The effect of salt stress on respiration, PSII function, chlorophyll, carbohydrate and nitrogen content in crop plants

Ebrahim Sabbagh¹, Mohammad Lakzayi², Abbas Keshtehgar¹ and Khashayar Rigi¹*

1. Department of plant Production, Khash Branch, Islamic Azad University, Khash, Iran
2. Department of Agronomy, Zahedan Branch, Islamic Azad University, Zahedan, Iran

Corresponding author: Khashayar Rigi

ABSTRACT: Salinity is the major environmental factor limiting plant growth and productivity. Plants are subjected to various stresses, which they express by their response in the form of various biochemical changes in them, which may or may not beneficial to them. Salinity has a two-phase effect on plant growth, an osmotic effect due to salts in the outside solution and ion toxicity in a second phase due to salt build-up in transpiring leaves. Salt tolerance in higher plants is regulated by a number of different physiological and biochemical processes. There is evidence that high levels of salt cause an unbalance of the cellular ions leading in both ion toxicity and osmotic stress, leading to the production of active O₂ species (AOS) such as superoxide (O₂⁻), hydrogen peroxide (H₂O₂) and hydroxyl radicals (OH⁻). Basic metabolic pathways such as photosynthesis and respiration are affected by salinity. A response of respiration to salinity is primarily associated with the direct effects of salinity on enzyme function. Decrease in chlorophyll content caused by salinity have already been reported by many authors.

Keywords: malondialdehyde, sensitivity, salt tolerance, Potassium uptake

INTRODUCTION

Salinity is the major environmental factor limiting plant growth and productivity (Allakhverdiev, 2000). Growth of wheat seedlings (Triticum aestivum L.), like other crops, is negatively affected by salinity stresses (Soltania, 2006). Breeding for adaptation to abiotic stress is extremely challenging due to the complexity of the target environments as well as that of the stress-adaptive mechanisms adopted by plants (Reynolds, 2005). Plants are subjected to various stresses, which they express by their response in the form of various biochemical changes in them, which may or may not beneficial to them. Salinity has a two-phase effect on plant growth, an osmotic effect due to salts in the outside solution and ion toxicity in a second phase due to salt build-up in transpiring leaves. Some of these responses are adaptive. The ability of variety; Kiran-95 to maintain optimum K level in addition to saline condition may be the reason of its better survival (Shirazi, 2002).

Accumulation of malondialdehyde (MDA)

It has been shown that under stress conditions, MDA (malondialdehyde) accumulation takes place in plants due to membrane lipid peroxidation. It is an effective means of assessing oxidative stress induced membrane damage (Shao, 2005) and cell membrane stability has been used an efficient criterion to discriminate among crop cultivars with respect to degree of salt tolerance (Meloni, 2003; Sairam, 2005).
The sensitivity of crops to salinity

Kumar (2005) revealed that all the major processes such as photosynthesis, protein synthesis, and energy and lipid metabolism are affected by salt stress. The sensitivity of some crops to salinity (e.g., Flowers, 1995) has been attributed to the inability to keep Na\(^+\) and Cl\(^-\) out of the transpiration stream (Hollington, 1998).

Physiological and biochemical processes

Salt tolerance in higher plants is regulated by a number of different physiological and biochemical processes. There is evidence that high levels of salt cause an unbalance of the cellular ions leading in both ion toxicity and osmotic stress (Ashraf & Harris, 2004), leading to the production of active O2 species (AOS) such as superoxide (O2\(^.-\)), hydrogen peroxide (H2O2) and hydroxyl radicals (OH\(^-\)) (Neill, 2002). The production of AOS creates oxidative stress in plants exposed to salinity or other stresses. For example, AOS have been shown to cause oxidative damage to DNA and proteins and peroxidation of lipid structures (Neill, 2002; Ashraf & Foolad 2007; Ashraf, 2009) as well as inactivation of antioxidant enzymes (Teisseire & Guy, 2000). Some reports suggest that resistance to oxidative stress is one of the prominent aspects of plant salt tolerance (Mittova, 2002; Badawi, 2004).

