Nano-cuprous oxide enhances seed germination and seedling growth in Lycopersicum esculentum plants

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ABSTRACT

This study was carried out to determine the influence of cuprous oxide nanoparticles (Cu$_2$O NPs) biosynthesised from leaf extracts of Flacourtia montana on the tomato Lycopersicum esculentum seed germination, seedling growth and vigour index. Here we examined the promotory and phytotoxic effect of Cu$_2$O NPs (0-160ppm) on tomato seeds resulted in dosage dependent response. The highest germination percentage (95%) was observed at 20ppm Cu$_2$O NPs, however, above 20ppm Cu$_2$O NPs, there is a reduction in the seed germination. The tomato seedlings showed increased root and shoot elongation up to 20ppm Cu$_2$O NPs concentration, further increase in NPs concentration caused the negative effect on plants growth and development. The leaf pigments showed increasing trend in tomato plants after treatment with Cu$_2$O NPs up to 20ppm as compared to control. Phtotoxicity of Cu$_2$O NPs in tomato seedlings demonstrated by lower contents of chlorophyll a, b and carotenoid pigments. The study of effect on antioxidant enzymes showed increases in activity with increase in Cu$_2$O NPs concentration for two enzymes, Superoxide dismutase (SOD) and Glutathione Peroxidase (GPX) out of five enzymes treated. High antioxidant activity of enzymes is followed by the increased lipid peroxidation and decrease in free radical scavenging activity by the DPPH. The activity of Catalase, Phenyl Alanine Aminolyase and Poly Phenol Oxidase enzymes were found to increase up to 20ppm as compared to control and above this, all three enzymes showed decrease in activity. Uptake of Cu$_2$O NPs nanoparticle by tomato seedling was confirmed by atomic absorption spectroscopy.

Keywords: Nano-Cuprous Oxide, Flacourtia montana, Tomato, antioxidant enzymes, lipid peroxidation

INTRODUCTION

Nanomaterials have many applications in agriculture in terms of plant protection and nutrition due to their size-dependent qualities, high surface-to-volume ratio and unique optical properties. Research and development in this field growing rapidly. Hence it pave way for wide advances in agricultural research, transfer of agricultural and food wastes to energy and other useful by-products through enzymatic nanobio processing, disease prevention, and treatment in plants using various nanocides.

Nanoparticles in agriculture can act as potential candidates for modulating the redox status thereby changing the development of the plants. It is reported that ionic silver (Ag+) released from AgNPs inhibits respiratory enzymes and induces oxidative stress by generation of reactive oxygen species (ROS). The interaction mechanisms at the molecular level between nanoparticles and biological systems are largely unknown.

Choosing an appropriate technique to increase seed tolerance to adverse environmental conditions will enhance the seed germination percentage. Nanoparticles of many metal oxides by absorbing water, oxygen and nutrients and having the antimicrobial properties can affect the seed germination, improve growth and plant metabolism.

NPs closely interact with their surrounding environment and plants are essential base component of all ecosystem. There is considerable concern about the potentially harmful effects of these NPs and they can have significant negative effects on many organisms, especially plants. NPs will inevitably interact with plant and these interactions such as uptake and accumulation in plant biomass will greatly affect their fate and transport in the environment. 

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Recently many studies have showed the physiological responses of plant seedlings to nanoparticles during germination, but the influence on the seed germination and root growth varied significantly among the plants and nanoparticle types. For example, TiO₂ on fennel seed germination, ZnO on cucumber seed germination, Ag NPs increased the germination percent of Pennisetum glaucum. Graphene had no obvious effects on wheat seed germination, while decreased the number of wheat roots. CuO nanoparticles have no effects on maize seeds germination, while inhibited the root elongation.

Copper as a micro element required for the normal growth and development of the plants. A nano metal copper functions as that of copper by slow release of ions. In present study green synthesised cuprous oxide nanoparticle from Flacourtia montana and characterized was used to check their role in enhancing the germination of tomato seeds and seedling stage growth and also the phytotoxicity effects on plants.

MATERIALS AND METHODS

Collection of Tomato (Lycopersicum esculentum) seeds

Tomato seeds of PKM-1 variety procured from local market and surface sterilized in 5% Sodium hypochlorite solution for 10 min followed by multiple washing in distilled water.

Seed germination test

The disinfected tomato seeds were soaked with sonicated CuO NPs arranged in the proportion of 1:10 (w/v) and control in distilled water for 12 h with gentle shaking in an orbital shaker at 150 rpm to ensure every one of the seeds were evenly in contact with the solutions.

