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CADMIUM TOXICITY IN PLANTS: REMEDIAL STRATEGY THROUGH SEED PRIMING

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ABSTRACT

Heavy metals (HMs) Hg > Cd> Pb> As> Ag> Ni > Co > Cu > Zn is the most popular environmental pollutants known since a long time ago as a major environmental threat; Cd is one of them. It has around 25-30 years of persistence in the environment, therefore, poses a hazardous impact on entire living things on the planet including plants, animals and human beings. Anthropogenic activities such as urban waste disposal, smelting, mining and the use of synthetic phosphate fertilizers are the major source of Cd in the soil. Plants grown in Cd-contaminated soil absorb the heavy metal through their roots and accumulate in different parts of the plant consequently limiting the entire phase of plant growth and development. It reduces the potential of water and nutrient uptake while it accelerates the production of reactive oxygen species (ROS) and oxidative damage to the cell membrane. Seed priming may be a dynamic approach to overcome phytotoxicity caused by the presence of cadmium more than the threshold level which is (3-5 mg g^{-1}). Seed priming with various salts such (KNO^3, Mg (NO_3^2) and Ca (NO_3^2) and Growth hormones (Auxin, GA_3 and Salicylic acid) participate in the betterment of seed germination, seedling establishment till the maturity of the crop by improving the defense system against the Cd toxicity.

KEY WORDS : Cadmium, Heavy metal, ROS, Seed germination and Seed Priming

INTRODUCTION

Cadmium is a prevalent heavy metal that is almost ubiquitous, non-degradable and highly mobile among the HMs, appears like silver-white metals having an average 25-30 years of half-life in the soil. Anthropogenic activity such as industrialization, mining, intensive agriculture and deforestation is a major drift in the soil. Persistence and uptake of Cd more than the threshold level of 3-5 mg g^{-1}, shows their initial toxicity on plant leaf via necrosis, chlorosis and stunting growth (Haider *et al*., 2021 and Ismael *et al*., 2019). Phytotoxicity of Cd caused ROS-mediated peroxidation of membrane and oxidative damage to the photosystem consequently limiting the rate of photosynthesis (Anjum *et al*., 2015; Shanying *et al*., 2017 and Abbas *et al*., 2017). It also reduces the potential for uptake and translocation of water and nutrient within the plant body which adversely affects the morphophysiological growth and alters the metabolic process (Haider *et al*., 2021). Cd also interacts with other biomolecules such as protein, carbohydrate and lipids, and at the molecular level are well advocated for the detrimental impact on the activity of the linked enzymes (Khan *et al*., 2020 and Yang *et al*., 2018). Seed priming with a wide range of organic and inorganic compounds has already proven its defensive role in plants against adverse conditions hence; in the current review, we considered the most versatile approach to seed priming to ameliorate the phytotoxic effect of cadmium in the plant (Anaytullah and Bose (2007) and Siddique and Dubey, 2017).

Impact of cadmium accumulation on soil health

Cadmium is found mostly in Cd^{2+} while it is also available as a Cd-chelate in the soil solution.

Elevated levels of Cd in the soil is also depending upon the source of availability, plant cultivar, ability to transport, soil physicochemical parameters, and Cd uptake potential (Abedi and Mojiri, 2020 and Benavides *et al*., 2005). A wide range of sources is responsible for the release of Cd in soil that broadly can be grouped into two categories natural and anthropogenic activities which are volcanic eruption, smelting, mining, industrialization forest fire, sea spray and use of phosphate fertilizer. However, the main reason the natural sources of the environmental contamination with Cd is wind blown followed by wildfires, sea spray and volcanic eruption (Khan *et al.,* 2010; Liu *et al.,* 2013 and Dutta *et al*., 2020). The bio-availability of Cd in the soil is regulated by a series of factors like pH, CEC, soil moisture, soil texture and clay content in the soil (Hasan *et al*., 2009; Dutta *et al.,* 2020 and Lahori *et al.,* (2017). Cd is highly mobile in the soil because of it weaker bonding at the soil exchange site. Even though immobilizing agents may reduce the availability of Cd in the soil and its bioaccumulation in the plant because in polluted soils but not the concentration (Kubier *et al.,* 2019). Its higher concentration not only imposes harmful effect on human and animal but also deteriorate the physical, biochemical and biological quality of the soil. Microbes play a vital role in most of the nutrient recycling process which is being negatively affected in Cd polluted soil consequently it reflects in the soil productivity and fertility (Zulfiqar *et al.,* 2021 and Lenart Boron and Boron, 2014).

