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Research Communication

Effects of ZnO nano-particles embedded nitrogen, phosphorus and potassium fertilizer on productivity, physical grain quality and nutrient harvest indices of aromatic rice (*Oryza sativa*)

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ABSTRACT

A field experiment on aromatic rice (*Oryza sativa* L.) was conducted during *kharif* 2018 at the research farm of ICAR–Indian Agricultural Research Institute, New Delhi, to know the effect of ZnO nano-particles [Nps; 38 nanometer (nm) mean particle size] embedded NPK fertilizer on grain yield, protein content and protein yield, physical grain quality, nitrogen harvest index (NHI), phosphorus harvest index (PHI) and potassium harvest index (KHI). The experiment consisting of 10 treatments, viz. control (0 : 0 : 0 N : P_2O_5 : K_2O kg/ha), 7.5 g ZnO Nps/ha alone, 100% nitrogen, phosphorus and potassium (NPK), 100% NPK (120, 60 and 40 kg/ha N, P_2O_5 and K_2O, respectively) + 5 kg Zn/ha through $ZnSO_4.7H_2O$, 100% NPK + 5 kg Zn/ha through ZnO (Bulk, i.e. size > 100 nm), 100% NPK + 7.5 g ZnO Nps/ha, 75% NPK + 7.5 g ZnO Nps/ha, 50% NPK + 7.5 g ZnO Nps/ha, 25% NPK + 7.5 g ZnO Nps/ha and 12.5% NPK+ 7.5 g ZnO Nps/ha, were laid out in a randomized block design with 3 replications. Application of 100% NPK + 7.5 g ZnO Nps/ha registered the highest grain yield and crude protein content which was at par with 75% NPK + 7.5 g ZnO Nps/ha. Not only yield and protein content, application of 100% NPK + 7.5 g ZnO Nps/ha also recorded the highest hulling, milling and head rice recovery which were statistically similar to application of 75% NPK + 7.5 g ZnO Nps/ha. However, non-significant difference was observed among fertilizer treatments with respect to rice grain length, breadth and length : breadth of milled rice. Significant improvement in nutrient harvest indices was noticed owing to combined application of ZnO Nps with NPK fertilizers over the control. Hence, it can be concluded that application of 75% NPK + 7.5 g ZnO Nps/ha is the best option for increased productivity and nutrient-use efficiency.

Key words: Grain yield, Head rice recovery, Nutrient harvest indices, Protein content, ZnO nano-fertilizer

Rice is one of the most widely cultivated crops, ranking third in area and second in production among arable crops in the world with an area and production of 159.8 million ha (Mha) and 740.9 million tonnes respectively (FAI, 2017–18). Being the staple food of south and south-east Asia, it occupies a crucial place in Indian agriculture, as it occupies the largest area (43.79 Mha) among the field crops and also stands first in production (112.9 million tonnes (DOES, 2019). However, since green revolution in India, the practice of intensive cultivation has deteriorated soil health due to imbalance, indiscriminate and non-judicious use of agro-inputs. Thereby, a decline in factor productivity of various agro-inputs has been seen over the years. Being an essential input for raising crops, nutrients play a significant role in achieving desired productivity of crops. However, faulty management practices like both over-use and under-use of fertilizers, imbalanced fertilization, lack of proper technical know-how are still prevailing among farmers. One of the most important problems among these is the imbalanced fertilization which has serious implications like nutrient mining. Therefore, balanced fertilization of soil should be taken into consideration for overcoming these issues. Nano-particles (Nps) are the materials of dimension 1–100 nano-meter (nm). These particles have unique characteristics which make them different from corresponding bulk particles of size having greater than 100 nm. It is the size, bonding properties of atoms, properties and behaviour of surface atoms in nanoparticles make it distinct *vis-a-vis* bulk particles. Due to larger surface area per unit volume, these particles behave

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differently. Of late, the use of ZnO nano-particles has occupied a unique place in agriculture. Prasad *et al*. (2012) noted that application of ZnO nano-particles at 1,000 ppm improved the germination of seeds, root growth, seedling vigour index, flowering and pod yield in peanut (*Arachis hypogaea* L.). Likewise, positive response has been seen in biomass production, the chlorophyll content and total soluble leaf protein content in *Cyamopsis tetragonoloba* and *Solanum lycopersicum* by foliar, applied nano-scale ZnO particles (Raliya and Tarafdar, 2013; Raliya *et al*. 2015). However, most of the earlier researchers have studied the effect of ZnO nano-particles on supplying zinc to plants *vis-a-vis* commonly used conventional source of zinc, i.e. zinc sulphate hepta-hydrate or zinc oxide. Limited literature is available on its use in combination with any sources of fertilizer like nitrogenous, phosphatic and potassium fertilizer on quality parameters of rice. Therefore, an investigation was conducted by conjunctively applying ZnO nano-particles with nitrogen, phosphorus and potassium (NPK) fertilizers to examine its impact on grain quality, nutrient harvest indices, protein content and protein yield and productivity of aromatic rice.