To contemplate the impact of NPs on seed germination, the 12 h CuO NPs treated seeds in various nanoparticle concentrations were exchanged onto wet cotton two fold layer filter paper in transparent box having size 15° 6.5 cm for 14 days until two cotyledon leaves arise and in each treatment, fifty seeds were taken, all kept 1 cm apart from each other. 10 ml of appropriate concentrations of NPs arrangement was included and distilled water was used as control. After a time of 14 days, the tomato seedlings were randomly taken out to quantify the seed germination parameters, chlorophyll content, antioxidant properties and nanoparticle uptake by the plant.

Seed germination percentage

The seed germination was recorded from 2-6 days interval. Seeds were considered as germinated when their radicle showed at least 2 mm length. The germination percentage was calculated according to formula

\[ \text{Germination percentage (GP %)} = \left( \frac{Gf}{n} \right) \times 100 \]

Where, 'Gf' is the total number of germinated seeds at the end of the experiment, 'n' is the total number of seeds used in the test.

Root and shoot length

The root and shoot length was measured at 14 days after treatment using a meter scale and expressed in centimetre.

Seedling vigour index

The seedling vigour index (VI) was calculated by using the method suggested by 22.

Vigour Index =

\[ (\text{Mean root length} + \text{Mean shoot length}) \times \text{Germination (\%)} \]

Biomass study

The randomly selected 10 plants after 14 days were washed with distilled water, blotted dried and fresh weight was determined. Dry weight was determined after drying the plant material in oven at 70°C for 24 h and recorded.

Estimation of leaf Chlorophyll pigment

Chlorophyll estimation was carried out as described by Lichtenthaler and expressed in mg/g fresh weight. Briefly seedlings were ground in 5 ml of 80% of acetone and supernatant was measured at 470, 645 and 663 nm. Leaf pigments were analysed by using the formula

\[ \text{Chl a (mg/g FW)} = 12.21 \times A_{663} - 2.81 \times A_{645} \]

\[ \text{Chl b (mg/g FW)} = 20.13 \times A_{645} - 3.27 \times A_{663} \]

Carotenoids (mg/g FW) =

\[ \left( 1000 \times A_{470} - 3.27 \times (\text{Chl a} - 104(\text{Chl b})) \right) / 198 \]

Were, \( A \) = Absorbance at respective wavelength, \( V \) = Volume of extract [ml], \( W \) = Fresh weight of the sample [mg]

Antioxidant enzyme activities

Preparation of crude enzyme extract

Crude enzyme extract was prepared by grinding tomato plant seedlings (500 mg) of 14 days old in 10 ml of 50 mM sodium phosphate buffer (pH 7) containing 5 mM EDTA. All the steps in the extraction process were carried out at 0 to 4°C. The activity of enzyme assay was expressed as \( \mu \text{mol of enzyme} / \text{ml/min of protein (Activity)} / \text{mg of protein} \).

Superoxide dismutase (SOD: EC 1.15.1.1) assay

SOD activity was carried out by measuring inhibition of the photochemical reduction of nitroblue tetrazolium (NBT) as described Mirsa and Fridovich with some modification. Briefly, the reaction mixture contained 0.1 ml of enzyme extract, 0.5 ml of sodium phosphate buffer, 1 ml of Na₂CO₃, 0.4 ml of NBT and 0.2 ml of EDTA and 0.4 ml of Hydroxylamine hydrochloride. After 15 min incubation the absorbance was recorded at 560 nm against the blank without extract. The activity was calculated using molar extinction coefficient of 4020 M⁻¹ cm⁻¹.

Glutathione Peroxidase (GPX: EC 1.6.4.2) assay

It was measured according to Mohandas et al. with some modification. Briefly, reaction mixture contained sodium phosphate buffer, EDTA, sodium azide, 0.1 ml of extract, glutathione, NADPH, hydrogen peroxide, and 0.1 ml of PMS. The activity was calculated as \( \mu \text{mol NADPH oxidized/min of mg of protein using molar extinction coefficient of 6220 M⁻¹ cm⁻¹ at 560 nm} \).

Catalase (CAT: EC 1.11.1.6) assay

Catalase activity was carried out as described by Aebi at 240 nm using a molar absorption of 43.6 M⁻¹ cm⁻¹ by monitoring the decrease in absorbance resulting from the decomposition of H₂O₂. The reaction mixture contained 1.5 ml of sodium phosphate buffer, 0.5 ml of H₂O₂ and 0.1 ml of enzyme extract. The activity expressed using coefficient of absorbance at 40 M⁻¹ cm⁻¹.

