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Impact of salt-induced toxicity on growth and yield-potential of local wheat cultivars: oxidative stress and ion toxicity are among the major determinants of salt-tolerant capacity

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HIGHLIGHTS

- Salt-toxicity on growth and production of ten local wheat cultivars were investigated.
- PCA and cluster analyses enabled us to identify differential salt-tolerant genotypes.
- Na^+/K^+ ratio and proline content positively correlated with growth of tolerant cultivars.
- BARI Gom 28 (tolerant) exhibited lower oxidative damage than Gourab (sensitive).

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ABSTRACT

High salinity is a major constraint for wheat productivity in many countries, including Bangladesh. Here, we examined the effects of salt-induced toxicity on growth and production of 10 local wheat cultivars by analyzing physiological, biochemical and agronomical responses to identify the salt-tolerant attributes among the contrasting genotypes. Results of cluster analyses based on salt tolerance indices of plant growth-related and yield-contributing parameters, ionic balance (Na^+, K^+ and Na^+/K^+ ratio), and stress indicators (SPAD values and proline) revealed Gourab and Shatabdi as salt-sensitive, BARI Gom 27 and 28 as salt-tolerant and the other six examined varieties as moderately salt-tolerant cultivars. Hierarchical clustering and principle component analyses also demonstrated BARI Gom 27 and 28 as the highest salt-tolerant cultivars, especially in terms of Na^+/K^+ ratio and proline level. Additionally, lower accumulations of hydrogen peroxide and malondialdehyde, and higher activities of antioxidant enzymes catalase, peroxidase and ascorbate peroxidase in the salt-tolerant BARI Gom 28 than in the salt-sensitive Gourab indicated reduced oxidative damage in BARI Gom 28 relative to that in Gourab. Collectively, our findings suggest that the optimum growth and yield of salt-tolerant cultivars are associated with decreased Na^+/K^+ ratio, increased proline level and reduced oxidative stress. Furthermore, BARI Gom 27 and 28 could be suggested as suitable cultivars for cultivation in salt-affected areas, and the contrasting salt-responsive genotypes can be used as valuable genetic resources in breeding and dissection of molecular mechanisms underlying wheat adaptation to high salinity.

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1. Introduction

Plant growth and productivity are diversely affected by various environmental stresses, including high salinity, cold, drought and metal toxicity (Thao and Tran, 2012; Gupta and Huang, 2014; Mostofa et al., 2015a,b; Thao et al., 2015). Salinity is one of the major abiotic constraints, limiting wheat (*Triticum aestivum* L.) production over 400 million hectares of land across the world, including 950,780 ha in Bangladesh (SRDI, 2010). The coastal areas of Bangladesh constitute about 20% of the country, of which approximately 53% are affected by diverse ranges of salinity (Minar et al., 2013). Agricultural land use and cropping practices in these salinity-prone areas are very limited, consequently affecting the country's overall crop-productivity. Thus, selection of salinity-tolerant wheat varieties and understanding the mechanisms regulating wheat responses and tolerance to salt stress has a great importance for food security and sustainable agriculture in the country.

Wheat is a staple food grain for more than 35% of world's population, and has been cultivated as the second most economically important cereal crops after rice in Bangladesh (Hossain et al., 2015). It occupies about 11% of the winter cropped area and 4% of the total cropped area, which largely contributes approximately 7% of the total production of food cereals in Bangladesh (Hossain and Teixeira da Silva, 2013). Consumption of wheat is gradually increasing in Bangladesh and can be connected to the increase in human population, as well as changes in eating habits. Considering food security issue, breeding efforts for developing high-yield potential varieties has been continuing in the country, which has resulted in several high-yielding wheat varieties (Hossain and Teixeira da Silva, 2013). However, extreme climate change due to global warming has already raised a radical change in salinity regimes in Bangladesh and threatened the productivity of the existing wheat varieties. Thus, it has been raising gradually an urgent need to explore the possibilities to increase wheat production in the salinity-invaded lands. Cereals, including wheat, are generally known as salt-sensitive crops that are highly vulnerable to salinity throughout their life cycles, particularly at vegetative and early reproductive stages (Darwish et al., 2009; Kumar et al., 2013). Also, the salt-tolerant capacity may vary among the cultivars at different stages of their growth and development (Kumar et al., 2013). Thus, the evaluation of salinity-induced changes, including those in agronomical, physiological and biochemical attributes, at different growth stages of cereal crops is prerequisite for selection of salt-tolerant varieties and understanding their responses to salt stress.

