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Nanoparticle-Mediated Alleviation of Copper Heavy Metal Stress in Armenian Barley (*Hordeum vulgare* L.) Genotypes to Enhance Germination and Seedling Growth Traits

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ABSTRACT

Soil pollution with heavy metals, particularly copper (Cu), poses a serious threat to agricultural ecosystems owing to its long-term persistence and phytotoxic effects. Increasing concentrations of copper in arable lands, mainly resulting from mining activities, industrial effluents, and overuse of fertilizers, leads to a decline in soil fertility and reduces the viability of agricultural production, especially in regions already facing limited cultivable land. To solve this problem, we used the potential of nanotechnology to mitigate copper toxicity in plants. We examined the effect of 30 mg/l and 60 mg/l concentrations of zinc oxide (ZnO) and silicon dioxide (SiO_2) nanoparticles on seed germination and early seedling development of three Armenian barley (*Hordeum vulgare* L.) genotypes (V1 – Gayane, V2 – Gyumri, and V3 – Hayk). Several germination and stress indices were evaluated to assess the genotypes' tolerance to Cu stress, including *mean germination time* (MGT), *germination energy* (GE), *germination rate* (GR), *mean daily germination* (MDG), and *seedling vigor index* (SVI). Stress-related physiological responses were assessed using the *Germination Stress Tolerance Index* (GSTI), *Promptness Index* (PI), *Shoot and Root Length Reductions* (SLR, RLR), and the *Stress Susceptibility Index* (SSI). In addition to the above studies, we also evaluated physiological indicators. The results of the study showed that nanoparticles improved the germination and seedling growth of barley genotypes under conditions of heavy metal exposure, especially copper. The data obtained indicate that the application of nanoparticles to plants can alleviate heavy metal stress-specifically copper toxicity and is promising for improving plant resistance in contaminated soils.

Keywords: barley, zinc oxide nanoparticles, silicon dioxide nanoparticles, seed germination, Cu stress

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