A field investigation was conducted during the rainy season (*kharif,* July–November) of 2018 at the research farm of the ICAR-Indian Agricultural Research Institute, New Delhi (28°38' N, 77°10' E and 228.6 metres above the mean sea-level). The texture of the experimental site was sandy clay loam (typic *Ustochrept*). Before conducting experiment, initial soil samples were analyzed to know about the fertility status of the soil. The soil was found to contain medium organic carbon (0.53%), low available N (210 kg/ha), medium available P (12.3 kg/ha) and medium available K (210.4 kg/ha) as per the procedures described by Prasad *et al.* (2006). The DTPA-extractable zinc in the experimental soil was 0.61 mg/kg (Lindsay and Norvell, 1978). Ten treatments, consisting of control (0 : 0 : 0 NPK kg/ha), 7.5 g ZnO Nps/ha alone, 100% NPK, 100% NPK + 5 kg Zn/ha through $ZnSO_4.7H_2O$, 100% NPK + 5 kg, Zn/ha through ZnO (Bulk), 100% NPK + 7.5 g ZnO Nps/ha, 75% NPK+ 7.5 g ZnO Nps/ha, 50% NPK + 7.5 g ZnO Nps/ha, 25% NPK + 7.5 g ZnO Nps/ha and 12.5% NPK+ 7.5 g ZnO Nps/ha, were laid out in a randomized block design with 3 replications. The gross plot size was 5 m × 4 m. Twenty-five kg seed of 'Pusa 1612' aromatic rice variety was used for raising nursery to transplant on 1 ha land. The entire amount of P, K, zinc sulphate heptahydrate, ZnO bulk as per the treatments were applied basal and 3 splits applications of N were done, i.e. 50% at transplanting and remaining through 2 equal splits 22 and 45 days after transplanting (DAT). The nano-zinc oxide fertilizer was dissolved uniformly in 1 litre water to make the suspension and it was added to NPK fertilizers. Then NPK fertilizers added with nano-zinc oxide fertilizer were uniformly applied to the soil before transplanting of the rice seedlings. The 24-day old seedlings were transplanted at spacing of 20 cm × 10 cm in the first fortnight of July, 2018. Other standard recommended agronomic practices were adopted for cultivation of rice. Hulling (%), milling (%) and head rice recovery (%) were calculated as per Cruz and Khush, (2000) and Govindswamy and Ghosh, (1969). The nutrient-harvest index (%) was computed as:

$$\text{Nutrient-harvest index (\%)} = \frac{\text{Nutrient uptake (kg/ha) by grain}}{\text{Nutrient uptake (kg/ha) by both (grain + straw)}} \times 100$$

The crude protein content (%) in rice grain was determined by multiplying N content obtained in grain with 5.95 (Juliano, 1985). The length (L), breadth (B) and length : breadth (L : B) of milled rice were recorded by taking 10 random milled rice from each tested treatment with the help of Seed Analyser Version 3.0 software (Osaw industrial Pvt. Ltd, Ambala, India). All the data collected during experimentation were statistically analyzed with the help of analysis of variance (ANOVA) using the F-test as per the procedure given by Gomez and Gomez (1984). Least significant difference (LSD) values at P=0.05 were used to determine the significance of difference between treatment means.

