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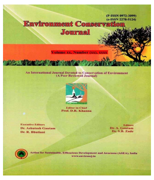

# Effect of zinc and silicon nanoparticles on yield, quality and economics of lowland paddy

**Soumya Karchedu** ✉

Department of Agronomy, KSNUAHS, Navile, Shivmogga., India.

**Gubbi Koteodayar Girijesh**

Department of Agronomy, KSNUAHS, Navile, Shivmogga.India.

**Sarvajna Basavarajayya Salimath**

Department of Soil science and Agricultural Chemistry, KSNUAHS, Navile, Shivmogga, India.

**Veeranna Hanchinmani**

Department of Agronomy, KSNUAHS, Navile, Shivmogga., India.

**Dushyanthkumar Banur Marulasiddappa**

Department of Genetics and Plant Breeding, KSNUAHS, Navile, Shivmogga., India.

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## ABSTRACT

**An investigation to know the effect of nano zinc and silicon on quality and yield of rice was conducted at AHRS, Bavikere, KSNUAHS, Shivamogga. The experiment consisted 12 treatments replicated thrice and was laid in completely randomized block design. The different treatment combinations of seed treatment of nano zinc and silicon, foliar spray of zinc and silicon nanoparticles were compared with conventional sources and the control. Application of both zinc and silicon (T6) in nano form as foliar @ 40 ppm each at 40 DAT registered significantly higher no. of productive tillers (18.72), protein content (11.41 %), starch content (75.70 %) grain yield (6034 kg/ha), straw yield (6693 kg/ha) with higher economic net returns (98631 Rs ha$^{-1}$), foliar spray of zinc nano particles alone @ 40 ppm at 40 DAT showed next best results.**

## Introduction

Rice, grown in global area of 162.06 m ha, serves as a staple food crop of most populated continent Asia and alone in India it occupies 43.39 m ha area with 104.32 million tonnes of production and 2404 kg/ha of productivity (Anon., 2020). About two billion people are benefitted with secure livelihood through paddy cultivation. Exponentially growing population in the country is barring boundaries and the demand to fulfill the hungry stomach is a nutcracking job. To ensure national food security and food sufficiency, by the end of this decade there is an urge for increasing productivity by 4.03 t/ha in order to meet the growing demand of milled rice (130 m tonnes) (Anon., 2021). Nutrient management is the most effective agronomic key factor for enhancing productivity in rice cultivation as it has quick response. The importance of macro nutrients (nitrogen, phosphorus and potassium) is well-known by the farmers and supplementing these by chemical fertilizers is now a mandatory practice. But, micro and beneficial nutrients are also deciding factors for good harvest in rice. Any deficiency during critical stages-tillering, panicle initiation and grain filling results in drastic yield loss (Boonchuay *et al.*, 2013). Zinc, a micronutrient is inevitably important to humans, animals and plants as well. It is directly involved in reducing oxidative stress which safeguards plant cell wall and stabilize chromosomal fraction. Being directly involved in auxins and nitrogen metabolism it has a vital role to play in enhancing enzymatic activities. Silicon, Despite the fact that it doesn't fix in an essential element list but tops at beneficial elements especially for rice. Wholesome effect of silicon is evidently seen in cereals particularly in rice and is tagged as siliciferous cereal. Silicon is less mobile in plants

**Corresponding author E-mail:** *soumyak12796@gmail.com*

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and its constant supply is essential for sustainable production (Pati *et al.,* 2016). Silicon has ample of benefits like protection from abiotic and biotic stress, reduce toxicity of elements like Mn, Fe, Cd and Al. it also enhances the availability of nutrients to the plant (N, P, K, Ca, Mg, S, and Zn) (Wattanapayapkul *et al.*, 2011). Today major constrain in rice cultivation that has to be addressed right away is low nutrient use efficiency caused due to runoff, leaching (less retention in soil) resulting in low absorption by the plants. Best way to tackle this problem is by adopting innovative technologies that are effective. in increasing nutrient use efficiency. Nanotechnology which is an engineering technique of manipulating of materials at smallest scale of 1 to 100 nanometers size. Its small size reduces the quantity of application when compared to conventional fertilizers and are also environmentally friendly. Application of nanotechnology in agriculture was seldom and now it is holding its ground in agricultural as nano fertilizers or some time quoted as smart fertilizers. What makes them smart is the increase in release rate of elements and reduce the time of uptake that would coincide to the critical stages of the crop and fulfill its nutritional demands. In Indian nanotechnology has an ability to bring huge transformation in fertilizer manufacturing, usage pattern and reducing losses.

