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REVIEW

Effects of salt stress on rice growth, development characteristics, and the regulating ways: A review

Sajid Hussain, ZHANG Jun-hua, ZHONG Chu, ZHU Lian-feng, CAO Xiao-chuang, YU Sheng-miao, Allen Bohr James, HU Ji-jie, JIN Qian-yu

State Key Laboratory of Rice Biology, China National Rice Research Institute, Hangzhou 310006, P.R.China

Abstract

Rice (*Oryza sativa* L.) is highly susceptible to the rhizosphere salinity than other cereals. High sensitivity has been observed, mainly at vegetative and reproductive stages in rice. It is the duty of plant physiologists to comprehend the growth, development, and physiological processes of rice plants under stress. This paper includes the overview of rice growth and developmental processes influenced by salt stress and the regulation pathways involved in these processes. It also includes the promising salt tolerance strategies, i.e., genetic modification techniques, agronomic practices to improve rice growth, yield, and role of phytohormones and their management, especially inhibition of ethylene biosynthesis by using inhibitors 1-methylcyclopropene (1-MCP). Rice cultivation may be a first choice for improvement of salt tolerance through plant growth regulators and improved cultivation techniques. This study will significantly improve the understanding toward low rice grain yield and poor rice resistance under salt stress and will also stream scientific knowledge for effective utilization of salt affected soils by using different regulating ways.

Keywords: rice, salt stress, ethylene, 1-methylcyclopropene (1-MCP), physiology

1. Introduction

Rice (*Oryza sativa* L.) is grown in many parts of the world especially in Asia, Latin America, and Africa, and used as staple food for more than 50% population of the world (Lou *et al*. 2012). Almost 90% rice is cultivated in Asia, of which China, India, and Pakistan contribute 30, 21, and 18%, respectively, while remaining 30% is contributed by Thailand, Indonesia, Burma, and Japan (Khush 2005; Calpe 2006). Rice is high yielding crop, but current average yield is 10 t ha^{-1} for *indicia* rice, 10 to 15% yield is lower than its potential (Virmani *et al*. 1991; IRRI 1998). There are many reasons for this yield gap, i.e., environmental stresses (biotic or abiotic), management strategies, and nutrients deficiencies. Abiotic stresses (especially salt stress) are among the major causes of this low yield.

Salt stress has been a serious threat for crop production in irrigated land, as expected salt stressed irrigated land is more than 20% (Pitman and Lauchli 2002), and estimated stressed area will expand to 50% of irrigated land by 2050 (Wang *et al*. 2003). Plant physiological physiognomies are extensively susceptible to the highly saline rhizosphere. High salt level affects seed germination, plant life, and crop

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Sajid Hussain, E-mail: Sajid_2077uaf@yahoo.com; Correspondence JIN Qian-yu, Tel/Fax: +86-571-63370122, E-mail: jinqianyu@caas.cn; ZHANG Jun-hua, Tel/Fax: +86-571-63370122, E-mail: zhangjunhua@caas.cn

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productivity (Munns *et al*. 2008). Among the monocot crops, rice is salt sensitive (Maas and Hoffman 1997; Ashraf *et al*. 2009), and its productivity is severely affected by the accumulation of soluble salts in soils (Ashraf 2009).

There are many growth inhibiting effects of salt stress on rice plants, such as reducing rates of net CO_2 assimilation, leaf growth, leaf cell enlargement, dry matter accumulation, and relative growth (Cramer *et al*. 2001; Khan and Abdullah 2003; Amirjani 2010). Rice plant responses to salt stress are complex and depend on duration and type of salt stress, development stage of rice, day length, and other factors (Bernardo *et al*. 2000; Cramer *et al*. 2001). Salinity stress is dominated by sodium (Na^+) and chloride ($Cl^–$) ions (Serrano *et al*. 1999) affect rice growth and development by creating ionic, osmotic and oxidative stresses (Borsani *et al*. 2001; Tarakcioglu *et al*. 2002; Eraslan *et al*. 2007). Higher amount Na^+ in saline medium inhibits uptake and transport of Ca^{2+} and might induce Ca^{2+} deficiency in plants because of higher Na^+/Ca^{2+} ratios (Lynch *et al*. 1985). Entrance of high concentration of salt to rice plant will ultimately raise toxicity level in adult leaves causing early leaf senescence and decreasing the photosynthetic leaf area of rice (Munns *et al*. 2002; Shereen *et al*. 2005). During early period of salt stress, rice faces osmotic stress, and decreases leaf development, while in long-term salinity stress, rice plants experiences (Na^+ and $Cl^–$) ionic stress, and leads early senescence of older leaves (Amirjani 2011).