Respiration

Basic metabolic pathways such as photosynthesis and respiration are affected by salinity. A response of respiration to salinity is primarily associated with the direct effects of salinity on enzyme function (Walker, 1981; Seemann and Critchly, 1985). High concentrations of salinity have often been reported to increase in respiration. This increase in respiration is greater in salt sensitive than salt tolerant species (Semikhatova, 1993).

Salt tolerance

The salt-tolerance of many plants depended on the contents of carbohydrates, proteins and amino acids, K\(^+/\)Na\(^+\) and the abilities of the anti-oxidation enzymes (Weimberg, 1987; Hamada and Khulaef, 1995). However, the selective uptake of K\(^+\) as opposed to Na\(^+\) and chlorophyll (CHL) content was considered to be the most important physiological mechanism contributing to salt tolerance in winter wheat (Greenway and Munns, 1980; Srivastava, 1998; Hernandez, 1995). Salt tolerance is usually associated with comparative biomass (or grain yield) reduction when plants are exposed for longer periods of time to a saline environment (Faroop and Azam, 2005). Since the effect of salinity at every stage of plant growth is different (Munns, 2002).

Chlorophyll (CHL) content

Decrease in CHL content caused by salinity have already been reported by many authors (e.g., Thind and Malik, 1988; Srivastava, 1998; Hernandez, 1995), who suggested CHL was one of the best parameters indicating salt tolerance in crop plants. Salinity significantly reduces the total chlorophyll content and the degree of reduction in total chlorophyll depending on salt tolerance of plant species and salt concentrations. In salt-tolerant species, chlorophyll content increased, while in salt-sensitive species it was decreased (Ashraf and McNeilly, 1988). According to Velegaleti. (1990), the reduction in chlorophyll content was significant for salt-sensitive species, which is correlated with Claccumulation.

Reduce the stability of the PSII function

As accumulation of excess in Na\(^+\) ions may reduce the stability of the PSII function (Watson, 2001), the salt-tolerant cultivars here could avoid this harmful effects by maintaining lower leaf Na\(^+\) content, higher K\(^+\) versus Na\(^+\)
through selective ion transport from soil to leaf. Therefore, a relatively stable $\frac{K^+}{Na^+}$ ratio was maintained, which might be conducted to the special structure and root plasma membrane ATPase activity of the salt-tolerant cultivars (Mansour, 2000).

![Figure 2. Arbuscular mycorrhizal fungi in alleviation of salt stress](image)

**Potassium uptake**

At the same time that $K^+$ uptake is impaired by salinity, higher $K^+$ levels in tissue are required for shoot growth (Grattana and Grattana, 1999). While increases in leaf-$Na^+$ concentrations may help to maintain plant turgor, $Na^+$ cannot completely substitute for $K^+$ which is specifically required for protein synthesis and enzyme activation (Marschner, 1995). High $K^+$ concentrations in the stroma are necessary for the maintenance of optimum photosynthetic capacity under stress conditions (Chow, 1990). Cellular injury also showed a significant positive correlation with $Na^+$ and a negative correlation with $K^+$ and grain yield (Faroop and Azam, 2005).

**Antioxidant metabolites in plant stress tolerance**

To reduce AOS-induced damage, plants have evolved an intricate antioxidative system, involving antioxidative enzymes, as well as low-molecular mass secondary metabolites such as ascorbate, glutathione, tocopherols, carotenoids and phenolic compounds (Posmyk, 2009). However a lot of research is being conducted these days to elucidate the role of various antioxidant metabolites in plant stress tolerance. Biological and antioxidant properties of phenolic compounds among other metabolites have been studied to a great extent (Tsai, 2002; Wang & Lin, 2000; Posmyk, 2009). Higher activity of phenolics could be due to the greater H-donating ability and radical stabilization than a variety of other antioxidant metabolites (Rice-Evans, 1996).

**Carbohydrate contents**

Salt stress has a different effect on carbohydrate contents. Some authors have reported carbohydrates accumulation in various plants under salinity condition (Abd El- Samad and Azooz, 2002; Parida, 2003 and Azooz, 2004). On the other hand, Mostafa (2004) observed that at low and moderate salinity levels, sugars and consequently the total carbohydrates are decreased. Soluble protein is generally decreased in response to salinity (Parida, 2002 and Abed-Latef, 2005).

