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FUNCTION AND TOXICITY OF NICKEL IN PLANTS

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Introduction:

Nickel was suspected of possessing a metabolic role in plants when discovered as a constituent of plant ash in the early 20th Century. Various nickel salts; including the sulfate, chloride, and bromide were used in human medicine during the mid- to late-1800's to treat headache, diarrhea, and epilepsy and as an antiseptic. Later, some nickel salts have been incorporated into fungicides to combat plant pathogens. The discovery that Ni is a component of the plant urease in 1975 (Dixon et al., 1975) prompted a renewed interest in the role of Ni in plant life. Now, nickel is considered as an essential element for plant growth (Brown et al., 1987). There are numerous reports of growth stimulation in higher plants by lower concentrations of Ni (Mishra and Kar, 1974). Nickel even though recognized as a trace element, its role in metabolism for certain enzyme activities, various other biochemical, physiological and growth responses is very decisive. The metabolic process particularly under increased nitrogen metabolism on application of Ni has emphasized the need to study the dual behavior of Ni in plants.

Ni uptake, transport and distribution in plants:

The uptake of Ni in plants is carried out mainly by root systems via passive diffusion and active transport (Seregin and Kozhevnikova, 2006). The ratio of uptake between active and passive transport varies with species, Ni form and concentration in the soil or nutrient solution. The uptake of Ni by plants depends on Ni2+ concentrations, plant metabolism, the acidity of soil or solution, the presence of other metals and organic matter composition. Ni is transported from roots to shoots and leaves through the transpiration stream via the xylem. This transport is tightly regulated by metalligand complexes and proteins that specifically bind Ni (Colpas and Hausinger, 2000). Metal ligands, such as nicotianamine (NA), histidine (His) and organic acids (citric acid and malate ions), can act as intracellular chelators, which bind Ni in the cytosol or in subcellular compartments for transport, translocation and accumulation within plants. Over 50% of the Ni absorbed by plants is retained in the roots.

Furthermore, a high percentage (over 80%) of Ni in the roots is present in the vascular cylinder, while less than 20% is present in the cortex.

Deficiency / disorders by Ni in plants:

The metabolic effect of Ni deficiency has only been reported for a few annual species. Ni deficiency caused accumulation of N metabolites and affected amino acid metabolism in cowpea (Walker et al., 1985). Bai et al. (2006) has also reported that Ni deficiency disrupts metabolism of ureides, amino acids, and organic acids of young Pecan [Carya illinoinensis (Wangenh.) K. Koch] foliage.

Enzyme activities as affected by Ni:

Application of Ni increases the activity of catalase, peroxidase and urease enzymes in tomato plants at higher doses, while optimum activities were noticed on application of Ni at 30 ppm on tomato plants (Gad et al., 2007) which resulted in higher plant biomass. Gajewska et al. (2006) showed that application of Ni caused an increase in H2O2 content in wheat roots. They reported that Ni stress at 200µM application led to the inhibition of SOD activity in the roots significantly. The lack of induction of APX and CAT activities in response to Ni stress favored accumulation of H2O2 in the root tissue. Enhancement of H2O2 concentration did not lead to the induction of lipid peroxidation in the root. The results indicate that inhibition of root growth in wheat under Ni stress may be related to the increase in H2O2 content, but not to lipid peroxidation. Nickel deficiency also reduced urease enzyme activity (Gerendas and Sattelmacher, 1997) which induced metabolic nitrogen deficiency and also affected amino acids content in several non-woody species (rye, wheat, soybean, rape, zucchini, and sunflower).

Effect of Ni on antioxidants:

In response to Ni application, activities of enzyme like CAT, SOD, APX, POD and GST were found significantly altered in response to production of hydrogen peroxide and showed differential pattern in shoots and roots of wheat (Gajewska and Skłodowska, 2008).