Application of 100% NPK + 7.5 g ZnO Nps/ha (~5.82 t/ha) resulted in the highest grain yield (Table 1) followed by 75% NPK + 7.5 g ZnO Nps/ha (~5.53 t/ha) which were significantly higher than rest of the treatments. The grain yield was comparable between 100% NPK + 5 kg Zn/ha through $ZnSO_4.7H_2O$ and 100% NPK + 5 kg Zn/ha through ZnO and remained significantly different from the other treatments. Application of 100% NPK resulted in grain yield of ~4.15 t/ha which remained significantly different from rest of the fertilizer treatments. The lowest grain yield was obtained in the control (~2.40 t/ha) being statistically at par with 7.5 g ZnO Nps/ha alone (~2.68 t/ha). The highest crude protein content in grain (Table 1) was found with the application of 100% NPK + 7.5 g ZnO Nps/ha which was similar to 75% NPK + 7.5 g ZnO Nps/ha. However, crude protein content was comparable between 100% NPK + 5 kg Zn/ha through $ZnSO_4.7H_2O$ and 100% NPK + 5 kg Zn/ha through ZnO bulk. The lowest crude protein content was observed in the control and followed by application of 7.5 g ZnO Nps/ha alone. The highest crude protein yield was produced with application of 100% NPK + 7.5 g ZnO Nps/ha which was significantly higher than the fertilizer treatments. Application of 75% NPK + 7.5 g ZnO Nps/ha resulted in crude protein yield of ~ 485.1 kg/ha. Applications of 100% NPK + 5 kg Zn/ha through $ZnSO_4.7H_2O$ and 100% NPK + 5 kg Zn/ha through ZnO bulk were comparable with respect to crude protein yield. The rice grain produced under the control treatment had the lowest crude protein yield. Application of ZnO nano-particles in conjunction with NPK fertilizers had a significant effect on hulling, milling and head rice recovery (Table 1). The highest hulling (%) was recorded with application of 100% NPK + 7.5 g ZnO Nps/ha followed by 75% NPK + 7.5 g ZnO Nps/ha. The hulling percentage was comparable between 100% NPK + 5 kg Zn/ha through $ZnSO_4.7H_2O$ and 100% NPK + 5 kg Zn/ha through ZnO bulk. Likewise, application of 100% NPK registered significant increase in hulling percentage compared to absolute control and also application of 7.5 g ZnO Nps/ha and remained at par with 50% NPK + 7.5 g ZnO Nps/ha. There was non-significant difference in hulling percentage recorded among treatments, viz. control, 7.5 g ZnO Nps/ha, 25% NPK + 7.5 g ZnO Nps/ha and 12.5% NPK + 7.5 g ZnO Nps/ha. The lowest milling recovery was recorded in the control, being at par with 7.5 ZnO Nps/ha and 12.5% NPK + 7.5 g ZnO Nps/ha, while milling recovery was the highest in 100% NPK + 7.5 ZnO Nps/ha which was statistically at par with 75% NPK + 7.5 ZnO Nps/ha. The milling recovery was comparable between 100% NPK + 5 kg Zn/ha through $ZnSO_4.7\ H_2O$ and 100% NPK + 5 kg Zn/ha through ZnO bulk. With respect to head rice recovery (%), it was the lowest in absolute control which was at par with 7.5 g ZnO Nps/ha, and 12.5% NPK + 7.5 g ZnO Nps/ha. Application of 100% NPK + 7.5 g ZnO Nps/ha recorded head rice recovery of ~62.9%. The head rice recovery was comparable between 100% NPK + 5 kg Zn/ha through $ZnSO_4.7\ H_2O$ and 100% NPK + 5 kg Zn/ha through ZnO bulk. The increase in hulling, milling and head rice recovery percentages with combined application of NPK fertilizers with ZnO nano-particles might be attributed to increasing N concentration of grain, consequently, the increased crude protein content of grain. It is well established fact that protein imparts strength to the grains. Thus, higher crude protein content owing to higher crude nitrogen content in grain resulted in decreased breakage loss. A researcher reported that the varieties with higher protein content suffered less breakage loss and attained increased milling percentage (Rani 2003). Moreover, enhancement in K concentration owing to combined application of both NPK and ZnO nano-particles might have helped in increasing crude protein content in grain, as the formation of proteins is catalyzed by the enzyme nitrate reductase and K is likely responsible for its activation and synthesis. The rice grain length, breadth and L : B of milled rice (Table 2) was not affected due to combined application of NPK fertilizers along with ZnO nano-particles. During experiment, it was found that nitrogen harvest index (NHI) was comparable among 100% NPK + 5 kg Zn/ha through $ZnSO_4.7\ H_2O$, 100% NPK + 5 kg Zn/ha through ZnO bulk, 100% NPK + 7.5 g ZnO Nps/ha and 75% NPK + 7.5 g ZnO Nps/ha. The treatments, viz. absolute control, 7.5 g ZnO Nps/ha alone and 25% NPK + 7.5 g ZnO Nps/ha, were also comparable with respect to NHI. The lowest phosphorus harvest index (PHI) was obtained under the control which remained at par with 7.5 ZnO Nps/ha alone, 100% NPK, 100% NPK + 5 kg Zn/ha through $ZnSO_4.7H_2O$, 100% NPK + 5 kg Zn/ha through ZnO bulk and 50% NPK + 7.5 g ZnO Nps/ha. There was non-significant difference with respect to potassium harvest index (KHI) (Table 2) in 100% NPK + 7.5 g ZnO Nps/ha and 75% NPK + 7.5 g ZnO Nps/ha; however, these treatments were significantly higher from rest of fertilizer treatments. Application of 100% NPK + 5 kg Zn/ha through $ZnSO_4.7H_2O$ was comparable with 100% NPK +

