**CQD PRIMING AND SEED GERMINATION:**

Priming seeds with pristine or doped CQDs has shown remarkable results in strengthening of vulnerable seedling stages. The priming of seeds allows the dormancy-breaking, acceleration and synchronization of germination as well as a better growth, an earlier flowering, a greater tolerance to abiotic stress and higher yields. Various molecular, physiological, and biochemical analytical tools are used to understand and measure these mentioned aspects at different life stages of plant. Following are a few examples of doped CQD priming and their effects on the overall plant’s life cycle especially on seed germination:

* Cerium-oxide:

Ce-oxide nanoparticles are also known as nanoceria. poly (acrylic acid)-coated cerium oxide nanoparticles (PNC) impacts seedling morphological, physiological, biochemical, and transcriptomic traits under various biotic and abiotic stresses. They are reported to induce beneficial properties in the seedling by controlling various chemical and physical processes. For example; (An et al., 2020) investigated the mechanisms of cerium oxide seed priming in inducing salinity stress tolerance in cotton seedlings. They concluded that PNC improved the salinity stress tolerance by altering seedling phenotype (increasing root length and fresh and dry weight of the seedling), reducing ROS levels (by increasing the antioxidant enzymatic activity and ROS scavenging), enhancing the ion-content responses (reduces the apoplastic barriers) and regulating ROS scavenging genes and ion binding genes. They showed how ce-oxide nanoparticles modifies cotton seedling development under salinity stress majorly through signalling ion and antioxidant pathways.

* Plastic-derived nanoparticles (PDNs):

Several carbon dots derived from biodegradable and non-biodegradable plastic wastes are also reported to have promising effects on plant development. (Liang et al., 2023) Used polyethylene terephthalate (PET) bottles as the carbon source for synthesizing and priming peas seedling (*Pisum Sativum).* They demonstrated positive effects of PDN seed priming at different CD concentrations (0.25–2 mg/mL), including accelerated seed germination rate, increased shoot and root elongation, biomass accumulation, and increased root moisture levels compared to the control groups. Surface erosion of seed coat was observed after CD priming, which effectively promoted seed [imbibition](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/imbibition) capability. Enhanced seed antioxidant [enzyme activity](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/catalytic-activity), augmented root vigor, chlorophyll content, and carbohydrate content was also observed.

* Zinc-oxide:

Zinc-oxide doped CQDs reduce the level of salt concentrations in different plants under stress. They have been tested on different plant species to confirm their role of inducing salinity stress tolerance. (Abdel Latef et al., 2017) also confirmed it by ZnO seed priming of Lupine (*Lupinus Termis)* and its effects in mitigating salinity stress. It was concluded that ZnO priming enhances the reinforcement of the levels of photosynthetic pigments, organic solutes, total phenols, ascorbic acid and Zn, as well as the activities of superoxide dismutase (SOD), peroxidase (POD), and ascorbate peroxidase (APX) and catalase (CAT). This reduces the negative impacts of NaCl on lupine plants and enhances the photosynthetic pigments, adjusts osmoregulation, and lowers the contents of malondialdehyde (MDA).

(Sathya Moorthy et al., 2021) also reported the positive effect of ZnO quantum dots in enhancing seed germination and seedling vigor in blackgram (*Vigna Mungo).*

* Putrescine-functionalized CQD priming (Put-CQD):

Positive effects of some NPs on agronomic traits under salinity stress has been widely observed. Put-CQD priming is one of the most effective techniques to combat salinity stress. (Gohari et al., 2021) also reported the same; specifically on grapevines (*Vitis vinifera cv. ’Sultana).* Put-CQD reduces the effects of salinity on the grapevines by increasing fresh and dry weight, enhancing ionic homeostasis, increasing chlorophyll and carotenoid concentrations, reducing cellular damage (lowering the concentrations of H2O2 and MDA), neutralizing proline and total phenolic compounds and increasing antioxidant enzymatic activities.

* Graphene doped CQDs:

Graphene itself is very harmful for plants as it inhibits the growth and biomass production of plant, increases ROS production and inducing cell death (Begum et al., n.d.). But CQDs doped with graphene are observed showing promising results in seed germination and plant growth by diminishing the toxicity of graphene. (López-Vargas et al., 2020) reported the positive effects of graphene quantum dots on enhancement of seed germination, growth and antioxidant status of tomato seedlings. They increased the concentration of photosynthetic pigments (chlorophylls and carotenoids), decreased ROS production, reduced hydrogen-peroxide concentrations and enhanced enzyme activity in tomato seedlings.

* Nitrogen doped CQDs:

N-doped CQDs seed priming is said to have major supporting role to plants especially their fight against biotic stresses e.g diseases. It was reported by (Luo et al., 2021) that N- doped CQDs alleviate the damage from tomato bacterial wilt syndrome by enhancing ROS scavenging, exhibiting higher oxidative stress alleviation, activation of salicyclic and jasmonic acid dependent systematic acquired resistance, inhibition of in-vivo pathogen control and increasing polyacrylic acid for to eliminate the pathogen stress effects.

(Wang et al., 2021) also reported effect of N-doped CQD seed priming in enhancing the yield of corn. It was observed that they increased the light conversion and electron supply to the corn photosystem and enhanced other growth mechanisms.