 500 ppm over the control. The increase in phosphorus content in stover might be due to the higher stover yield produced by the application of different zinc sources and also it might be due to high phloem mobility by foliar application of Zn (Bhantana *et al.*, 2020) [5]. However, the phosphorus content in grain and straw was found to decrease with the application of zinc. It might be due to the antagonistic effect of zinc on P absorption. Zinc was found to inhibit the translocation of P from root to top as reported by Apoorva *et al.* (2017) [4] in rice.

Phosphorus uptake in sorghum recorded significantly higher with FS of green ZnO NPs @ 1000 ppm in stover (93.96 kg ha^{-1}) and grain (18.65 kg ha^{-1}) which was followed by FS of chemical ZnO NPs @ 1000 ppm in stover (86.79 kg ha^{-1}) and grain (17.12 kg ha^{-1}) while control recorded the least stover and grain uptake of phosphorus. The lower concentration of zinc in soil significantly influenced the P uptake by stover. Foliar application of Nano Zn which has a large surface area and particle size less than the pore size of leaves of the plant can increase penetration into the plant tissues from the applied surface and improves uptake and nutrient use efficiency (Christian *et al.*, 2017) [6].

Table 2: Effect of different nano zinc treatments on phosphorus content and uptake by sorghum

	Content (%)		Uptake (kg ha^{-1})		
Treatments	**Grain**	**Stover**	**Grain**	**Stover**	**Total**
T_1	0.47	0.22	7.98	40.03	48.01
T_2	0.56	0.34	11.93	69.35	81.28
T_3	0.50	0.25	10.58	49.49	60.07
T_4	0.67	0.39	17.12	86.79	103.91
T_5	0.52	0.29	11.61	55.92	67.53
T_6	0.54	0.26	12.47	49.75	62.22
T_7	0.70	0.40	18.65	93.96	112.61
T_8	0.51	0.32	12.22	62.00	74.22
T_9	0.63	0.35	15.56	76.23	91.79
T_{10}	0.52	0.31	10.48	60.17	70.65
T_{11}	0.53	0.28	10.50	53.07	63.57
T_{12}	0.60	0.35	13.22	73.48	86.70
S.Em±	0.02	0.01	0.55	2.49	3.38
CD @ 5%	0.07	0.04	1.63	8.48	9.93

Potassium content and uptake in stover and grain of sorghum

The data pertaining to potassium content and its uptake by grain and straw are summarized in Table 3. Potassium content in sorghum was recorded higher with FS of chemical ZnO NPs @ 1000 ppm stover (1.68%) and grain (0.48%) followed by FS of green ZnO NPs @ 1000 ppm in stover (1.67%) and grain (0.46%) over the control (1.34% and 0.36%) in stover and grain of sorghum and rest of the treatments were found to be on par. These results conformed to Jangid *et al.* (2018) [7] by the application of RDF + nano ZnO foliar application at 1000 ppm. Due to the synergistic effect of zinc and potassium on the shoot and root growth, it enhanced the potassium content in grains of sorghum. The results were in agreement with the findings of (Apoorva *et al.*, 2017) [4].

Potassium uptake in sorghum significantly found higher results with FS of green ZnO NPs @ 1000 ppm in stover (378.15 kg ha^{-1}) and grain (12.88 kg ha^{-1}) which was followed by FS of chemical ZnO NPs @ 1000 ppm in stover (369.42 kg ha^{-1}) and grain (11.73 kg ha^{-1}). Due to the synergistic interaction between K and Zn, the increased photosynthetic activity in leaf exerted by micronutrient present in foliar spray indirectly lead to fruitful utilization of potassium. Applied zinc helps in the synthesis and translocation of enzymes and thus facilitates photosynthesis to enhance the potassium uptake in grain (Kumar and Singh, 2010) [8].

Table 3: Effect of different nano zinc treatments on potassium content and uptake by sorghum

	Content (%)		Uptake (kg ha^{-1})		
Treatments	**Grain**	**Stover**	**Grain**	**Stover**	**Total**
T_1	0.36	1.34	6.10	254.74	260.84
T_2	0.40	1.63	8.50	330.45	338.95
T_3	0.37	1.55	7.78	308.79	316.57
T_4	0.46	1.67	11.73	369.42	381.15
T_5	0.39	1.51	8.84	295.05	303.89
T_6	0.39	1.53	8.99	294.66	303.65
T_7	0.48	1.68	12.88	378.15	391.03
T_8	0.36	1.56	8.76	302.23	310.99
T_9	0.45	1.66	11.14	357.19	368.33
T_{10}	0.40	1.62	8.07	312.50	320.57
T_{11}	0.38	1.57	7.64	297.58	305.22
T_{12}	0.41	1.67	9.16	346.40	355.56
S.Em±	0.01	0.05	0.39	14.29	15.00
CD @ 5%	0.03	0.17	1.17	41.92	44.01

Conclusion

Foliar spray of chemical ZnO NPs @ 1000 ppm recorded higher nitrogen content in grain and stover of sorghum. Foliar spray of green ZnO NPs @ 1000 ppm recorded significantly higher nutrient content of phosphorus and potassium, uptake of nitrogen, phosphorus, and potassium in sorghum grain and stover. The biosynthesized ZnO NPs had a significant effect on nutrient uptake in sorghum grain and stover.

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