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Review Article

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Toxicity of Nickel in Plants

Satish A. Bhalerao*, Amit S. Sharma and Anukthi C. Poojari
Environmental sciences research laboratory, Department of Botany, Wilson College,
Mumbai 400007, M.S., University of Mumbai
*Corresponding Author E-mail: drsatishbhalerao@yahoo.com

ABSTRACT

Nickel (Ni) is the 22nd abundant element in the earth crust and holds a special place among the heavy metals. Ni is an essential micronutrient for plant growth and it is also a component of the enzyme urease which is required for nitrogen metabolism in higher plants. Nickel and nickel compounds have many industrial and commercial use s, and the progress of industrialization has led to increased emission of pollutants into the environment. Ni is absorbed and redistributed in plants via cation and/or metal –ligand complex transport system.

Ni is strongly phytotoxic at higher concentration. In several plants Ni induces change in activity of antioxidant enzymes like superoxide dismutase (SOD), Ascorbate peroxides (APX) and Catalase (CAT). The most common symptoms of nickel toxicity in plants are inhibition of growth, induction of chlorosis, necrosis and wilting. Nickel strongly influences metabolic reaction in plants and has the ability to generate Reactive Oxygen Species (ROSs) which may cause oxidative stress.

Elevated levels of Ni can inhibit cell division at root meristem in non- tolerant plants and decreases plant growth. Studies have shown that Ni has a negative effect on photosynthesis and respiration. High uptake of Ni induces a decline in water content of dicot and monocot plant species. The decrease in water can act as an indicator for Ni toxicity in plants. Ni is associated with proteins inhibition germination and chlorophyll synthesis.

Nickel received very little attention due to its dual character and complicated electronic chemistry which acts as barrier to reveal the toxicity mechanism in plants. The objective of this review paper is to summarize the overview of the sources, essentiality, uptake and toxicity in plants.

Nickel pollution is a serious environmental concern which led to research on phytoremediation. However, studies are needed to know the details at both biochemical and molecular levels to understand the Ni tolerance of Ni hyper accumulators.

***Keywords**: micronutrient, phytotoxic, chlorosis, necrosis, toxicity mechanism, hyper accumulators.*

INTRODUCTION

In recent years, as a result of uncontrolled industrial development worldwide, many chemical substances have resulted in significant air, water and soil pollution, to such an extent that environmental pollution is now a serious worldwide problem. Nickel (Ni) is just one of a variety of ubiquitous trace metals emitted into the environment from both natural and anthropogenic sources[1]. Of particular concern is the increasing concentration of Ni deposited in agricultural soils by airborne Ni particles. The primary sources of Ni emissions into the ambient air are combustion of coal and oil for heat or power generation, Ni mining, steel manufacture, and other miscellaneous sources, such as cement manufacture. Nickel is an essential micronutrients for plant growth and it is also a component of the enzyme urease which is required require for nitrogen metabolism in higher plants. Ni is strongly phytotoxic at high concentration.

The most common symptoms of Ni toxicity in plant are inhibition of growth, photosynthesis, seed germination, sugar transport and induction of chlorosis, nacrosis and wilting.

Ni was discovered in 1975 as a component of the enzymes urease, which is present in a wide range of plant species[2]. Since then, there has been renewed scientific interest and research concerning the role of Ni in the higher plants.

Nickel is the 28th element of the periodic table. It is a silver-white metal found in several oxidation states (ranging from -1to4); however, the 2 oxidation state [Ni(II)] is the most common one in biological systems[3]. Nickel readily forms nickel-containing alloys, which over the last 100 years have found an ever increasing variety of uses in modern technologies. Global input of Ni to the human environment is approximately 150,000 and 180,000 metric tonnes per year from natural and anthropogenic sources, respectively, including emissions from fossil fuel consumption, and industrial production, use, and disposal of Ni compounds and alloys[4].

