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Effect of Nanoparticles Seed Treatment on Yield Attributes of Chickpea (*Cicer arietinum* L)

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ABSTRACT: The studies were carried out on chickpea variety Pusa 547 at ICAR- Indian Agricultural Research Institute, New Delhi during 2020-21 with the objective to the effect of nanoparticles on seed yield attributes. 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 concentrations. Along with the two controls *i.e.,* untreated and treated with recommended PoP (Thiram treated @2g/Kg of seeds), treated seeds were evaluated for seed yield attributes. The result revealed that significantly highest field emergence percentage (90.67%), plant height (53.07cm), number of branches per plant (8.27), number of pods per plant (63.67), seed yield per plant (12.83g), harvest index (39.95) and test weight (24.53g) and lowest days to 50% flowering (125.3 days), were recorded in seed treated with dry nano ZnO @ 250ppm compare to both the controls. The conclusion drawn from the study was that dry nano ZnO @ 250ppm was most effective treatment for enhancement of yield attributes in chickpea.

Keywords: Chickpea, Nanoparticles, Zinc oxide, Yield, Dry nano, Treatment

Chickpea (*Cicer arietinum* L.) is a winter grain legume with a wide geographical distribution, which is cultivated and consumed all over the world, especially in Afro-Asian countries. It's a self-pollinated crop with chromosome number of 2n=16. It has considerable amount of proteins and carbohydrates, and the protein quality is believed to be superior to that of other pulses. All of the essential amino acids are present in significant amounts in chickpea. It also contains dietary fibre (6%), lipids (6%) and minerals such as calcium, magnesium, phosphorous and especially potassium. It can be utilised to make nutritious value-added foods that can be used as nutritious food for low-income people in developing countries as well as those suffering from lifestyle diseases [1].

Crop yield stagnation has become one of the most significant challenges for the world's rising population in the previous decade. A crop's production can be increased by either increasing the area under cultivation or improving the productivity per unit area. Because of limitation in the area, the yield per unit area must be raised to assure the nation's food security. On the other hand, in chickpea seed deterioration is a major issue caused by exposure to harsh environmental conditions. Seed treatment is one of the simple methods that can promote seedling vigour and counteract the harmful effects of seed deterioration in order to improve crop growth, yield, and limit seed deterioration. As a result, improving the seed's physiological state, germination, and seedling development became critical in this area [2].

Several seed quality enhancement strategies are employed to improve seed quality, each with its own set of benefits. When compared to its application in the medicinal and industrial sectors, the use of nanomaterials in agriculture is relatively new, but has shown immense potential in agricultural sectors opening up new possibilities in the field of agricultural biotechnology [3]. The incorporation of nanoparticles into plants could have a substantial effect, and thus could be used for agricultural purposes to improve growth and yield. Metal oxide nanoparticles were found to have a positive effect on seed quality attributes [4]. Therefore, the present study was conducted to investigate the effects of seed treatments with three metal oxide nano-particles *viz*.; zinc oxide NP, titanium dioxide NP and silicon dioxide NP with different concentrations to elucidate the effect on the seed yield attributes of chickpea.

MATERIALS AND METHODS

Seeds of chickpea variety Pusa 547 were treated in Tamil Nadu Agricultural University with nano and bulk forms of Zinc oxide, Titanium dioxide, Silicon dioxide at the concentrations of 50, 100, 250, 500, and 750 mg kg^{-1} of seeds in both dry and wet formulations and those treated seeds were received and used for study along with two control *i.e.,* Untreated and treated with recommended fungicides (Thiram 2g/Kg) as per package of practices (PoP).

Treatment combinations (62)

Formulations: 2 (Dry and Wet)

Forms: 2 (Bulk and Nano)

Metal oxides: 3 (Zinc oxide, Titanium dioxide and Silicon dioxide)

Concentrations: 5 (50, 100, 250, 500 and 750 mg kg-^{1})

Controls: 2, untreated (control 1) and recommended PoP (control 2). Details of the treatments are given (Table 1).

The field studies were conducted at experimental farms of the Division of Seed Science and Technology at ICAR-IARI, New Delhi. Sowing was done on 28th October 2020 with three replications in randomized block *design* during *rabi* season and evaluated for the various seed quality characters and yield attributing traits.

100 seeds in four replications were sown in a well prepared field. The emerged seedlings were counted on 15th day after sowing, mean of field emergence was calculated and expressed in percentage. Number of days taken for 50% flowering by the crop was recorded in each replication of each treatment plot when at least one flower appeared on at least 50% of the plants and the average worked out. Five plants selected at random from each replication of each treatment plot and they were tagged and measured for plant height from the base to the tip of the terminal leaf of the main stem, counted number of branches per plant that arose from the base of the plant and recorded total number of pods per plant at harvesting stage and mean was worked out. The pods from randomly selected five tagged plants from each replication of each treatment plot were harvested, threshed and weight of seeds was recorded, worked out the average and expressed seed yield in grams per plant. Four replicates of 100 seeds were counted and weighed to the minimum number of two decimal places using an analytical balance. The average weight of 100 seeds was calculated and test weight was expressed in grams. The harvesting index was calculated using the formula; Harvest index (%) = [Economic yield (grain)/Biological yield (Grain + straw)] × 100.