## Material and Methods

This investigation was conducted in the field of Zonal Agricultural and Horticultural Research Station (AHRS), Bavikere, UAHS, Shivamogga (Figure 1) located at 75°51` E longitude and 13°42` N latitude at an altitude of 695 meters above the mean sea level. The 12 treatments were laid in randomized block design. The variety used was Sahyadrimegha, and the crop was taken up in *Kharif.* The treatment details are seeds were treated with zinc nanoparticles (100 ppm) ($T_1$), seeds treated with silicon nanoparticles (200 ppm) ($T_2$), combination of $T_1$ and $T_2$ ($T_3$), foliar spray of zinc nanoparticles (40 ppm) at 40 DAT ($T_4$), foliar spray of silicon nanoparticles (40 ppm) at 40 DAT ($T_5$), combination of $T_4$ and $T_5$ ($T_6$), EDTA $ZnSO_4$ (0.5%) foliar spray at 40 DAT ($T_7$), potassium silicate (0.5%) foliar spray at 40 DAT ($T_8$), EDTA $ZnSO_4$ and Potassium silicate foliar spray @ 0.5% at 40 DAT ($T_9$), zinc sulphate soil application @ 25 kg/ha ($T_{10}$), rice hull ash soil application @ 2 t/ha ($T_{11}$) and control ($T_{12}$). All the treatments were replicated thrice. The seeds were subjected to priming with nano zinc and silicon for twelve hours as per the treatments. The sowing of these treated seeds was taken up in different nursery beds. Two to three seedling per hill were transplanted at 20*10 spacing. The nano zinc and silicon solution of different concentrations were prepared with the help of sonicator and was sprayed to the crop at prescribed intervals. Along with FYM @ 10 t/ha, recommended dose of fertilizers (100:50:50 kg N: $P_2O_5$: $K_2O$) were applied in common to all the treatments. The timely observations on growth, yield attributes and yield were recorded at different growth stages of the crop (30, 60, 90 DAT and at harvest). leaves (YFELs) were used to examine leaf morphology and structure using scanning electron microscope (SEM) following processing as described by Li *et al.* (2017).