OCCURRENCE AND SOURCES

Nickel (Ni) is the 24th most abundant element in the Earth's crust, comprising about 3% of the composition of the earth. It is the 5th most abundant element by weight after iron, oxygen, magnesium and silicon. It is a member of the transition series and belongs to group VIII B of the periodic table along with iron, cobalt, palladium, platinum and five other elements. Nickel is a naturally occurring element that can exist in various mineral forms. As a member of the transition metal series; it is resistant to corrosion by air, water and alkali, but dissolves readily in dilute oxidizing acids. Natural nickel is a mixture of five stable isotopes; nineteen other unstable isotopes are known. Although it can exist in several different oxidation states, the prevalent oxidation state under environmental conditions is Ni (II), nickel in the +2 valence state. Other valences (-1, +1, +3, and +4) are also encountered, though less frequently[5-7].

Nickel is a ubiquitous trace metal emitted into the environment from both natural and anthropogenic sources which are found in soil, water and air samples within the biosphere[8,9]. The compounds such as nickel acetate, nickel carbonate, nickel hydroxide and nickel oxide are used in a variety of industrial process[1]. These compounds ultimately accumulate in the soil and environment, and can be easily taken up by plants. Thus, they can enter the food chain and cause deleterious effects to animals and human[11,12]. While the level of Ni in ambient air is generally small (about 6–20 ng m-3), levels up to 150 ng Ni m-3 could be present in air contaminated by anthropogenic sources. In water, Ni derives from biological cycles and solubilization of nickel compounds from soils, as well as from the sedimentation of Ni from the atmosphere. Uncontaminated water usually contains about 300 ng dm-3 Ni. Farm soils contain approximately 3–1,000 mg kg-1 Ni soil, but the Ni concentration can reach up to 24,000 mg kg-1 Ni in soil near metal refineries and 53,000 mg kg-1 Ni in dried sludge. At pH\6.5, Ni compounds present in soil are relatively soluble, whereas at pH -6.7, most Ni exists as insoluble hydroxides.

A. Air

Occupational exposure to nickel compounds is dependent upon industrial processing and is usually substantially higher than work-unrelated nickel exposure. The form of nickel to which workers are exposed differs in the various industries in which nickel is used and occurs through inhalation or dermal contact (inhalation is the primary route of exposure), with ingestion taking place where there are poor industrial hygiene practices[13-14]. It usually involves the inhalation of one of the following substances: dust of relatively insoluble nickel compounds, aerosols derived from nickel solutions (soluble nickel) and gaseous forms containing nickel (usually nickel carbonyl)[15]. Many measurements conducted at various workplaces at risk (casting, welding, battery manufacture etc.) have revealed that the occupational concentrations may vary in a wide range from micrograms to milligrams of nickel per m3 of air[16]. In nickel-producing or nickel-using industries, about 0.2% of the work force may be exposed to considerable amounts of airborne nickel, which may lead to the retention of 100 μg of nickel per day[17].

B. Water

The stability of plant water regime depends on the balance between water uptake and transpiration. Many authors reported that Ni induced the decline in plant transpiration and water content[18-22].

Following four days of growth of *Triticum aestivum* plants in the sand culture, with 10 mM Ni added to the nutrient solution, leaf water potential, stomatal conductance, the transpiration rate, and total moisture content decreased, especially in the uppermost leaf where in the metal accumulation was most pronounced.

Transpiration may decline as a consequence of several metal-induced changes that are also produced by other heavy metals. First, the toxic effect of Ni^{2+} on plant growth would decrease the area of leaf blades, the major transpiring surface. Such decrease of leaf area by 40% was observed in *Cajanus cajan* plants grown in sand with 1 mM $NiCl_2$ added to the nutrient solution. Similarly the leaf area was diminished in *Brassica oleracea* plants grown in agar in the presence of 5–20 g/m3 $NiSO_4.7H_2O$.

Second, transpiration may decrease because of lower stomata numbers per unit of leaf area nonetheless in some cases, stomata density may even increase due to the reduction of leaf area and the size of epidermal cells.

