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Evaluation of effect of Nano Particles on Seed Quality Attributes in Paddy (*Oryza sativa* L.)

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ABSTRACT: The studies were carried out on paddy variety Pusa Basmati 1509 at ICAR- Indian Agricultural Research Institute, New Delhi during 2020-21 with the objective to study the effect of nanoparticles on seed quality parameters. The goal of this study is to draw a systematic and comprehensive picture of quality attributes on seed of paddy which enhance the production and productivity of paddy. The seeds were dry dressed and infused with each of nano and bulk forms of Zinc oxide, Titanium oxide, Silicon dioxide @ 50, 100, 250, 500 and 750ppm along with the two controls *i.e.*, untreated and treated with recommended PoP (Thiram treated @2g/Kg of seeds) and were evaluated for various seed quality parameters Present investigation revealed that, the highest radicle emergence percentage (95.3%) and numerically highest field emergence percentage (97.3%) was recorded in Dry Nano ZnO@250ppm as compared to both the controls. Highest germination percentage (94.7%) in Dry Bulk ZnO@50ppm and highest average shoot length (33.3 cm) in Dry Bulk ZnO@100ppm were recorded as compared to both the controls. Significant highest average root length (40.5 cm), average normal seedling length (67.5 cm) and highest seedling vigour index I (6129) was reported in Dry bulk ZnO@250ppm as compared to both the controls. Significant highest seedlings dry weight (0.2603g) and seedling vigour index II (23.4) was reported in Dry Bulk Zno@750ppm as compared to both the controls.

Keywords: Nano-particle, radicle emergence, seedling vigour, germination.

INTRODUCTION

Rice, *Oryza sativa* (2n = 24) (Poaceae; subfamily Oryzoides), is the nourishment for half of the world's population and accounts for nearly 20% of all cereal-growing land. Rice bran is used in baked goods such as pizza, chips, cookies, and biscuits. Defatted bran is also used as cattle feed, organic fertilizer (compost), medicinally, and in the production of wax. Paddy is used to make puffed rice, which is then eaten whole. Parboiled rice is used to make parched rice, which is quickly digestible. Rice husk is used as a fuel, as well as in the production of board and paper, packaging and construction materials, and as an insulator.

It has a wide range of applications and is second only to wheat in terms of area and production. India and China account for 48% of total land area and 53.4 per cent of global rice production (FAO, 2019). Total production of rice during 2019-2020 is estimated at record 117.94 million tonnes (DAC&FW, 2019-2020). West Bengal, Andhra Pradesh, Uttar Pradesh, Tamil Nadu, and Karnataka are the India's most important rice producing states. It is classified as a semi-aquatic annual grass crop. There are about 25 species of *Oryza*, but *O. sativa* L. accounts for nearly all cultivated rice. In Africa, *Oryza glaberrima*, a perennial species, is grown in small quantities. Wild rice (*Zizania aquatica*) is more closely related to oats than rice and is grown in the Great Lakes area of the United States (FAO, 2019).

Low and uncertain income, degraded natural resource base, growing labour and energy shortages and threats of climate change are making Indian agriculture highly vulnerable and unsustainable (Pathak *et al.*, 2018b). Environmentally safe and economically viable disposal of rice straw is another challenge of rice farming in many, particularly the north-western part of the country. Indian rice farming thus seems to be in a cross-road once again. Producing enough rice for the increasing Population against the backdrop of reducing natural resource base is, therefore, the primary task of Indian rice sector.

Excessive use of pesticides and even fertilizers in rice farming pollutes water and creates health hazards. Conventional fertilizers help increase yield in many crops, but they have a negative impact on the environment by causing eutrophication and contaminating water bodies. As a result, providing critical nutrients in the form of nanoparticles may increase crop nutrient uptake while lowering environmental impact. One of the concerns for nanomaterial applications in seed germination is their phytotoxicity and the level of phytotoxicity may depend on the type of nanomaterial and its potential application. There is little knowledge about the mode of action of nanoparticles in relation to plant systems. Thus, before using the nanomaterials in the field, the phytotoxic behavior of nanomaterials must be fully understood (Gokhade, 2010). In recent years nanotechnology is gaining importance in different field such as industry, including pharmaceutics, food, cosmetics, electronics, textiles, energy, environmental bioremediation, and so on (Banik and Luque, 2017). It is also showing promising response in agricultural sectors and opened up new possibilities in the field of agricultural biotechnology (Plaksenkova *et al.*, 2019).

Nanoparticles, according to IUPAC, are "particles of any form with a dimension in the range of 10^{-9} to 10^{-7}, and possessing distinct physical, chemical and biological properties''. Carbon-based nanoparticles, metallic nanoparticles, metal oxide nanoparticles, polymeric nanoparticles, and lipid-based nanoparticles are the most commonly used nanoparticles in agriculture.

Metals and metal oxides (e.g., TiO_2, SiO_2, Fe ZnO, Al_2O_3, CeO_2, Cu, and Ag), carbon nanotubes, nano clay composites, and graphenes are the most common engineered nano materials (Keller and Lazareva 2014). The mesoporous structure of zinc oxide, titanium dioxide and silicon dioxide nano particles make them perfect nanocarriers for a wide range of compounds that could be useful in agriculture (Rastogi *et al*., 2019). ZnO nanoparticles increased germination rate and early flowering and also potential to boost the yield and growth of food crops and release fertilizers which saves fertilizer consumption and minimize environmental pollution (Afrayeem and Chaurasia 2017). Zn is absorbed by higher plants as a divalent cation (Zn^{2+}), which serves as a metal part of enzymes as well as a functional structural or regulatory co-factor in a wide range of enzymes (Khan *et al.,* 2004; Hafeez *et al.,* 2013). Another commonly used metal oxide nanoparticle is SiO_2, which is used in photo catalysis, cosmetics, fertilizers, cancer treatment, and bio-imaging (Cheng *et al.,* 2010; Slowing *et al.,* 2008; Rosenholm *et al.,* 2010). Nano titanium oxide particles could be used in agriculturally valuable crops as a weapon. The impact of titanium nanoparticles differs between species and doses (Mattiello, *et al.,* 2018).

