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# Effect of nanofertilizers on growth and yield of selected cereals - A review

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## ABSTRACT

Nanoscience coupled with nanotechnology has emerged as possible cost-cutting measure to prodigal farming and environmental clean-up operations. Nanoscale science, engineering, and technology, which is more widely known using the novel term 'nanotechnology', is an emerging multidisciplinary field that can have enormous potential impact on our society. Nanofertilizers facilitate slow and steady release of nutrients and thereby reduce the loss of nutrients and enhance the nutrient use efficiency. The full recommended rate of conventional and nanofertilizer (FRR-CF+FRR-NF) enhanced the plant height, chlorophyll content, number of reproductive tillers, panicles, and spikelets in rice. The magnitudes of increase over the FRR-CF were 3.6%, 2.72%, 9.10%, 9.10%, and 15.42%, respectively. In rice, an exposure to Zn NP (at 0, 25, 50, 75, 100 & 150 mg $L^{-1}$) caused significant changes in root and shoot length and mass (fresh and dry mass). The ZnO nanoparticles increased the shoot dry matter and leaf area indexes by 63.8% and 69.7% respectively in mineral poor soils. The effect of $TiO_2$ Nano particles was significant on number of corn in plant, maize dry weight and corn yield in $P \leq 0.05$ in . Mean comparison showed that the highest number of corn in plant (10.10), maize dry weight (2396.35 kg $ha^{-1}$) and corn yield (1744.13 kg $ha^{-1}$) were achieved by flowering stage. Silver nanoparticles in 25 ppm concentration have showed significant improvement in maximum leaf area and highest grain yield while 75 ppm concentration resulted in decrease in grain yield in wheat. Maximum number of grains per spike was recorded with 25 ppm followed by 50 ppm whereas maximum 100-grain weight was obtained for 25 and 125 ppm soil applied silver nanoparticles in wheat.

**Key words:** Chelate, Nanofertilizer, Nanoparticles, Nanosilver, Surface area, Yield.

Nanoscience and Nanotechnology represent a new frontier for the research community. Nanotechnology is working with the smallest possible particles which raise hopes for improving agricultural productivity through encountering problems unsolved conventionally. Nanotechnology has as its goal the realization of novel materials and devices with features on the nanoscale, drawing from fields such as colloidal science, device physics, and supramolecular chemistry. Improvement of crops in agriculture is a continuous process. In the management aspects, efforts are made to increase the efficiency of applied fertilizer with the help of nano clays and zeolites and restoration of soil fertility by releasing fixed nutrients. It has found potential applications in controlling nutrient release and availability, characterization of soil minerals, weathering of soil minerals and development, nature of soil rhizosphere, nutrient ion transport in soil plant system, emission of dusts and aerosols from agricultural soils and their nature, soil and water conservation, water treatment and efficient management, remediation of soils and water pollution and precision farming.

The term "Nanotechnology" was first used by Norio Taniguchi in 1974. The word "Nanotechnology" has originated from a Greek word **'nanos'** which means **"dwarf"**. Nanotechnology is defined as understanding and control of matter at dimensions of roughly 1-100 nm, where unique physical properties make novel applications possible (EPA, 2007).

**Nanoparticles :** Nanoparticle is defined based on the size at which fundamental properties differ from those of the corresponding bulk material (Banfield and Zhang, 2001). Nanoparticles overlap in size with colloids, which ranges from 1 nm to 1 mm in diameter (Buffle, 2006). Novel properties that differentiate nanoparticles from the bulk material typically develop at a critical length scale of under 100nm. The "novel properties" mentioned are entirely dependent on the fact that at the nano-scale, the physics of nanoparticles mean that their properties are different from the properties of the bulk material.

**Unique features of nanoparticles:**

1. Due to small size, there are more atoms on the surface compared to the interior of the nanoparticles. This leads to large surface to volume ratio which inturn leads to higher charge density and higher reactivity of nanoparticles.
2. As the surface area increases in comparison to volume, the behavior of the atoms on the surface of the particles becomes more than the inside the particles. Once the particles become small enough they exhibit quantum mechanical behavior.

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3. As a result of large surface to volume ratio there is more interaction between atoms in intermixed with materials in nanoparticles, which leads to increased strength, increased heat resistance, decreased melting point and different magnetic properties of nanoclusters.
4. Differences in the exposed surfaces of different nanoparticles of various shapes leads to differences in atomic distribution across the nanoparticles. This inturn affects the electron transfer rate kinetics between metal nanoparticles and corresponding adsorbed species.
5. Nanoparticles have higher catalytic activity when they are present in tetrahedral structure followed by cubic and spherical structure, attributed to enhancement of chemical reactivity at the sharp edges and corner of the former.
6. The different nanoparticles except hydroxy apatite, have zeta potential in between +30 and -30 mv and show high tendency to agglomerate to higher particles sizes (Adhikari *et al.,* 2010).