The induction of stomata closure is among the primary effects of heavy metals[23] such closure would also diminish transpiration. In addition, damaged and therefore permanently closed stomata were found in *B. oleracea*. The presence of Ni in *Phaseolus vulgaris* leaf tissues was shown to elevate the level of ABA, which is known to induce stomata closure (cited after).

The decrease in moisture content and stomatal conductance induced by Ni is also one of the mechanisms of its toxicity towards photosynthesis; we will deal with this phenomenon below.

The major sources of trace metal pollution in aquatic ecosystems, including the ocean, are domestic wastewater effluents (especially As, Cr, Cu, Mn and Ni) and non-ferrous metal smelters (Cd, Ni, Pb and Se). Nickel is easily accumulated in the biota, particularly in the phytoplankton or other aquatic plants, which are sensitive bio indicators of water pollution. It can be deposited in the sediment by such processes as precipitation, complexation and adsorption on clay particles and via uptake by biota[24,26].

In lakes, the ionic form and the association with organic matter are predominant. On the basis of complex investigations on lakes (more than 100 km distant from the nearest source of pollution – enterprises of the copper nickel industry), it was discovered that there is intensive precipitation of heavy metals and acid oxides within the catchment area of Lake Kochejavr. Levels of precipitation of Ni of 0.9 mg/m2/year over long periods were found to be dangerous for biological systems of fresh water catchments[27].

In rivers, nickel is transported mainly as a precipitated coating on particles and in association with organic matter. The concentrations of nickel in the biggest and only navigable river in the South of Iran (River Karoon) were from 69.3 to 110.7 µg/l in winter, and from 41.0 to 60.7 µg/l in spring, respectively. The results show that the pollution has increased along the river, down to the estuary at Persian Gulf. Part of the nickel is transported via rivers and streams into the ocean. In Poland, nickel is generally transported via rivers into the Baltic Sea and in this way the average value of anthropogenic Ni input is 57%. Generally, in sea water nickel is present at concentrations of 0.1- 0.5 µg/l [28].

C. Soil

Nickel is generally distributed uniformly through the soil profile but typically accumulates at the surface from deposition by industrial and agricultural activities. Nickel may present a major problem in land near towns, in industrial areas, or even in agricultural land receiving wastes such as sewage sludge. Its content in soil varies in awide range from 3 to 1000 mg/kg [29].

Nickel can exist in soils in several forms: inorganic crystalline minerals or precipitates, complexed or adsorbed on organic cation surfaces or on inorganic cation exchange surfaces, water soluble, and free-ion or chelated metal complexes in soil solution [30]. This metal apparently does not seem to be a major concern outside urban areas at this time but may eventually become a problem as a result of decreased soil pH caused by reduced use of soil liming in agriculture and mobilization as a consequence of increased acid rain[31]. Farm soils contain approximately 3–1,000 mg kg-1 Ni soil, but the Ni concentration can reach up to 24,000 mg kg-1 Ni in soil near metal refineries and 53,000 mg kg-1 Ni in dried sludge. At pH<6.5, Ni compounds present in soil are relatively soluble, whereas at pH >6.7, most Ni exists as insoluble hydroxides.

ESSENTIALITY OF Ni

Ni as an essential micronutrient, which is required by urease for hydrolysing urea. Observed an improvement in plant growth and N uptake of Wheat (*Triticum aestivum* L.) from urea by Ni application on a calcareous soil[32]. Several investigators have also shown beneficial effects of Ni on ureas activity and improving N use efficiency by plants in hydroponic studies. However, deficiency of Ni in soil has rarely been reported showed that Ni deficiency affects plant growth, plant senescence, nitrogen (N) metabolism and Fe uptake and may play role in disease resistance.

Ni is essential for plants, but the concentration in the majority of plant species is very low (0.05-10 mg/kg dry weight). Further. With increasing Ni pollution, excess Ni rather than a deficiency, is more commonly found in plants. Toxic effects of high concentrations of Niin plants have been frequently reported. For example inhibition of mitotic activity of pigeon pea (*Cajanus caja*n L.), reductions in plant growth of cabbage (Brassica oleraceae) and adverse effects on fruit yield and quality of Wheat (*Triticum aestivum* L.). Extremely high in soil Ni concentrations have left some farmland unsuitable for growing crops, fruits, vegetables[33].