MATERIAL AND METHODS

A. Radicle emergence (%)

Randomly selected 100 seeds from each treatment combination were kept for germination in three replications using rolled towel paper method and placed at recommended temperature of 25±1ºC (ISTA, 2019). The number of seeds with 2 mm or more radicle length was counted at 6 hours ± 15 min interval till 72 hr and percentage of radicle emergence was calculated (Table 1).

B. Germination percentage

Germination percentage was recorded by the using rolled towel paper method. From each treatment combination 100 seeds were placed in three replications on moist towel paper, rolled appropriately and kept for germination at constant temperature (25±1ºC) and 90% relative humidity (Table 1). The first and final counts were recorded on 5th and 14th day. The seedlings were evaluated for normal seedlings, abnormal seedlings, fresh un-germinated (FUG) and dead seeds. Total numbers of normal seedlings counted were considered for calculation of germination and were expressed in percentage (ISTA, 2019).

$$\text{Germination (\%)} = \frac{\text{No. of normal seedling}}{\text{Total no. of seeds}} \times 100$$

C. Root, shoot and total length of seedlings (cm)

Ten random seedlings from each replication were used for measuring root, shoot and total length of seedlings by scale and expressed in centimeters (cm) (Table 1).

D. Seedling dry weight

Those ten seedlings that were used for recording seedling length were dried in hot air oven at 80±1ºC for 17 hrs. Seedling dry weight was taken after cooling them for half an hour in desiccator and weight was expressed as mg/10 seedlings (Table 1).

E. Seedling vigor index

Seedling vigour indices (Table 1) were estimated following the procedure suggested by the Abdul-Baki and Anderson (1973) with the using of following formula:

Seedling vigour index I = Germination (%) × Mean Seedling length

Seedling vigour index II= Germination (%) × Mean seedling dry weight

Where; Seedling length (cm) = Shoot length (cm) + Root length (cm)

F. Field emergence (%)

The seed lots were sown at a depth of approximately 20 mm in experimental field in a randomized block design (RBD) with three replicates. Seed emergence above ground (the coleoptile appeared out of ground to approximately 10 mm) was counted daily until 14 days after sowing (Table 1).

Table 1: Enlisted treatments were used for above different observations.

Treatments	Remarks	Treatments	Remarks
T1	Control	**T32**	Dry Nano SiO_2@750ppm
T2	Thiram@2g/kg(recommended PoP: control2)	**T33**	Wet Bulk SiO_2@50ppm
T3	Dry Bulk Zno @50ppm	**T34**	Wet Bulk SiO_2@ 100ppm
T4	Dry Bulk Zno @100ppm	**T35**	Wet Bulk SiO_2@250ppm
T5	Dry Bulk Zno@250ppm	**T36**	Wet Bulk SiO_2@500ppm
T6	Dry Bulk Zno@500ppm	**T37**	Wet Bulk SiO_2@750ppm
T7	Dry Bulk Zno@750ppm	**T38**	Wet Nano SiO_2@50ppm
T8	Dry Nano Zno@50ppm	**T39**	Wet Nano SiO_2@100ppm
T9	Dry Nano Zno@ 100ppm	**T40**	Wet Nano SiO_2@250ppm
T10	Dry Nano Zno@250ppm	**T41**	Wet Nano SiO_2@500ppm
T11	Dry Nano Zno@500ppm	**T42**	Wet Nano SiO_2@750ppm
T12	Dry Nano Zno@750ppm	**T43**	Dry Bulk TiO_2@50ppm
T13	Wet Bulk Zno@50ppm	**T44**	Dry Bulk TiO_2@100ppm
T14	Wet Bulk Zno@100ppm	**T45**	Dry Bulk TiO_2@250ppm
T15	Wet Bulk Zno@250ppm	**T46**	Dry Bulk TiO_2@500ppm
T16	Wet Bulk Zno@500ppm	**T47**	Dry Bulk TiO_2 @750ppm
T17	Wet Bulk Zno@750ppm	**T48**	Dry Nano TiO_2@50ppm
T18	Wet Nano Zno@50ppm	**T49**	Dry Nano TiO_2@ 100ppm
T19	Wet Nano Zno@100ppm	**T50**	Dry Nano TiO_2 @250ppm
T20	Wet Nano Zno@250ppm	**T51**	Dry Nano TiO_2@500ppm
T21	Wet Nano Zno@500ppm	**T52**	Dry Nano TiO_2@750ppm
T22	Wet Nano Zno@750ppm	**T53**	Wet Bulk TiO_2@50ppm
T23	Dry Bulk SiO2@50ppm	**T54**	Wet Bulk TiO_2@100ppm
T24	Dry Bulk SiO2@100ppm	**T55**	Wet Bulk TiO_2@250ppm
T25	Dry BulkSiO2@250ppm	**T56**	Wet Bulk TiO_2@500ppm
T26	Dry Bulk SiO2@500ppm	**T57**	Wet Bulk TiO_2@750ppm
T27	Dry Bulk SiO2@750ppm	**T58**	Wet Nano TiO_2@50ppm
T28	Dry Nano SiO2@50ppm	**T59**	Wet Nano TiO_2@100ppm
T29	Dry Nano SiO2@100ppm	**T60**	Wet Nano TiO_2 @250ppm
T30	Dry Nano SiO2@250ppm	**T61**	Wet Nano TiO_2@500ppm
T31	Dry Nano SiO2@500ppm	**T62**	Wet Nano TiO_2@750ppm