**Figure 1: General view of experimental plot**

## Results and Discussion

### Yield attributes

Increased no. of productive tillers hill$^{-1}$ (18.72), filled grains (100.5 hill$^{-1}$), panicle length (27.6 cm), grain yield hill$^{-1}$ (13.63) and test weight were obtained with foliar spray of zinc and silicon nanoparticles each @ 40ppm @ 40 DAT. This was statistically best when compared to remaining treatments with regard to productive tillers, panicle length and grain yield per hill except foliar spray of zinc nanoparticles (40 ppm) at 40 DAT (17.26, 26.5 and 12.7, respectively) which recorded on par results. Whereas, in the case of number of filled grains hill$^{-1}$, zinc treatments ($T_4$, $T_1$, and $T_7$) were found on par and significantly excelled over soil application of $ZnSO_4$ (25 kg/ha). The 1000 grains weighed (test weight) across treatments indicate significant differences among treatments with highest being registered with zinc and silicon nanoparticles (40 ppm) foliar spray @ 40 DAT (24.82 g). This was significantly superior over treatments; control (22.30 g) and rice hull ash application @ 2 t/ha (22.77 g) and on par with rest of the treatments. Foliar spray of zinc either in the form of EDTA $ZnSO_4$ (0.5%) or nanoparticles, seed treatment with nano zinc @ 100 ppm were found to be significantly superior over plots which received $ZnSO_4$ as soil application @ 25 kg/ha with respect to panicle baring tillers, length of the panicle, no. of filled grains panicle$^{-1}$ and yield hill$^{-1}$. The 1000 grain weight did not vary among zinc treatments irrespective of source and method.The silicon treatment viz., seed treatment in nano form @ 200 ppm, foliar application @ 40 ppm @ 40 DAT and potassium silicate (0.5 %) foliar spray @ 40 DAT were found to be statistically significant over soil application of rice hull ash @ 2 t/ha in recording productive tiller, panicle length and filled grains panicle$^{-1}$ over rice hull ash which registered the least values for these parameters (10.65, 19.2 cm and 73, respectively). All silicon treatments ($T_2$, $T_5$, $T_8$ and $T_{11}$) are on par with respect to grain yield per hill and test weight but in order of merit numerically. The plots which received both zinc and silicon ($T_6$, $T_9$ and $T_3$) showed statistical differences in yield parameters except test weight. Foliar spray of zinc and silicon nanoparticles both @ 40 ppm @ 40 DAT resulted in significantly higher number of productive tillers (18.72) and panicle length (27.6 cm) over EDTA $ZnSO_4$ (0.5 %) and potassium silicate (0.5%) foliar spray (16.18 and 22.4 cm) and seed treatments with nano from (14.72 and 22.1 cm). With respect to filled grains and grain yield hill$^{-1}$, nano form is on par with conventional source of silicon and significantly superior over seed treatment. Treatment $T_6$, $T_9$ and $T_3$ is in the order of merit and is presented in the Table 1. In paddy, panicle size is affected by adverse environmental conditions. Any biotic or abiotic stress like drought, high temperature and diseases can reduce panicle length, hence application of silicon helps the plant to overcome the stress there by increase panicle size. Silicon is reported to improve panicle fertility and number of filled grains; and panicle length (Wang *et al.*, 2015) and are less prone to blast (Wattanapayapkul *et al.*, 2011). Further, nano zinc is also known to increase panicle length (Anzer-Alam and Kumar, 2015), number of spikelets per panicle and test weight and grain weight (Ghasemi *et al.*, 2014). Application of nano zinc at panicle initiation meet out the nutritional requirement and helps in grain filling, silicon on the other hand reduce stress level. Therefore, the synergetic effect of both zinc and silicon is reflected in grain yield of rice, since, most of the dry matter accumulation in the grain gets increased up to 15 to 20 days after flowering. Hence, applying silicon and zinc in nano form at panicle initiation will help to overcome stress, meet out nutritional demand thereby increased filled grains and test weight. Test weight (1000 grains) is an index of grain yield. The grain weighed across treatments indicates significant variations among treatments with highest being registered with foliar spray of both zinc (40 ppm) and silicon (40 ppm) nanoparticles at 40 DAT (24.82 g) (Table 1). Zinc deficiency can lead to reduction in grain number and grain weight and the response of plant also related to uptake of Zn from soil. Ghasemi *et al.* (2014) reported highest grain weight with nano zinc oxide application @ 20 and 40 ppm at panicle initiation and full heading stage.Further, lesser chaffy seeds were recorded in treatment with foliar spray of both zinc (40 ppm) and silicon (40 ppm) nanoparticles at 40 DAT ($T_6$) i.e., 67.11 per cent less than control, 12.5 per cent less than $T_3$ and 6.58 per cent less than $T_9$ is another reason for higher grain yield. As a result of less carbohydrate accumulation in the plant, insufficient carbohydrates translocation to sink (lower harvest index) leading to more chaffiness in treatments viz., control, rice hull ash application and conventional sources (Table 1). The results are in line with findings of Lavinsky *et al.* (2016) who reported higher filled grains per hill with the application of nano silicon at reproductive stage. As per grain yield is concerned, it is directly influenced by the yield attributes the best treatment $T_6$ recorded highest grain yield, straw yield and harvest index.