UPTAKE OF Ni

Nickel is delivered into the environment by several pathways: (1) as factory waste of high-temperature technologies of ferrous and nonferrous metallurgy, cement clinker production, and burning liquid and solid fuels; (2) field irrigation with water high in heavy metal content and transfer of sewage residue into soil; (3) transfer of heavy metals from mine tailings and metallurgical factories by water and air flows; (4) steady application of high rates of organic and mineral fertilizers and pesticides contaminated with heavy metals [34]. On the average, the total Ni content in soil varies from 2 to 750 mg/kg soil, with the maximum content reported in the serpentine soils. The major nickel ores are garnierite $[(Ni, Mg)_6Si_4O_{10}(OH)_2]$ and penlandite $[(Ni, Fe)_9S_8]$ [35].

Plants can absorb nutrients only from the soil solution phase and cannot directly access nutrients from the soil solid phase. Thus, the problem with accessing micro-elements is their limited solubility of solid phase nutrients, which limits their presence in soil solution. Plant uptake from soil solution occurs in three major ways: root interception, mass flow and diffusion.

Currently few papers describe the mechanism and kinetics of Ni^{2+} absorption by plants Plant absorption of Ni^{2+}, same as of other metals, may proceed due to passive diffusion and active transport. To elucidate the role of metabolic processes in Ni^{2+} absorption, the rates of Ni^{2+} translocation were compared at various temperatures and in relation to the aeration of nutrient solutions. At 23° C, Ni^{2+} uptake by *Avena sativa* roots directly depended on the incubation period. Low temperature, such as 2° C, considerably lowered Ni^{2+} absorption from the nutrient solution. The relationship between Ni^{2+} absorption and temperature was described by an S-like curve, with the maximum between 23 and 30° C. Both the addition of 20μ M 2, 4- dinitrophenol to the nutrient solution and the anaerobic conditions of plant growth inhibited Ni uptake by 91 and 86%, respectively. These data presume that the metabolically active uptake considerably exceeds the passive entry of Ni^{2+} ions[36].

Thus, the specific mechanisms of Ni^{+} uptake have not been as yet disclosed. It is not clear whether the hyper accumulator species acquired particular absorption mechanisms selective towards Ni^{2+} and the ability to increase its accessibility. It is not known whether the tolerance of particular plant species relies on the lowered Ni^{2+} uptake or, quite the reverse, depends mostly on the characteristic patterns of Ni^{2+} translocation and distribution and binding Ni into insoluble complexes. Below we will consider numerous and widely conflict- $NH4^{+}$ing data concerning Ni transport and allocation in plant organs.

NICKEL TOXICITY IN PLANTS

Nickel is a heavy metal and an essential microelement for plants, animals, and humans, but toxic at high concentrations, exceeding optimum intake values. As with other heavy metals, excess concentrations of Ni in plants cause chlorosis and necrosis, due to disruption of Fe uptake and metabolism[37,38]. Elevated concentrations of Ni can inhibit cell division at root meristems in non-tolerant plants[39] and decrease plant growth.

1. Effect on plant growth

The plant growth is a very essential process to maintain the life on earth. There are many factors that influence the internal and external growth of plants such as mineral resources present in soil, air and genotype of plant species. The access amount of Ni in ecosystem severely affected the growth and development of plants.

The toxic effects of Ni and other heavy metals are primarily manifested by the inhibition of plant growth [40] an index widely employed to assess environmental pollution[41]. Growth inhibition gains strength at higher metal concentration. In excluder species, which accumulate Ni mostly in their roots, root growth is inhibited more heavily than the growth of shoots[41,42] and therefore the root test is widely used for evaluating the toxicity of various agents, including heavy metals[43-44]. The tolerance index was determined between the root/shoot length of the heavy metal-stressed plant and that of the control plant[45] and LC50, the metal concentration that inhibits root growth by 50 %, are the indices of plant tolerance toward heavy metals[46].