RESULTS AND DISCUSSION

A. Radicle Emergence Percentage

The results obtained on effect of different nano particle seed treatments on the radicle emergence percentage of paddy variety, Pusa Basmati 1509 have been given in Table 2. The results revealed that there were significant differences in percent radicle emergence among the paddy seeds treated with different nano particles. Overall differences between all the treatments were in the range of 80.7% (T38) to 95.3% (T10). Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) divided radicle emergence percentage means of all treatments in six homogeneous subsets. Among the subsets a large numbers of treatment means were noticed to be grouped together. The NP treatments *viz.*; T23 (90.0%), T20 (89.7%), T26 (88.7%), T19 (88.7%), T12 (88.7%), T28 (88.3%), T51 (88.0%), T25 (88.0%), T14 (88.0%), T13 (88.0%), T8 (87.3%), T29 (87.0%), T18 (87.0%), T9 (87.0%), T45 (86.7%), T17 (86.7%), T27 (86.3%), T2 (86.0%), T43 (85.7%) and T11 (85.7%), were found at par among themselves as well as with all other treatments. The radicle emergence percentage in T1 was 83.3% which was at par with T2 (86.0%). significantly higher radicle emergence percentage was found in T10 which was at par with T7 (93.0%), T4 (93.0%), T6 (92.7%) T5 (92.3%), T3 (92.3%), T50 (91.7%), T23, T20, T26, T19, T12, T28, T51, T25, T14, T13, T8, T29, T18, T9, T45, T17, T27, T2, T11, and T43. Significantly lower radicle emergence percentage was found in T38 (80.7%), T55 (80.7%), T41 (81.0%), T37 (81.3%), T40 (81.7% and T58 (81.7%) which were not only at par among themselves but were also at par with other NP treatments; T15 (82.0%), T42 (82.0%), T62 (82.0%), T30 (82.3%), T33 (82.3%), T34 (82.3%), T31 (82.7%), T59 (82.7%), T61 (82.7%), T49 (83.0%), T53 (83.0%), T57 (83.0%), T60 (83.0%), T36 (83.3%), T16 (83.7%), T32 (83.7%), T35 (83.7%), T47 (83.7%), T48 (83.7%), T54 (83.7%), T39 (84.0%), T21 (84.3%), T24 (84.3%), T46 (84.3%), T56 (84.7%), T22 (85.0%), T52 (85.0%), T44 (85.3%), T11, T43, T1, T27, T17, T45, T9, T18, T29, T8, T13, T14, T25, T51, T28, T12, T19, T26, T20, T23 and the control 2 (Thiram treatment, recommended PoP:). Similar results were findings and they concluded that the studies on morphological attributes discovered that ZnO-NPs capsicum seed treatments significantly ($p \leq 0.01$) affected the radicle length while these treatments showed non-significant effects on plumule development (García-López, *et al.*, 2018). If the size of plant cell pores is bigger than nanoparticles, it can easily be absorbed by the plant cells and internalized. The metal oxides, their concentrations and solubility, size of the nano particle and size of cell pores besides the permeability and structure of seed coat are some of the important factors largely responsible for determination of certain type of effects of nanoparticles. There are reports available on some toxic effects of nanoparticles in literature (Verma *et al.*, 2020; Daohui and Baoshan, 2007). Zeynep *et al.* (2019) reported the phytotoxicity (but not always) on seed germination and/or radicle–plumule elongation.

Table 2: Effect of nanoparticle seed treatments on radicle emergence percentage, germination percentage and field emergence percentage of paddy variety Pusa Basmati 1509.

Treatments	Radicle emergence percentage	Germination percentage	Field emergence percentage
T1	$83.3^{abcdef*}$	$87.3^{bcde\,*}$	84.2
T2	86.0^{bcdef}	85.0^{abcde}	81.0
T3	92.3^{abcd}	94.7^{a}	90.0
T4	93.0^{ab}	92.3^{ab}	90.7
T5	92.3^{abcd}	90.7^{abc}	88.2
T6	92.7^{abc}	91.0^{abc}	88
T7	93.0^{ab}	90.0^{abcd}	88.7
T8	87.3^{abcdef}	86.3^{abcde}	85.3
T9	87.0^{abcdef}	86.3^{abcde}	85.7
T10	95.3^{a}	84.7^{bcde}	97.3
T11	85.7^{abcdef}	85.0^{bcde}	83.2
T12	88.7^{abcdef}	86.0^{abcde}	84
T13	88.0^{abcdef}	82.3^{cde}	84.0
T14	88.0^{abcdef}	85.0^{bcde}	84.7
T15	82.0^{ef}	81.7^{cde}	86.7
T16	83.7^{bcdef}	82.7^{cde}	94.0
T17	86.7^{abcdef}	84.7^{bcde}	82.7
T18	87.0^{abcdef}	82.7^{cde}	90.0
T19	88.7^{abcdef}	86.7^{abcde}	87.3
T20	89.7^{abcdef}	82.3^{cde}	88.7
T21	84.3^{bcdef}	82.0^{cde}	94.7
T22	85.0^{bcdef}	82.7^{cde}	91.3
T23	90.0^{abcdef}	83.3^{bcde}	89.3
T24	84.3^{bcdef}	86.3^{abcde}	91.3
T25	88.0^{abcdef}	86.0^{abcde}	91.3
T26	88.7^{abcdef}	88.0^{abcde}	86.3
T27	86.3^{abcdef}	85.0^{bcde}	88.0
T28	88.3^{abcdef}	85.0^{bcde}	87.3
T29	87.0^{abcdef}	86.0^{abcde}	85.3
T30	82.3^{ef}	87.0^{abcde}	88.0
T31	82.7^{ef}	82.0^{cde}	87.3
T32	83.7^{bcdef}	83.3^{bcde}	91.3
T33	82.3^{ef}	88.0^{abcde}	87.3
T34	82.3^{ef}	84.7^{bcde}	88.7
T35	83.7^{bcdef}	86.3^{abcde}	87.3
T36	83.3^{bcdef}	86.7^{abcde}	91.3
T37	81.3^{a}	82.7^{cde}	91.3
T38	80.7^{f}	81.0^{de}	90.7
T39	84.0^{bcdef}	83.0^{bcde}	86.0
T40	81.7^{f}	86.0^{abcde}	86.7
T41	81.0^{f}	84.7^{bcde}	87.3
T42	82.0^{ef}	85.7^{abcde}	88.7
T43	85.7^{abcdef}	80.3^{e}	89.3
T44	85.3^{bcdef}	82.0^{cde}	90.0
T45	86.7^{abcdef}	83.3^{bcde}	88.7
T46	84.3^{bcdef}	85.0^{abcd}	90.7
T47	83.7^{bcdef}	82.7^{cde}	90.7
T48	83.7^{bcdef}	87.3^{abcde}	94.7
T49	83.0^{cdef}	86.3^{abcde}	93.3
T50	91.7^{abcde}	88.7^{abcde}	93.3
T51	88.0^{abcdef}	89.0^{abcde}	87.3
T52	85.0^{bcdef}	82.0^{cde}	92.0
T53	83.0^{cdef}	86.0^{abcde}	91.3
T54	83.7^{bcdef}	83.0^{bcde}	85.3
T55	80.7^{f}	85.0^{bcde}	86.0
T56	84.7^{bcdef}	88.3^{abcde}	81.3
T57	83.0^{cdef}	85.3^{abcde}	86.0
T58	81.7^{f}	82.7^{cde}	81.3
T59	82.7^{def}	85.7^{abcde}	92.0
T60	83.0^{cdef}	82.7^{cde}	84.7
T61	82.7^{def}	88.0^{abcde}	86.7
T62	82.0^{ef}	84.7^{bcde}	87.3
Mean	**85.6**	**85.3**	**89.1**
CD (p=0.05)	**4.28**	**3.88**	**NS**

