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Physiological Responses and Toxic Effects of Nickel (Ni) on Cereals

Botany

KEYWORDS : Nickel Chloride, Chlorosis, Plant Growth, Photosynthesis

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ABSTRACT

In this paper, toxic effects of Ni on plants, in general, have been reviewed. In short, the essential role of Ni has also been described. The increases concentration of Ni2+ inhibits seed germination and seedling growth in different plant species. Ni toxicity symptoms are also associated with chlorosis, necrosis and wilting. The toxicity symptoms generated by nickel include chlorosis, necrosis, inhibition of shoot and root growth and decrease in leaf area.

Studies have shown that Ni has a negative effect on photosynthesis. Ni is also retards chlorophyll synthesis. High concentration of Ni interferes with the function of many cellular components, and there by altering the normal metabolism and causing cellular injuries. It may lead to loss in agricultural productivity and hazardous health effects.

Introduction

Heavy elements are the elements with specific gravity more than 5.0 and atomic weight ranging from 63 to 200 (NCSU Water Quality; 2006). There are two important facts about the heavy metals. Firstly, heavy metals are generally non-toxic but when their quantity exceeds the limit they become toxic. Some of the heavy metals are essential for development and growth of plants like cobalt (Co), copper (Cu), iron (Fe), manganese (Me), molybdenum (Mo), nickel (Ni) and zinc (Zn) studied by Rengel (2004). According to Kristina *et al.*, (2012) Heavy metals induced oxidative stress in wheat (*Triticum aestivum*) plants .Nickel was first discovered by Swedish Chemist Ronstadt in 1975 as a component of these enzymes urease, which is present in a wide range of plant species. Ni is the 28th elements of the

Essential role and Toxic effects of Ni on plants



Ni is the 28th elements of the periodic table and an atomic weight 58.71. Nickel is a hard ductile and silver-white heavy metal found in several oxidation states: however, the oxidation state of nickle is the most common one in biological system (Denkhaus and Salnikow; 2002), but it could also exist as Ni^{+} and Ni^{+3} (Marschner, 2002). Ni is chemically related to iron (Fe) and cobalt (Co). Ni present in soil solution is the hydrate form as Ni $(H_2O)_2^{+6}$ (Yusuf *et al.,* 2011). Ni as an essential trace element affects a number of biochemical and physiological processes in plants in toxic level. Ni is essential mineral elements for higher plants although failure to complete the life cycle in the absence of Ni has only been demonstrated in a few plant species. Ni is widely distributed throughout the physical and biological world. In the soil, it is present in the form of its mineral ores; the important ones are linnacite $[(Fe.Co.Ni)_3S_4]$ and spies cobalt $[(Co.Fe.Ni)_4S_2)]$. Ni is also occurs in water bodies and in atmosphere, usually in trace amount. According to Orlov *et al.,* (2002) the source of Ni into the soil involves the following:

- Transfer of heavy metals from mine tailings and metallurgical factories through water flow and air flow.
- Burning liquid and solid fuels.
- Factory waste of high-temperature technologies of ferrous and non ferrous metallurgy.
- Cement clinker production.
- Application of organic and mineral fertilizers and pesticides contaminated with heavy metals.

Ni should be classified as a micronutrient element essential for higher plants (Sengar *et al.,* 2008; Gerendas *et al.*, 1999; Sirko and Brodzik, 2000; Bloom, 2002; Marschner, 2002) and it was added to the US Department of Agriculture (USDA) list of essential plant nutrients (Hull, 2003). Ni in adequate quantities has vital roles in a wide range of morphological and physiological functions, starting from germination to the productivity (Sreekanth *et al.,* 2013). Ni is an essential micronutrient for barley (*Hordium bulgare*) which failed to complete its life cycle in the absence of nickel and addition of the growth medium completely alleviated its deficiency symptoms had been observed by Brown *et al.,* (1987). Ni can be present in waste used for irrigation, and sewage sludge applied to agricultural soils as fertilizer or soil amendments (Aguilar *et al.,* 2001). Nickel holds a special place among the heavy metals. Unlike Cd, Pb, Hg, Ag, and several other metals that are not the components of plant enzymes, Ni is a constituent of urease, and small quantities of Ni (0.01 to 5µg/g dry wt.) are essential for some plant species (Seregin and Kozhevnikova, 2006).