**Nano-fertilizer affects the growth, development and chemical properties of rice:** The experiment was conducted by Benzon *et al.* (2015) under greenhouse conditions at the Agricultural Experiment Station and Research Facility, Kyungpook National University, Daegu, South Korea. The experimental set up was arranged in a Completely Randomized Design with five replications. Soil samples were potted into 15 kg quantities using 31 × 27 cm pots. Split application of the conventional fertilizer was done in the designated pots. Previously grown rice seedlings cv. Ilpum (10-15 days old) were transplanted onto pots and allowed to grow until maturity. The nanofertilizer (N>1.2%; $P_2O_5$>0.001%; $K_2O$>0.0001%) used in the experiment. The treatments include:

1. Control (no conventional fertilizer and nanofertilizer)
2. Full Recommended Rate of conventional fertilizer (FRR-CF)
3. Half Recommended Rate of conventional fertilizer (HRR-CF)
4. Full Recommended Rate of nanofertilizer (FRR-NF)
5. Half Recommended Rate of nanofertilizer (HRR-NF)
6. FRR-CF + FRR-NF
7. FRR-CF + HRR-NF
8. HRR-CF + FRR-NF
9. HRR-CF + HRR-NF

The results indicated that, the number of reproductive tillers, number of panicles and total number of spikelets were significantly affected by the application of conventional fertilizer and its combination with nanofertilizer (Table 1). In addition, the parameters were enhanced best with the application of FRR-CF+FRR-NF. The percentage increase over the FRR-CF was 9.10%, 9.10% and 15.42%, respectively.

The panicle weight, total grain weight (unpolished and polished), total shoot dry weight and harvest index were observed to have the same trends in the following order: FRR-CF + FRR-NF > FRR-CF + HRR-NF > FRR-CF > HRR-CF > HRR-CF + FRR-NF > HRR-CF + HRR-NF > FRR-NF > HRR-NF > Control as reflected in Table 2. All treatments were significantly higher over the control except for the treatments applied with nanofertilizer alone. An increase in harvest index would mean improvement in grain yield. It seems that the function of nanofertilizer at the reproductive stage of rice was only supplemental. Nonetheless, it was evident that nanofertilizer application enhanced the abovementioned parameters. Nanofertilizer may have synergistic effect on the conventional fertilizer for better nutrient absorption by plant cells resulting to optimal growth.

Compared to the FRR-CF + FRR-NF treatment, the total phenolic content, reducing power and ABTS scavenging activity were enhanced significantly by HRR-NF by 51.67%, 36.28%, and 20.93% respectively (Table 3). While the results were comparable to the control, the application of HRR-NF considerably increased these parameters compared to the other treatments. Several studies have indicated that the phenolic compounds in grains have effective antioxidant properties, due to the presence of one or more aromatic rings with one or more hydroxyl groups (Zielinski and Kozlowska, 2000). The TPC of the extracts ranged from 232.84 to 557.55 mg GAE/100g residue. The highest TPC was obtained by applying HRR-NF which was higher compared to the black

**Table 1:** Number of reproductive tillers, panicles and total number of grains as affected by chemical and nanofertilizer application under greenhouse conditions

| Treatment | Number of reproductive tillers² | Number of panicles² | Total number of grains² |
|---|---|---|---|
| Control | 4 c | 4 c | 235 d |
| FRR-CF | 30 a | 30 a | 3213 ab |
| HRR-CF | 22 b | 22 b | 2424 bc |
| FRR-NF | 4 c | 4 c | 332 d |
| HRR-NF | 4 c | 4 c | 297 d |
| FRR-CF + FRR-NF | 33 a | 33 a | 3799 a |
| FRR-CF + HRR-NF | 29 a | 29 a | 3266 ab |
| HRR-CF + FRR-NF | 22 b | 22 b | 2455 bc |
| HRR-CF + HRR-NF | 18 b | 19 b | 2069 c |

¹Means in a column followed by the same letter(s) are not significantly different at P≤ 0.05 based on Tukey's HSD test.

**Table 2:** Influence of chemical and nanofertilizer application on the panicle weight, total grain weight (unpolished and polished rice), total shoot dry weight and harvest index of rice under greenhouse conditions[1].

| Treatment | Panicle weight[2] | Total grain weight[2] | | Total shoot dry weight[2] | Harvest index |
|---|---|---|---|---|---|
| | | Unpolished | Polished | | |
| Control | 6.54 d | 6.27 d | 4.62 d | 13.94 e | 0.437 c |
| FRR-CF | 78.95 ab | 75.92 ab | 51.36 b | 125.93 abc | 0.601 ab |
| HRR-CF | 63.12 bc | 60.94 bc | 42.44 bc | 101.66 bcd | 0.596 ab |
| FRR-NF | 8.95 d | 8.56 d | 6.22 d | 17.03 e | 0.522 abc |
| HRR-NF | 7.98 d | 7.69 d | 5.85 d | 15.09 e | 0.502 bc |
| FRR-CF + FRR-NF | 95.57 a | 92.07 a | 64.78 a | 148.69 a | 0.619 a |
| FRR-CF + HRR-NF | 79.63 ab | 76.67 ab | 52.62 ab | 126.09 ab | 0.608 a |
| HRR-CF + FRR-NF | 61.61 bc | 59.26 bc | 40.84 bc | 99.26 cd | 0.587 ab |
| HRR-CF + HRR-NF | 53.57 c | 51.65 c | 35.84 c | 88.72 d | 0.582 ab |

[1]Means in a column followed by the same letter(s) are not significantly different at P≤0.05 based on Tukey's HSD test. [2]Grams per plant.