*Values superscripted with same alphabet are not significantly different from each other for the treatment means independently

B. Germination (%)

The results obtained on effect of different nano particle seed treatments on the germination percentage of paddy variety, Pusa Basmati 1509 have been given in Table 2. The results demonstrated, in different parameter there was observed significant differences in germination percentage among the paddy seeds treated with different nano particles. Overall differences between all the treatments were in the range of 80.3% (T43) to 94.7% (T3). Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) divided germination percentage means of all treatments in 5 homogeneous subsets. The germination percentage in T1 was 87.3% which was at par with T2 (85.0%). Significantly higher germination percentage was found in T3 which was at par with T4 (92.3%), T6 (91%), T5 (90.7%), T7 (90%), T51 (89%), T50 (88.7%), T56 (88.3%), T61 (88%), T33 (88%), T26 (88%), T48 (87.3%), T1 (87.3%), T30 (87%), T36 (86.7%), T19 (86.7%), T8 (86.3%), T9 (86.3%), T24 (86.3%), T35 (86.3), T49 (86.3%), T12 (86%), T25 (86%), T29 (86%), T40 (86%), T53 (86%), T42 (85.7%), T59 (85.7%), T57 (85.3%), T2 (85%), T11 (85%), T14 (85%), T27 (85%), T28 (85%) and T55 (85%). Significantly lower germination percentage was found in T43 (80.3%) at par with other NP treatments T38 (81%), T15 (81.7%), T31 (82%), T52 (82%), T44 (82%), T21 (82%), T13 (82.3%), T20 (82.3%), T58 (82.7%), T60 (82.7%), T47 (82.7%), T37 (82.7%), T22 (82.7%), T18 (82.7%), T16 (82.7%), T54 (83%), T39 (83%), T23 (83.3%) and T32 (83.3%). Similar results was reported by Montanha *et al.* (2020) and concluded that seeds were coated with $ZnSO_4$, 40 nm ZnO, and 5 µm ZnO at 4 mg of Zn per kg of seed affected soybean seed germination, ZnO-based treatments increased germination ratio, seedlings root, and shoot development, whereas $ZnSO_4$ suppressed them. Regardless of the source, the ZnO seed treatment boosted the germination by ca. 40%, compared to the control; it yielded longer roots with more developed architecture, compared to the control. The average Zn was higher in roots and soil of rhizoboxes that received the treated seed. Hence, the Zn employed in the treatment is either transferred during the imbibition or it provides a fertile microenvironment that favors the initial seedling development. Perhaps, one of the leading advantages seed coatings consists in delivering the desired nutrient in the soil region where the roots will grow. Zinc oxide-based treatments represent a viable alternative to Zn supply in order to boost soybean germination and seedling development.

C. Field emergence percentage

The results obtained on effect of different nano particle seed treatments on the field emergence percentage of paddy variety, Pusa Basmati 1509 have been given in Table 2. The results illustrated, in different parameter there was observed non-significant differences in field emergence percentage among the paddy seeds treated with different nano particles. Overall differences between all the treatments were in the range of 81.3% (T58) to 97.3% (T10). Based on observed means for various treatments, the field emergence percentage in T1 was 84.2% which was at par with T2 (81.0%). Numerically higher field emergence percentage was found in T10 which was at par with T21(94.7%), T48 (94.7%), T16 (94%), T49 (93.3%), T50 (93.3%), T59 (92%), T52 (92%), T22 (91.3%), T24 (91.3%), T25 (91.3%), T32 (91.3%), T36 (91.3%), T37 (91.3%), T53 (91.3%), T46 (90.7%), T47 (90.7%), T38 (90.7%), T4 (90.7%), T3 (90%), T18 (90%) and T44 (90%). Numerically lower field emergence percentage was found in T58 (81.3%) at par with other NP treatments T56 (81.3%), T17 (82.7%), T13 (84%), T14 (84.7%), T60 (84.7%), T8 (85.3%), T29 (85%) and T54 (85.3%). Similar findings were reported by (Korishettar *et al.*, 2016). It could be due to the overall beneficial effects of Zn *viz.*, higher precursor activity of nanoscale Zn in production of essential bio-molecules, improved cofactor activity in important enzymatic systems and encouraging effect on reactivity of the phytohormones during the germination (Krishna Shyla and Natarajan, 2014).

