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RESEARCH ARTICLE

Comprehensive evaluation of tolerance to alkali stress by 17 genotypes of apple rootstocks

ZHANG Kun-xi[1*], WEN Tian[1*], DONG Jun[1], MA Feng-wang[1], BAI Tuan-hui[2], WANG Kun[3], LI Cui-ying[1]

[1] *State Key Laboratory of Crop Stress Biology for Arid Areas/College of Horticulture, Northwest A&F University, Yangling 712100, P.R.China*
[2] *College of Horticulture, Henan Agricultural University, Zhengzhou 450002, P.R.China*
[3] *Institute of Pomology, Chinese Academy of Agricultural Sciences, Xingcheng 125100, P.R.China*

Abstract

Alkaline soils have a great influence on apple production in Northern China. Therefore, comprehensive evaluations of tolerance to such stress are important when selecting the most suitable apple rootstocks. We used hydroponics culturing to test 17 genotypes of apple rootstocks after treatment with 1:1 Na_2CO_3 and $NaHCO_3$. When compared with the normally grown controls, stressed plants produced fewer new leaves, and had shorter roots and shoots and lower fresh and dry weights after 15 d of exposure to alkaline conditions. Their root/shoot ratios were also reduced, indicating that the roots had been severely damaged. For all stressed rootstocks, electrolyte leakage (EL) and the concentration of malondialdehyde (MDA) increased while levels of chlorophyll decreased. Changes in root activity (up or down), as well as the activities of peroxidase (POD), superoxide dismutase (SOD), and catalase (CAT) were rootstock-dependent, possibly reflecting their differences in alkali tolerance. Using alkali injury index (AI), adversity resistance coefficients (ARC), cluster analysis, and evaluation of their physiological responses, we classified these 17 genotypes into three groups: (1) high tolerance: Hubeihaitang, Wushanbianyehaitang, Laoshanhaitang Ls2, Xiaojinbianyehaitang, and Fupingqiuzi; (2) moderate tolerance: Pingyitiancha, Laoshanhaitang Ls3, Hubeihaitang A1, Deqinhaitang, Balenghaitang, Maoshandingzi, Shandingzi, and Xinjiangyepingguo; or (3) low tolerance: Pingdinghaitang, Hongsanyehaitang, Xiaojinhaitang, and Sanyehaitang. These results will significantly contribute to the selection of the most suitable materials for rootstocks with desired levels of tolerance to alkali stress.

Keywords: alkali stress, apple rootstock, alkali tolerance

1. Introduction

Soil salinization is a widespread environmental problem. Among all of the areas cultivated around the world, approximately 0.34×10^9 ha (23%) are saline and 0.56×10^9 ha (37%) are sodic (Tanji 1990). In northwestern China, reduced rainfall combined with greater soil evaporation led to soil alkalization. This important agricultural contaminant has complex impacts on plant growth, metabolism, and economic yields. Whereas salt stress refers to the challenges

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ZHANG Kun-xi, E-mail: kunxi66@163.com; WEN Tian, E-mail: wentian0427@sina.com; Correspondence LI Cui-ying, E-mail: lcy1262@sina.com

[*] These authors contributed equally to this study.

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associated with neutral salts, the term alkali stress applies to scenarios involving alkaline salts (Shi and Sheng 2005; Shi and Wang 2005; Yang *et al.* 2008a). The latter has more severe effects on plant development (Shi and Yin 1993; Yang *et al.* 2008a, b). In addition to osmotic stress and ion-induced injuries (Munns 2002), plants under alkali stress must cope with high pH levels (Keutgen and Pawelzik 2009) that not only affect normal root functioning in the rhizosphere and destroy cell structure, but also reduce their absorption capacity due to diminished root respiration (Yang *et al.* 2008a, b). These factors lead to reduced root growth (Bingham and Stevenson 1993; Alhendawi *et al.* 1997) and the precipitation of other mineral ions, which decreases the availability of essential nutrients (Shi and Zhao 1997; Li *et al.* 2010; Gong *et al.* 2014). Shoot development is also indirectly but significantly inhibited because stressed plants produce smaller leaves (Pearce *et al.* 1999). Consequently, growth and photosynthesis are negatively affected by alkaline conditions (Yang *et al.* 2009).