**Grain yield**

The treatments receiving both zinc and silicon nanoparticles foliar spray ($T_6$) each at 40 ppm each

Table 1: Effect of application methods of nano zinc and silicon on yield parameters of paddy

| Treatments | No. of productive tillers hill$^{-1}$ | Panicle length (cm) | No. of filled grains Panicle$^{-1}$ | Grain Yield hill$^{-1}$ (g) | Chaffiness (%) | Test weight (g) |
|---|---|---|---|---|---|---|
| $T_1$: ST with nano zinc @ 100 ppm | 13.14 | 22.0 | 92.9 | 10.87 | 06.0 | 22.87 |
| $T_2$: ST with nano silicon @ 200 ppm | 13.77 | 21.9 | 90.0 | 09.38 | 07.9 | 22.77 |
| $T_3$: ST with zinc (100 ppm) and silicon (200ppm) nanoparticles | 14.72 | 22.1 | 93.0 | 10.68 | 06.9 | 23.53 |
| $T_4$: FA of zinc (40 ppm) nanoparticles at 40 DAT | 17.26 | 26.5 | 95.4 | 12.87 | 05.1 | 23.91 |
| $T_5$: FA of silicon (40 ppm) nanoparticles at 40 DAT | 12.82 | 22.5 | 89.1 | 08.76 | 07.1 | 22.98 |
| $T_6$: FA of zinc and silicon nano particles both @ 40 ppm at 40 DAT | 18.72 | 27.6 | 100.5 | 13.63 | 05.0 | 24.82 |
| $T_7$: EDTA $ZnSO_4$ foliar spray @ 0.5% at 40 DAT | 12.88 | 21.7 | 90.0 | 09.49 | 06.0 | 23.71 |
| $T_8$: Potassium silicate foliar spray @ 0.5% at 40 DAT | 13.48 | 21.0 | 80.3 | 08.10 | 08.1 | 22.71 |
| $T_9$: EDTA $ZnSO_4$ and Potassium silicate foliar spray @ 0.5 % at 40 DAT | 16.18 | 22.4 | 95.9 | 12.00 | 06.0 | 23.84 |
| $T_{10}$: Zinc sulphate soil application @ 25 kg/ha | 12.06 | 19.2 | 68.4 | 08.45 | 13.7 | 22.49 |
| $T_{11}$: Rice hull ash soil application @ 2 t/ha | 10.65 | 18.6 | 73.0 | 07.85 | 12.4 | 22.77 |
| $T_{12}$: Control | 9.89 | 18.2 | 68.2 | 07.18 | 15.2 | 22.30 |
| S.Em+/- | 0.73 | 0.62 | 2.48 | 00.59 | 0.77 | 0.76 |
| C.D. at 5% | 2.15 | 1.83 | 7.27 | 01.72 | 2.26 | 2.22 |