Phenyl Alanine Aminolyase (PAL) (PAL: EC 1.10.3.1) assay

PAL assay was carried out as given by Goldson and co-workers by using L-phenylalanine as a substrate. The total
volume 3ml of reaction mixture contained 0.1 ml enzyme extract with 50 mM potassium phosphate buffer (pH 7) and 200 mL of substrate and incubated at 37°C for 15min. The change in the activity was measured for 1min at 290nm and activity was expressed using molar absorptivity of 19.73 mM⁻¹ cm⁻¹.

**PolyPhenol Oxidase (PPO) Assay**

Polyphenol oxidase activity was determined as per the procedure given by Mahadevan and Sridhar.²⁹ The reaction mixture consists of 3.0 ml of 0.5 mM sodium phosphate buffer (pH 6.5) and 0.1 ml of the enzyme extract. To start the reaction 1.0 ml of 0.01 M catechol was added and the rate of increase in absorbance was measured at 420 nm for one min. The activity was expressed as change in absorbance/min/mg protein using a molar absorptivity of 1010 M cm⁻³.

**Antioxidant properties**

**Determination of Malondialdehyde (MDA) content:** Lipid peroxidation was determined by measuring MDA formation using the thioarbituric acid (TBA) reaction.²⁸ Briefly the reaction mixture contained 2ml trichloro acetic acid leaf extract, 2ml 0.6% TBA and the mixture was incubated in boiling water for 30min and the absorbance was recorded at 532nm and 450nm and 600nm against TCA blank. After subtracting the non-specific absorbance at 600nm, the MDA content was determined by its extinction coefficient of 155 mM/cm and is expressed as nano moles per ml of fresh weight.

**Determination of free radical scavenging activity by 2,2-diphenyl-1-picrylhydrazyl (DPPH) method**

Protocol of Lee et al.³¹ was followed with some modifications. The reaction mixture containing 0.5ml of methanolic extracts of sample and 1.5ml of 0.2 mM DPPH methanol solution was incubated at dark for 30min at room temperature and absorbance was recorded at 515nm. The scavenging activity of the extract was calculated using the formula and expressed as percentage of DPPH discoloration using the equation.

\[
\% \text{ DPPH scavenging} = \frac{(AC – AS)}{AC} \times 100
\]

Where, ‘AC’ is the absorbance of the control and ‘AS’ is the absorbance of the sample.

**Determination of Total Antioxidant Capacity (TAC)**

The reaction mixture contained 0.5ml of extract with 0.45ml of reagent solution (0.6 M sulphuric acid, 28mM sodium phosphate and 4mM ammonium molybdate). The extract was kept in water bath at 95°C for 90min and then cooled. The absorbance was measured at 695nm against methanol and expressed as the number of milligram equivalent of ascorbic acid (GAE) per gram of fresh weight.³²

**Nanoparticle uptake in plant tissues by Atomic Absorption Spectroscopy**

Tomato seedlings 0.1–0.4g were pre-treated with 1% HNO₃ solution for 2h heated to 80°C for 2h in sand bath. Then, 10mL of 70% perchloric acid was added and the solution was heated to 200°C until it became clear and filtered through 0.45µm Whatman filter paper. The filtrate was analysed for Cu concentrations using inductively coupled plasma atomic absorption spectroscopy (Agilent technologies, 200 Series).

**Estimation of Total Soluble Protein:** By using BSA as a standard curve, protein concentration of leaf extract was determined by the method of Lowery et al.³³

**Statistical Analysis**

Each treatment in the experiment was conducted with three replications and the results were presented as Mean ± SE (Standard error). One-way ANOVA was conducted to identify significant differences between treatments, the differences were considered significant when P < 0.05.

**RESULTS AND DISCUSSION**

Nanomaterials have many applications in agriculture in terms of plant protection and nutrition due to their size-dependent qualities, high surface-to-volume ratio and unique optical properties. Nanoparticles in the field of agriculture can act as potential candidates for modulating the redox status thereby changing the growth and development of the plants at various stages. The accumulation of NPs of metals at high levels in the plant not only impact their growth, but can cause phytotoxicity effect on plants and also pose a route for contamination of the food chain. Here we studied the effect of Cu₂O NPs on tomato (Lycopersicum esculentum) seed germination and seedling vigour.