Impact of cadmium on plant growth

Cd^{2+} concentration more than the threshold level poses a detrimental impact on the entire phase of plant growth from seed germination to the maturity of the plant because it suppresses the uptake and translocation of water consequently limiting the rate of photosynthesis. The symmetry among the synthesis and generation of antioxidants and ROS also destroyed by the elevated concentration of Cd in the plant (El-Amier *et al.,* 2019 and Balabanova *et al.,* 2018). Out of the entire phase of plant life, seed germination is one of the sophisticated stages which require a very smooth environment to facilitate the germination followed by the seedling establishment (Ismael *et al.,* 2018; Huybrechts *et al.,* 2019). Delimited supply of water due to Cadmium toxicity at this stage, suppresses the activity of important enzyme base release of starch from the cotyledons which is α-amylase followed by the supply of soluble sugar to the growing embryonic axis (Guilherme *et al.,* 2015; Sami *et al.,* 2018; Raza *et al.,* 2020 and Kalai *et al.,* 2016). Cd^{2+} is a highly mobile and assimilable heavy metal; therefore it enters the plants via the roots and is translocated by the ascent of sap is known as bioaccumulation of cadmium in the plants (Sulaiman *et al.,* 2018). Cd^{2+} translocate within the plant in the form of Metallo-organics which is a class of metals and ligands (Perri *et al.,* 2017 and Wahid *et al.,* 2008). A rivalry mechanism exists in the soil during the uptake of Cd^{2+} and another mineral nutrient by the plant root therefore, the amount of Mg, Ca and K have been reported vice-versa in Cd^{2+} prone soil (Kubier *et al.,* 2019 and Hasan *et al*., 2009). Cd^{2+} uptake via the root may be in both the forms inorganic and organic such as Cd_2+ SO_4, CdCl+, $CdCl_2$ and complex Phyto-metallophore (Kubier *et al*., 2019). Long time exposure to cadmium in the soil, the root becomes putrefy and mucilaginous consequently elongation of the root followed by shoot affected in the plant (Ismael *et al*., 2019 and Raza *et al*., 2020).

Remedial strategy via seed priming approach

The elevated amount of heavy metals (HMTs) in soils caused a kind of toxicity/stress that has the potential to reduce the growth of the entire phase of the plant. To endure heavy metals stress plant develops various morpho-physiological, biochemical and molecular changes *viz*. modification in root architecture, insulation of heavy metals in the vacuole and bursting of antioxidant (SOD, CAT, GPX, GSH and POX) and production of osmoregulatory compound (Proline, Glycine and Betaine) which act as defensive mechanism (Siddique and Dubey, 2017; Singhal *et al.,* 2022; Indu *et al.,* 2021 and Haider *et al.,* 2021). Antioxidant enzymes have a specific role in plant systems which act as a scavenger of ROS (O2-, H_2O_2 and OH*) from plant cells and cell organelles. Healthy growth of the plant is not possible under the prevailing circumstances because the advancement in agriculture, industrialization and urbanization enhance the heavy metals including cadmium in the soil which may not be sufficient for plant defense mechanism. In this regard, one of the finest, cheapest and environmentally friendly approaches which is seed priming may be useful to overcome the prevailing situation. Priming is a kind of hydration approach which allows controlled imbibition and induces the pre-germinative stage of seed while intercepting this process before the