Statistical analysis of data

The data collected from the field experiments were

Table 1. Treatment details

T1= Untreated control	T22= Dry bulk ZnO @750ppm	T43= Wet nano TiO2 @50ppm
T2= Thiram treated @2g/kg (Recommended PoP)	T23= Wet nano SiO2 @50ppm	T44= Wet nano TiO2 @100ppm
T3= Wet nano ZnO @50ppm	T24= Wet nano SiO2@100ppm	T45= Wet nano TiO2 @250ppm
T4= Wet nano Zno @100ppm	T25= Wet nano SiO2 @250ppm;	T46= Wet nano TiO2 @500ppm
T5= Wet nano ZnO @250ppm	T26= Wet nano SiO2 @500ppm	T47= Wet nano TiO2 @750ppm
T6= Wet nano ZnO @500ppm	T27= Wet nano SiO2 @750ppm	T48= Wet bulk TiO2 @50ppm
T7= Wet nano ZnO @750ppm	T28=Wet bulk SiO2 @50ppm	T49= Wet bulk TiO2 @100ppm
T8= Wet bulk ZnO @50ppm	T29= Wet bulk SiO2 @100ppm	T50= Wet bulk TiO2 @250ppm
T9= Wet bulk ZnO @100ppm	T30= Wet bulk SiO2 @250ppm	T51=Wet bulk TiO2 @500ppm
T10= Wet bulk ZnO @250ppm	T31= Wet bulk SiO2 @500ppm	T52= Wet bulk TiO2 @750ppm
T11= Wet bulk ZnO @500ppm	T32 = Wet bulk SiO2 @750ppm	T53= Dry nano TiO2 @50ppm
T12= Wet bulk ZnO @750ppm	T33= Dry nano SiO2 @50ppm	T54= Dry nano TiO2 @100ppm
T13= Dry nano ZnO @50ppm	T34= Dry nano SiO2 @100ppm	T55= Dry nano TiO2 @250ppm
T14= Dry nano ZnO @100ppm	T35= Dry nano SiO2 @250ppm	T56= Dry nano TiO2 @500ppm
T15= Dry nano ZnO @250ppm	T36= Dry nano SiO2 @500ppm	T57= Dry nano TiO2 @750ppm
T16= Dry nano ZnO @500ppm	T37= Dry nano SiO2 @750ppm	T58= Dry bulk TiO2 @50ppm
T17= Dry nano ZnO @750ppm	T38= Dry bulk SiO2 @50ppm	T59= Dry bulk TiO2 @100ppm
T18= Dry bulk ZnO @50ppm	T39= Dry bulk SiO2 @100ppm	T60= Dry bulk TiO2 @250ppm
T19= Dry bulk ZnO @100ppm	T40= Dry bulk SiO2 @250ppm	T61= Dry bulk TiO2 @500ppm;
T20= Dry bulk ZnO @250ppm	T41= Dry bulk SiO2 @500ppm	T62= Dry bulk TiO2 @750ppm.
T21= Dry bulk ZnO @500ppm	T42= Dry bulk SiO2 @750ppm	

subjected to appropriate statistical analysis. The correlation coefficient between different parameters was also worked out using SPSS 17 software. The values in percentage were converted to arc sine values using percentage transformation for the calculation of critical difference (C.D. at p=0.05).

RESULTS AND DISCUSSION

The results obtained on the effects of seed treatments with different nanoparticles on seed quality parameters are discussed hereunder:

Field emergence percentage: The results determined that there were significant differences in field emergence percentage among the chickpea seeds treated with different nano particles (Table 2). Overall differences between all the treatments were in the range of 54.67% (T32) to 90.67% (T15). Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) separated field 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 field emergence percentage in T1 and T2 was 80.00%. Significantly higher field emergence percentage was found in T15, T54, T36, T20, T59, T55, T41, T35, T16, T60, T40, T37, T22, T21, T53, T34, T19, T17 and T14 which were not only at par among themselves but were also at par with other NP treatments; T13, T58, T42, T56, T39, T57, T33, T18, T2, T1, T62, T61 and T38. Significantly lower field emergence percentage was found in T32, T8, T28, T48, T3, T23, T43, T52, T12, T31, T47, T7, T50, T29, T51, T9, T11, T24, T27,T46 and T45 which were not only at par among themselves but were also at par with other NP treatments; T4, T6, T25, T30, T10, T26, T44, T49 and T5. The increased emergence could be attributed to the good impacts of ZnO NPs, such as increased nanoscale Zn precursor activity in the formation of essential biomolecules, increased cofactor activity in key enzyme systems, and favourable effects on phytohormone reactivity during germination [5]. Additionally, cell activation leads to enhanced mitochondrial activity, which leads to the creation of higher-energy compounds and essential biomolecules that are available during the early stages of germination. In addition, zinc absorption could have triggered the cell cycle [6].

