INTRODUCTION

Plant stress can be defined from a physiological point of view, as any factor altering the homeostatic equilibrium of the plant; on the agricultural side, it is measured as the economic loss due to the same factor. Based on the nature of its causes, stress may be categorized as biotic and abiotic stress. The first case includes the interactions with living organisms and viruses, which use the plant as a source of food or a means for their reproduction. The abiotic stresses are nonoptimal growth conditions, such as drought, salinity, chilling temperatures, nutritional deficiency or pollutants, which prevent the plant to express its full genetic potential, in terms of carbon fixation or production. The severity of a stressing agent depends on the evolutionary background of the plant species or variety.

Drought, salinity, metal toxicity and extreme temperature are major adverse environmental factors that limit plant productivity. Sensors initiate a signaling cascade to transmit the signal and activate nuclear transcription factors to induce the expression of specific sets of genes. Ionic and osmotic stress signal transduction triggers the ionic and osmotic homeostasis signaling pathways, detoxification response pathways, and pathways for growth regulation. The ionic stress is signaled via the SOS pathway where an SOS3-SOS2 complex controls the expression and activity of ion transporters. Osmotic stress activates several protein kinases which mediate osmotic homeostasis and/or detoxification responses. Understanding the mechanisms by which plants perceive and transduce the stress signals to initiate adaptive responses is essential for engineering stress-tolerant crop plants. Based on their solubility under physiological conditions, 17 heavy metals may be available for living cells and of importance for organism and ecosystem (Weast, 1984). Among these metals Fe, Mo and Mn are important as micronutrients. Zn, Ni, Cu, V, Co, W, and Cr are toxic elements with high or low importance as trace elements. As, Hg, Ag, Sb, Cd, Pb and U have no known function as nutrients and seem to be more or less toxic to plants and microorganisms (Godbold and Hutterman, 1985). Although many heavy metals when in trace amounts are essential for various metabolic processes in organisms, they create physiological stress leading to
generation of free radicals out of which nitric oxide is the potent free radical reactive gas known to cause physiological changes and oxidative aberrations in plants including rice and also induces synthesis of phytochelatins (Liu et al., 2001).

Rice is the most important food crop in the world. All most half of the world population depends on rice as their staple food (Coffman and Juliano, 1987). Rice, the most important dietary cereal crop plant suffers both from the Biotic and Abiotic stress in the natural environment. Rice is among the few food grain crops amenable to genetic transformation and has recently emerged as the model cereal for the study of genome organization, gene expression and function as well as the fate of transgenes (Bajaj and Mohanty, 2005). As very little is done on the NO signaling in plants, the current work focuses on NO signaling under abiotic stress in Rice, the most important dietary cereal crop plant.

Over the past decade, considerable progress has been made in understanding the roles of NO in plants. NO functions as an ubiquitous signal involved in diverse physiological processes that include germination, root growth, stomatal closing, and adaptive response to biotic and abiotic stresses and it provokes both beneficial and harmful effects in plant cells. This dual role probably depends on the local concentration of NO as an effect of the rate of synthesis, translocation, effectiveness of removal of this reactive nitrogen species, as well as its ability to directly interact with other molecules and signals. Our understanding of the mechanisms underlying NO synthesis and signaling activities within plant cells is still rudimentary.

NO is synthesized by NO synthase (NOS) in animal cells, which converts l-arginine into l-citrulline in a NADPH-dependent reaction releasing equimolar quantity of NO (Neil et al. 2003). NOS-type enzyme also occurs in plants (Del Rio et al. 2004). Plants also synthesize NO through other biochemical routes like the reduction of nitrite and nitrate. In these cases, NO is likely to be produced by nitrate reductase (NR), which reduces nitrate to NO through nitrite (Planchet and Kaiser 2006). NO production by NR in vitro under pure nitrogen (or argon) is higher than in oxygenic conditions or in pure air (Planchet et al. 2005). The low yield of NO in oxygenic cell-free system is attributed to
auto-oxidation of NO or by its reaction with ROS produced simultaneously by NR (Yamasaki and Sakihama 2000). Several plant systems synthesise NO by cytosolic or plasma membrane-bound NiR, mitochondrial electron transport, Xanthine dehydrogenase/oxidase and nonenzymatic NO formation at acidic pH in the apoplasts. Other enzymes may also be involved in NO production. NO can diffuse within a cell from the site of synthesis to other regions of the cell where it might induce an effect by interaction with specific target proteins. NO is lipophilic and may accumulate or move through membranes (Leshem 1996) or can be stored as transportable compounds like SGNO (S-nitrosoglutathione) (Valderrama et al. 2007).