**Effect on Seed Germination**

There is no negative effect of Cu₂O NPs on the tomato seed germination (Figure 1). All the treatments were prompted more than 85% of germination. The highest germination percentage 95% was observed at 20ppm Cu₂O NPs, however, above 20ppm NPs concentration there is a reduction in the seed germination as compared to control.

Seed germination gives an appropriate establishment for further plant development, improvement and good economic yield. During germination, the NPs were presumed to diffuse through nano gaps on seed coats, bringing about enhanced germination, followed by slow and minimal release of NPs and also probably due to the seed coat, which can act as protector for the embryo. In the meantime higher concentration on Cu₂O NPs acted as toxic for the development of plants which suggests that the seeds were likely stressed by the presence of Cu₂O NPs at higher concentrations. Similar results were reported by Singh and his co-workers³⁵.

**Figures 1:** Effect of Cuprous oxide nanoparticle on seed germination

The phytotoxicity of NPs was assessed according to the root and shoot length and biomass study. In the present study, the tomato seedlings showed increased root and shoot elongation up to 20ppm NPs concentration, further increase in NPs concentration caused the negative effect on plants growth and development. The root and shoot length (Figure 2) observed to be maximum of 12.4 ± 0.31 cm and 5.55 ±
The impact of Cu NPs and its oxide forms has been studied on various plants which had given conflicting outcomes. De la Rosa and co-workers\(^{33}\) reported the 20% decrease in seed germination and 50% decrease in root elongation with 800 and 1600 mg/l concentration of NPs and an increase in biomass weight at 250 mg/l of when tomato seeds treated with 8nm size ZnO NPs. Song et al.\(^{35}\) reported the inhibition of root length, biomass and chlorophyll pigments at lower concentration of 40nm CuO on \textit{L. minor}. Singh co-workers\(^{34}\) have reported the plant exposure to 10mg/l NPs has showed increased in anti oxidant activity and above this concentration there is a decrease in the antioxidant activity in the Petriplate assay.

The major reason for the decrease in the root length might be due to aggregation of nano particles and stopping up of root pores along these lines which lessen the uptake of water by the seeds\(^{36}\) and increment in the root length might be because of the antimicrobial activities that enhances the plant opposition against stress\(^{37}\). Biomass production was in accordance with the root and shoot length of tomato seedlings. There is decrease in biomass under high concentration of cuprous oxide NPs treatment suggesting the toxic effect of NPs at higher concentrations. These results were similar to the results reported by Fatma et al.\(^{38}\).

The increase in photosynthesis rate is affected by NPs might be because of correlative impact of Iron (Fe), Magnesium (Mg), and sulphur (S) on plants. The NPs can enhance the structure of chlorophyll, better capture of daylight and transfer of light energy to active electrons, increase light absorbance and facilitate formation of pigments and chemical activities\(^{39}\). The decrease in the photosynthetic pigment may be due to formation reactive oxygen species (ROS) by NPs at higher concentration. The similar outcomes were reported by Fatma et al.\(^{39}\) when tomato plant exposed to Ag NPs. Kareem et al.\(^{40}\) reported decrease in the pigments concentration when \textit{C. sativus} exposed to Cu NPs.

The study of effect of NPs on antioxidant enzymes showed increases in activity with increase in NPs concentration for two enzymes, Super oxide dismutase (SOD) and Glutathione Peroxidase (GPX) out of five enzymes treated. The activity of

\[\text{Leaf pigment} \times 100 = \text{Seedling vigour index}\]

\[\text{Seedling vigour index} = \frac{\text{Biomass study at 20 ppm NPs}}{\text{control}} \times 100\]

The seedling vigour index which is calculated based on the biomass and the photosynthetic pigment activity.

\[\text{Effect on Photosynthetic Pigments (Chl-a, b and Carotenoids)}\]

The leaf pigments showed increasing trend in tomato plants after treatment with Cu2O NPs up to 20ppm as compared to control and observed to be 16.94 mg/g fresh weight (FW), 14.11 mg/g FW and 21.24 mg/g FW (Figure 5) for Chl-a, Chl-b and Carotenoids respectively. The concentration of leaf pigments at 160ppm NPs was found to be lowest 8.47±0.31 mg/g FW, 7.82±0.49mg/g FW and 10.70±0.096mg/g FW respectively for chl-a, chl-b and carotenoids. However the outcomes were statistically significant in comparison to control.