Table 1. Effect of ZnO nano-particles embedded nitrogen, phosphorus and potassium fertilizer on grain yield, crude protein content, protein yield and physical grain quality parameters of aromatic rice

Treatment	Grain yield (t/ha)	Crude protein content (%)	Protein yield (kg/ha)	Hulling (%)	Milling (%)	Head rice recovery (%)
Absolute control	2.40	6.7	160.4	72.0	61.8	53.0
7.5 g ZnO Nps/ha	2.68	6.9	186.0	72.0	61.9	53.1
100% NPK	4.15	8.3	345.7	76.0	65.9	57.5
100% NPK + 5 kg Zn/ha through $ZnSO_4.7\ H_2O$	5.10	8.4	429.0	78.0	67.9	59.5
100% NPK + 5 kg Zn/ha through ZnO	4.85	8.4	406.0	77.5	67.5	59.1
100% NPK + 7.5 g ZnO Nps/ha	5.82	8.8	513.6	80.3	70.3	62.9
75% NPK + 7.5 g ZnO Nps/ha	5.53	8.8	485.1	80.0	69.8	61.9
50% NPK + 7.5 g ZnO Nps/ha	3.65	8.0	292.5	74.9	64.8	56.2
25% NPK + 7.5 g ZnO Nps/ha	3.10	7.6	234.3	73.5	63.4	54.6
12.5% NPK + 7.5 g ZnO Nps/ha	2.84	7.1	201.9	72.9	62.9	54.1
SEm±	0.10	0.10	8.70	0.47	0.50	0.48
CD (P=0.05)	0.30	0.31	25.86	1.39	1.48	1.41

ZnO Nps, ZnO nano-particles; 100% NPK, 120 : 60 : 40 (N : P_2O_5 : K_2O) kg/ha.

Table 2. Effect of ZnO nano-particles embedded nitrogen, phosphorus and potassium fertilizer on grain length, breadth and length : breadth ratio of milled rice and nutrient harvest indices of aromatic rice

Treatment	Length (mm)	Breadth (mm)	Length : breadth ratio	Nitrogen harvest index (%)	Phosphorus harvest index (%)	Potassium harvest index (%)
Absolute control	5.30	1.21	4.32	61.1	55.2	11.5
7.5 g ZnO Nps/ha	5.38	1.19	4.58	59.1	55.9	11.9
100% NPK	5.42	1.22	4.46	61.8	55.8	13.7
100% NPK + 5 kg Zn/ha through $ZnSO_4.7H_2O$	5.44	1.22	4.50	64.5	56.2	14.8
100% NPK + 5 kg Zn/ha through ZnO	5.42	1.20	4.53	64.4	56.7	15.1
100% NPK + 7.5 g ZnO Nps/ha	5.51	1.19	4.62	65.3	58.5	17.3
75% NPK + 7.5 g ZnO Nps/ha	5.46	1.26	4.36	65.6	57.5	16.5
50% NPK + 7.5 g ZnO Nps/ha	5.41	1.24	4.38	63.0	55.4	13.3
25% NPK + 7.5 g ZnO Nps/ha	5.33	1.20	4.48	61.9	59.1	12.7
12.5% NPK + 7.5 g ZnO Nps/ha	5.32	1.21	4.42	61.0	57.5	12.2
SEm±	0.07	0.02	0.11	0.77	0.62	0.38
CD (*P*=0.05)	NS	NS	NS	2.30	1.85	1.14

ZnO Nps, ZnO nano-particles; 100% NPK, 120 : 60 : 40 (N : P_2O_5 : K_2O) kg/ha; NS, non-significant.

5 kg Zn/ha through ZnO bulk with respect to KHI. The lowest KHI was obtained in control which remained at par with 7.5 g ZnO Nps/ha alone and 12.5% NPK + 7.5 g ZnO Nps/ha. The higher harvest index at higher rate of NPK along with ZnO nano-particles was owing to combined result of higher NPK concentration and higher grain yield.

Based on the results obtained from the experiment, it may be inferred that combined application of NPK fertilizer along with ZnO nano-particles can be an effective strategy for balanced fertilization and improvement of productivity and grain quality of aromatic rice.

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