**Table 3:** Total phenolic content, reducing power and ABTS scavenging activity of rice extracts as affected by chemical and nanofertilizer application under greenhouse conditions[1].

| Treatment | Total phenolic content (mg GAE/100g residue) | Reducing power | ABTS radical scavenging activity (%) |
|---|---|---|---|
| Control | 557.35 a | 0.1359 a | 98.27 a |
| FRR-CF | 246.67 c | 0.0849 b | 78.74 b |
| HRR-CF | 232.84 c | 0.0811 b | 73.69 b |
| FRR-NF | 400.49 b | 0.1227 a | 82.60 b |
| HRR-NF | 557.55 a | 0.1381 a | 97.23 a |
| FRR-CF + FRR-NF | 269.51 c | 0.0880 b | 76.88 b |
| FRR-CF + HRR-NF | 292.65 c | 0.0868 b | 76.07 b |
| HRR-CF + FRR-NF | 305.00 bc | 0.0911 b | 77.31 b |
| HRR-CF + HRR-NF | 248.73 c | 0.0780 b | 72.77 b |

[1]Means in a column followed by the same letter(s) are not significantly different at P≤0.05 based on Tukey's HSD test.

and red rice cultivars studied by Ham *et al*. (2013). In addition, the experiment conducted on different pigmented landraces of rice showed lower values (233.92-251.38 mg GAE $100g^{-1}$). This implies that the TPC can be enhanced in white rice cultivars through nanofertilizer application and can even exceed the pigmented rice cultivars.

The plant height was enhanced by the application of full recommended rate of nanofertilizer at 15 and 30 DAT (Fig. 1). Moreover, FRR-NF treatment significantly increased plant height compared to the control as the plant matures. General observations showed that all treatments except for HRR-NF were able to significantly increase plant height. Overall rankings revealed that FRR-CF + FRR-NF treatment performed best.

The plant height was enhanced by the application of full recommended rate of nanofertilizer at 15 and 30 DAT. Moreover, FRR-NF treatment significantly increased plant height compared to the control as the plant matures. Overall rankings revealed that FRR-CF + FRR-NF treatment performed best. These suggest that nanofertilizer can either provide nutrients for the plant or aid in the transport or absorption of available nutrients resulting in better crop growth. Related study by Liu and Lal (2014) revealed similar findings in soybean. They synthesized a new type of hydroxyapatite phosphorus nanoparticles (NPs) of ~16 nm in size and assessed fertilizing effect of the NPs on soybean in inert growing medium in a greenhouse experiment. The data revealed that growth rate was increased by 33% using phosphorus NPs.

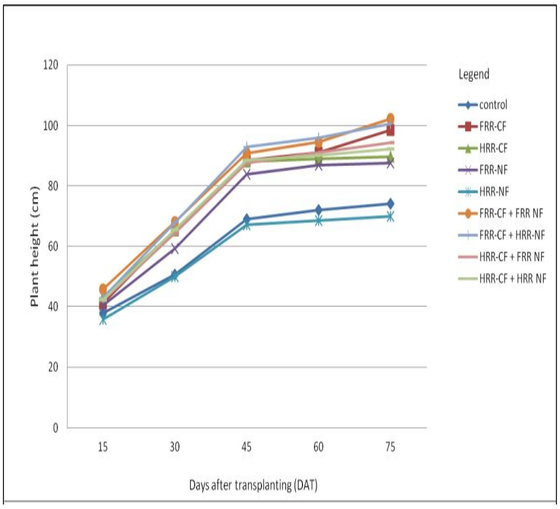


**Fig 1:** Plant height of rice cv. Ilpum as influenced by conventional and nanofertillzer application under greenhouse conditions

**Effect of Zn nano-particles on growth responses of rice:** A laboratory experiment was conducted by Upadhyaya *et* *al.* (2015) at Regional Agricultural Research Station, Akbarpur, Karimganj, Assam. Rice (KMJ-6-1-2) seeds were used during the experiment. Seeds of selected cultivars were surface sterilize with 0.1% $HgCl_2$ and wash thoroughly with distilled water several times. After that, the seeds were plated in petridish containing moisten filter paper and incubated in dark at 28 °C for 48 h. After 48 h, germinating seeds were transferred on a cup containing Hoagland solution at pH 6.8 and grown under light at room temperature. After 5 days of growth, plants were treated with zinc nanoparticle suspension (0, 25, 50, 75, 100 & 150 mg $L^{-1}$ Zn NP) prepared in Hoagland solution. Zinc nanoparticles (30-60 nm diameter) of Nanoshel purchased from Intelligent Materials, Pvt. Ltd, Haryana, India was used in the experiment. Required amount of Zinc nanoparticles was taken to prepare a 500 mg $L^{-1}$ stock suspension, which was used to prepare different concentration of Zn NP suspension. After 48 h of treatment, at least 10 plants per treatment were sampled and root and shoot lengths were measured using a centimeter ruler.