@ 40 DAT recorded highest grain yield of 6034 kg/ha (Table 2.) which was significantly superior over all other treatments excluding the treatments with zinc nanoparticles (40 ppm) foliar spray at 40 DAT which recorded 5720 kg/ha of grain yield. Foliar application of both zinc and silicon in nano form was found to be superior over corresponding seed treatment (5212 kg/ha). In treatments with zinc alone; zinc and silicon nanoparticles foliar spray both @ 40 ppm @ 40 DAT registered highest grain yield of 5720 kg/ha than nano zinc (100 ppm) seed treatment (4815 kg/ha) and EDTA zinc sulphate (0.5 %) foliar (4624 kg/ha) and $ZnSO_4$ (25 kg/ha) as soil application (4732 kg/ha) including control. With regard to silicon, foliar application of nano form (4391 kg/ha) and spray of potassium silicate at 40 DAT (4300 kg/ha) recorded lower yield when compare to seed treatments with nano silicon (5308 kg/ha). Among nano particle treatments, foliar application of nano zinc was found superior than nano zinc seed treatment and EDTA form and the results were in line with Rana *et al.*, 2014. Similarly, in silicon applications, seed treatment with nano form significantly excelled over other foliar application of nano form and conventional potassium silicate and rice hull ash soil application at 2 t/ha. The treatment receiving both zinc and silicon showed that foliar applications > conventional form > seed treatments are in the order. Least grain yield was registered in control plot (4274 kg/ha). Grain yield is the result of genotype, climate, soil and also the agronomic management practices. Grain is the final economical part of the plant which is of greater importance. Similarly, Kheyri *et al.* (2019) have reported no significant difference between combined and sole application of zinc and silicon nano particles for foliar application. The yield improvement in these two treatments was to an extent of 41 and 33.83, 20 and 11.8, and 12 and 4.72 per cent over control ($T_{12}$), seed treatments with both nano silicon and silicon ($T_3$) and combined application of zinc and silicon in conventional form ($T_9$), respectively. The increase in yields due to application of both silicon and zinc in nano form as foliar @ 40 DAT is attributed to higher silicon and zinc uptake i.e., 0.98 and 20.8 and 0.86 and 20.9

**Table 2: Effect of zinc and silicon nanoparticles on straw yield, grain yield and harvest index of paddy**

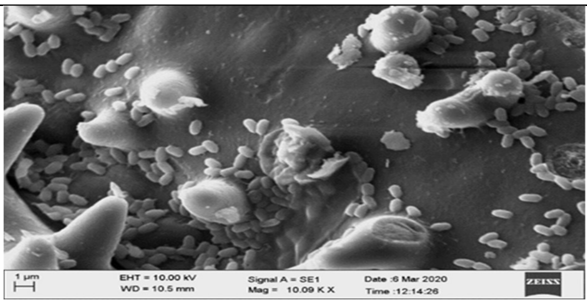
| Treatments | Grain yield (kg/ha) | Straw yield (kg/ha) | Harvest index (%) |
|---|---|---|---|
| T1: ST with nano zinc @ 100 ppm | 4815 | 5329 | 47.5 |
| T2: ST with nano silicon @ 200 ppm | 5308 | 5947 | 47.2 |
| T3: ST with zinc (100 ppm) and silicon (200ppm) nanoparticles | 5212 | 5761 | 47.5 |
| T4: FA of zinc (40 ppm) nanoparticles at 40 DAT | 5720 | 6131 | 48.3 |
| T5: FA of silicon (40 ppm) nanoparticles at 40 DAT | 4391 | 4991 | 47.0 |
| T6: FA of zinc and silicon nanoparticles both @ 40 ppm at 40 DAT | 6034 | 6693 | 48.4 |
| T7: EDTA ZnSO4 foliar spray @ 0.5% at 40 DAT | 4624 | 5152 | 47.3 |
| T8: Potassium silicate foliar spray @ 0.5% at 40 DAT | 4300 | 4971 | 46.4 |
| T9: EDTA ZnSO4 and Potassium silicate foliar spray @ 0.5 % at 40 DAT | 5541 | 6084 | 47.7 |
| T10: Zinc sulphate soil application @ 25 kg/ha | 4732 | 5734 | 46.8 |
| T11: Rice hull ash soil application @ 2 t/ha | 4278 | 4823 | 46.2 |
| T12: Control | 4274 | 4550 | 45.2 |
| S.Em+/- | 148.79 | 137.1 | 1.57 |
| C.D. at 5% | 436.4 | 461 | 4.61 |