Ni has significance as a nutritive as well as a potentially toxic element in the plants and environment (Sengar *et al.,* 2008). Ni increase the crop yield and improves the appearance and quality of products (Brake *et al.,* 2004 and Gad *et al.,* 2007). The beneficial effect is attributed to the alleged role of this element in reactions involving enzymes, such as superoxide dismutase (SOD), change in nitrogen metabolism due to the contribution of Ni (Brown; 2006) and the possible toxicity of Ni to the pathogen (Malavolta and Moraes; 2007). The beneficial effect of Ni in the management of agents causing fungal diseases, such as rust of cereal crops (Brown, 2006 and Malavolta and Moraes, 2007). Addition of chelating agents to soils with high contents of Ni may be an effective practice to increase the metal concentration in soil solution, but have a low effect on increasing of Ni absorption by plants in barley (Molas and Baran; 2004). Ni generates toxicity, above the permissible limit, interferes with the functions of many cellular components, and there by altering the normal metabolism and causing cellular injuries, and in extreme cases, causes the death of the plant, which leads to the loss in agricultural productivity and hazardous health effects (Yusuf *et al.,* 2010).

SPECIFIC EFFECTS OF NICKLE ARE GIVEN AS BELOW:

EFFECT OF SEED GERMINATION

The excessive Ni can inhibit seed germination, plant growth and mitotic activities (Rao and Sresty, 2000). Ni, like other toxic heavy metals (Cd, Cr, Co, Zn, and Pb) is reported to cause Fe deficiency either by retarding the uptake or by causing its immobilization in roots (Mysliwa-Kurdziel *et al.,* 2004). The plasma membrane (PM) of root cells constitutes the first barrier for the entry of heavy metals but also a target of their toxic action (Liamas *et al.,* 2008).

The increasing concentration of Ni^{2+} has been shown to inhibit seed germination and seedling growth of different plant species (Espen *et al.,* 1997; Farooqi *et al.,* 2009). In maize (*Zea mays)* Ni decreased the seed germination by 10.84% at 10 µM (Bashmakov *et al.,* 2005). In another study on maize, at 50 mg L^{-1} Ni the seed germination was decreased by 11.70% (Nasar *et al.,* 2013). Ni is an essential component of the urease enzyme which hydrolyses urea and catalyzes the nitrogen metabolism during seed germination and fruit formation (Hanch and Dalton, 2009 and Dalton *et al.,* 1998). Increasing concentration of Ni up to 100 mg/L, the seed germination was decreased as compared to control (Kaveriammal *et al.,* 2015). Root and shoot growth and fresh weight of the seedlings were also reduced at 100 mg/L treatment of Ni. Seregin *et al.,* (2003) observed that Ni accumulation in the pericycle limited branching of root in maize (*Zea mays)* plants. Ni did not change the final cell length, and the final cell length, and the inhibition of seed growth resulted from censored cell division.

EFFECTS ON LEAF GROWTH

The toxicity symptoms generated by nickel include chlorosis, necrosis, inhibition of shoot and root growth and decrease in leaf area (Shaw *et al.,* 2004). Ni at a concentration of 0.5 mM produced dark brown necrotic spots along the leaf margins and decreased water potential and transpiration rate, resulting in wilting of outer leaves and necrosis of inner leaves of cabbage (Pandey and Sharma, 2002). Ni is apparent from long-term experiments that it reduces the growth of leaves, changes the structure of chloroplast, reduces the content of photosynthetic pigments and reduces the enzymes activity for CO_2 assimilation (Dan *et al.,* 2002). According to Liamas *et al.,* (2008) rice (*Oryza sativa)* grown in a nutrient medium containing 0.5 mM Ni showed a significant decrease in water content.

It is important to state that Ni in leaves may enter the food chain if the whole plant is used for *Silage* production (Silva *et al.,* 2006). The higher Ni content in yellow than green leaves tends to indicate accumulation of Ni in the senescence tissues and more difficult reutilization (Tuma *et al.,* 2010). The number of leaves and chlorophyll contents decreased with 24% and 47%, respectively under the Ni concentration of 0.025 mM (Wheeler *et al.,* 2001). According to Chen *et al.,* (2004) the toxicity of Ni^{2+} reduced the area of transpiring surface of plant.

The difference in the Ni content between the yellowing leaves and green, photo-synthetically active leaves should indicate the possibilities of reutilization of Ni-D. Young Ni-D (deficient) leaflets also exhibited considerably more reddish pigmentation than Ni-S (sufficient) seedlings (Bai *et al.,* 2006). As leaflets aged, Ni-D leaflets became darker green, thicker, and remained much smaller in leaf area than Ni-S leaflets. One key symptom is dwarfing of leaves and leaflets (Wood *et al*., 2004a).