Results with rice seedlings revealed that Zn NP caused increase of root and shoot length in rice. As depicted in Figure 2, a significant morphological changes i.e., length of root and shoot was shown in response to Zn NP treatment when subjected to 0, 25, 50, 75, 100 and 150 mg $L^{-1}$ of Zn NP solution. There is gradual increase in the length of the root and shoot with increase in the concentration of Zn NP solution. As shown in Figure 1, Zn NP caused gradual increase in root and shoot fresh mass as well as dry mass of rice cultivars. Zn NP promoted plant growth as evidenced from increased total fresh and dry mass of root and shoot, highest rate being shown with increasing level of Zn NP, which may be attributed to increased antioxidant responses in plants treated with Zn NP.

The level of zinc nutrition may affect plant water relations and alter stomatal conductance. Stomatal conductance and transpiration rates also declined under zinc deficiency. Possible roles of zinc in protecting plant cells from damage by reactive oxygen species and its effect on plant metabolism has also been well reviewed (Cakmak, 2000; Broadley *et al.,* 2006 and Cakmak, 2008). However, little information about the effect of zinc nano particle induced biochemical damages in rice seeds is available. The role of Zn in protecting plant cells from damage by reactive oxygen species may be an important response in plants growth and not simply affecting RWC, dry matter accumulation and changes in antioxidant balance during growth of plant.

**The effects of zinc-oxide nanoparticles on growth parameters of corn (SC704):** Melika *et al.* (2015) conducted a pot culture experiment to investigate the effects of zinc-oxide nanoparticles on the growth and dry weight of corn-SC704 in mineral poor soils. Corn (SC 704) seeds were cultivated in four liter pots filled with mineral poor soil (cultivation depth 3 cm). Five seeds were cultivated in each pot. After a while, extra plants were eliminated and three plants were kept. Pots were divided into four groups with eight pots in each group. In order to maintain the soil moisture at field capacity, irrigation was performed daily.

Group 1. Normal irrigation was performed.

Group 2. Irrigation with zinc nanocolloid was applied in three stages: one, two, and three weeks after corn emergence.

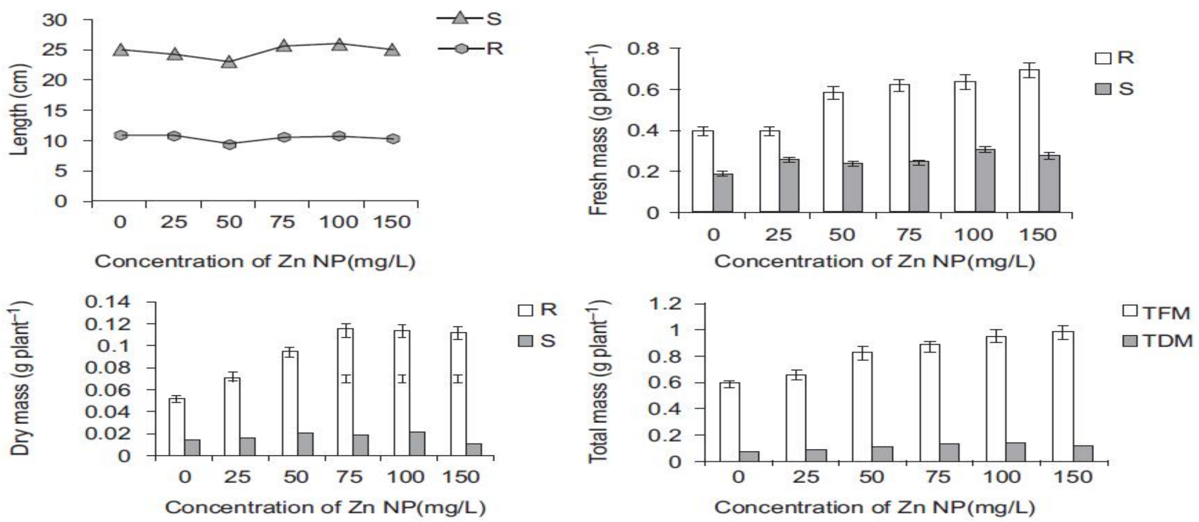


**Fig. 2:** Changes in length, fresh and dry mass of root and shoot and total fresh and dry mass of rice plant subjected to different concentration of Zn NP treatment.

Data presented are mean ± SE (n=3)

Group 3. Irrigation with zinc nanoparticles 2 ppm was applied in three stages: one, two, and three weeks after corn emergence (pH was decreased from 7.4 to 7 to increase the solubility of zinc oxide).

