**Copper nanoparticles hold promise in the effective management of maize diseases without impairing environmental health**

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**Supplementary Figure 1** Concentration-dependent percent growth inhibition of (A) *Rhizoctonia solani* f. sp. *sasakii*, (B) *Bipolaris maydis*, (C) *Fusarium verticillioides*, (D) *Macrophomina phaseolina*, and (E) *Sclerotium roflsii in vitro* exposed to chemically synthesized copper nanoparticles. Data (Mean±Standard errors) with different letters are significant in each graph (ANOVA, LSD, P**≤**0.01)

**(A)**

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**(B)**

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**(C)**

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**(D)**

**(E)**

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**Table 1** Efficacy of synthesized copper nanoparticles on phytopathogenic bacteria

|  |  |
| --- | --- |
| ***Erwinia carotovora*** | ***Ralstonia solanacearum*** |
| **Treatment** | **Optical density****at 600 nm\*** | **CFU/ml****(1OD =1× 109)** | **Treatment** | **Optical density****at 600 nm\*** | **CFU/ml****(1OD =1× 109)** |
| Control | 3.05±0.209 **ab** | 3.05 × 109 | Control | 2.34±0.184 **a** | 2.34 × 109 |
| Strep @200 ppm | 1.16±0.005 **i** | 1.16 × 109 | Strep @200 ppm | 0.14±0.021 **g** | 0.13 × 109 |
| COC @ 1000 ppm | 0.25±0.084 **j** | 0.25× 109 | COC @ 1000 ppm | 1.28±0.023 **d** | 1.26 × 109 |
| CN 10 ppm | 3.20±0.049 **a** | 3.20 × 109 | CN 10 ppm | 2.18±0.048 **ab** | 2.17 × 109 |
| CN 20 ppm | 2.80±0.063 **bc** | 2.80 × 109 | CN 20 ppm | 2.08±0.011 **ab** | 2.08 × 109 |
| CN 30 ppm | 2.54±0.167 **cd** | 2.54 × 109 | CN 30 ppm | 1.98±0.032 **bc** | 1.98 × 109 |
| CN 40 ppm | 2.25±0.051 **de**  | 2.24 × 109 | CN 40 ppm | 1.78±0.012 **c** | 1.78 × 109 |
| CN 50 ppm | 2.03±0.093 **ef**  | 2.02 × 109 | CN 50 ppm | 1.71±0.018 **c** | 1.71 × 109 |
| CN 60 ppm | 1.95±0.064 **f** | 1.95 × 109 | CN 60 ppm | 1.35±0.130 **d** | 1.35 × 109 |
| CN 70 ppm | 1.91±0.154 **fg** | 1.90 × 109 | CN 70 ppm | 1.11±0.103 **de** | 1.10 × 109 |
| CN 80 ppm | 1.63±0.066 **gh** | 1.63 × 109 | CN 80 ppm | 0.93±0.134 **e** | 0.93 × 109 |
| CN 90 ppm | 1.46±0.001 **h** | 1.46 × 109 | CN 90 ppm | 0.85±0.162 **e** | 0.84 × 109 |
| CN 100 ppm | 1.16±0.070 **i** | 1.16 × 109 | CN 100 ppm | 0.54±0.072 **f** | 0.53 × 109 |

**\*Data are the mean of three replications. (Data) Mean ± Standard errors followed by different letters indicate a significant difference (ANOVA, LSD, P<0.01). CN: Copper nanoparticles. Strep: Streptomycin, COC: Copper Oxychloride CFU: Colony Forming Unit**

**Table 2** Effect of synthesized copper nanoparticles (CuNPs) on the growth of beneficial fungi

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatment** | ***Trichoderma virens*** | ***Chaetomium globosum*** | ***Paecilomyces lilacinus*** |
| **Radial growth (cm)\*** | **Inhibition****(%)** | **Radial growth (cm)\*** | **Inhibition (%)** | **Radial growth (cm)\*** | **Inhibition (%)** |
| Control | 7.00±0.0 | 0.00 (0.00±0.0)# **d** | 7.00±0.0 | 0.00 (0.00±0.0)# **f** | 7.00±0.0 | 0.00(0.00±0.0)# **g** |
| Carbendazim@1000 ppm | 0.00±0.0 | 100.00 (90±0.0) **a** | 0.00±0.0 | 100.00 (90±0.0) **a** | 2.86±0.033 | 59.05 (50.19±0.278) **c** |
|  CN 20 ppm | 7.00±0.0 | 0.00 (0.00±0.0)  **d** | 5.30±0.424 | 24.24 (29.04±4.333) **d** | 7.00±0.0 | 0.00 (0.00±0.0) **g** |
| CN 50ppm | 7.00±0.0 | 0.00 (0.00±0.0)  **d** | 6.00±0.029 | 14.23 (22.15±0.341) **e** | 7.00±0.0 | 0.00 (0.00±0.0)  **g** |
| CN 80 ppm | 6.03±0.120 | 13.81 (21.73±1.405) **c** | 5.63±0.101 | 19.52 (26.18±1.045) **de** | 7.00±0.0 | 0.00 (0.00±0.0)  **g** |
| CN 100 ppm | 2.88±0.233 | 58.81 (50.07±1.949) **b** | 4.71±0.087 | 32.76 (34.89±0.757) **c** | 6.82±0.096 | 2.52 (7.42±3.798) **g** |
| CN 200 ppm | 0.20±0.058 | 97.14 (80.45±1.471) **a** | 0.83±0.033 | 88.10 (69.79±0.418) **b** | 6.30±0.101 | 10.00 (18.33±1.435) **f** |
| CN 300 ppm | 0.00±0.00 | 100.00 (90.00±0.0)  **a** | 0.00±0.0 | 100.00 (90.00±0.0) **a** | 5.65±0.362 | 19.29 (25.68±3.811) **e** |
| CN 400 ppm | 0.00±0.00 | 100.00 (90.00±0.0)  **a** | 0.00±0.0 | 100.00 (90.00±0.0)  **a** | 3.42±0.096 | 51.10 (45.61±0.786) **d** |
| CN 500 ppm | 0.00±0.00 | 100.00 (90.00±0.0)  **a** | 0.00±0.0 | 100.00 (90.00±0.0)  **a** | 2.23±0.0.073 | 68.10 (55.59±0.639) **b** |
| CN 600 ppm |  |  |  |  | 0.00±0.0 | 100.00 (90.00±0.0) **a** |

