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RESEARCH ARTICLE

Influence of drought hardening on the resistance physiology of potato seedlings under drought stress

ZHANG Shu-han[1], XU Xue-feng[1], SUN Ye-min[1], ZHANG Jun-lian[1, 2], LI Chao-zhou[1]

[1] *Gansu Key Laboratory of Crop Genetics & Germplasm Enhancement, College of Life Sciences and Technology, Gansu Agricultural University, Lanzhou 730070, P.R.China*

[2] *College of Horticulture, Gansu Agricultural University, Lanzhou 730070, P.R.China*

Abstract

In this paper, the influence of drought hardening on the growth, development, resistance physiology, leaf microstructure and stomatal behavior of potato seedlings under drought stress was studied, and the mechanism of drought hardening improvement of potato seedling drought resistance was elucidated. We found that drought stress had several adverse effects on potato seedlings, yet drought hardening alleviated the decrease in relative water content (RWC), net photosynthetic rate (P_n) and chlorophyll content and inhibited the increase in relative electric conductivity and malondialdehyde (MDA) content. Compared with contrast seedlings, drought-hardened seedlings also had enhanced root vigor, increased antioxidant enzyme activity and higher levels of abscisic acid (ABA), proline (Pro), soluble sugars and polyamines (PAs) under drought stress. In addition, the stomatal density of potato seedling leaves increased significantly, while the leaf area, stomatal size and stomatal aperture decreased with drought hardening treatment. These changes led to reduced leaf transpiration rate (T_r) and improved water utilization efficiency (WUE). The changes in leaf microstructure also had a positive effect on the drought resistance of the drought-hardened potato seedlings. So it can be concluded that through increasing the content of some endogenous hormones, osmotic regulatory substances and the activities of antioxidant enzymes, the resistance physiology of drought-hardened potato seedlings was enhanced.

Keywords: drought, drought hardening, potato, resistance physiology

1. Introduction

As a result of global warming, extreme weather conditions, such as drought, have widely expanded and this has resulted in a series of serious problems in many regions around the world, especially in arid and semi-arid areas (Wang *et al*. 2003; Adams *et al*. 2009). Drought is an important abiotic stress that affects cell membrane integrity, osmotic adjustment and photosynthetic ability (Bartels and Sunkar 2005; Benjamin and Nielsen 2006; Ravikumar *et al*. 2014), and thus poses a major limitation to plant growth and development. Severe drought stress reduces crop productivity and can lead to catastrophic crop failure (Sato and Yokoya 2008; Serraj *et al*. 2009; Budak *et al*. 2013; Kabira and Muthoni 2016). To cope with water deficit, plants have evolved a suite of strategies ranging from morphological or physiological adaptations to biochemical

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ZHANG Shu-han, E-mail: 2352167641@qq.com; Correspondence ZHANG Jun-lian, E-mail: zhangjl@gsau.edu.cn

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responses so as to survive better under drought stress conditions (Anirban *et al*. 2010).

There are four major mechanisms of plant drought resistance: drought avoidance, drought tolerance, drought escape and drought recovery (Fang and Xiong 2015). Of these, drought avoidance and drought tolerance are the two primary mechanisms for survival under drought conditions. Drought avoidance refers to the ability of plants to sustain high water status by increasing water uptake or reducing water loss in dry conditions (Yue *et al*. 2005). For example, increasing the root/shoot ratio improves the ability to uptake water, and closing stomata reduces water loss from transpiration. The main drought avoidance traits include root morphological traits and physiological traits (such as stomatal conductance and leaf relative water content (RWC)). Drought tolerance is defined as the ability of plants to maintain a certain level of physiological activity. This is accomplished through the regulation of numerous genes (for example, those related to stress signal transduction) (Zhang *et al*. 2014) and a series of metabolic pathways that reduce or repair the resulting stress damage. Drought tolerance is usually associated with physiological parameters related to osmotic adjustment (such as proline (Pro), soluble sugar and abscisic acid (ABA) content) and the alleviation of drought damage (such as the activities of protective enzymes and chlorophyll content) (Luo 2010; Fang and Xiong 2015).

In order to reduce the adverse impact of drought stress on crop production, several methods and technologies have been put to use to enhance the drought resistance of crops. Drought hardening is a convenient and feasible method and involves exposing plants to arid conditions such as reduced irrigation or partial drought during the seedling stage so as to improve the ability to adapt to subsequent serious drought (Thomas 2009; Huang *et al*. 2013). The effectiveness of drought hardening lies in the fact that young plants are malleable and are usually more able to survive under arid conditions if they have undergone a previous period of low moisture stress. It has been found that drought hardening applied in the nursery before planting improved the seedling survival rate under extreme xeric conditions (Driessche 1991). In addition, seedling hardening can improve the growth adaptability and drought resistance of mulberry (Huang *et al*. 2013). This strategy has been widely adopted in wheat, rice and other plants (Villar-Salvador *et al*. 2004; Yang *et al*. 2015).

Potato is the fourth most important food crop in the world, with an annual production exceeding 300 million tons, and is pivotal to agricultural production and people's livelihood (http://faostat.fao.org/). Compared to other crops, potato is considered to be more sensitive to drought, and even a short period of stress may cause significant reduction in tuber yield (Loon 1981).

To date, numerous studies on potato drought resistance have been reported (Zhang *et al*. 2014; Banik *et al*. 2016; Cioloca *et al*. 2016; Kabira and Muthoni 2016). Most of them have focused on the physiological and biochemical responses to drought stress and the signal transduction pathways involved. In this study, we investigated drought resistance in both contrast seedlings and drought-hardened potato seedlings in terms of resistance physiology, growth status and leaf anatomical structure, and in this paper we discuss the connection between certain indexes with the aim of gaining a more comprehensive understanding of the mechanisms of drought resistance in potato seedlings after drought hardening.

2. Materials and methods

2.1. Plant culture and stress treatments

Potato (*Solanum tuberosum* L. *cv*. cultivar Atlantic) tubers with one apical bud were germinated in pots (diameter in 35 cm, height in 40 cm) in a greenhouse at a temperature of (25±1)°C with a 13 h photoperiod and a photon flux density of approximately 400 μmol m^{-2} s^{-1}. All potato samples were divided randomly into two equal-sized groups. One group (regarded as the contrast) was watered normally, and the soil water content was maintained at approximately 15.0% by weighting before imposing drought stress. Another group was treated by the same method as the contrast group before germination and at the beginning 24 days after germination, then drought hardening was carried out for 25 days by withholding water and maintaining the soil water content at approximately 12.5%. On the 26th day the soil water content of drought hardening groups was increased to 15%, the same water content as the contrast, for 2 days. The soil water content was measured by weighing, and a moderate amount of water was added to maintain the desired soil water content. On the 28th day drought stress was imposed by withholding water from both groups. After 7 and 14 days of the drought treatment (the first day of no watering was regarded as 0 day), the second leaves from the base and white new roots of the potato seedlings were harvested for the experiments described below.

2.2. Determination of RWC, relative electric conductivity, malondialdehyde (MDA) content and root vigor

RWC of the potato seedling leaves was calculated as follows: RWC (%)=100×(FW–DW)/FW, where, FW is the fresh weight and DW is the dry weight (Barrs and Weatherly 1962). Relative electric conductivity of the potato seedling leaves was measured according to the method of Liu *et al*.