D. Average shoot length (cm)

The results established on effect of different nano particle seed treatments on the average shoot length of paddy variety, Pusa Basmati 1509 have been given in Table 3. The results illustrated, in different parameter there was observed significant differences in average shoot length among the paddy seeds treated with different nano particles. Overall differences between all the treatments were in the range of 7.5cm T25 to 33.2cm (T4) Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) divided average shoot length means of all treatments in fifteen homogeneous subsets. The average shoot length in T1 was 13.9cm which was at par with T2 (14.6cm). Significantly higher average shoot length was found in T4 (33.2cm) which was at par with T3 (29.6cm), T7 (28.1cm), T5 (27.2cm), T6 (26.4cm), T51 (26.3cm), T10 (21.4cm), T49 (21cm), T9 (20.3cm), T61 (20.3cm), T48 (20cm), T50 (20cm), T60 (20cm), T54 (19.6cm), T46 (19.5cm), T58 (19cm), T59 (19cm), T47 (18.7cm), T52 (18.5cm), T32 (18.5cm), T45 (18.2cm) and T53 (18.1cm). Significantly lower average shoot length was found in T25 (7.5cm), T21 (7.8cm), T26 (7.8cm) and T28 (7.9cm) which were not only at par among themselves but were also at par with other NP treatments; T24(8.1cm), T27(8.1cm), T19 (8.2cm), T13 (8.5cm), T31 (8.8cm), T16 (8.8cm), T22 (8.7cm), T14 (8.8cm), T20 (9cm), T23 (9.1cm), T17 (9.2cm), T29 (9.2cm), T12 (9.5cm), T18 (9.5cm) and T15 (9.6cm). Kobayashi and Mizutani (1970) in corn observed that increased shoot and root length might be due to extended inter-nodal length which can be ascribed to enhanced precursor activity of zinc in auxin production. Cakmak (2000) reported that zinc causes membrane stability and enhanced cell elongation and hence increase in seedling dry weight. Sayed *et al.* (2014) reported that root length, shoot length and seedling dry weight increased with the application of zinc in rice. Prasad *et al.* (2012) found that the groundnut seeds treated with ZnO at a concentration of 1000 ppm showed enhanced shoot length and root length compared to contol. Similar findings were obtained by Jayarambabu *et al.* (2014).

E. Average root length (cm)

The results established on effect of different nano particle seed treatments on the average root length of paddy variety, Pusa Basmati 1509 have been given in table 3. The results illustrated, in different parameter there was observed significant differences in average root length among the paddy seeds treated with different nano particles. Overall differences between all the treatments were in the range of 9.4cm T25 to 40.4cm (T5) Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) divided average root length means of all treatments in twelve homogeneous subsets. The average root length in T1 was 18.9cm which was at par with T2 (16.8cm). Significantly higher average root length was found in T5 (40.4cm) which was at par with T4 (30.5cm), T7 (28.3cm), T6 (25.8cm), T3 (22.1cm), T49 (19cm), T1 (18.9cm), T42 (18.8cm), T61 (18cm), T53 (17.6cm), T50 (17.2cm), T51 (17.2cm), T54 (17.2cm), T10 (17.1cm), T55 (16.9cm), T57 (16.9cm), T41 (16.9cm), T2 (16.8cm), T40 (16.8cm), T9 (16.7cm), T52 (16.6cm), T62 (16.6cm), T59 (16.6cm), T47 (16.5cm), T36 (16.4cm), T34 (16.4cm), T46 (16.4cm), T8 (16.3cm) and T56 (16.2cm). Significantly lower average root length was found in T25 (9.4cm), T24 (9.5cm), T27 (9.9cm) which were not only at par among themselves but were also at par with other NP treatments; T23 (10.1cm), T28 (10.1cm), T29 (10.2cm), T26 (10.4cm), T12 (11cm), T14 (11.4cm), T30 (11.5cm), T19 (11.8cm), T13 (11.9cm), T15 (11.9cm) and T17 (12cm). Similar results were finding by Kobayashi and Mizutani (1970) in corn observed that increased shoot and root length might be due to extended inter-nodal length which can be ascribed to enhanced precursor activity of zinc in auxin production. Sayed *et al.,* (2014) reported that root length, shoot length and seedling dry weight increased with the application of zinc in rice. According to Mahajan *et al.,* (2011), as the concentration of ZnO rises, root and shoot growth accelerates. In comparison with controls, 1 ppm treatment for gram seedlings enhanced a considerable increase in root growth and shoot growth. It has been discovered that phytohormones, such as Indole Acetic Acid (IAA), are involved in phytostimulatory actions. Because of oxygen vacancies, the oxygen-deficient, ZnO increased the level of IAA in roots, indicating an increase in plant growth rate. Similar results obtained by Pham *et al.,* (2018) in soybean seeds. Ghodake *et al.,* (2011) found that, with an increased nanoparticle concentration compared to control, the root elongation was severely inhibited while investigating on onion roots treated at different concentrations (5, 10, and 20 µg ml^{-1}) with cobalt and zinc oxide nanoparticles.

F. Average normal seedling length (cm)

The results established on effect of different nano particle seed treatments on the average normal seedling length of paddy variety, Pusa Basmati 1509 have been given in Table 3. The results illustrated, in different parameter there was observed significant differences in average normal seedling length among the paddy seeds treated with different nano particles. Overall differences between all the treatments were in the range of 17cm T25 to 67.5cm (T5) Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) divided average normal seedling length means of all treatments in seventeen homogeneous subsets. The average normal seedling length in T1 was 32.8cm which was at par with T2 (31.4cm). Significantly higher average normal seedling length was found in T5 (67.5cm) which was at par with T4 (63.6cm), T7 (56.4cm), T6 (52.2cm), T3 (51.7cm), T51 (43.5cm), T49 (40cm), T10 (38.4cm), T61 (38cm), T50 (37.2cm), T9 (36.9cm), T54 (36.8cm), T46 (36cm), T53 (35.7cm), T59 (35.6cm), T47 (35.3cm), T52 (35.1cm), T32 (34.9cm), T11 (34.8cm), T58 (34.8cm), T42 (34.5cm), T55 (34.2cm), T41 (34.1cm) and T48 (34cm). Significantly lower average normal seedling length was found in T25 (17cm), T24 (17.5cm) which were not only at par among themselves but were also at par with other NP treatments; T27 (18cm), T28 (18cm), T26 (18.2cm), T23 (19.2cm), T29 (19.3cm), T19 (20cm), T14 (20.2cm), T13 (20.5cm), T12 (20.5cm), T31 (20.6cm), T16 (20.9cm), T17 (21.2cm), T20 (21cm), T15 (21.5cm), T21 (22.1cm), T19 (22.2cm) and T22 (22.6cm). Similar results were supported by Raskar and Laware (2014) reported that Low concentrations of ZnO enhanced the seed germination and seedling growth of onion seeds. At low ZnO concentration, Root/shoot length was enhanced but reduced at high concentration compared to untreated seeds. This increase in seed quality parameters might be attributed to improved hydrolytic enzyme synthesis and activity during the early stages of germination, as well as effective mobilisation of the available food stores in the seeds, which resulted in early seedling emergence and growth.

