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REVIEW ARTICLE **OPEN ACCESS**

Targets of Aluminium Toxicity in Plants

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ABSTRACT
Aluminium is the third most copious element in soil. In the soil at neutral or alkaline pH, aluminium remains in insoluble form but as the pH drops down to the acidic level, the aluminium ions get rapidly solubilized and hence in this form, can be uptaken by plants and plants start showing aluminium toxicity symptoms. As reported, the plants show stunted root growth and thereby limiting production of crops. This review addresses the significant symptoms of aluminium toxicity mainly focusing on root growth inhibition, imbalance of nutrition and oxidative stress.
Keywords: *Aluminium, nutrient uptake, plants, root growth, soil, reactive oxygen species*

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INTRODUCTION

In several parts of the world, crop production is facing major constraints due to soil acidity and their associated mineral activity [15]. Majority of the tropic soils become acidic due to continuous weathering and consequently many soluble nutrients like potassium, calcium, etc. are leached from the upper layer of soil through rain water accumulating aluminium, hydrogen, etc. at the leached surface.

Aluminium is one of the major element in earth crust and at normal pH, it exists in insoluble form exerting no harm to plants but as the soil becomes acidic, aluminium becomes soluble thereby inhibiting growth and development of roots in plants. Aluminium is known to inhibit the growth of roots even at micromolar concentrations in several plant species [20]. In soil, aluminium reacts with soluble phosphorus converting it into insoluble aluminium phosphate thereby rendering it unavailable to plants.

Farmers are trying new ways of rice cultivation to conserve water and resist climate changes. As a part of this practice rice farmers have begun to turn wet paddies to dry paddies but in this attempt, they are facing aluminium toxicity issues [16]. Earlier during indigenous rice cultivation practice, the harmful effects of aluminium concentration present in soil were diluted as rice paddies were flooded but in dry paddies, aluminium toxicity level remains the same affecting cultivation of rice. High levels of redeemable aluminium are tolerated by many crops such tea, pineapple, etc but still this toxicity remains a major constraint for production of a majority of crops. The aluminium tolerance level of species varies not only among species but it also varies for genotypes within species. Fertilizers and liming can be used as a source of remediation to reduce toxicity effect of aluminium but they are not much effective and in many cases, economical constraints also jeopardize the use of these strategies for mitigating toxicity [13]. Owing to this, there is an urgent need to decipher the possible mechanism of tolerance which can be used by these species to deal with aluminium toxicity and moreover to identify the most tolerant genotype of cereal species which can grow even in acidic soil thereby increasing the cereal production in the world. In addition to this, a better economic solution for aluminium toxicity could be obtained by developing new cultivars having increased aluminium tolerance capacity.

ALUMINIUM TOXICITY

Root Growth

During the last century inhibition of root growth has been reported as a major consequence of aluminium toxicity [8] for a number of species [10]. As a result, this inhibition of root growth acts as a potential measure of aluminium toxicity. The cell division and elongation together contribute in root growth but during last decades cell cycle (de) regulation by aluminium toxicity has been focused [18]. In wheat [9], beans, maize [7] and barley [4], a decrease in mitotic activity have been reported in conditions of aluminium toxicity. Besides this, some authors still fortified that cell elongation inhibition primarily leads to inhibition of growth of roots [5]. The roots exposed to aluminium toxicity show an increase in diameter of roots indicating cytoskeleton as a target of aluminium phytotoxicity [2]. Root cap was earlier thought to play an important role in aluminium toxicity [1]. But later on, studies revealed that there was no effect of root cap removal on root growth inhibition under aluminium phytotoxicity. In fact, meristem was suggested as a primary region of aluminium toxicity [15].

NUTRITIONAL IMBALANCE

In several plant species, aluminium exposure has been found to induce nutritional unbalance. Based on aluminium accretion, differences in nutritional imbalance have been found in various families of pteridophytes [14]. Aluminium toxicity has been found to impair the growth of both macronutrients (viz. Mg and Ca) and micronutrients (viz. Mn and Zn) in maize [11, 13]. In wheat, a decline in K and Mg nutrient and an incline in Ca, Si content was found in sensitive and tolerant cultivars respectively [18]. A high accumulation of Ca was found under aluminium exposure conditions in sensitive rye genotypes as compared to tolerant rye genotypes [18]. In rice plants, a decrease in P, Ca and Mg uptake was found [11]. Moreover, aluminium exposure led to a decrease in Ca, Mg, Fe, Mn and Zn content in tomato cultivars [19]. Among and within plant species, a variation in uptake and accumulation of nutrients, as well as its translocation, has been evident. So, it is complex to generalize an accurate model for nutritional imbalance caused by aluminium toxicity.

OXIDATIVE STRESS

Aluminium toxicity has been reported to induce changes in cell wall properties as well as oxidative stress. Disturbance occurring in cellular redox homeostasis results in oxidative stress. Cellular contents such as proteins, nucleic acids, enzymes, and lipids are oxidized by reactive oxygen species (ROS) which eventually lead to cell death. During the production of reactive oxygen species (ROS), metals work as catalyst inducing oxidative damage to plants. As aluminium is not a transition metal, it cannot catalyze redox reactions but its exposure induces oxidative stress in plants [3]. As a defending mechanism to ROS plants cells produces certain antioxidative enzymes namely ascorbate peroxidase (APX), glutathione-S-transferase (GST), catalase (CAT), superoxide dismutase (SOD), guaiacol peroxidase (GPOX), dehydroascorbate reductase (DHAR) and also some non enzymatic oxidants as α-tocopherol, ascorbate (AsA), carotenoids, glutathione (GSH) as a aid to detoxify ROS. Maize roots have been to show an increase of SOD and APX activities [3] and in addition to this it has also been reported that aluminium exposure induces the change in gene expression in maize plants [12] conferring resistance to oxidative stress.

CONCLUSION

Aluminium absorbs in acidic soil and rapidly taken up by plants impairing its root growth and development. Consequently, the nutrient and water uptake by roots is also affected leading to decreased crop production. Also, aluminium in soil reacts with soluble phosphorus leading to the formation of insoluble complexes making it unavailable to plants. The lime application can also raise soil pH but is not a remedy in the subsoil layer. Apart from this, different studies performed on aluminium toxicity involve the different composition of media, concentration of aluminium and time of exposure of aluminium to concerned species. The aluminium tolerance level of species varies not only among species but it also varies for genotypes within species. This kind of noncoordinated experimental data hinders during interpretation of overall responses. So, in order to cope up with this, uniform experimental protocols should be formulated so that plant responses to aluminium exposure and the mechanism of aluminium tolerance in plants could be more precisely deciphered.

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