**\*Data are the mean of three replications. Data (Mean ± Standard errors) followed by different letters in each column indicate a significant difference (ANOVA, LSD, P<0.01). #Data within parentheses are Angular transformed value ± Standard errors. CN: Copper nanoparticles, Carbendazim: carbendazim 50%**

**Supplementary Figure 2** Concentration-dependent growth inhibition of (A) *Bacillus subtilis* and (B) *Pseudomonas putida* *in vitro* exposed to synthesized copper nanoparticles. Data (Mean±Standard errors) with same letters are insignificant from each other and with different letters are significant in each graph (ANOVA, LSD, P**≤**0.01). COC: Copper Oxychloride (Blitox), Streptomycin: Streptomycin Sulphate

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**(A)**

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**(B)**

**Supplementary Table 3** Dehydrogenase activity of soil treated with copper nanoparticles (CuNPs) and copper oxychloride (COC) at different time intervals

|  |  |
| --- | --- |
| **Treatment** | **Dehydrogenase activity(µg TPF g soil-1 hr-1)** |
| **COC** | **CuNPs** |
| 1st day\* | 15th day\* | 30th day\* | 1st day\* | 15th day\* | 30th day\* |
| **Control** | 47.56±9.6 | 47.35±9.6 | 46.41±9.6 | 47.41±9.6 | 47.09±9.6 | 46.72±9.6 |
| **200 ppm** | 51.23±9.6 | 52.86±9.6 | 47.35±9.6 | 53.43±9.6 | 70.89±9.6 | 61.92±9.6 |
| **400 ppm** | 54.27±9.6 | 50.50±9.6 | 48.72±9.6 | 61.77±9.6 | 64.60±9.6 | 61.61±9.6 |

\*Data are the mean of three replications. Data (Means ± Standard errors) (ANOVA, LSD, P**≤**0.05)

**Supplementary Table 4 Alkaline phosphatase activity of soil treated with CuNPs and copper**

 **Oxychloride (COC) at different time intervals**

|  |  |
| --- | --- |
| **Treatment** | **Alkaline phosphatase activity (µg pNPP g soil-1 hr-1)** |
| **COC** | **CuNPs** |
| 1st day\*\* | 15th day\*\* | 30th day\*\* | 1st day\*\* | 15th day\*\* | 30th day\*\* |
| **Control** | 316.52±1.47 | 313.70±1.47 | 311.82±1.47 | 317.46±1.47 | 315.58±1.47 | 314.64±1.47 |
| **200 ppm** | 466.80±1.47 | 445.19±1.47 | 490.28±1.47 | 667.79±1.47 | 784.25±1.47 | 772.04±1.47 |
| **400 ppm** | 497.79±1.47 | 540.06±1.47 | 472.43±1.47 | 653.70±1.47 | 832.15±1.47 | 713.81±1.47 |

\*Data are the mean of three replications. Data (Means ± Standard errors) (ANOVA, LSD, P**≤**0.05)

**Supplementary Table 5 Urease activity of soil treated with CuNPs and (COC) at different time**

 **Intervals**

|  |  |
| --- | --- |
| **Treatment** | **Urease activity (µg NH4 g soil-1 hr-1)** |
| **COC** | **CuNPs** |
| 1st day\*\* | 15th day\*\* | 30th day\*\* | 1st day\*\* | 15th day\*\* | 30th day\*\* |
| **Control** | 3.582±1.2 | 3.532±1.2 | 3.378±1.2 | 3.523±1.2 | 3.494±1.2 | 3.290±1.2 |
| **200 ppm** | 3.669±1.2 | 3.727±1.2 | 3.465±1.2 | 3.756±1.2 | 3.844±1.2 | 3.523±1.2 |
| **400 ppm** | 3.698±1.2 | 3.758±1.2 | 3.494±1.2 | 3.814±1.2 | 3.931±1.2 | 3.669±1.2 |

\*Data are the mean of three replications. Data (Means ± Standard errors) (ANOVA, LSD, P**≤**0.05)