Group 4. Irrigation with micrometric zinc oxide (2 ppm) was applied in three stages: one, two, and three weeks after corn emergence (pH was decreased from 7.4 to 7 to increase the solubility of zinc oxide). (Figure 3)

According to the results, each treatment with zinc oxide increased leaf area. Studies have reported differing reactions amongst corn hybrids to nitrogen and zinc fertilizer (Cicek and Cakirlar, 2002). The lack of zinc and nitrogen or reduction of supplementation delayed leaf appearance. Supplementation expedited leaf appearance. By increasing fertilizer levels, grain yield per area unit was increased in all corn cultivars (McMaster, 2007). Using 240 kg $ha^{-1}$ of nitrogen (in vitro) accelerated leaf appearance of C-404 cultivar, reduced phyllochron and increased grain yield.

In this current study, irrigation with zinc oxide nanoparticles improved growth, leaf area, and leaf dry weight (Table 4). Both nanoparticles met corn's need for zinc. Additionally, both nanoparticle groups were formed better than the zinc oxide group due to their nano properties. This was attributed to higher specific surface area of ZnO nanoparticles compared to micro particles. The higher surface area led to better contact between ZnO and soil elements. In other words ZnO nanoparticles absorbed more efficiently and were the probable cause of increased plant growth.

**$TiO_2$ nano particles affected on maize (*Zea mays* L.):** A field experiment was carried out by Payam and Tayyebe (2011) using a factorial complete randomized block design with four replications in a year planting (2010-2011) at Islamic Azad University Shahr-e-Qods branch, Tehran, Iran. The factor of study included of $TiO_2$ nano particles affected on maize (*Zea mays* L.). These assays were consisting of the growth stages of plant in two levels (steaming stage and flowering stage). In addition, spraying stages with five levels [(control), nano $TiO_2$, $TiO_2$ nano particles (0.01%, 0.02% and 0.03%, the percentage of weight 20% cloied)]. The field soil texture was lemon-clay. The field area was 1600 m in 40×40 dimension. Fertilizers were added into the field as normal suggest. The characters were measured consist of number of corn in plant, maize dry weight and corn yield.

The results showed that the higher number of corn in plant (10.10), maize dry weight (2396.35 kg $ha^{-1}$) and highest corn yield (1744.13 kg $ha^{-1}$) were achieved by flowering stage and lower number of corn in plant (9.94), maize dry weight (2364.38 kg $ha^{-1}$) and lowest corn yield (1743.36 kg $ha^{-1}$) was achieved by steaming stage (Table 5).

The nano $TiO_2$ treatment has obvious effects on the improvement of growth and development in spinach. However, bulk $TiO_2$ treatment shows little effect (Gratzel, 2001). Nano anatase $TiO_2$ could increase light absorbance, accelerate transport and transformation of light energy (Hussain *et al.,* 2004). Application of $TiO_2$ has been found to show an excellent efficacy with a correspondent 20% increase in grain weight due to the growth promoting effect of $TiO_2$ nano particles (Anderson *et al.,* 2002). It has been suggested that could promote growth of soybeans and could increase the strength of roots, enhancing the roots ability to absorb water and fertilizers (Burnside *et al.,* 1998). It is investigated that nano $TiO_2$ will have an important role on

**Table 4:** Leaves morphological properties

| | |
|---|---|
| Control group | Tiny terminal leaves, bright coloured, decreased growth yellow veins, burned end of some leaves |
| Zinc nanocolloid group | Broad, green fresh leaves with green veins and unburned ends |
| Zinc nanoparticle | Broad, green fresh leaves with green veins and unburned ends |
| Three zinc oxide groups | Broad, green fresh leaves with green veins and unburned ends |

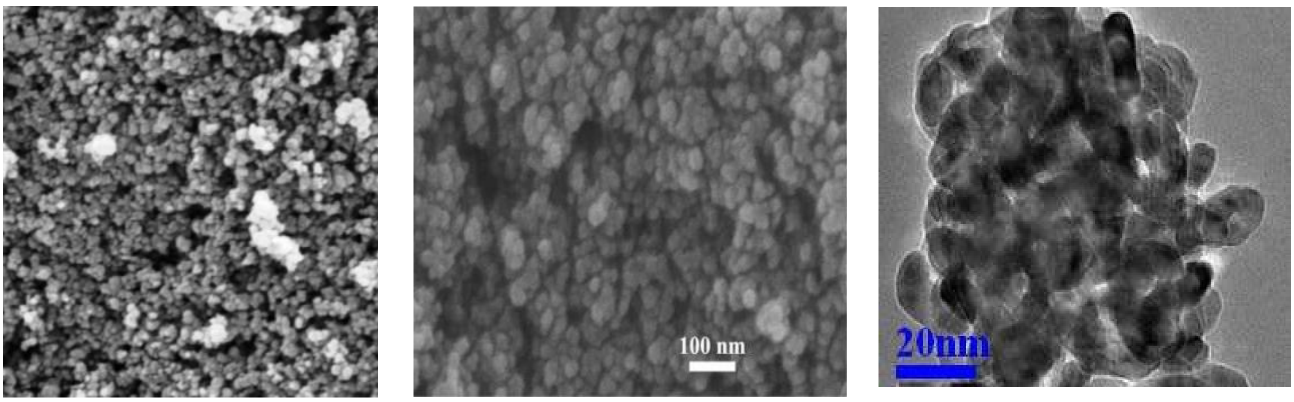


**Fig 3:** Electron microscope images of nanoparticles. Scanning electron microscope (SEM) of nanoparticles (Group 3) are shown.