Days to 50% flowering: Seed treatment of chickpea seeds with different nanopaticles had significantly influenced the days to 50% flowering (Table 2). Overall differences between all the treatments were in the range of 125.3 (T15) to 128.0 (T48). Based on observed means for different treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) divided days to 50% flowering means of all treatments in four homogeneous subsets. Among the subsets a large numbers of treatment means were noticed to be grouped together. The NP treatments *viz*.; T32, T31, T30, T29, T28, T27, T26, T25, T23, T12, T11, T10, T22, T13, T58, T37, T21, T19, T18, T14 and T1 were found at par among themselves as well as with all other treatments. The days to 50% flowering in T1 was 126.3 which was at par with T2 (128.0). Significantly lower days to 50% flowering was found in T15 (125.3) which was at par with other NP treatments; T36, T39, T54, T16, T17, T20, T24, T33, T34, T35, T38, T40, T41, T42, T53, T55, T56, T57, T59, T60, T62, T1, T14, T18, T19, T21, T37, T58, T13, T22, T10, T11, T12, T23, T25, T26, T27, T28, T29, T30, T31 and T32. Significantly higher number of days to 50% flowering was found in T48, T47, T46, T45, T44, T43, T6, T4, T3 and T2 which were not only at par among themselves but were also at par with other NP treatments; T52, T51, T50, T49, T9, T8, T7, T5, T32, T31, T30, T29, T28, T27, T26, T25, T23, T12, T11, T10, T22, T13, T58, T37, T21, T19, T18, T14 and T1. In this study lowest days to 50% flowering was found in Dry nano ZnO@250ppm treated seeds, this is supported by others findings such as, treatment of nano scale ZnO (25 nm mean particle size) at 1000 ppm concentration promoted both seed germination and seedling vigor and in turn showed early establishment in soil manifested early flowering in peanut [7]. Laware *et al.* [8] reported that plants treated with ZnO NPs at concentrations of 20 and 30 g ml^{-1} grew faster and bloomed 12-14 days earlier than control plants of onion.

Plant height (cm): The treatment of chickpea seeds with different nanopaticles had significantly influenced the plant height (Table 2). Overall differences between all the treatments were in the range of 36.07cm (T48) to 53.07cm (T15). Based on observed means for diverse treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) alienated plant height means of all treatments in thirteen homogeneous subsets. The plant height in T1 was 42.00cm which was at par with T2 (44.07cm). Significantly higher plant height was found in T15 which was at par with T54, T20, T16, T59, T21, T36, T17, T41, T55, T37, T42, T60, T35, T14, T19, T56, T61, T22, T40, T34, T62 and T39. Significantly lower plant

Table 2. Effect of NP seed treatments on field emergence percentage, days to 50% flowering, plant height and number of branches per plant of chickpea variety Pusa 547