Table 3: Effect of nanoparticle seed treatments on average shoot length, average root length and total seedling length percentage of paddy variety Pusa Basmati 1509.

Treatments	Average shoot length (cm)	Average root length (cm)	Total seedling length (cm)
T1	$13.9^{ghijklmno\ *}$	$18.9^{efghijkl\ *}$	$32.8^{efghijklm\ *}$
T2	$14.6^{ghijklmno}$	16.8^{defg}	$31.4^{defghij}$
T3	29.6^{ab}	22.1^{cde}	51.7^{bc}
T4	33.2^{a}	30.5^{b}	63.6^{a}
T5	27.2^{abcd}	40.4^{a}	67.5^{a}
T6	26.4^{abcde}	25.8^{bcd}	52.2^{bc}
T7	28.1^{abc}	28.3^{bc}	56.4^{ab}
T8	16.9^{ghijk}	$16.3^{efghijkl}$	33.2^{defghi}
T9	20.3^{cdefg}	$16.7^{efghijkl}$	36.9^{def}
T10	21.4^{bcdefg}	17.1^{efghij}	38.4^{def}
T11	20^{cdefg}	$14.8^{efghijkl}$	34.8^{def}
T12	$9.5^{ijklmno}$	11^{hijkl}	20.5^{lmnopq}

T13	8.5^{lmno}	11.9^{fghijkl}	20.5^{mnopq}
T14	8.8^{klmno}	11.4^{ghijkl}	20.2^{mnopq}
T15	9.6^{ijklmno}	11.9^{fghijkl}	21.5^{jklmnopq}
T16	8.8^{klmno}	12.1^{fghijkl}	20.9^{klmnopq}
T17	9.2^{ijklmno}	12^{fghijkl}	21.2^{klmnopq}
T18	9.5^{ijklmno}	12.7^{fghijkl}	22.2^{ijklmnopq}
T19	8.2^{mno}	11.8^{fghijkl}	20.0^{nopq}
T20	9^{klmno}	12.2^{fghijkl}	21.2^{klmnopq}
T21	7.8^{no}	14.2^{fghijkl}	22.1^{ijklmnopq}
T22	8.7^{klmno}	13.9^{fghijkl}	22.6^{hijklmnopq}
T23	9.1^{jklmno}	10.1^{jkl}	19.2^{opq}
T24	8.1^{mno}	9.5^{kl}	17.5^{q}
T25	7.5^{o}	9.4^{l}	17.0^{q}
T26	7.8^{no}	10.4^{ijkl}	18.2^{pq}
T27	8.1^{mno}	9.9^{jkl}	18.0^{pq}
T28	7.9^{mno}	10.1^{jkl}	18.0^{pq}
T29	9.2^{ijklmno}	10.2^{ijkl}	19.3^{nopq}
T30	11.6^{hijklmno}	11.5^{ghijkl}	23.2^{ghijklmnopq}
T31	8.8^{abcde}	11.8^{fghijkl}	20.6^{lmnopq}
T32	18.5^{efgh}	16.4^{efghijkl}	34.9^{def}
T33	15.6^{ghijklmno}	14.8^{efghijkl}	30.5^{efghijklmno}
T34	15.4^{ghijklmno}	15.2^{efghijkl}	30.6^{efghijklmn}
T35	14.5^{ghijklmno}	13.5^{fghijkl}	28.1^{efghijklmnopq}
T36	16.8^{ghijk}	16.4^{efghijkl}	33.2^{defghi}
T37	14.6^{ghijklmno}	15.1^{efghijkl}	29.7^{efghijklmno}
T38	14.5^{ghijklmno}	14.4^{fghijkl}	28.9^{efghijklmnop}
T39	15.6^{ghijklmno}	15.7^{efghijkl}	31.4^{efghijklm}
T40	15.1^{ghijklmno}	16.8^{efghijkl}	31.9^{efghijkl}
T41	17.3^{ghij}	16.9^{efghijk}	34.1^{defg}
T42	15.7^{ghijklmno}	18.8^{defg}	34.5^{defg}
T43	16.8^{ghijkl}	13.2^{fghijkl}	30.0^{efghijklmno}
T44	16.7^{ghijkl}	15.4^{efghijkl}	32.0^{efghijk}
T45	18.2^{efgh}	15.4^{efghijkl}	33.7^{defgh}
T46	19.5^{defgh}	16.4^{efghijkl}	36.0^{def}
T47	18.7^{efgh}	16.5^{efghijkl}	35.3^{def}
T48	20.0^{cdefg}	13.8^{fghijkl}	34.0^{defgh}
T49	21.0^{cdefg}	19.0^{def}	40.0^{de}
T50	20.0^{cdefg}	17.2^{efghij}	37.2^{def}
T51	26.3^{abcdef}	17.2^{efghij}	43.5^{cd}
T52	18.5^{efgh}	16.6^{efghijkl}	35.1^{def}
T53	18.1^{fgh}	17.6^{efghi}	35.7^{def}
T54	19.6^{defgh}	17.2^{efghij}	36.8^{def}
T55	17.4^{ghi}	16.9^{efghijk}	34.2^{defg}
T56	16.8^{ghijk}	16.2^{efghijkl}	33.0^{defghi}
T57	15.8^{ghijklmn}	16.9^{efghijk}	32.7^{defghij}
T58	19.0^{defgh}	15.8^{efghijkl}	34.8^{def}
T59	19.0^{defgh}	16.6^{efghijkl}	35.6^{def}
T60	20.0^{cdefg}	14.3^{fghijkl}	34.3^{defg}
T61	20.3^{cdefg}	18.0^{efgh}	38.2^{def}
T62	16.2^{ghijklm}	16.6^{efghijkl}	32.7^{defghij}
Mean	**15.8**	**15.7**	**31.5**
CD (p=0.05)	**3.9**	**3.5**	**5.4**