**Table 3: Effect of zinc and silicon nanoparticles on protein and starch content of rice**

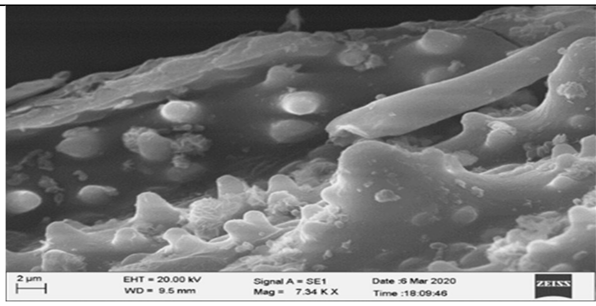
| Treatments | Proteincontent (%) | Starch content (%) |
|---|---|---|
| $T_1$: ST with nano zinc @ 100 ppm | 11.27 | 72.00 |
| $T_2$: ST with nano silicon @ 200 ppm | 10.87 | 74.97 |
| $T_3$: ST with zinc (100 ppm) and silicon (200ppm) nanoparticles | 11.33 | 72.81 |
| $T_4$: FA of zinc (40 ppm) nanoparticles at 40 DAT | 11.34 | 74.80 |
| $T_5$: FA of silicon (40 ppm) nanoparticles at 40 DAT | 10.42 | 73.11 |
| $T_6$: FA of zinc and silicon nanoparticles both @ 40 ppm at 40 DAT | 11.41 | 75.70 |
| $T_7$: EDTA $ZnSO_4$ foliar spray @ 0.5% at 40 DAT | 10.69 | 71.56 |
| $T_8$: Potassium silicate foliar spray @ 0.5% at 40 DAT | 10.40 | 74.82 |
| $T_9$: EDTA $ZnSO_4$ and Potassium silicate foliar spray @ 0.5 % at 40 DAT | 10.96 | 74.23 |
| $T_{10}$: Zinc sulphate soil application @ 25 kg/ha | 10.53 | 73.38 |
| $T_{11}$: Rice hull ash soil application @ 2 t/ha | 10.45 | 73.78 |
| $T_{12}$: Control | 10.34 | 70.17 |
| S.Em+/- | 0.49 | 3.64 |
| C.D. at 5% | NS | NS |

kg/ha zinc and silicon by straw and grain, respectively and improvement in yield components. The SEM analysis of the leaf sample (Fig. 1) collected after the foliar application showed the presence of nano particles which justifies the fast entry of the nutrients into the site of action. This hampers the accumulation of the zinc and silicon in the plant system. It was seen that the more nano particles were accumulated near and around the chloroplast. The nano particles took their entry through the epidermis as well as stomata. However, the leaf samples of the treatment receiving seed priming (Fig. 2) did not exhibit any nano particles this was due to the fact that nano particles absorbed during priming were completely utilized by the plant system.

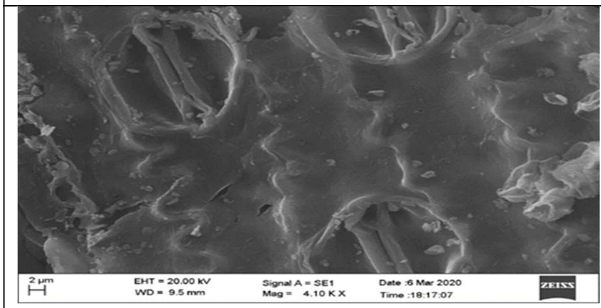
Higher silicon uptake was noticed in seed treatment than foliar application and conventional source. Similarly, Lavinsky *et al.* (2016) reported 45 per cent higher grain yield due to application of silicon at panicle initiation stage. It is in line as opined by Kheyri *et al.* (2019) that the higher yields due to foliar application of nano zinc and silicon can be reasoned out for zinc activity which involved in enzyme activation and thereby increases dry matter production. Which will be stored in the sink.