Treatments	Field emergence %	Days to 50% flowering	Plant height (cm)	Number of branches per plant
T1	*80.00^{bcdef} (63.54)**	*126.3^{abcd}	*42.00^{abcdefghij}	*6.13^{abcdefghi}
T2	80.00^{bcdef} (63.49)	128.0^{d}	44.07^{abcdefghijkl}	6.53^{abcdefghij}
T3	59.33^{a} (50.41)	128.0^{d}	38.93^{abcde}	5.33^{ab}
T4	65.33^{ab} (53.96)	128.0^{d}	41.13^{abcdefghi}	5.53^{abc}
T5	68.00^{abcde} (55.59)	127.3^{bcd}	44.07^{abcdefghijkl}	6.07^{abcdefgh}
T6	65.33^{ab} (53.96)	128.0^{d}	42.20^{abcdefghij}	6.07^{abcdefgh}
T7	62.00^{a} (52.00)	127.3^{bcd}	40.07^{abcdefgh}	5.53^{abc}
T8	57.33^{a} (49.25)	127.3^{bcd}	39.07^{abcde}	5.40^{ab}
T9	63.33^{a} (52.79)	127.3^{bcd}	41.13^{abcdefghi}	5.60^{abcd}
T10	66.00^{ab} (54.38)	127.0^{abcd}	43.00^{abcdefghijk}	5.93^{abcdef}
T11	63.33^{a} (52.79)	127.0^{abcd}	42.93^{abcdefghijk}	5.67^{abcd}
T12	60.67^{a} (51.23)	127.0^{abcd}	41.07^{abcdefghi}	5.53^{abc}
T13	82.67^{ef} (65.53)	126.7^{abcd}	44.20^{abcdefghijkl}	6.73^{abcdefghijk}
T14	83.33^{f} (66.05)	126.3^{abcd}	47.13^{efghijklm}	7.53^{fghijk}
T15	90.67^{f} (72.41)	125.3^{a}	53.07^{m}	8.27^{k}
T16	85.33^{f} (67.66)	126.0^{abc}	50.93^{klm}	7.67^{ghijk}
T17	83.33^{f} (65.99)	126.0^{abc}	50.00^{jklm}	7.20^{cdefghijk}
T18	80.00^{bcdef} (63.52)	126.3^{abcd}	43.07^{abcdefghijk}	6.33^{abcdefghij}
T19	83.33^{f} (66.05)	126.3^{abcd}	46.53^{efghijklm}	6.93^{abcdefghijk}
T20	87.33^{f} (69.20)	126.0^{abc}	51.07^{klm}	7.80^{ijk}
T21	84.00^{f} (66.48)	126.3^{abcd}	50.33^{jklm}	7.40^{efghijk}
T22	84.00^{f} (66.56)	126.7^{abcd}	46.07^{defghijklm}	7.00^{bcdefghijk}
T23	59.33^{a} (50.43)	127.0^{abcd}	37.53^{abc}	5.27^{a}
T24	63.33^{a} (52.79)	126.0^{abc}	40.07^{abcdefgh}	5.53^{abc}
T25	65.33^{ab} (53.96)	127.0^{abcd}	42.00^{abcdefghij}	5.80^{abcde}
T26	66.67^{abc} (54.77)	127.0^{abcd}	43.07^{abcdefghijk}	6.00^{abcdefg}
T27	63.33^{a} (52.81)	127.0^{abcd}	41.53^{abcdefghi}	5.80^{abcde}
T28	57.33^{a} (49.26)	127.0^{abcd}	36.33^{ab}	5.33^{ab}
T29	62.67^{a} (52.37)	127.0^{abcd}	39.20^{abcdef}	5.40^{ab}
T30	65.33^{ab} (53.98)	127.0^{abcd}	40.13^{abcdefghi}	5.53^{abc}
T31	60.67^{a} (51.23)	127.0^{abcd}	42.07^{abcdefghij}	5.93^{abcdef}
T32	54.67^{a} (47.71)	127.0^{abcd}	41.40^{abcdefghi}	5.60^{abcd}
T33	80.00^{bcdef} (63.66)	126.0^{abc}	42.07^{abcdefghij}	6.20^{abcdefghi}
T34	83.33^{f} (65.99)	126.0^{abc}	46.07^{defghijklm}	6.53^{abcdefghij}
T35	85.33^{f} (67.91)	126.0^{abc}	47.13^{efghijklm}	7.00^{bcdefghijk}
T36	87.33^{f} (69.24)	125.7^{ab}	50.27^{jklm}	7.80^{ijk}
T37	84.00^{f} (66.63)	126.3^{abcd}	48.00^{ghijklm}	7.40^{efghijk}
T38	79.33^{bcdef} (63.16)	126.0^{abc}	41.07^{abcdefghi}	6.00^{abcdefg}
T39	81.33^{cdef} (64.56)	125.7^{ab}	44.73^{bcdefghijklm}	6.33^{abcdefghij}
T40	84.00^{f} (66.48)	126.0^{abc}	46.07^{defghijklm}	6.93^{abcdefghijk}
T41	85.33^{f} (67.59)	126.0^{abc}	49.33^{ijklm}	7.27^{defghijk}
T42	82.00^{def} (65.20)	126.0^{abc}	47.53^{fghijklm}	7.00^{bcdefghijk}
T43	60.00^{a} (50.80)	128.0^{d}	38.00^{abcd}	5.53^{abc}
T44	67.33^{abcd} (55.18)	128.0^{d}	43.67^{abcdefghijkl}	6.13^{abcdefghi}
T45	64.00^{a} (53.20)	128.0^{d}	41.93^{abcdefghij}	5.93^{abcdef}
T46	63.33^{a} (52.82)	128.0^{d}	41.33^{abcdefghi}	5.93^{abcdef}
T47	61.33^{a} (51.61)	128.0^{d}	39.67^{abcdefg}	5.40^{ab}
T48	58.00a (49.65)	128.0^{d}	36.07^{a}	5.33^{ab}
T49	67.33^{abcd} (55.21)	127.7^{cd}	42.20^{abcdefghij}	6.00^{abcdefg}
T50	62.00^{a} (51.98)	127.7^{cd}	40.07^{abcdefgh}	5.73^{abcde}
T51	62.67^{a} (52.37)	127.7^{cd}	39.40^{abcdef}	5.47^{ab}
T52	60.00^{a} (50.80)	127.7^{cd}	36.40^{ab}	5.27^{a}
T53	83.33^{f} (66.09)	126.0^{abc}	36.07^{a}	6.80^{abcdefghijk}
T54	88.00^{f} (70.13)	125.7^{ab}	51.87^{lm}	8.00^{jk}
T55	85.33^{f} (67.56)	126.0^{abc}	48.40^{hijklm}	7.60^{fghijk}
T56	81.33^{cdef} (64.56)	126.0^{abc}	46.33^{defghijklm}	7.53^{fghijk}
T57	80.00^{bcdef} (63.59)	126.0^{abc}	43.47^{abcdefghijkl}	7.00^{bcdefghijk}
T58	82.00^{def} (65.02)	126.3^{abcd}	43.07^{abcdefghijk}	6.53^{abcdefghij}
T59	85.33^{f} (67.59)	126.0^{abc}	50.33^{jklm}	7.73^{hijk}
T60	84.00^{f} (66.48)	126.0^{abc}	47.13^{efghijklm}	7.40^{efghijk}
T61	79.33^{bcdef} (63.07)	126.0^{abc}	46.13^{defghijklm}	7.20^{cdefghijk}
T62	79.33^{bcdef} (63.16)	126.0^{abc}	45.00^{cdefghijklm}	6.80^{abcdefghijk}
Mean	73.22 (59.41)	126.7	43.62	6.39
CD (p=0.05)	4.9	0.82	3.98	0.79