*Values superscripted with same alphabet are not significantly different from each other for the treatment means independently

G. Seedling dry weight (g)

The results obtained on effect of different nano particle seed treatments on the dry weight of paddy variety, Pusa Basmati 1509 have been given in table 4. The results revealed that there were significant differences in dry weight among the paddy seeds treated with different nano particles. Overall differences between all the treatments were in the range of 0.0718g (T16) to 0.2603 (T7). Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) separated dry weight means of all treatments in thirteen homogeneous subsets. The dry weight in T1 was 0.1077g which was at par with T2 (0.1131g). Significantly higher dry weight was found in T7 (0.2603g) which was at par with T6 (0.2518g), T5 (0.2461g), T4 (0.2061), T3 (0.1854), T37 (0.1311g), T33 (0.1306g), T34 (0.1289g), T36 (0.1288g), T42 (0.1256g), T29 (0.1255g), T31 (0.1238g), T41 (0.1231g), T40 (0.1230g), T24 (0.1208gm) and T39 (0.1200g). Significantly lower average dry weight was found in T16 (0.0718g) which were not only at par among themselves but were also at par with other NP treatments; T21 (0.0737g), T8 (0.0739g), T14 (0.0748g), T20 (0.0740g), T17 (0.0771g), T13 (0.0797g), T18 (0.0801g), T9 (0.0807g), T11 (0.0812g), T22 (0.0814g), T12 (0.0844g), T10 (0.0856g) and T15 (0.0856g). Cakmak (2000) reported that zinc causes membrane stability and enhanced cell elongation and hence increase in seedling dry weight. Sayed *et al.*, (2014) reported that root length, shoot length and seedling dry weight increased with the application of zinc in rice.

H. Seedling vigour index I

The results obtained on effect of different nano particle seed treatments on the seedling vigour index I of paddy variety, Pusa Basmati 1509 have been given in Table 4. The results revealed that there were significant differences in seedling vigour index I among the paddy seeds treated with different nano particles. Overall differences between all the treatments were in the range of 1459 (T25) to 6129 (T5). Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) separated seedling vigour index I means of all treatments in twenty homogeneous subsets. The seedling vigour index I in T1 was 2859 which was at par with T2 (2671). Significantly higher seedling vigour index I was found in T5 (6129) which was at par with T4 (5881), T7 (5077), T3 (4891), T6 4752), T51 (3859), T49 (3453), T50 (3309), T61 (3371), T10 (3251), T9 (3185), T54 (3063), T53 (3062), T46 (3057), T59 (3048), T48 (2970), T42 (2962), T11 (2960), T47 (2917), T56 (2913)), T55 (2908) and T32 (2905). Significantly lower seedling vigour index-I was found in T25 (0.1459g) which were not only at par among themselves but were also at par with other NP treatments; T24(1514), T27 (1530), T28 (1531), T23 (1599), T26 (1605), T29 (1662), T31 (1662), T13 (1682), T14 (1714), T16 (1726), T19 (1729), T20 (1747), T15 (1751), T12 (1766) and T17 (1796). The similar findings were reported by (Korishettar *et al.*, 2016). The seedling vigour index also significantly increased due to Zn and Fe NPs.

I. Seedling vigour index –II

The results obtained on effect of different nano particle seed treatments on the seedling vigour index –II of paddy variety, Pusa Basmati 1509 have been given in Table 4. The results revealed that there were significant differences in seedling vigour index –II among the paddy seeds treated with different nano particles. Overall differences between all the treatments were in the range of 5.9 (T16) to 23.4 (T7). Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) separated seedling vigour index –II means of all treatments in sixteen homogeneous subsets. The seedling vigour index –II in T1 was 9.4 which were at par with T2 (9.6). Significantly higher seedling vigour index –II was found in T7 (23.4) which was at par with T6 (22.9), T5 (22.3), T4 (19.5), T3 (17.5), T33 (11.5), T36 (11.2), T34 (10.9), T37 (10.9), T42 (10.8), T29 (10.8), T51 (10.6), T24 (10.4), T41 (10.4), T56 (10.4), T35 (10.3), T31 (10.2), T50 (10.2), T49 (10.1) and T26 (10). Significantly lower seedling vigour index-I was found in T16 (5.9) which was not only at par among themselves but were also at par with other NP treatments; T21 (6), T14 (6.3), T8 (6.4), T19 (6.4), T20 (6.5), T17 (6.5), T18 (6.6), T13 (6.6), T22 (6.7), T11 (6.9), T9 (7), T10 (7.2) and T12 (7.2). Similar result was finding by (Mansoor *et al.*, 2019).

Table 4: Effect of nanoparticle seed treatments on seedling dry weight, seedling vigour index I and seedling vigour index II of paddy variety Pusa Basmati 1509.