PHOTOSYNTHESIS AND CHLOROPHYLL CONTENTS

Higher concentration of Ni has negative effects on photosynthesis and respiration (Bhalerao *et al.,* 2015). The photosynthetic effectiveness was influenced on all leaves of metals for tested plants. Among the photosynthesis, effects of Ni on plants, it is known the Ni inhibitions photosynthesis, in particular the exchange of gases, and it inhibition the Photo system II (PS II) at the oxidation point (Dan *et al.,* 2002). Elevated levels of Ni can inhibit cell division at root meristem in non-tolerant plants and decreased plant growth. According to Ouzounidou *et al.,* (2006) Ni stress reduced the growth and photosynthesis in wheat (*Triticum aestivum)*. Nutrients status (Ca, Mg, Fe, K and Na), growth and photosynthesis showed a distinct decrease related to the period of Ni treatment. Photophosphorylation, activities of the photosynthetic enzymes and PS-I are the other possibilities of action of Ni^{2+}. Long-term exposure results in reduced leaf growth, decreased photosynthetic pigments, changed chloroplast structure and decreased enzyme activities for CO_2 assimilation (Dan *et al.,*2002). The physiological makers included photosynthetic pigments content, the rate of hill reaction, K^+ efflux and carbohydrates leakage from the roots to the external solution and cell death as Ni-induced membrane damage (Ghasemi *et al.,* 2012).

Ni deficiency in plants reduce urease activity, disturb N assimilation, and reduce scavenging of superoxide free radical (Ahmad, 2011). Additionally, excess Ni also affects nutrient absorption b roots, impairs plant metabolism, inhibits photosynthesis and transpiration, and causes ultra structural modifications. Ultimately, all of these altered processes produce reduced yields of agricultural crops when such crops encounter excessive Ni exposures. Excessive Ni value in plants inhibit photosynthesis by disturbing the electron transport chain and assimilation of CO_2 (Sabir *et al.,* 2014 and Velikova *et al.,* 2011) and stomatal conductance (Ouzounidou *et al.,* 2006 and sheoran, *et al.,* 1990). Increasing Ni concentration up to 100 µmol, the content of chlorophyll a increased, but decreased Ni concentration at 200 µmol. The influence of Ni on photosynthesis is persistent, occurring both in isolated chloroplast and whole plants (Molas, 2002 and Chen *et al.,* 2009). Ni is associated with proteins inhibition germination and chlorophyll synthesis (Bhalerao *et al.,* 2015).

Long-term of wheat (*Triticum aestivum*) plants to 1mmol Ni^{2+} reduces Fe content and results in Fe and Mg deficiency symptoms (Ouzounidou *et al.,* 2006). Induce chlorophyll degradation, chlorosis. necrosis, wilting and interfere with photo-system activity (Leon *et al.,* 2005). Decreased chlorophyll content associated with heavy metal stress may be the result of inhibition of the enzymes responsible for chlorophyll biosynthesis and inhibit protochlorophyll reductase and aminolevulinic acid (ALA) synthesis (Rahman *et al.,* 2005). The chlorophyll decrease in the presence of Ni could be caused both by intensified chlorophyll action in the plant treated with the metal and sensitivity of other enzymes of porphyrins synthesis pathway as well as by synthesis (Liamas *et al.,* 2008). The decreased action of iron porphyrins enzymes-

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catalase and peroxidase, or form decreased availability of iron needed for chlorophyll synthesis (Pandey and Sharma, 2002). Ni can displace manganese ion that is coordinated to the nitrogen (N) atoms of the tetrapyrolles of the chlorophyll molecule. This alteration in chlorophylls structure could lead to a loss of absorbing properties and hence the green coloration (Gajewska *et al.,* 2007; Pandey and Sharma, 2002). It is worthy of note that this decline in chlorophyll content may account for the stunted growth. Therefore, yellowing of the leaves is an indicate that the chlorophyll content is low.

Gajewska and Sklodowska (2007) studied the influence of different Ni levels (50 and 100µM) on chlorophyll in shoots of wheat (*Triticum aestivum)*. Biochemical analysis (chlorophyll a, b, total chlorophyll and carotenoids contents) and physiological parameters (photosynthetic rate, transpiration rate and stomatal conductance) of respective plants was carried out in laboratory in which decreasing trend was also recorded (Shafeeq *et al.,* 2012) from T_1 to T_6 as compared to control. Bhattacharjee and Mukherjee (2003) performed experiment on *Amaranthus lividus* seedlings and found that heavy metal caused decrease in pigment contents (chlorophyll, carotenoid). Although, the loss of chlorophyll b was more than chlorophyll a under the equal conditions of heavy metal treatments, the decrease in these plant pigments might be due to the cellular disorganization under Ni toxicity, which causes agglutination of chloroplasts (Pandey and Pathak, 2006). In Ni treated (50 and 100µM) wheat decrease in chlorophyll content of shoots has been shown (Gajewska and Sklodowska, 2007). The exposure to Ni which could be due to a decreased concentration of Fe and Mg in the plants which play important roles in the chlorophyll biosynthesis (Ouzounidou *et al*., 2006). Excess Ni has been shown to decrease the contents of Fe (Pandey and Sharma, 2002), Cu and Zn (Parida *et al.,* 2003).