Salt stress reduced rice growth rate, promoted metabolic alterations, and decreased ability to uptake water and nutrients (Munns *et al*. 2002). Moreover, poor development of rice spikelets, especially inferior spikelets caused by salt stress significantly reduced rice grain yield (Fu *et al*. 2011; Zhang *et al*. 2015). According to FAO (2009), 70% more food is required for 2.3 billion people in the world by 2050. So, it is necessary to improve food production in future especially rice yield under salt stress (Heong and Hardy 2009).

In plant life cycles, many phytohormones (especially ethylene) play important roles in plants and environmental interactions, i.e., salt stress, being considered as coordinators between stress response and plant growth (Abeles *et al*. 1992), as ethylene signaling and production are essential for plant quick response to salt stress and adaptation resistance (Tao *et al*. 2015). Extreme ethylene productivity tends to reduce plant growth and development, leading to mortality. Therefore, ethylene homeostasis is important for rice plants to survive under salt stress. Amongst the prevailing ethylene inhibition approaches, chemical control of ethylene biosynthesis under salt stress by using inhibitors has become popular. The inhibitors like aminoethoxyvinylglycine (AVG) and 1-methylcyclopropene (1-MCP) are useful ethylene inhibitors for crops to maintain grain yield (Watkins *et al*. 2008). Zhang *et al*. (2015) reported that 1-MCP played positive effect on starch content in superior and inferior spikelets, spikelet fertility, grain yield, and harvest index for rice cultivars.

This review paper will cover (i) effects of salt stress on rice growth and development, (ii) effects of salt stress on rice physiological characters, (iii) role of ethylene in rice growth and development, and (iv) amelioration ways for increasing rice grain yield under salt stress.

2. Salt stress

Normal soil has pH=4.5–7.5, electrical conductivity (EC)< 4 dS $m^{–1}$, exchangeable sodium percentage (ESP)<15, and sodium absorption ration (SAR)<15, make most favorable environment for nutrient availability and plant growth (Bohn *et al*. 1985). However, salt stressed soil is that one has a high concentration of soluble salts that may negatively affect plant growth. According to FAO report (FAO 2009), soils affected by salt have a high soluble salt like sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride ($Cl^–$), and sulphate ($SO_4^{2–}$) (Bohn *et al*. 1985; Manchanda and Garg 2008). Saline soil has EC>4 dS $m^{–1}$, ESP<15, and SAR<15. Sodic soil is another category of soil affected by salt, which has EC less than 4 dS $m^{–1}$, ESP≥15, and SAR≥15 (Bohn *et al*. 1985; SSSA 1997). Salt stress occurs due to natural or anthropogenic activities that result in the high accumulation of soluble salts in the underground water. According to the FAO, more than 6% land in the world is affected through salinity or sodicity, and more than 20% of irrigated land has become salt stressed (Pitman and Lauchli 2002; Munns 2005).

Under salt stress, there are many explanations for poor plant performances, i.e., agronomic management, assimilate supply, enzyme activity, nutritional management, genotypic traits, and hormonal imbalance (Yang *et al*. 2000).

2.1. Ion toxicity

The most harmful effect of salt stress is the Na^+ and $Cl^–$ accumulation in plant tissues and soil (Eraslan *et al*. 2007; Nishimura *et al*. 2011). Entrance of Na^+ and $Cl^–$ into the plant cell causes ion imbalance in plant and soil, and uptake of Na^+ and $Cl^–$ in excess by plant might cause major physiological disorders in plant (James *et al*. 2011). High concentration of salts in soil profile may cause reduction in water uptake due to salt accumulation in root zone (physiological drought) (Munns 2005), reduction in osmotic potential of plant, and disruption of cell metabolic functions due to toxicity (Rozema and Flowers 2008; Evelin *et al*. 2009; James *et al*. 2011). According to an estimate, salt stress has reduced crop production about 20% of irrigated lands worldwide, and the loss of 50% arable land due to salt stress up to mid of the