rupturing of the seed coat which led to the foundation of better seed germination, establishment and seed vigor. During the 1st phase of seed priming, different signaling pathways based on ROS-mediated are activated. A wide range of seed priming methods has been introduced such as Hydro, Hormonal, Chemical, Osmo, halo and Bio-priming (Nedunchezhiyan *et al.*, 2020; Hussain *et al.*, 2018 and Thongbam *et al.*, 2022). Eruption of ROS during the heavy metal stress cause lipid peroxidation, protein and DNA damage consequently poor germination and seedling establishment but the antioxidative system which is naturally available in the seed tries to limit damage up to somehow while at the same time priming treatment with a wide range of chemicals such as KNO_3, Mg $(NO_3)_2$ Ca $(NO_3)_2$, $CaCl_2$, Salicylic acid and ascorbate and kinetin provide additional support by activating a series of interlink biochemical compounds such as antioxidative enzymes (SOD, CAT, GPX, GSH and POX), osmoregulatory compound (Proline, Glycine and Betaine) and phytohormones Gibberellic acid and ABA in which ABA regulate a downstream ABA-dependent process during the germination while the balance between GA and ABA maintains by the cross-talk that help to accelerate the seed germination, seedling establishment. They may be a kind of approach to overcome the effect of cadmium toxicity at the initial stage of growth while its carryover effect may appear in vegetative as well as at the reproductive stage by maintaining the oxidative damage of cell organelles. This paper adumbrates the effects of seed priming approaches on Cd toxicity to overcome the prevailing situation via modulating the physiological, biochemical antioxidative defense system from the entire phase of plant growth and development (Chen *et al.*, 2022). The following table is a glimpse of the work regarding the impact of different priming agents

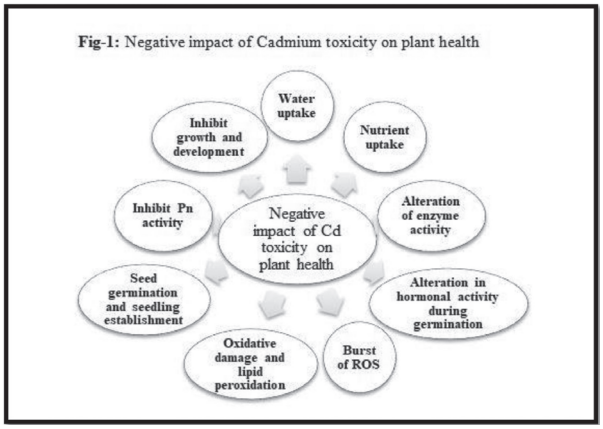

Fig-1: Negative impact of Cadmium toxicity on plant health

Table 1. Effect of various seed priming agents to improve the performance of plants

Name of Priming agents	Name of crops	Function	References
Water	Rice	Induced resistance against oxidative damage	Nedunchezhiyan *et al.,* (2020)
CaCl2	Faba bean	Alleviate cadmium-induced Geno and cytotoxicity	Nouairi *et al.,* (2019)
CaCl2	Wheat	Induced resistance against drought	Hussain *et al.*, (2018)
Cytokinin	Wheat	Induced salinity stress	Iqbal *et al.,* (2006)
Cytokinin	Soybean	Induced drought tolerance	Mangena, (2020)
Mg (NO3)2	Wheat	Improved seed germination against cold stress	Anaytullah and Bose, (2007)
Salicylic acid	Black cumin	Improves seed germination under cadmium stress	Espanany *et al.,* (2016)
Salicylic acid	Wheat	Modulates morphology, nutrient relations and photosynthetic process under cadmium toxicity	Gul *et al.,* 2020
KNO3	Maize	Mediated in biochemical processes to educed lead toxicity	Nawaz *et al.,* (2017)
KNO3	*Foeniculum vulgare* Mill	Alleviated the cadmium-induced toxicity damage	Aslam, (2020)
Bio-priming with *Pseudomonas fluorescens*	Groundnut	Mitigated salinity stress	Saravanakumar and Samiyappan, (2007)
ZnO nano priming	Rice	Modulate early growth and fragrant against Cd toxicity	Li *et al.,* (2021)

against diverse environmental conditions.

CONCLUSION

Heavy metal contamination (HMs) in soil has long been known as a major environmental challenge that poses detrimental effects for both plants as well as mankind on the earth with which Cd toxicity is one of them. It promotes lipid per-oxidation, oxidative damage of chloroplast, mitochondria and DNA damage during the entire period of plant growth and development thereby speed of seed germination is delayed and the rate of photosynthesis is slowed. However, the metabolic pathways regulated at the molecular level by plants about cadmium toxicity the need to understand well for future research. To overcome cadmium toxicity, a wide range of approaches have been used. To enhance the antioxidative defense system seed priming with various compounds may be an effective treatment for reducing the detrimental effect of cadmium toxicity on the survival of plants on the planet.

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