**Table 5:** Means Comparison

| Treatment (Growth stages) | No. of corn in plant | Maize dry weight (kg $ha^{-1}$) | Corn yield(kg $ha^{-1}$) |
|---|---|---|---|
| Steaming stage | 9.94b | 2364.38b | 1743.36b |
| Flowering stage | 10.10a | 2396.35a | 1744.13a |

the corn as production and applications increase (Ci *et al.,* 2003). Thus understanding the fate and potential of this nanoparticle has become a necessity. The results showed that stages and dosages of nano $TiO_2$ have significant difference on morphological traits of corn such as plants height-corn dry weight. Researchers believed that presence of nanoparticles might cause an alternation in the available root surface area, which can increase absorption ability and yield components.

**Silver nano-particles enhance the growth and yield of wheat:** Present study was carried out by Hafiz *et al.* (2015) to determine the role of SNPs for improving (NUE) in wheat. The SNPs were synthesized chemically by reducing silver nitrate with trisodium citrate and size was 10-20 nm according to X-Ray Diffraction analysis. Completely randomized design with seven graded doses of SNPs (0, 25, 50, 75, 100, 125, 150 ppm) and four replications was employed for experimental layout. Seedlings of wheat variety NARC-2009 were transplanted to pots. Pot soil was soaked with SNPs solution up to field capacity levels and distilled water was applied in control treatment. Sterilized seeds of wheat were placed in petridishes containing three layers of filter papers for germination. Soil analysis was performed before the experiment for nutrient status of soil. Recommended doses of N, P, K (90, 60 and 60 kg $ha^{-1}$) were applied by using urea, diammonium phosphate and potassium chloride respectively. Calculated amount of N, P and K based on recommended doses @ 0.73, 0.65 and 0.5 g $pot^{-1}$ were applied in pots. Ten seedlings were transplanted to each clay pot. Solutions equivalent to field capacity containing different concentrations of SNPs were applied to pots. Growth attributes *viz.,* leaf area, shoot weight and chlorophyll contents ware measured at flag leaf stage. Average values were used for statistical analysis. At maturity, plants were harvested and different yield parameters were recorded. Five plants from each pot were selected and data on number of grains $spike^{-1}$, 100 grains weight (g) and grain yield $pot^{-1}$ (g) was recorded.

The pH of the soil was 7.09, electrical conductivity 0.79 dS $m^{-1}$, nitrate nitrogen 0.035 mg $kg^{-1}$, available phosphorous 5.30 mg $kg^{-1}$ and available potassium is 80.0 mg $kg^{-1}$.

**Wheat growth attributes:** Different treatments of SNPs greatly affected the leaf area (Table 6). Maximum leaf area (19.7 $cm^2$) was with 25 ppm of SNPs followed by 50 ppm (18.18 $cm^2$) SNPs, while in control it was (15.0 $cm^2$). Further increase in concentration of SNPs reduced the leaf area. Liu *et al*., (2005) reported that nano calcium carbonate increased leaf area of peanut significantly. Shoot fresh weight and dry weight did not increase by the application of SNPs. Significantly at 5% probability level higher shoot fresh weight (4.75 g) and dry weight (0.90 g) were recorded in control where SNPs were not applied. The lowest shoot fresh weight (0.10 g) and dry weight (0.03 g) were recorded at 150 ppm of SNPs applied. Increasing concentration of SNPs significantly reduced shoot fresh weight and dry weight of wheat plant. Similar results were reported by Mirzajani *et al*., (2013) in rice with application of SNPs. Lin and Xing (2008) found that in the presence of ZnO nano particles rye grass biomass reduced significantly. When *Phaselous radiatus*, *Sorghum bicolor* and *Lolium multiflorum* were subjected to SNPs, reduced root growth, root length and biomass were observed (Yin *et al*., 2011; Lee *et al*., 2012).

Chlorophyll content of wheat plant differed significantly by application of SNPs (Table 6). Maximum chlorophyll content (51.2) was recorded at 75 ppm followed by 100 ppm (46.1) of SNPs as compare where as in control, it was (45.1). The lowest chlorophyll content (39.8) was recorded at 150 ppm of SNPs. Gao *et al*., (2006) tested that *Spinacia oleracia* treated with nano-anatase $TiO_2$ induced 2.67 times more activity of *Rubisco carboxylase* than that