The mechanisms of inhibition of plant growth and development by Ni^{2+} are insufficiently clarified. In addition to general metabolic disorder, heavy metals are known to decrease the plasticity of cell walls, probably by direct binding to pectins and by promoting peroxidase activity in the cell walls and intercellular space; these peroxidases are essential for lignification and linkage between extensin and polysaccharides containing ferulic acid.

To conclude, plant growth inhibition by nickel and other heavy metals results from general metabolic disorder and immediate inhibition of cell divisions. However, it is not clear whether Ni enters cell nuclei at high concentrations and, if it does, how important is immediate Ni interaction with DNA and nuclear proteins. The possible effect of Ni^{2+} on fragmoplast formation is also unknown. By elucidating these issues, we will better understand the toxic effects of nickel on plant growth and morphogenesis.

2. Effect on plant morphology

In addition to toxic effects on growth, heavy metals may induce changes in plant morphology and anatomy. Thus, exposure to 1 mM $NiSO_4$ solution decreased the mesophyll thickness, the size of vascular bundles, the vessel diameter in the main and lateral vascular bundles, and the width of epidermal cells in Triticumaestivum leaves[47] whereas in the leaves of Brassica oleracea plants grown in agar in the presence of $NiSO_4$-$7H_2O$ (10–20 g/m3), the volumes of intercellular spaces and palisade and sponge mesophyll decreased relative to control plants[48]. In addition to general metabolic disorder, heavy metals are known to decrease the plasticity of cell walls, probably by direct binding to pectines and by promoting peroxidise activity in the cell walls and intercellular space. These peroxidases are essential for lignifications and linkage between extensin and polysaccharides containing ferulic acid.

3. Inhibition of photosynthesis

Heavy metals are known to cause non-specific inhibition of photosynthesis, by several direct and indirect means. The diminished rate of photosynthesis is related to disrupted chloroplast structure, blocked chlorophyll synthesis, disordered electron transport, inhibited activities of the Calvin cycle enzymes, and CO_2 deficiency caused by stomatal closure[49].

The decrease in chloroplast size and numbers and the disorganization of chloroplast ultrastructure, including the diminished numbers of grana and thylakoids, their deformation, the formation of plasto globuli, and the changes in the membrane lipid composition, were reported in *Brassica oleracea* plants grown in agar in the presence of $NiSO_4.7H_2O$ (10–20 g/m3). Such changes seemed to arise from the Ni-induced decline in cell moisture content or from an oxidative stress resulting in peroxidation of membrane lipids[50]. When inspected in more detail, Ni was shown to inhibit electron transport from pheophytin via plastoquinone QA and Fe to plastoquinone QB by changing the structure of carriers, such as plastoquinone QB, or the reaction center proteins[51,52]. In the thylakoids, Ni ions also decreased the contents of cytochromes *b*6*f* and *b*559, as well as ferredoxin and plastocyanin; as aresult, the efficiency of electron transport droppeddown[53].

The toxic effects of heavy metals on many other metabolic processes would amplify the direct inhibition of photosynthesis. All these metabolic changes inhibit plant growth and disrupt morphogenesis; the ensuing phenomena are often used to assess the phytotoxicity of heavy metals.