The effects of HCO_3^- have been investigated with several commercial crops, including bean (Valdez-Aguilar and Reed, 2008), cucumber (Rouphael *et al.* 2010), wheat (Yang *et al.* 2008b), maize, barley (Alhendawi *et al.* 1997), sunflower (Shi and Sheng 2005), tomato (Navarro *et al.* 2000; Bialczyk *et al.* 2004), pea (Zribi and Gharsalli 2002), and rice (Hajiboland *et al.* 2005). Decreased Na^+ exclusion and ion imbalances associated with alkali stress, along with an elevated pH, lead to toxic accumulations of Na^+, which induces osmotic stress (Yang *et al.* 2007). When the pH of a saline growth medium is increased, cell membranes are more severely damaged. However, research with roots from alkali-stressed tomato has shown that the activities of superoxide dismutase (SOD) and catalase (CAT), combined with the ascorbate-glutathione cycle, play important roles in alleviating oxidative stress (Gong *et al.* 2014). Because the physiological responses to these combined stresses are regulated by different pathways in various species, it is important that investigations should focus on how plants can adapt to high alkali stress over an entire life cycle.

Apple (*Malus*) is one of the most important temperate fruits, but its productivity is adversely affected by many environment factors. The arid and semi-arid regions in China are the optimal ecological zones for this crop because environmental conditions such as wide temperature fluctuations between day and night, deep soils, and adequate light support cultivation. However, increased levels of pH in the soil (i.e., alkali stress) influence fruit yield and quality, particularly in conjunction with drought and salt stresses in those regions, which further seriously affects the apple fruit industry. The susceptibility to damage from alkali stress is determined by the degree of tolerance by an apple rootstocks. Although dwarfing cultivation methods are becoming more popular, their need for certain environmental conditions and orchard management techniques mean that such practices are not necessarily suitable for arid and semi-arid apple production areas in other parts of China. Because dwarfed interstocks are still utilized there on a large scale, breeders require more comprehensive information about the characteristics of tolerant rootstocks. Abundant germplasm resources of apple rootstocks with strong tolerance to various environmental challenges are already available in China, but the alkali tolerance of some apple rootstocks has not yet been fully evaluated. Therefore, it is critical that researchers screen for that desirable characteristic in order to improve regional recommendations for appropriate rootstocks. Here, we examined the seedlings of 17 genotypes of apple rootstocks (Table 1) to determine their relative alkali tolerance based on growth parameters and morphological indexes.

Table 1 Apple rootstocks evaluated for alkali tolerance

Code	Genotype	Species	Apomictic	Origin in China
1	Pingyitiancha	*Malus hupehensis* Rehd.	Yes	Pingyi, Shandong
2	Laoshanhaitang Ls3	*M. hupehensis* Rehd.	Yes	Qingdao, Shandong
3	Wushanbianyehaitang	*M. toringoides* Rehd. Hughes	Yes	Xingcheng, Liaoning
4	Laoshanhaitang Ls2	*M. hupehensis* Rehd.	Yes	Qingdao, Shandong
5	Hubeihaitang A1	*M. hupehensis* Rehd.	Yes	Qingdao, Shandong
6	Hubeihaitang	*M. hupehensis* Rehd.	Yes	Xingcheng, Liaoning
7	Deqinhaitang	*M. sikkimensis* Koehne.	Yes	Xingcheng, Liaoning
8	Xiaojinbianyehaitang	*M. toringoides* Hughes.	Yes	Xingcheng, Liaoning
9	Pingdinghaitang	*M. micromalus* Makino.	No	Huailai, Hebei
10	Hongsanyehaitang	*M. sieboldii* Rehd.	Yes	Xingcheng, Liaoning
11	Balenghaitang	*M. robusta* Rehd.	No	Huailai, Hebei
12	Xiaojinhaitang	*M. tiaojinensis* Cheng et Jiang.	Yes	Xingcheng, Liaoning
13	Maoshandingzi	*M. mandshurica* Komarov.	No	Xingcheng, Liaoning
14	Sanyehaitang	*M. sieboldii* Rehd.	No	Qingdao, Shandong
15	Shandingzi	*M. baccata* Borkh.	No	Qingyang, Gansu
16	Fupingqiuzi	*M. prunifolia* Borkh.	No	Fuping, Shaanxi
17	Xinjiangyepingguo	*M. sieversii* Roem.	No	Yili, Xinjiang