**Table 6:** Effect of silver nano particles on leaf area, shoot fresh weight, shoot dry weight and chlorophyll content of wheat cultivar NARC -2009

| Treatments | Leaf area ($cm^2$) ± S.E | Shoot fresh weight (g)± S.E | Shoot dry weight (g) ± S.E | Chlorophyll contents ± S.E |
|---|---|---|---|---|
| 0 ppm | 14.96e±0.13 | 4.75a±0.02 | 0.90a±0.01 | 45.09b±0.01 |
| 25 ppm | 19.65a±0.13 | 4.05b±0.01 | 0.82b±0.01 | 45.58b±0.01 |
| 50 ppm | 18.19b±0.46 | 4.00b±0.01 | 0.73c±0.01 | 45.85b±0.02 |
| 75 ppm | 17.05c±0.45 | 4.04b±0.01 | 0.67d±0.01 | 51.18a±0.72 |
| 100 ppm | 16.26d±0.18 | 3.21c±0.01 | 0.60e±0.01 | 46.09b±0.01 |
| 125 ppm | 12.73f±0.16 | 3.06d±0.01 | 0.45f±0.01 | 43.55b±0.01 |
| 150 ppm | 10.04g±0.14 | 2.10e±0.01 | 0.32g±0.01 | 39.75c±0.02 |
| LSD values | 0.31 | 0.10 | 0.03 | 2.79 |

Means sharing common letters in column do not differ significantly at 5% probability level

**Table 7:** Effect of silver nano particles on number of grains/spike, 100-grains weight and yield/pot of the wheat cultivar NARC- 2009

| Treatments | No of Grains Spike$^{-1}$ ± S.E | 100 Grain Weight ± S.E | Yield Pot$^{-1}$ (g) ± S.E |
|---|---|---|---|
| 0 ppm | 18.5 c±0.18 | 3.35e±0.012 | 7.18 c±0.02 |
| 25 ppm | 29.0a±0.31 | 4.66ab±0.02 | 13.25 a±0.02 |
| 50 ppm | 22.0bc±0.31 | 4.73a±0.02 | 12.45 a±0.34 |
| 75 ppm | 25.0b±0.54 | 4.40 c±0.02 | 10.40 b±0.10 |
| 100 ppm | 22.3 b±0.27 | 4.43 bc±0.03 | 10.36 b±0.11 |
| 125 ppm | 22.5 b±0.34 | 3.94 d±0.02 | 9.90b±0.08 |
| 150 ppm | 11.5 d±0.34 | 3.78 d±0.03 | 9.73 b±0.06 |
| LSD values | 3.52 | 0.25 | 1.77 |

**Table 8:** Effect of copper nanoparticles on growth parameters of wheat

| Treatments | Concentration of Copper nanoparticles | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 ppm | 0.2 ppm | 0.4 ppm | 0.6 ppm | 0.8 ppm | 1 ppm | LSD |
| Leaf Area (cm2/plant) | 6.81 e | 8.87 c | 12.83 a | 10.53 b | 10.10 b | 7.90 d | 0.5974 |
| Chlorophyll Contents (SPAD units) | 38.28 c | 40.43 c | 51.23 a | 46.87 b | 48.50 ab | 37.97 c | 4.0357 |
| FW (g/plant) | 1.0467 c | 1.9167 b | 2.4900 a | 2.2967 a | 1.8800 b | 1.8600 b | 0.2291 |
| DW (g/plant) | 0.0633 c | 0.0967 b | 0.1167 a | 0.1133 b | 0.0933 b | 0.0867 b | 0.0126 |
| Root DW/plant (mg) | 0.0223 e | 0.0493 b | 0.0580 a | 0.0330 c | 0.0320 cd | 0.0253 de | 0.0072 |

**Table 9:** Effect of copper nanoparticles on yield parameters of wheat

| Treatments | Concentration of copper nanoparticles | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 ppm | 10 ppm | 20 ppm | 30 ppm | 40 ppm | 50 ppm | LSD |
| Leaf Area (cm2/plant) | 6.847 e | 8.980 c | 10.783 b | 12.793 a | 10.290 b | 8.263 d | 0.5473 |
| Chlorophyll Contents (SPAD units) | 38.433 c | 41.667 c | 46.480 b | 51.367 a | 50.400 ab | 37.833 c | 4.8054 |
| Grains per Spike | 23.333 cd | 25.333 b | 27.667 b | 30.667 a | 20.667 de | 19.333 e | 2.7175 |
| Spikes per Pot | 13.00 c | 13.33 c | 16.33 b | 19.33 a | 11.67 c | 9.00 d | 2.5506 |
| 100 Grain Weight (g) | 4.0800 d | 5.1033 c | 5.7567 b | 6.4500 a | 3.8067 d | 3.1800 e | 0.2805 |
| Grain yield per Pot (g) | 6.4200 d | 8.5700 c | 10.873 b | 13.513 a | 5.1000 e | 4.0867 f | 0.335 |

of control. Hence, nano anatase promoted photosynthesis by molecular mechanism of carbon reaction. SNPs induced enhancement of chlorophyll content may enhance photosynthesis leading to more production of bio-mass and yield.

**Wheat yield components:** SNPs applied @ 25 ppm produced significantly greater number of grains spike$^{-1}$ (29.0) followed by 75 ppm (25.0). The lowest number of grains spike$^{-1}$ (11.5) was recorded with 150 ppm of SNPs applied. Significant differences were observed among treatments for 100 grain weight. Maximum 100 grain weight (4.73 g) was produced with 50 ppm followed by 25 ppm (4.66 g) of SNPs against control (3.25 g). Minimum 100 grain weight (3.78 g) was recorded with 150 ppm treatment at 5% probability level. Maximum grain yield (13.3 g) was obtained with 25 ppm SNPs followed by 50 ppm (12.45 g) as compare to control (7.18 g) where no SNPs were applied (Table 7). SNPs increased the yield may be due to growth, stimulating effect of silver (Sharon *et al*. 2010).