MISCELLANEOUS EFFECTS

High uptake of Ni induces a decline in water content of dicot and monocot plant species. The decrease in water can act as indicator for Ni toxicity in plants (Bhalerao *et al.,* 2015). The shoot growth of wheat was clearly inhibited when treated with 0.02mM Ni (Gajewska *et al.,* 2006).Ni toxicity created disorders in metabolic system of plants and quickly inhibited the cell division (Yusuf *et al.,* 2010). Both plant growth and leaf chlorophyll content of the urea fed plants increased significantly with the increase in nickel content up to 0.1 mg L^{-1}. However, root fresh and dry weight increased up to Ni 0.01 mg L^{-1} and started to decrease with further increase in solution Ni content (Gheibi *et al.,* 2011).

An increase in proline content and the activities of catalase, peroxidase and superoxidase dismutase increase in Ni concentration (Yusuf *et al.,* 2010). Excess Ni medium alters various physiological processes, resulting in detrimental effects on plants and causing diverse toxicity symptoms (Chen, *et al.,* 2009). Ni 1000 mg L^{-1} induced symptoms of Ni toxicity and this effect may account for the lower concentration of potassium (K) in the shoot and root of plant exposed to this concentration, as well as for inducing higher concentration of soluble protein in the shoot (Sengar *et al.,* 2008).

Ni strongly influences metabolic reaction in plants and has the ability to generate oxygen species (Bhalerao *et al.,* 2015). The symptoms of Ni toxicity resemble the symptoms of iron (Fe) deficiency due to a reduced absorption of iron (Fe) in soils (Mengel and Kirkby, 2001). The response of plants to application of Ni is wide and includes effects on nitrogen fixation, seed germination and disease suppression. However, a much higher effect could be seen when nitrogen is provided in the form of urea or symbiotically fixed (Brown, 2006). The uptake of Ni in plants is mainly carried out through the root system via passive diffusion and active transport. The addition of 50 to 100 mg Ni/litre caused death of the plants due to toxic effects of Ni (Aguilar *et al.,* 2001). Addition of 10 mg Ni/litre in the nutrient solution had toxic effects were accumulated in shoots, limiting wheat (*Triticum aestivum* L.) growth (Aguilar *et al.,* 2001). This addition limited photosynthesis, chlorophyll content and divalent cation nutrient uptake in the vegetative growth stage.

Growth of most plant species is unfavorably affected by tissue concentration of Ni above 50mg/kg dry weight (Rahman and Mahmud, 2010). The most common symptoms of $NiCl_2$ toxicity in plants are inhibition of growth, photosynthesis, seed germination, sugar transport (Ali *et al.,* 2009 and Ahmad et al., 2009), and induced of chlorosis, necrosis and wilting (Pandey and Sharma 2002). Ni deficiency can lead to the disruption of the metabolism of ureides, amino acids and organic acids in plants advocating its essential role in plants (Bai *et al.,* 2006 and 2007). Urease contains two Ni ions at the active site (Ciurli, 2001). Ni is mobile in xylem and phloem and also reaches the grains (Zeller *et al.,* 1999 and Yuruk *et al.,* 2006). The accumulation of nickel ions in the roots and shoots seedlings stage of *Vicia sativa* L. at increasing concentration of $NiCl_2$ in the medium (Ivanishchev and Abramova, 2015). Ni was accumulated in leaf and stem but was not detected in grain, sewage sludge and mineral fertilization applied to soil for a long time caused similar effects on dry matter and grains production (Nogueira *et al.,* 2009).

Higher plants although failure to complete the life cycle in the absence of Ni has only been demonstrated in a few plant species (Gerendas *et al.*, 1999). Certain prominent symptoms of Ni deficiency in which dwarfed foliage and shoots and loss of apical dominance and resetting suggest an auxin deficiency and exceedingly brittle wood suggests poor lignifications (Wood et al., 2004a). Soil was mixed with different $NiCl_2$ concentrations (50, 100, 150, 200, 250 and 300 mg/kg of soil) to make the treatments from T1 to T6 (Shafeeq *et al.,* 2012). Malondialdehyde (MDA) concentrations, a marker of lipid per-oxidation, increased in shoots of plants from Ni^{2+} sensitive but not from tolerant population of *Silene* (Gonnelli *et al.,* 2001). All these changes might disturb membrane function and therefore the ion balance in the cytoplasm, particularly of K^+, the most mobile ion across plant cell membrane.

Ni has been shown to increase membrane permeability in rice (*Oryza sativa)* and maize (*Zea mays)* roots (Pavlovkin *et al.,* 2006). The decrease in water can act as an indicator for Ni toxicity in plants (Pandey and Sharma, 2002; Gajewska *et al*., 2006). Ni toxicity, reductions in plant yield can be attributed to poor plant development and reduced supply of nutrients to the reproduction parts (Ahmad *et al.,* 2007).

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