Treatments	Seedling dry weight (g)	Seedling vigour index I	Seedling vigour index II
T1	0.1077^{cdef*}	$2859^{fghijklmnopqr*}$	$9.4^{cdefghi*}$
T2	$0.1131^{cdefghij}$	$2671^{efghijklm}$	$9.6^{cdefghijk}$
T3	0.1854^{b}	4891^{bcd}	17.5^{b}
T4	$0.206l^{b}$	5881^{ab}	19.5^{b}
T5	0.2461^{a}	6129^{a}	22.3^{a}
T6	0.2518^{a}	4752^{cd}	22.9^{a}
T7	0.2603^{a}	5077^{abc}	23.4^{a}
T8	$.0739^{m}$	$2864^{efghijkl}$	6.4^{nop}
T9	$.0807^{ijklm}$	3185^{efg}	$7.0^{ghijklmnop}$
T10	$.0856^{efghijklm}$	3251^{efg}	$7.2^{fghijklmnop}$
T11	$.0812^{hijklm}$	2960^{efghi}	$6.9^{hijklmnop}$
T12	$.0844^{fghijklm}$	$1766^{mnopqrst}$	$7.2^{fghijklmnop}$
T13	$.0797^{ijklm}$	1682^{qrst}	6.6^{klmnop}
T14	$.0748^{lm}$	1714^{abcdef}	6.3^{nop}
T15	$.0856^{efghijklm}$	$1751^{nopqrst}$	$7.0^{ghijklmnop}$
T16	0.0718^{m}	1726^{opqrst}	5.9^{p}
T17	0.0771^{klm}	$1796^{lmnopqrst}$	6.5^{klmnop}
T18	0.080^{ijklm}	$1839^{jklmnopqrst}$	$6.6^{jklmnop}$
T19	0.0740^{m}	1729^{opqrst}	6.4^{mnop}
T20	0.0789^{jklm}	1747^{opqrst}	6.5^{lmnop}
T21	0.0737^{m}	$1811^{klmnopqrst}$	6.0^{op}
T22	$0.0814^{ghijklm}$	$1869^{ijklmnopqrst}$	$6.7^{ijklmnop}$
T23	0.1112^{cdefg}	1599^{rst}	$9.3^{cdefghijkl}$
T24	0.1208^{cd}	1514^{st}	10.4^{cde}
T25	0.1110^{cdefgh}	1459^{t}	$9.5^{cdefghij}$
T26	0.1132^{cdef}	1605^{rst}	10.0^{cdefg}
T27	0.1145^{cde}	1530^{st}	$9.7^{cdefghi}$
T28	0.1145^{cde}	1531^{st}	$9.7^{cdefghi}$
T29	0.1255^{cd}	1662^{qrst}	10.8^{cde}
T30	$0.1077^{cdefghij}$	$2023^{hijklmnopqrst}$	$9.3^{cdefghijkl}$
T31	0.1238^{cd}	1689^{pqrst}	10.2^{cdef}
T32	0.1170^{cd}	$2905^{efghijk}$	9.7^{cdefgh}
T33	0.1306^{c}	$2692^{fghijklmnopqr}$	11.5^{c}
T34	0.1289^{cd}	$2593^{fghijklmnopqrs}$	10.9^{cde}
T35	0.1194^{cd}	$2428^{fghijklmnopqrst}$	10.3^{cde}
T36	0.1288^{cd}	$2872^{efghijkl}$	11.2^{cd}

T37	0.1311^{c}	2457^{fghijklmnopqrst}	10.9^{cde}
T38	0.1134^{cdef}	2345^{ghijklmnopqrst}	9.2^{cdefghijkl}
T39	0.1200^{cd}	2600^{fghijklmnopqrs}	10.0^{cdefg}
T40	0.1230^{cd}	2755^{fghijklmnopq}	9.8^{cde}
T41	0.1231^{cd}	2892^{efghijkl}	10.4^{cde}
T42	0.1256^{cd}	2962^{efghi}	10.8^{cde}
T43	0.1006^{defghijklm}	2406^{fghijklmnopqrst}	8.1^{efghijklmnop}
T44	0.1048^{cdefghijkl}	2633^{fghijklmnopqr}	8.6^{cdefghijklmnop}
T45	0.1134^{cdef}	2808^{efghijklmno}	9.5^{cdefghij}
T46	0.1118^{cdef}	3057^{efgh}	9.5^{cdefghij}
T47	0.1137^{cdef}	2917^{efghij}	9.4^{cdefghijk}
T48	0.1112^{cdefg}	2970^{efgh}	9.7^{cdefghi}
T49	0.1170^{cd}	3453^{ef}	10.1^{cdef}
T50	0.1143^{cdef}	3309^{efg}	10.2^{cdef}
T51	0.1191^{cd}	3859de	10.6^{cde}
T52	0.1096^{cdefghi}	2881^{efghijkl}	9.0^{cdefghijklmno}
T53	0.1115^{cdef}	3062^{efgh}	9.6^{cdefghi}
T54	0.1082^{cdefghij}	3063^{efgh}	9.0^{cdefghijklmno}
T55	0.1146^{cde}	2908^{efghij}	9.8^{cdefgh}
T56	0.1170^{cd}	2913^{efghij}	10.4^{cde}
T57	0.1121^{cdef}	2790^{efghijklmno}	9.6^{cdefghi}
T58	0.1005^{defghijklm}	2888^{efghijkl}	8.3^{defghijklmnop}
T59	0.1081^{cdefghij}	3048^{efgh}	9.3^{cdefghijkl}
T60	0.1055^{cdefghijk}	2836^{efghijklmn}	8.7^{cdefghijklmnop}
T61	0.1052^{cdefghijk}	3371^{efg}	9.3^{cdefghijkl}
T62	0.1051^{cdefghijk}	2783^{fghijklmnop}	9.0^{cdefghijklmno}
Mean	**0.115**	**2710**	**9.9**
CD (p=0.05)	**0.01**	**516**	**1.42**

*Values superscripted with same alphabet are not significantly different from each other for the treatment means independently

SUMMERY AND CONCLUSION

The highest radicle emergence percentage (95.3%) and numerically highest field emergence percentage (97.3%) was recorded in Dry Nano ZnO@250ppm as compared to both the controls. Highest germination percentage (94.7%) in Dry Bulk ZnO@50ppm and highest average shoot length (33.3 cm) in Dry Bulk ZnO@100ppm were recorded as compared to both the controls. Significant highest average root length (40.5 cm), average normal seedling length (67.5 cm) and highest seedling vigour index I (6129) was reported in Dry bulk ZnO@250ppm as compared to both the controls. Significant highest seedlings dry weight (0.2603g) and seedling vigour index II (23.4) was reported in Dry Bulk Zno@750ppm as compared to both the controls.

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Conflict of Interest. None.

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