**Potential of copper nanoparticles to increase growth and yield of wheat:** A study was conducted in Pakistan to determine the potential of copper nanoparticles (Cu-NPs) for enhancing growth and yield of wheat (Abdul *et al.,* 2015). Completely randomized design with three replications was employed for experimental layout. Pakistani wheat cultivar Millat-2011 was used to conclude the role of Cu-NPs on growth and yield. Seeds were sown in petri-plate having filter papers soaked with distill water for seed germination. Plastic pots of 500 ml capacity were filled with MS medium blended initially with 0, 2, 4, 6, 8 and 10 ppm Cu-NPs. One week old seedlings were transferred to the solution supported by holes in thermopole sheets fitted in pots. Subsequently 0.2, 0.4,

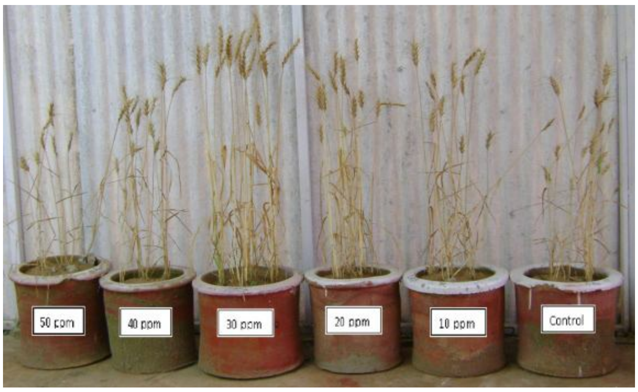


**Fig. 4:** Effect of copper nanoparticles on plant growth and yield

0.6, 0.8 and 1.0 ppm were used. MS without Cu-NPs served as control. After 4 weeks of seedling growth in solution culture data on leaf area, chlorophyll content, fresh weight, dry weight and root dry weight were recorded.

Another experiment was application of nanoparticles to soil filled in pots to investigate the effect of Cu-NPs on yield of wheat. One week old seedlings were transplanted into pots (ten $pot^{-1}$). Completely Randomized Design with three replications was employed for experimental layout. Solutions equivalent to field capacity water containing 0, 2, 4, 6, 8 and 10 ppm Cu-NPs were applied as different treatments.

Response of wheat seedlings grown in MS medium supplemented with different levels of Cu-NPs varied significantly (Table 8). Addition of Cu-NPs up to 0.4 ppm significantly increased leaf area, chlorophyll content, plant fresh weight, dry weight and root dry weight over control. Further increase in level of Cu-NPs caused significant drop in values of the growth parameters except plant fresh weight that started decreasing at 0.8 ppm. This might be due to more bioavailability, absorption and accumulation of nanoparticles leading to toxic effects. Concentration of Cu-NPs higher than 0.4 ppm in MS medium produced declining trend in growth parameters.

Impact of soil applied Cu-NPs to wheat plants in pots are presented in Table 9. Progressive increase in chlorophyll content and leaf area was observed with application of 10, 20 and 30 ppm Cu-NPs. Increasing the level of Cu-NPs to 40 and 50 ppm was accompanied by a significant reduction in chlorophyll and leaf area. In general, addition of 10 to 40 ppm Cu-NPs in pots produced significantly higher leaf area and chlorophyll than those of control plants. Similar trend was observed for number of spikes/pot, number of grains/ spike, 100 grain weight and grain yield per pot. Nonetheless, the best results were achieved with application of 30 ppm Cu-NPs to wheat in pots. Therefore, 30 ppm Cu-NPs applied in soil may be considered the best for inducing good growth and maximum yield (Figure 4) according to the results of this study. Thus, 30 ppm Cu NPs applied to soil seems equivalent to 0.4 ppm applied in MS medium. Declining trend in growth and yield at concentrations higher than 30 ppm might be due to more absorption of nanoparticles leading to phytotoxic effects. Several studies have reported phytotoxic effects of Cu-NPs on growth in contradiction with our results. Adverse effects of Cu-NPs on root (Adhikari *et al.,* 2012 and Stampoulis *et al.,* 2009), seedling growth (Shah and Belozerova, 2009), and shoot growth (Musante *et al.,* 2010) on different plants including wheat have been reported. Maximum growth and yield was recorded with 30 ppm in pots. Nanoparticles induced increased activity of chloroplast (Hong *et al.,* 2005), rubisco (Gao *et al.,* 2006), antioxidant enzyme system (Nekrasova *et al.,* 2011) and nitrate reductase (Lu *et al.,* 2002) might be the possible underlying mechanism responsible for enhanced growth and yield. So far, no study has reported effects of Cu-NPs on yield of wheat.

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