A great variety of abiotic stresses including drought, salinity, ultraviolet light, air pollutants and heavy metals cause molecular damage to plants, either directly or indirectly through reactive oxygen species (ROS) formation (Laspina et al., 2005), such as superoxide (O$_2^{•-}$) and hydroxyl (OH$^•$) radicals, hydrogen peroxide (H$_2$O$_2$), and oxygen singlet (‘O$_2$) (Thérond et al., 2000). Whereas some authors considered NO as a stress-inducing agent (Leshem, 1996), others have reported its protective role (Beligni and Lamattina, 1999), depending on its concentration, the plant tissue or age, and the type of stress. Literature data supply evidence showing that plant response to such stressors as drought (Mata and Lamattina, 2001), salinity (Zhao et al., 2004) and cadmium (Hsu and Kao, 2004), is regulated by NO.

Soil salinity is a major limiting factor to agricultural land productivity, especially in arid regions of the world. It is also a serious obstacle towards the reclamation and economic use of new salt-affected lands (Abogadallah et al. 2010). Nearly half of the irrigated land and 20 % of the world’s cultivated land are currently affected by salinity (Zhu 2001). The most common salt composition of saline soils is sodium chloride. Excessive salinity reduces the productivity of many agricultural crops including most of the vegetables. High salt concentration causes osmotic and ionic stress in plants. It limits growth and development of plants by affecting several key metabolic processes (Khan et al. 2010). Further, salinity alters the activities of many enzymes involving in nitrate and sulfate assimilation pathway in plants, lowers their energy status, and increases the
demand for nitrogen and sulfur (Siddiqui et al. 2009). Much of the injury at cellular level caused by salinity stress is associated with oxidative damage due to ROS. Plants appear to possess a wide array of defense strategies to protect from oxidative damage. However, less is known about NO involvement in tolerance to plants to salt stress.

As we know heavy metals (e.g-Cu, Cr & Pb) contamination affects the biosphere in many places worldwide. Several studies have been conducted in order to evaluate the effects and remedy of different heavy metals concentration on plants. NO also plays a vital role in enhancement of antioxidant enzymes activities and alleviates the toxicity of heavy metals. Copper (Cu) is an essential element in plants involved in various biochemical processes, but excess Cu (above 0.01mmol L\(^{-1}\)) in an incubation medium; (Wainwright and Woolhouse, 1977) is harmful to most plants (Femandes and Henriques, 1991). Due to its widespread industrial and agricultural use, Cu pollution is a major environmental problem. Excess Cu can generate active oxygen species (AOS), such as \(\text{H}_2\text{O}_2\) and \(\text{O}^2^-\) (Chen et al., 2000) and is able to stimulate the production of dHO in a Fenton-type reaction (Sandmann and Bo¨ger, 1980). Cu-increased lipid peroxidation has been demonstrated in Avena sativa (Luna et al., 1994), Brassica napus (Baryla et al., 2000), Helianthus annuus (Gallego et al., 1996), Holcus lanatus (Whitaker et al., 2001), Lycopersicon esculentum. Thus excess Cu leads to oxidative stress to plant cells. (Mazhoudi et al., 1997), Nicotiana plumbarinifolia (Savoure´ et al., 1999), Oryza sativa (Chen and Kao, 1999), Phaseolus vulgaris (Cuypers et al., 2000), and Silene cucubalus (De Vos et al., 1993).

Chromium (Cr) was first discovered in the Siberian red lead ore (crocoite) in 1798 by the French chemist Vauquelin. It is a transition element located in the group VI-B of the periodic table with a ground-state electronic configuration of Ar 3d\(^5\)4s\(^1\). The stable forms of Cr are the trivalent Cr (III) and the hexavalent Cr (VI) species, although there are various other valence states which are unstable and shortlived in biological systems. Cr (VI) is considered the most toxic form of Cr, which usually occurs associated with oxygen as chromate (CrO\(4^{2-}\)) or dichromate (Cr\(_2\text{O}_7^{2-}\)) oxyanions. Cr (III) is less mobile, less toxic and is mainly found bound to organic matter in soil and aquatic environments.
(Becquer et al., 2003). Contamination of soil and ground water due to the use of Cr in various anthropomorphic activities has become a serious source of concern to plant and animal scientists over the past decade.

Among different potentially toxic metals, lead (Pb) is one of the most common pollutants in the environment that readily accumulates in soils and sediments (Watanabe et al. 1997). Main sources of Pb release are mining and smelting of Pb ores, chimneys of factories using Pb, metal plating and finishing operations, effluents from the storage battery, industry, pesticides, fertilizers, and additives in pigments and gasoline, (Eick et al. 1999). Soil contamination with Pb has gained considerable attention in the recent era and it seems to be not mitigated in the near future, (Yang et al. 2000). Pb is typically nonessential metal because its biological function has not been reported in the literature, (Walker et. al, 1996). In plants, its uptake, transport, and accumulation have been reported to be mainly dependent on soil type and nature of a plant species. This metal is absorbed and accumulated in different plant tissues, (Kabata et al. 1999), generally with the highest amount in the root tissues, (Verma and Dubey, 2003).