*In a column, means followed by common letter(s) are not significantly (p=0.05) different; *Figures in parentheses are square root transformed values.

height was found in T48 and T53 (36.07cm) which were not only at par among themselves but were also at par with other NP treatments; T28, T52, T23, T43, T3, T8, T29, T51, T47, T24, T7, T50, T30, T12, T38, T4, T9, T46, T32, T27, T45, T1, T25, T31, T33, T6, T49, T11, T10, T18, T58, T26, T57, T44, T2, T5 and T13. Highest plant height among the treatments was found in Dry nano ZnO@250ppm treated seeds. This improvement can be linked to Zn's role in the formation of tryptophan, which is a precursor to the phytohormone indole-3-acetic acid. ZnO nanoparticles can also influence the biosynthesis of phytohormones such as cytokinins and gibberellins, resulting in an increase in the number of internodes per plant. Furthermore, in the early phases of plant development, increased cell elongation can contribute to an increase in plant height [9]. Similarly, Mahdieh *et al.* [10] found that seed treatment with ZnO NPs resulted in the maximum increase in plant height in pinto bean (*Phaseolus vulgaris* L.) at the concentration of 0.15%.

Number of branches per plant: The result revealed that there were significant differences in number of branches per plant among the chickpea seeds treated with different nano particles (Table 2). Overall differences between all the treatments were in the range of 5.27 (T52) to 8.27 (T15). Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) separated number of branches per plant means of all treatments in eleven homogeneous subsets. Among the subsets a large numbers of treatment means were noticed to be grouped together. The NP treatments *viz*.; T19, T40, T62, T53 and T13 were found at par among themselves as well as with all other treatments. The number of branches per plant in T1 was 6.13 which was at par with T2 (6.53). Significantly higher number of branches per plant was found in T15 which was at par with other NP treatments; T54, T36, T20, T59, T16, T55, T56, T14, T60, T37, T21, T41, T61, T17, T22, T57, T42 and T35 which were not only at par among themselves but were also at par with other NP treatments; T19, T40, T62, T53 and T13. Significantly lower number of branches per plant found in T52 and T23 (5.27) which were not only at par among themselves but were also at par with other NP treatments; T3, T28, T48, T8, T29, T47, T51, T4, T7, T12, T24, T30, T43, T9, T32, T11, T50, T25, T27, T31, T10, T45, T46, T38, T26, T49, T5, T6, T1, T44, T33, T39, T18, T2, T34, T58, T13, T53, T62, T40 and T19. Among the treatments, highest number of branches per plant was found in Dry nano ZnO@250ppm treated seeds. Better nutrient availability in numerous physiological and biochemical processes, such as root development, energy transfer reaction, photosynthesis, and nitrogen fixation, can be related to the increase number of branches per plant [11]. The number of branches and leaves per plant, fresh and dry weight of branches and leaves, as well as the highest yield of seeds in common bean plants treated with 40 ppm ZnO-NPs was also observed [12]. This effect showed that ZnO-NPs acts as co-enzyme to cell differentiation for stimulation plant growth, pods and seeds formation of common bean plant.

Number of pods per plant: The result established that there were significant differences in number of pods per plant among the chickpea seeds treated with different nano particles (Table 3). Overall differences between all the treatments were in the range of 36.13 (T52) to 63.67 (T15). Based on observed means for diverse treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) alienated number of pods per plant means of all treatments in sixteen homogeneous subsets. Among the subsets a large numbers of treatment means were noticed to be grouped together. The number of pods per plant in T1 was 46.20 which was at par with T2 (47.00). Significantly higher number of pods per plant was found in T15 which was at par with other NP treatments; T20 T54 T36 T16 T55 T59 T21 T14 and T41. Significantly lower number of pods per plant found in T52 and T28 (36.20) which were not only at par among themselves but were also at par with other NP treatments; T8, T47, T23, T12, T29, T51, T48, T7, T46, T3, T43, T9 T32, T24, T11, T30, T25, T50, T4, T45, T31, T6, T27, T49, T10, T26, T44, T5, T38 and T33.