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\[\text{Effect on Antioxidant Enzymes content}\]

The study of effect of NPs on antioxidant enzymes showed increases in activity with increase in NPs concentration for two enzymes, Super oxide dismutase (SOD) and Glutathione Peroxidase (GPX) out of five enzymes treated. The activity of
SOD was found to be highest 13.47±0.26 U/mg of protein and for GPX, 18.61±0.17 U/mg of protein at 160ppm. The activity of Catalase (CAT), Phenyl Alanine Aminolase (PAL) and Poly Phenol Oxidase (PPO) enzymes were found to increase up to the concentration of 20 ppm as compared to control and above 20 ppm NPs concentration, all three enzymes showed decrease in activity (Figure 6). Catalase enzyme showed lower activity than the control at 160ppm CuO NPs treatment where as the PAL and PPO showed lesser activity but more than the control even at highest NPs concentration.

During the stress condition the plants produce antioxidant enzymes which will scavenge the free radicals in the plant body. The SOD is a critical antioxidant enzyme having antitoxic impact against on superoxide anion, GPX scavenes peroxyl, CAT acts on H₂O₂ thereby keep up the functional integration of the cell membrane. In present investigation the SOD and GPX level was increased as compared to control at higher levels of NPs and this may be due to scavenging activity of the enzymes on the free radicals present in the plant. Hence in the present perception there was no significant damage observed in tomato plant. Further increase in concentration of NPs, the activity of the enzymes also increased due to ROS creation in the plant. The CAT, PPO and PAL activity initially increased and later decreased this may be due to the plants have produced more free radicals under NPs stress and the activities of antioxidants were not stimulated to the optimum level, thus the damage caused by free radicals was not counteracted.

The simultaneous decreasing and increasing trend in the different enzymes were also observed by Hesham et al. where they have reported increased activity of SOD and GPX activities at 15 mg/l and 30 mg/l concentration of ZnO-NP in callus of tomato plant. Rao and Shelkawat reported increasing level of antioxidant enzyme APOX, CAT, SOD with different amounts of CuO NPs (200, 500, 1000, and 1500 mg/L).

The antioxidant activity of the extracts was determined by the phosphomolybedum method. The total antioxidant activity (TAC) of the extracts increased with the increased concentration of the Cu₂O NPs (Figure 9). The TAC was found to be highest (4.66 mg GAE/g FW) at higher concentration of NPs (160ppm). The results were supported by Zaka et al. study where they have reported that the TAC was found to be 7µg Ascorbic acid/mg FW and DPPH 12% on *Eurica sativa* when exposed to CuO NPs.

Figure 8 shows the dose-response curve of DPPH radical scavenging activity of the aqueous extracts of the tomato seedlings. It was observed that 20 and 40ppm treatments showed more scavenging activity (50%) than other concentrations of Cu₂O NPs treatments. As the concentration increases beyond 40ppm, the scavenging activity was reduced and this might be due to the fact that the plants produce more ROS which is induced by Cu₂O NPs.

his co-worker have reported increased MDA content in *L. minor* when exposed to Cu₂O NPs at 50 mg/L.

Membrane damage was estimated as the contents of malondialdehyde (MDA). The MDA content was found to increase as the concentration of NPs increase and it was found to be maximum (0.84±0.033nmol/ml) at 160ppm treatment as compared to control (0.11±0.006 nmol/ml) (Figure 7). The increased level of MDA in plant cells is due to stress created by NPs which was associated with an increase in protein content and defense enzyme activities. Song and...
Nanoparticle uptake by tomato seedlings

The uptake of CuO NPs by tomato plant seedlings showed increasing trend with increased concentration of NPs up to 160ppm, but the rate of increase in uptake of CuO NPs was exponential only up to 20ppm (Figure. 10). At highest level of treatment (160ppm) of CuO NPs, the uptake was found to be 0.25ppm as compared to control 0.005ppm. The uptake of different NPs including copper oxide nanoparticles by plants has been reported by many workers.  

CONCLUSION

The cuprous oxide nanoparticles have enhanced the germination at lower concentration up to 20ppm. The exposure of tomato seedlings to cuprous oxide nanoparticles showed dose dependent response and maximum promotory activity of CuO NPs was seen at 20ppm. At higher concentrations, there is a decline in the trend for all parameters under study except for SOD and GPX. Hence by judicial use of CuO NPs at appropriate concentrations, the growth and development of the plant can be improved to greater extent in the plants. Further, there is more work to be done at green house and field conditions for determining the impact of NPs on plants for growth and development.

Conflict of Interest

There is no conflict of interest.

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