4. Effect on mineral nutrition

In the presence of Ni, the contents of mineral nutrients in plant organs may increase, decrease, or stay even. One of the probable mechanisms for decreasing the uptake of macro- and micronutrients relies on the competition for the common binding sites due to the comparable ionic radii of Ni^{2+} and other cations. Such mechanism may operate[54] when the uptake of Mg^{2+} (78 pm), Fe^{2+} (82 pm), and Zn^{2+} (83 pm) is decreased in the presence of Ni^{2+} (78 pm) (ionic radii in parentheses are from[55]. One should emphasize that the lowered uptake of Mg and Fe is one of the causes of chlorosis produced by the excess of Ni in the environment[56,57]. The decline in nutrient uptake may also result from the Ni-induced metabolic disorders that affect the structure and enzyme activities of cell membranes[58]. Thus, Ni^{2+} affected the sterol and phospholipid composition of the plasma membrane in *Oryza sativa* shoots, with concomitant changes in the ATPase activity[59]. Apparently, these changes affected the membrane permeability and in this way changed the ion balance in the cytoplasm. The effects of Ni on nutrient uptake depend in many aspects on Ni concentration in the environment. The experiments with ryegrass plants demonstrated that Fe content in the shoots increased at low Ni concentrations and decreased at higher concentrations. An increase in soil Ni content from 50 to 200 mg/kg soil decreased the contents of Cu and Mg in the caryopses and Mg and Ca in the shoots of *Triticum aestivum*.

5. Effect on enzyme activity

Same as other heavy metals, Ni affects various physiological processes in plants, starting from several enzyme activities. Many evidences indicated that the toxicity of Ni is associated with oxidative stress in plants[60-62].The H_2O_2 content in plant tissues is cleaned and controlled by different enzymatic and non-enzymatic antioxidants. Ni stress caused significant decline of superoxide dismutase (SOD) in wheat and ascorbate peroxidase (APX) activities increased in the leaves under the Ni stress. APX may play significant role in the cleaning of H_2O_2 from the leaves of Ni-stressed plants in wheat because the highest value of APX coincides with decline in H_2O_2 content.

The toxic effects of metals on enzyme activity *in vitro* do not always agree with the *in vivo* effects at the samesalt concentration. Such disagreement may stem fromthe presence of efficient cellular mechanisms for detoxificationand the physiological barriers that curb metaltranslocation into the cytoplasm. To illustrate, Ni^2+ was shown to promote *in vivo* Mg^{2+}-dependent ATPases in the plasmalemma of *Oryza sativa* shoots. Total decline of enzyme activities is sometimes observed due to decreased enzyme contents. Thus, the decrease in nitrate reductase activity in soil-grown *Beta vulgaris* plants following the addition of 1 mM $NiSO_4$ resulted from the diminished rates of nitrate uptake and translocation into the shoots wherein nitrate is reduced. Nitrate in the cytoplasm induces the expression of the nitrate reductase gene, and hence it is the shortage of nitrate in the cells that would primarily decrease the enzyme concentration. Besides, glutamine synthetase and alanine aminotransferase activities were also lowered in this case; both activities considerably depend on the cytoplasmic levels of nitrate and their substrates[63,64]. Similar mechanism of indirect influence on nitrate reductase activity was established for other heavy metals[65]. Depending on its concentration, nickel ion can both stimulate and inhibit enzyme activities in plant tissues.

6. Induction of oxidative stress

Increasing evidence suggests that Ni toxicity in plants is also associated with oxidative stress[66]. Excessive Ni leads to significant increases in the concentration of hydroxyl radicals, superoxide anions, nitric oxide and hydrogen peroxide[66-68]. Since Ni is not a redox-active metal, it cannot directly generate these reactive oxygen species (ROS). However, it interferes indirectly with a number of antioxidant enzymes[69] for example, SOD, CAT, glutathione peroxidase (GSH-Px), glutathione reductase (GR), peroxidase (POD), guaiacol peroxidase (GOPX), and Ascorbate peroxidase (APX). Exposure of plants to Ni at low concentrations (=0.05 mM) and/or for short times has been shown to increase the activities of SOD, POD, GR, and GOPX to enhance the activation of other antioxidant defences and hence lead to the removal (or scavenging) of ROS[70,71].

However, excess Ni has been found to reduce the activity of many cellular antioxidant enzymes, both in vitro and in vivo, and plant's capability to scavenge ROS, leading to ROS accumulation and finally oxidative stress in plants[72].