**Carotenoid (CAR)**

It was also reported CAR content reduced under salinity stress (Abd el Samad, 1993), as CAR was responsible for quenching of singlet oxygen (Knox and Dodge, 1985).

**Osmotic adjustment**

Osmotic adjustment is regarded as an important adaptation of plants to salinity because it helps to maintain turgor and cell volume. Plants are able to tolerate salinity by reducing the cellular osmotic potential as a consequence of a net increase in inorganic and solute accumulation (Hazegawa, 2000; Serraj and Sinclair, 2002). During osmotic adjustment, the cell tends to compartmentalize most of the absorbed ions in vacuoles at the same time they synthesize and accumulate compatible organic solutes in the cytoplasm in order to maintain the osmotic equilibrium between these two compartments (Serrano and Gaxiola, 1994; Hasegawa, 2000). Although the energetic cost of osmotic adjustment by inorganic ions is much lower than that conferred by organic molecules synthesized, this could also led to produce toxic effects because such high concentration of toxic ions may interfere with normal biochemical
activities within the cell (Yeo , 1985). Thus, a better understanding of these mechanisms and processes would enhance our efforts to improve the salinity tolerance of crop genotypes.

![Diagram of signalling pathways responsible for Na+ extrusion in Arabidopsis under salt stress](image)

**Nitrogen content**

It has also been reported that high salt concentration either causes an increase in the N-contents and high protein content in some glycophytic plants (Abed El- Baki, 1996; Jones and Mac Millan, 1987) or increase in soluble proteins (Shaddad, 2005). The Number of N-containing compounds accumulating in plants subjected to environmental stress (Robe" ,"1990 and Kuznetsov, 2007). The most frequently accumulating compounds include amides (glutamine and asparagines), amino acids (arginine, proline, citrulline and ornithine) and the amine putrescine.

**Grain quality**

Katerji . (2005) reported salinity did not affect the grain quality of the sensitive variety, but affected the grain quality of the tolerant variety, mostly in a positive way by a decrease of the ash-content. The relationship between ash content and water use efficiency may be useful for selecting varieties showing high water use efficiency under saline conditions.

**Photosynthesis**

However, elevated salt content in tissues directly influences photosynthetic enzymes and secondarily influences gas exchange and light reactions. Originally, the results of literature cleared that salinity was inhibiting photosynthesis by stomatal and non stomatal factors (Seemann and Critchley, 1985). In a study by Robinson . (1983), photosynthesis was inhibited by 65% under saline conditions. Stomatal conductance was also inhibited by a similar amount, while there was no change in chlorophyll concentrations. The reduction in photosynthesis due to non-stomatal factor may be caused by toxic ions. A negative relationship was found between photosynthesis activity and Na+ content in leaves in a number of crop species such as rice (Yeo, 1998), and Cl− content in woody perennials such as citrus (Waalker , 1981). A study with wheat (James, 2002) found that photosynthesis rate was reduced by a further 50% with Na+ concentration in leaves of about 350 mM. Seemann and Critchley (1985) found that high Cl− concentrations (250-300 mM) in the chloroplast of Phaseolus were correlated with the efficiency of Rubisco. Therefore, the tolerance of photosynthetic system to salinity may be associated with the capacity of the plant species to effectively compartmentalize the salts in the vacuole.
Proline accumulation

Amino acids such as proline, asparagine and amino butyric can play important roles in osmotic adjustment of plant under saline conditions (Gilbert, 1998). Proline accumulation might be used as an indicator in selection for withstanding saline stress through the involvement in osmoregulation (Haroun, 2002 and Ueda, 2007). Expression of one or more additional genes for proline accumulation can be induced by stress (Stewart, 1986). Additionally, proline accumulation under stress conditions may be caused by induction of proline biosynthesis enzymes, reduction the rate of proline oxidation conversion to glutamate, decrease utilization of proline in proteins synthesis and enhancing proteins turnover (Claussen, 2005).

REFERENCES