In this study, highest number of pods per plant was found in in seeds treated with Dry nano ZnO@250ppm. Unaborted reproductive structures that may have resulted from enhanced photosynthetic activity can also be attributed for the increased pod output in NP treated seeds. The physico-chemical treatments may have facilitated the biosynthesis of nucleic acids and proteins, and hence improved cell division, resulting in higher seed yield per plant. Furthermore, enhanced plant metabolic activity resulted due to higher nutrient absorption and availability, which boosted the seed and pod formation as well as pod and grain yield [13]. Substantial increase in the number of pods per plant, shelling percentage, and pod yield in groundnut due to the application of P and nano Zn was also observed [14]. Similarly, pod yield/ plant was 34 percent higher in ZnO NPs treated groundnut compared to bulk $ZnSO_4$ and at higher concentration [7].

Table 3. Effect of NPs on seed yield per plant of chickpea variety Pusa 547

Treatments	Number of pods per plant	Seed yield per plant (g)	Harvest index (%)	Test weight (g)
T1	*$46.20^{bcdefghijkl}$	*6.80^{abcde}	*$35.47^{abcdefghijklmno}$ (36.56)**	*22.12^{bcd}
T2	$47.00^{cdefghijklm}$	7.00^{abcdef}	$35.59^{abcdefghijklmno}$ (36.64)	22.44^{cde}
T3	39.07^{abcd}	5.27^{a}	28.90^{abc} (32.52)	20.13^{a}
T4	40.40^{abcde}	5.60^{a}	29.98^{abcdef} (33.21)	20.34^{a}
T5	$43.33^{abcdefghi}$	6.53^{abcd}	$33.15^{abcdefghijklmno}$ (35.16)	20.91^{abc}
T6	41.00^{abcdef}	6.20^{abc}	$30.92^{abcdefghijkl}$ (33.79)	20.73^{ab}
T7	38.60^{abcd}	5.90^{ab}	$30.13^{abcdefg}$ (33.29)	20.45^{a}
T8	37.20^{ab}	5.13^{a}	28.03^{a} (31.98)	19.94^{a}
T9	39.20^{abcd}	5.40^{a}	28.87^{abc} (32.51)	20.13^{a}
T10	$42.07^{abcdefg}$	6.30^{abc}	$32.11^{abcdefghijklmno}$ (34.53)	20.51^{ab}
T11	39.33^{abcd}	6.03^{abc}	$30.39^{abcdefghi}$ (33.46)	20.42^{a}
T12	38.00^{abcd}	5.77^{ab}	29.31^{abcd} (32.79)	20.31^{a}
T13	$49.07^{efghijklmn}$	8.90^{efghij}	$37.09^{defghijklmno}$ (37.53)	23.40^{defg}
T14	55.20^{lmnop}	9.33^{ghijk}	38.36^{jklmno} (38.28)	23.81^{efg}
T15	63.67^{p}	12.83^{q}	39.95^{o} (39.22)	24.53^{g}
T16	57.07^{nop}	11.53^{lmnopq}	39.33^{no} (38.86)	23.99^{efg}
T17	54.00^{klmno}	$10.27^{hijklmno}$	$37.24^{efghijklmno}$ (37.63)	23.30^{defg}
T18	$47.13^{defghijklm}$	7.80^{bcdefg}	$36.18^{cdefghijklmno}$ (36.99)	23.07^{defg}
T19	53.13^{jklmno}	8.83^{efghij}	$37.33f^{ghijklmno}$ (37.68)	23.41^{defg}
T20	59.33^{op}	12.20^{opq}	38.33^{jklmno} (38.27)	24.10^{efg}
T21	55.20^{lmnop}	$10.97^{jklmnopq}$	$37.11^{defghijklmno}$ (37.55)	23.71^{defg}
T22	53.13^{jklmno}	$9.90^{ghijklmn}$	$37.00^{defghijklmno}$ (37.48)	23.40^{defg}
T23	37.60^{abc}	5.13^{a}	29.02^{abc} (32.60)	20.02^{a}
T24	39.27^{abcd}	5.30^{a}	29.91^{abcdef} (33.17)	20.26^{a}