7. Effect on yield

The toxicity of heavy metals is directly associated with crop yield. The high concentration of Ni has devastating effects on plants which ultimately caused reduction in crop yield[73]. The fresh weight of shoots of sun flower constantly decreased with increasing concentration of Ni from 10 to 40 mgL^{-1} in root medium (accepted manuscript results). All yield attributed to sunflower significantly decreased under the Ni stress. 50% reduction in all yield parameters was observed under the Ni stress (40 mgL^{-1}) as compared to control. Reduction in the yield of different crops like; cucumber[74], tomato[75] and mungbean[76] was observed in previous studies. The reduced yield of sunflower is mostly associated with Ni's quantity that accumulates in plant's leaf[77]. The total dry matter deposited in upper and lower part of plants and total biomass reduction was attributed to Ni stress[78]. The yield of *Vigna radiata* clearly reduced at the concentration of 50 mg Ni kg-1 soil.

8. Chlorophyll content

Ni was positively associated with proteins inhibition germination and chlorophyll production[79]. The high concentration of Ni significantly decreased the chlorophyll content, stomatal conductance and a potential inhibitor of photosynthesis[80,81]. The number of leaves and chlorophyll contents decreased with 24 and 47%, respectively under the Ni concentration of 0.025 mM[82]. In the fresh leaves of maize, the concentration of chlorophyll content decreased with increased concentration of Ni from 20 to 100 μM. it was observed that chlorophyll-a decreased with 70% and chlorophyll-b decreased 50% under the Ni stress of 100 μM in maize as compared to control plants. But there was no significant effect on 250 and 500 μM Ni concentrations on the chlorophyll content in maize. Accumulation of Ni in lower and upper parts of mung been's plants significantly decreased the chlorophyll content in the upper parts of plant. The Ni stress in black gram *(Vigna mungo)* created a significant reduction in photosynthetic pigments[83].

9. Water relation

It was reported that heavy metals can cause severe dehydration in shots by restricting the movement of water from roots to upper parts of plants[84,85]. Generally, heavy metals can alter the water relation in plants[86]. The toxic effects of heavy metals were observed on multiple levels like stomatal functioning, movement of water through apoplast and symplast and water uptake etc[87]. Water stability in plants depends on the balance between transpiration and water uptake.

The toxicity of Ni^{2+} reduced the area of transpiring surface (leafs Blades) of plants[88]. The 40% reduction in leaf area of *Cajanu scajan* plant was observed under the Ni stress of 1 mM in nutrient solution. When 4-day old plants of in sand culture treated with 10 mM Ni added in nutrient solution transpiration rate, stomatal, conductance, leaf water potential, and total moisture content were decreased[89].

10. Reactive oxygen species (ROS)

ROS continually produced as off-spins of different metabolic reactions that take place in different cellular parts of plants like mitochondria and chloroplast. In plants, the mitochondria (energy factories) are the major responsible site for the production of ROS[90]. Many abiotic and biotic stresses disturb the equilibrium between the cleaning and production of ROS like heavy metals, salinity, droughts, ultraviolet (UV)-radiation, air pollution, extremes of temperature, pathogens and herbicides[91]. The ROS are comparatively more reactive than O_2 and thus they have severe toxic impacts on living system. The toxicity of ROS can destroy the DNA structure; it can also stimulate the oxidation of lipids and proteins and degradation of chlorophyll pigments.

CONCLUDING REMARK

This review provides quick access to aspects related to the essentiality of Ni in proper growth and development of the plants. Ni in adequate quantities has vital roles in a wide range of morphological and physiological functions, starting from germination to the productivity. Moreover, plants cannot complete their life cycle without adequate supply of this metal.

Excess Ni toxicity is illustrated by the inhibition of lateral root development, photosynthesis, mineral nutrition and enzymatic activity and it is in this aspect where Ni toxicity differs from that of other heavy metals such as Ag, Cd, Pb, Zn, Cu, Co, and Hg. Thus, one of our future challenges to understand Ni role in plants would be to unravel the complete picture of translocation, partitioning and required amounts at different stages of plant development.

FUTURE PERSPECTIVE

Scientific advances over the past 20 years suggest that Ni is absorbed and redistributed in plants via cation and or metal ligand complex transport system.

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