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Potassium nitrate application alleviates sodium chloride stress in winter wheat cultivars differing in salt tolerance

Yanhai Zheng[a,b], Aijun Jia[c], Tangyuan Ning[b], Jialin Xu[d], Zengjia Li[b,1], Gaoming Jiang[b,a,*]

[a]*Key Laboratory of Vegetation and Environmental Change, Institute of Botany, the Chinese Academy of Sciences, 20 Nanxincun, Xiangshan, 100093 Beijing, China*
[b]*Key Laboratory of Crop Biology , Shandong Agricultural University, 61 Daizong Street, 271018 Taian, China*
[c]*Dezhou Hengdong Pesticide & Chemical Co. Ltd. 18 Tianqu Industrial Park, 231025 Dezhou, China*
[d]*Dezhou Virescence Institute of Salty & Alkaline Soil, 156 Tianqu East Road, 253016 Dezhou, China*

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Summary

A sand culture experiment was conducted to answer the question whether or not exogenous KNO_3 can alleviate adverse effects of salt stress in winter wheat by monitoring plant growth, K^+/Na^+ accumulation and the activity of some antioxidant enzymes. Seeds of two wheat cultivars (CVs), DK961 (salt-tolerant) and JN17 (salt-sensitive), were planted in sandboxes and controls germinated and raised with Hoagland nutrient solution (6 mM KNO_3, no NaCl). Experimental seeds were exposed to seven modified Hoagland solutions containing increased levels of KNO_3 (11, 16, 21 mM) or 100 mM NaCl in combination with the four KNO_3 concentrations (6, 11, 16 and 21 mM). Plants were harvested 30 d after imbibition, with controls approximately 22 cm in height. Both CVs showed significant reduction in plant height, root length and dry weight of shoots and roots under KNO_3 or NaCl stress. However, the combination of increased KNO_3 and NaCl alleviated symptoms of the individual salt stresses by improving growth of shoots and roots, reducing electrolyte leakage, malondialdehyde and soluble sugar contents and enhancing the activities of antioxidant enzymes. The salt-tolerant cultivar accumulated more K^+ in both shoots and roots compared with the higher Na^+ accumulation typical for the salt-sensitive cultivar. Soluble sugar content and activities of antioxidant enzymes were found to

Abbreviations: CAR, carotenoid; CAT, catalase (EC 1.11.1.6); CHL, chlorophyll; cv(s), cultivar(s); EL, electrolyte leakage; MDA, malondialdehyde; POD, peroxidase (EC 1.11.1.7); SOD, superoxide dismutase (EC 1.15.1.1).

*Corresponding author at: Key Laboratory of Vegetation and Environmental Change, Institute of Botany, the Chinese Academy of Sciences, 20 Nanxincun, Xiangshan, 100093 Beijing, China. Tel.: +86 1062836286; fax: +86 1062830843.
E-mail address: jianggm@126.com (G. Jiang).
[1]Also for correspondence.

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be more stable in the salt-tolerant cultivar. Our findings suggest that the optimal K^+/Na^+ ratio of the nutrient solution should be 16:100 for both the salt-tolerant and the salt-sensitive cultivar under the experimental conditions used, and that the alleviation of NaCl stress symptoms through simultaneously applied elevated KNO_3 was more effective in the salt-tolerant than in the salt-sensitive cultivar.

Introduction

Soil salinity, which is a worldwide problem, severely limits crop production. Traditionally, this problem has been approached by altering farming practices to prevent soil salinization and/or by implementing schemes to remedy salt-stressed soils, such as plastic foil covers, foliar application of glycinebetaine or establishing deep-rooted plantings (Chen et al., 2005). The most promising solution to overcome the soil salinity problem, however, might be the use of salt-tolerant species that show high yields in saline soils and/or decrease farmland pollution through remediation (Ashraf and O'Leary, 1996). To achieve this goal, efficient breeding programs towards more salt-tolerant plants, including traditional and genetic engineering strategies, have to be developed (Gorham et al., 1997).

Potassium plays an important role in balancing membrane potential and turgor, activating enzymes, regulating osmotic pressure, stoma movement and tropisms (Cherel, 2004). To maintain normal cell metabolism, the K^+ content in wheat cells is kept around 150 mM and the Na^+ content at about 30 mM, resulting in a K^+/Na^+ ratio of approximately 5 (Carden et al., 2003). A suitable K^+/Na^+ ratio is important for the adjustment of cell osmoregulation, turgor maintenance, stomatal function, activation of enzymes, protein synthesis, oxidants metabolism and photosynthesis (Shabala et al., 2003). However, overproduction of reactive oxygen species (ROS) caused by salinity usually leads to lipid peroxidation and induces K^+ leak from the cell by activating K^+ efflux channels (Demidchik et al., 2003; Cuin and Shabala, 2007). Tester and Davenport (2003) reported that one of the key features of plant salt tolerance is the ability of plant cells to maintain an optimal K^+/Na^+ ratio. Under salinity stress, the K^+/Na^+ ratio shows a tendency to decrease. This occurs as a result of either excessive Na^+ accumulation in plant tissue or enhanced K^+ leakage from the cell. Potassium leakage normally happens as a result of NaCl-induced membrane depolarization under saline conditions (Shabala et al., 2003).

Previous studies revealed that supplying low levels of KNO_3 could alleviate the NaCl-induced decreases in seed germination of certain grass species (Neid and Biesboer, 2005). However, none of these studies has focused on the differential responses of salt-tolerant and salt-sensitive crop cultivars (cvs) to increased levels of KNO_3 in the absence and presence of NaCl stress. Can increased levels of KNO_3 alleviate damages induced by NaCl stress? What is the optimal K^+/Na^+ ratio under stress conditions? The major objectives of this study were, therefore, to determine in winter wheat the extent to which KNO_3 can ameliorate the effect of salt stress, and to compare the responses of two wheat varieties differing in their degree of salt tolerance.

Materials and methods

Plant growth conditions and treatments

Seeds of two wheat (*Triticum aestivum* L.) cvs, DK961 (salt-tolerant) and JN17 (salt-sensitive), were sown in sandboxes ($22 \times 16 \times 5\,cm^3$, length × width × height) in a greenhouse. Controls were irrigated with Hoagland nutrient solution (6 mM KNO_3, no NaCl). Experimental seeds were exposed to seven modified Hoagland solutions containing increased levels of KNO_3 (11, 16, 21 mM) or 100 mM NaCl in combination with the four KNO_3 concentrations (6, 11, 16 and 21 mM). Water lost by evapotranspiration was replenished each day. The average day/night temperature was kept at 16–26 and 10–16 °C, respectively, with a mean photoperiod being 14 h. All the treatments were arranged in a randomized complete block design. Measurements were carried out at 30 d after treatment.

Plant growth, water and soluble sugar contents

Growth parameters (plant height, root length and dry weight) were recorded 30 d after treatment. Thirty individual wheat seedlings were randomly harvested from each sandbox. Shoots and roots were separated and carefully washed with distilled water and dried with tissues before fresh weights were recorded. Fresh samples were oven-dried at 70 °C to a constant dry weight before the dry weights were recorded. Water