T25	40.13^{abcde}	5.80^{ab}	$30.83^{abcdefghijk}$ (33.74)	20.50^{ab}
T26	$42.8^{abcdefgh}$	6.33^{abc}	$32.69^{abcdefghijklmno}$ (34.88)	20.84^{abc}
T27	41.00^{abcdef}	5.87^{ab}	$31.69^{abcdefghijklmn}$ (34.27)	20.63^{ab}
T28	36.20^{a}	5.10^{a}	28.29^{ab} (32.14)	19.82^{a}
T29	38.00^{abcd}	5.23^{a}	28.91^{abc} (32.53)	20.05^{a}
T30	39.73^{abcde}	5.60^{a}	$30.35^{abcdefghi}$ (33.43)	20.26^{a}
T31	41.00^{abcdef}	6.10^{abc}	$31.92^{abcdefghijklmn}$ (34.40)	20.50^{ab}
T32	39.20^{abcd}	5.53^{a}	$30.63^{abcdefghij}$ (33.61)	20.40^{a}
T33	$45.13^{abcdefghijk}$	8.53^{defghi}	$36.06^{bcdefghijklmno}$ (36.92)	22.92^{defg}
T34	$47.07^{defghijklm}$	9.27^{ghijk}	$37.30^{efghijklmno}$ (37.66)	23.29^{defg}
T35	$52.20^{hijklmno}$	$10.23^{hijklmno}$	$37.97^{hijklmno}$ (38.06)	23.63^{defg}
T36	57.07^{nop}	12.23^{opq}	39.08^{mno} (38.71)	24.20^{fg}
T37	52.93^{jklmno}	11.5^{lmnopq}	38.53^{klmno} (38.38)	23.92^{efg}
T38	$44.13^{abcdefghij}$	$8.13^{cdefghi}$	$35.39^{abcdefghijklmno}$ (36.52)	22.6^{def}
T39	$45.80^{bcdefghijkl}$	9.00^{fghij}	$37.04^{defghijklmno}$ (37.51)	22.92^{defg}
T40	$50.00^{fghijklmno}$	$9.93^{ghijklmn}$	$37.26^{efghijklmno}$ (37.64)	23.44^{defg}
T41	55.13^{lmnop}	11.93^{mnopq}	$38.00^{ijklmno}$ (38.07)	24.02^{efg}
T42	$50.93^{ghijklmno}$	$11.23^{klmnopq}$	$37.37^{fghijklmno}$ (37.70)	23.61^{defg}
T43	39.07^{abcd}	5.53^{a}	29.89^{abcdef} (33.15)	20.30^{a}
T44	$43.00^{abcdefghi}$	6.43^{abcd}	$32.83^{abcdefghijklmno}$ (34.96)	20.80^{abc}
T45	40.73^{abcdef}	6.23^{abc}	$31.47^{abcdefghijklm}$ (34.13)	20.50^{ab}
T46	39.07^{abcd}	5.90^{ab}	$30.13^{abcdefgh}$ (33.30)	20.31^{a}
T47	37.20^{ab}	5.73^{ab}	30.00^{abcdef} (33.22)	20.10^{a}
T48	38.13^{abcd}	5.33^{a}	29.46^{abcde} (32.88)	20.22^{a}
T49	$42.07^{abcdefg}$	6.20^{abc}	$32.08^{abcdefghijklmn}$ (34.51)	20.60^{ab}
T50	40.33^{abcde}	6.10^{abc}	$30.93^{abcdefghijkl}$ (33.80)	20.40^{a}
T51	38.13^{abcd}	5.70^{ab}	29.32^{abcd} (32.79)	20.12^{a}
T52	36.13^{a}	5.53a	28.63^{abc} (32.35)	20.00^{a}
T53	53.20^{jklmno}	$10.10^{hijklmno}$	$37.93^{ghijklmno}$ (38.03)	23.48^{defg}
T54	59.07^{op}	12.43^{pq}	39.40^{no} (38.90)	24.41^{g}
T55	56.60^{nop}	$11.33^{klmnopq}$	38.71^{lmno} (38.49)	24.12^{fg}
T56	53.07^{jklmno}	$10.53^{ijklmnop}$	$36.95^{defghijklmno}$ (37.45)	23.95^{efg}
T57	$51.27^{ghijklmno}$	$9.83^{ghijklm}$	$36.44^{cdefghijklmno}$ (37.15)	23.73^{defg}
T58	$52.13^{hijklmno}$	$9.97^{hijklmn}$	$37.10^{defghijklmno}$ (37.53)	23.26^{defg}
T59	56.33^{mnop}	12.03^{nopq}	$38.11^{ijklmno}$ (38.13)	24.12^{fg}
T60	$52.33^{ijklmno}$	$10.93^{jklmnopq}$	$37.32^{fghijklmno}$ (37.67)	23.88^{efg}
T61	$51.07^{ghijklmno}$	$10.00^{hijklmn}$	$36.87^{defghijklmno}$ (37.40)	23.89^{efg}
T62	$49.07^{efghijklmn}$	9.63^{ghijkl}	$36.95^{defghijklmno}$ (37.44)	23.47^{defg}
Mean	46.16	8.032	34.02 (35.66)	22.010
CD (p=0.05)	4.45	1.01	2.24	0.78