Nitrogen metabolism as influenced by Ni:

There are at least three key enzymes involved in urea metabolism in plants: arginase, urease and glutamine synthetase. The primary role of urease is to allow the organism to use external or internally generated urea as a nitrogen source. Significant amounts of plant nitrogen flows through urea. This compound derives from arginine and possibly from degradation of purines and ureides. The nitrogen present in urea is unavailable to the plant unless hydrolyzed by urease. The product of urease activity is ammonia which is incorporated into organic compounds mainly by glutamine synthetase (Marschner, 1995). Gheibi et al. (2009) reported increase in urease enzyme activity of maize plants supplied with Ni in combination with urea as N source. The increase in urease activity was pronounced in increasing shoot dry weight of maize.

The growth of rice plants was significantly affected by N sources and Ni supply (Gerendas et al., 1998). They reported that Ni did not affect significantly the growth of rice when applied with ammonium nitrate as N source; while dry matter production was significantly reduced in absence of Ni when urea N was applied; and excess urea was accumulated in plant parts. The urease enzyme activity was significantly improved on application of urea in combination with Ni which resulted in higher amino acid content. The similar results were also observed in rape plants (Gerendas and Sattelmacher, 1999).

Toxicity:

Excess Ni leads to deficiencies of other essential metals in plants via competition and/or the formation of chelate complexes with metal ligands. These processes ultimately result in the retardation of germination, induction of leaf chlorosis and wilting, alteration of enzymes' activities, metabolic disturbance, induction of oxidative stress, disruption of photosynthesis, inhibition of growth and reductions in yields. Many enzymes, such as superoxide dismutase (SOD) and catalase (CAT), are metalloenzymes containing Fe, Cu, Zn, or Mn as their prosthetic groups. Since excess Ni has been shown to decrease the contents of Fe, Cu and Zn in plant tissues, it can be speculated that Ni may reduce the biosynthesis of these metalloenzymes by causing deficiencies of these essential metals. Pandey and Gopal (2010) reported decrease in catalase and peroxidase acitivites on increasing levels of Ni on eggplant; while SOD and ribonuclease activities were increased. They also reported reduction in biomass along with accumulation of Ni on increasing levels of Ni. Same results like decrease in catalase and amylase activities were noticed by Gautam and Pandey (2008) in Lentil on increasing levels of Ni; whereas protein and total chlorophyll content were found highest at 0.5 ppm Ni application then a reduction was noticed. Length and fresh weight of the leaves of wheat were substantially reduced, up to 25% and 39%, respectively on application of 100µM Ni. Treatment with Ni resulted in the increase in O2- and H2O2 contents in the leaves. SOD and CAT activities decreased significantly in response to Ni treatment; however a several-fold increase in APX and POD activities was found (Gajewska & Skłodowska, 2007). Ni toxicity induces oxidative stress in rice plants (Maheshwari and Dubey, 2009) resulting in increased generation of H2O2, among antioxidant enzymes induced as defence system, Cu-Zn SOD, Fe-SOD and Mn-SOD appears to play key roles in scavenging H2O2 generated.

Physiological role of Ni:

Gerendas and Sattelmacher (1997) reported increase in chlorophyll content of various crops viz. rye, wheat, soybean, rape, zucchini, and sunflower on application of lower concentration of Ni. Tabatabaei (2009) reported that use of Ni in the nutrient solutions containing urea has an important role to promote cucumber plants growth and increase yield. Ni supplements enhanced the growth and yield of urea-fed plants presumably by increasing Photosynthetic rate.

Quality of produce as affected by Ni:

Application of Ni increased tomato fruit quality in terms of titratable acidity, Vitamin C content and total soluble sugar contents at all levels of applications (Gad et al., 2007). Reduction of nitrate concentration of the fruits in urea-fed plant at 0.5 mg L−1 Ni improves the fruit quality (Tabatabaei, 2009).

Conclusion:

- Ni is an essential component of the enzyme urease
- Elevated levels of Ni hampers yield by disturbing plant metabolic processes
- Application of Ni increases quality parameters in vegetables like Vit. C, protein, TSS etc.
- It helps in reducing nitrate content - an anti-nutritional factor
- Optimum conc. of Ni increases amino acids, chlorophyll content and growth of plants

Future Perspectives:

- Role of Ni in other metabolic processes of plants needs to be established
- Information on Ni and some other enzymes is lacking
- There is a need to establish critical limit or toxic level for particular crops
- Ni favours seed germination/ viability and seedling vigour but reasons are yet to be explored

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