Salinity exerts its toxicity at the cellular level by inducing ionic, osmotic and oxidative stresses (AbdElgawad et al., 2016; Akram et al., 2017). Excessive sodium (Na^+) in the soils can cause nutritional deficiencies, such as potassium (K^+) deficiency by restricting K^+ uptake and prompting its leakage from the cells (Ding et al., 2010; Mostofa et al., 2015b; Ma et al., 2016). To survive under salt stress, plant cells are equipped with intrinsic adaptive mechanisms that include maintenance of ionic balance by minimizing Na^+ uptake, increasing intracellular Na^+ sequestration, regulating osmotic balance through the production of compatible solutes like proline (Pro) and trehalose, and reducing oxidative damage through enhanced detoxification of reactive oxygen species (ROS) (Ding et al., 2010; Gupta and Huang, 2014; Mostofa et al., 2015b). Plant cells have also armed with a distinct antioxidant defense system that keeps ROS at minimal level by employing various enzymes like peroxidase (POD), ascorbate peroxidase (APX) and catalase (CAT) (Gill and Tuteja, 2010; Mostofa et al., 2017). Since antioxidant capacity varies between the species as well as among the species, selection of varieties with foremost antioxidant power is crucial for suggesting varieties that are suitable for combating oxidative stress under saline environments.

In the present study, we have selected ten local high-yielding wheat cultivars to assess their differential salt-tolerant degrees by evaluating their agronomical, physiological and biochemical attributes associated with wheat responses to salt stress to identify the best salt-tolerant cultivars for cultivation in salt-affected areas, as well as to gain a mechanistic insight associated with their tolerance. Our data indicated that cultivars BARI Gom 27 and 28, and cultivars Gourab and Shatabdi are the highest and lowest salt-tolerant genotypes, respectively, which could be explained by their differential antioxidant responses against salt-induced oxidative damage as evidenced by the results of assays for accumulations of hydrogen peroxide (H_2O_2) and malondialdehyde (MDA), and activities of several important antioxidant enzymes like POD, CAT and APX in contrasting genotypes. These findings suggest that (i) BARI Gom 27 and 28 can be recommended to farmers for cultivating in salt-affected soils, and (ii) the four contrasting genotypes (BARI Gom 27 and 28, and Gourab and Shatabdi) can be used as potential genetic resources for molecular breeding programs, as well as comparative genomic research to gain further insight into the regulatory mechanisms underlying wheat responses and adaptation to salt stress.

2. Materials and methods

2.1. Plant materials, growth conditions and treatments

Ten high-yielding cultivars of spring wheat (*Triticum aestivum* L.), released and recommended by Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh, were used in this study. These cultivars include Sourav (BARI Gom 19) and Gourab (BARI Gom 20) released in 1998; Shatabdi (BARI Gom 21) in 2000; Sufi (BARI Gom 22), Bijoy (BARI Gom 23) and Prodip (BARI Gom 24) in 2005; BARI Gom 25 and 26 in 2010; and BARI Gom 27 and 28 in 2012 (Hossain and Teixeira da Silva, 2013). Eight cultivars were recommended for cultivation across the country, whereas BARI Gom 25 was suggested to be suitable for southern part (8–10 ds m^{-1} salinity level) and BARI Gom 26 was advised to cultivate all over the country, except in areas having salinity level > 6 dS m^{-1} (Hossain and Teixeira da Silva, 2013). According to their pedigree, the genetic background of all ten studied cultivars is totally different from each other (http://wheatatlas.org/country/varieties/BGD/0).

The experiment was conducted during the wheat-cultivating seasons 2013/14 and 2014/15 in Gazipur district, Bangladesh. The atmospheric temperature fluctuated within a range of 23–29 °C at day and 12–18 °C at night in both seasons. The relative humidity fluctuated between 48 and 87% at day and night, respectively. Loamy soil was collected from soil surface (0–20 cm) of the experimental field. The soil was ground and passed through a 5-mm mesh. This experimental soil consisted of 32.57% silt, 39.12% sand and 28.31% clay. Seeds of wheat cultivars were surface-sterilized by keeping the seeds in 1% $HgCl_2$ solution for 2 min, followed by rinsing thoroughly with distilled water. Twenty-five seeds of each variety were sown per pot (19 cm in height and 19 cm in diameter) containing 3.5 kg soil. N, P and K were supplied as 0.078 g urea, 20.04 g muriate of potash and 26.67 g triple super phosphate, respectively, per pot at days 0, 20th, 40th and 60th after sowing.

For evaluation of salt-tolerant capacity of the 10 wheat cultivars, a gradient of salt solutions (50, 100 and 150 mM NaCl) equivalent to an EC (electrical conductivity) of 7.01, 12.11 and 17.91 dS m^{-1}, respectively, was used. 500 mL of NaCl solution of different concentrations were applied to the topsoil of each pot at two-day interval from seed sowing until day 75th after sowing. For control