*In a column, means followed by common letter(s) are not significantly (p=0.05) different; *Figures in parentheses are square root transformed values.

Seed yield per plant (g): there were significant differences in seed yield per plant among the chickpea seeds treated with different nano particles (Table 3). Overall differences between all the treatments were in the range of 5.10g (T28) to 12.83g (T15). Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) separated seed yield per plant means of all treatments in seventeen homogeneous subsets. Among the subsets a large numbers of treatment means were noticed to be grouped together. The seed yield per plant in T1 was 6.80 which was at par with T2 (7.00g). Significantly higher seed yield per plant was found in T15 which was at par with other NP treatments; T54, T36, T20, T59, T41, T16, T37, T55, T42, T21 and T60. Significantly lower seed yield per plant found in T28, T8, T23, T29, T3, T24, T48, T9, T32, T43, T52, T4 and T30 which were not only at par among themselves but were also at par with other NP treatments; T51, T47, T12, T25, T27, T7, T46, T11, T31, T50, T6, T49, T45, T10, T26, T44, T5, T1 and T2. As mentioned above, among the treatments, highest seed yield per plant was found in Dry nano ZnO@250ppm treated seeds. Zinc functions as an enzyme activator in plants and is directly involved in the biosynthesis of auxin, which results in the production of additional cells and dry matter. Seeds treated with dry NP ZnO @1300 mg/kg showed increased number of seeds per fruit and seed yield in chilli [15]. Khanm *et al.* [16] found that using ZnO-NPs (400 ppm) through various ways such as seed priming, seed priming + foliar spray, and foliar spray showed a significant favourable influence on physiological and seed yield parameters.

Harvest index: There were significant differences in harvest index among the chickpea seeds treated with different NPs (Table 3). Overall differences between all the treatments were in the range of 28.03 (T8) to 39.95 (T15). Based on observed means for various treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) divided harvest index means of all treatments in sixteen homogeneous subsets. Among the subsets a large numbers of treatment means were noticed to be grouped together. The harvest index in T1 was 35.47 which was at par with T2 (35.59). The NP treatments *viz*.; T2, T1, T38 (35.39), T5 (33.15), T44 (32.83), T26 (32.69) and T10 (32.11), were found at par among themselves as well as with all other treatments. Significantly higher harvest index was found in T15 which was at par with other NP treatments; T54, T16, T36, T55, T37, T14, T20, T59, T41, T35, T53, T42, T19, T60, T34, T40, T17, T21, T58, T13, T39, T22, T62, T56, T61, T57, T18, T33, T2, T1, T38, T5, T44, T26 andT10. Significantly lower harvest index was found in T8 (28.03) which was at par with other NP treatments; T28, T52, T9, T3, T29, T23, T12, T51, T48, T43, T24, T4, T47, T7, T46, T30, T11, T32, T25, T6, T50, T45, T27, T31, T49, T10, T26 , T44, T5, T38, T1 and T2. As explained above, among the treatments, highest harvest index was found in Dry nano ZnO@250ppm treated seeds. As explained above, among the treatments highest harvest index was found in Dry nano ZnO@250ppm treated seeds. According to Naderi and Abedi [17] the key role of Zn in protecting and maintaining structural stability of cell membranes could explain the rise in vegetative development in plants. The influence of seed treatment with nanoparticles on increasing the photosynthesis cycle and translocating photosynthetic products to economic parts, as well as enzymatic activity and other biological activities, can result in increase in the harvest index of the plant [15]. Zinc functions as an enzyme activator in plants and is directly involved in the biosynthesis of auxin, which results in the production of additional cells and dry matter, and because of the increased physiological capacity for turning dry matter into grain yield, a higher harvest index was recorded [18].

Test weight (g): Significant differences in test weight were recorded among the chickpea seeds treated with different nano particles (Table 3). Overall differences between all the treatments were in the range of 19.82g (T28) to 24.53g (T15). Based on observed means for diverse treatments, Tukey's Honest Significant Difference (HSD) test (p=0.05) divided test weight means of all treatments in seven homogeneous subsets. Among the subsets a large numbers of treatment means were noticed to be grouped together. The test weight in T1 was 22.12 which was at par with T2 (22.44g). Significantly higher seed yield per plant was found in T15 and T54 (24.41g) which were not only at par among themselves but were also at par with other NP treatments; T36, T55, T59, T20, T41, T16, T56, T37, T61, T60, T14, T57, T21, T35, T42, T53, T62, T40, T19, T13, T22, T17, T34, T58, T18, T33 and T39. Significantly lower test weight per plant found in T28, T8, T52, T23, T29, T47, T51, T3, T9, T48, T30, T24, T43, T12, T46, T4, T32, T50, T11 and T7 which were not only at par among themselves but were also at par with other NP treatments; T25, T31, T45, T10, T49, T27, T6, T44, T26 and T5. As mentioned above, among the treatments, highest test weight was found in Dry nano ZnO@250ppm treated seeds. The accumulation of translocating sugars and assimilates in zinc treated seeds may be reason for heavier seed result [19]. Laware *et al.* [8] reported that plants treated with ZnO NPs at concentrations of 20 and 30 g ml^{-1} grew faster and bloomed 12-14 days earlier than control plants. Compared to control, treated plants had considerably greater seeded fruit per umbel, seed weight per umbel, and 1000 seed weight.

A comparative evaluation of results revealed that the dry formulations of NP ZnO @250ppm were the most effective treatment for the enhancement of seed yield attributes of chickpea compared to other treatments and controls. This showed highest field emergence percentage (90.67%), plant height (53.07cm), number of branches per plant (8.27), number of pods per plant (63.67), seed yield per plant (12.83g), harvest index (39.95) and test weight (24.53g) and lowest days to 50% flowering (125.3 days) compare to both the controls.

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