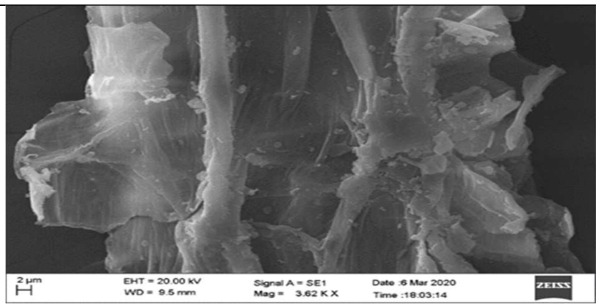
**a. SEM images of T6.**



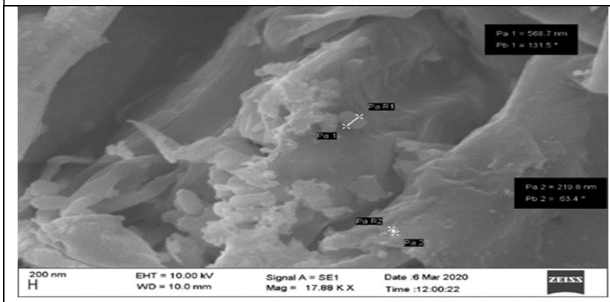
**d. SEM images of T3**



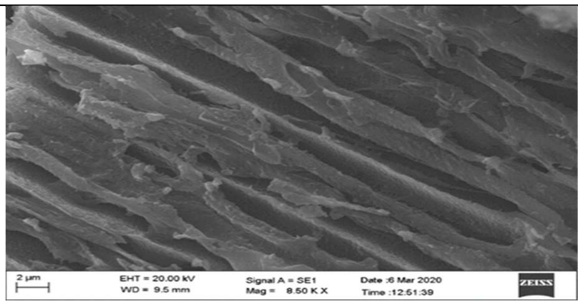
**b.SEM images of T5.**



**e.SEM images of T2.**



**c. SEM images of T4.**



**f. SEM images of T1.**

**Figure 2: SEM images of leaf samples of nano zinc and silicon treated treatments. (a. SEM images of treatment $T_6$, b-$T_5$, c-$T_4$, d-$T_3$, e-$T_2$, f-$T_1$ respectively).**

## Straw yield

The same trend as of yield attributes and grain yield was seen in straw yield and also harvest index. Highest straw yield (6693 kg/ha) was recorded in treatment $T_6$ (Table 2.), foliar application of zinc nanoparticles at 100 ppm (6131 kg/ha) was the next best treatment and followed by foliar application of EDTA zinc sulphate and potassium silicate each @ 0.5 per cent. Control treatment recorded the least with 4550 kg/ha. Harvest index was also recorded higher (48.4 %) in the same treatment and was closely followed by $T_4$ (48.3 %) and foliar application of both EDTA zinc and potassium @ 0.5 per cent (47.7 %).

## Quality parameters

### Protein content

Statistically no significant differences were observed among the treatments. However, numerically superior protein content (11.41 %) was recorded in treatment with foliar spray of zinc and silicon nanoparticles both at 40 ppm at 40 DAT, closely followed by the treatments receiving nano zinc as foliar @ 40 ppm at 40 DAT, treatment receiving both nano zinc (100 ppm) and silicon (200 ppm) seed treatment (11.33 %) and treatment receiving seed treatment with nano zinc (100 ppm) (11.27 %) as presented in Table 3.

**Table 4: Effect of zinc and silicon nanoparticles on economics of rice**

| Treatments | Gross returns (Rs/ ha) | COC (Rs/ha[1]) | Net returns (Rs/ha) | B:C |
|---|---|---|---|---|
| $T_1$: ST with nano zinc @ 100 ppm | 94663 | 33427 | 61236 | 1.8 |
| $T_2$: ST with nano silicon @ 200 ppm | 97465 | 35750 | 61715 | 1.7 |
| $T_3$: ST with zinc (100 ppm) and silicon (200ppm) nanoparticles | 102458 | 35217 | 67241 | 1.9 |
| $T_4$: FA of zinc (40 ppm) nanoparticles at 40 DAT | 112155 | 35347 | 76808 | 2.2 |
| $T_5$: FA of silicon (40 ppm) nanoparticles at 40 DAT | 92517 | 35276 | 57241 | 1.6 |
| $T_6$: FA of zinc and silicon nanoparticles both @ 40 ppm at 40 DAT | 138294 | 39663 | 98631 | 2.5 |
| $T_7$: EDTA $ZnSO_4$ foliar spray @ 0.5% at 40 DAT | 89969 | 34290 | 55679 | 1.6 |
| $T_8$: Potassium silicate foliar spray @ 0.5% at 40 DAT | 80883 | 32427 | 48456 | 1.5 |
| $T_9$: EDTA $ZnSO_4$ and Potassium silicate foliar spray @ 0.5 % at 40 DAT | 108840 | 35757 | 73083 | 2.0 |
| $T_{10}$: Zinc sulphate soil application @ 25 kg/ha | 82589 | 33010 | 49579 | 1.5 |
| $T_{11}$: Rice hull ash soil application @ 2 t/ha | 74133 | 31460 | 42673 | 1.4 |
| $T_{12}$: Control | 65008 | 29960 | 35048 | 1.2 |

Foliar application was superior over seed treatment and soil application. Treatments $T_6 > T_4 > T_3 > T_1 > T_9$ are in the order of merit. Protein content increased by 10.33 per cent in the plot treated with foliar spray of both zinc (40 ppm) and silicon (40 ppm) nanoparticles at 40 DAT ($T_6$) and 9.66 per cent with foliar application of zinc in nano form which was on par. Higher protein content is mainly attributed to role played by Zn enzyme activation which are directly involved in carbohydrate metabolism, protein synthesis, auxin regulation and pollen formation. Protein content is highly correlated with a value r = 0.82 to zinc and silicon uptake. Similar results recorded by Rehman *et al.* (2012). Further, Sharifi *et al.* (2016) have also recorded higher wet gluten content, sedimentation value and protein content in wheat due to zinc application. Silicon mitigates the adverse drought condition and increases amylose content which in later stages leads to protein formation. Improvement in crude protein and total carbohydrate of radish roots was reported by Mahmoud *et al.* (2019).

**Starch content**

The treatment with foliar spray of zinc and silicon nanoparticles both @ 40 ppm at 40 DAT recorded numerically higher starch content (75.7 %) closely followed by silicon nanoparticles (200 ppm) seed treatment (74.97 %), and treatment receiving potassium silicate foliar spray (0.5 %) at 40 DAT (74.82 %). Least starch content was noticed in control treatment (70.17 %). But no statistical significance was found among the treatments (Table 3.). Application of zinc and silicon nanoparticles as foliar spray or seed treatment did not have significant effect on starch content. Improvement in starch content was to an extent of 7.88 and 6.84 per cent in $T_6$ and $T_2$ when compared to control, respectively. It is due to the deficiency of other essential elements at the early stages.

**Economics**

Increased net returns, gross returns and B:C ratio were obtained in the treatment receiving foliar spray of zinc and silicon nanoparticles both @ 40 ppm at 40 DAT (Rs. 1,38,294, Rs. 98,631 and 2.5, respectively) as indicated in Table 4., followed by the treatment receiving foliar spray of zinc (40 ppm) nanoparticles at 40 DAT (Rs.1,12,155, Rs. 76,808 and 2.2, respectively) and the treatment receiving foliar application of both EDTA $ZnSO_4$ and potassium silicate each @ 0.5 per cent (Rs.1,08,840, Rs. 73,083 and 2.0, respectively). Whereas, least was recorded in the control (Rs. 65,008, Rs. 35,048 and 1:2, respectively). Zinc and silicon in nano forms are highly efficient and are required in less quantity when applied as foliar due to reduced losses. Higher benefit cost ratio is due to the higher yield and higher market prize for economic and biological yield.

## Conclusion

It is evident from the present investigation that the foliar application of both zinc (40 ppm) and silicon (40 ppm) nanoparticles at 40 DAT on enhanced no. of productive tillers, no. of panicles, filled grains, total grain yield, straw yield and net returns. Further nutrients supplied in nano form increases the efficacy by enhancing their availability directly at the site of action hence is the best know way to increase nutrient use efficiency and render higher returns to the farmers.

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## Conflict of interest

The authors declare that they have no conflict of interest.

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