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Early drought effect on canopy development and tuber growth of potato cultivars with different maturities

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ABSTRACT

The morphological growth characteristics of shoots, stolons, and tubers were measured on potatoes (*Solanum tuberosum* L.) grown in irrigation and drought from plant emergence. Three cultivars with a wide range of seasonal maturing patterns, Chubaek (very early), Superior (medium-early), and Jayoung (late), were used. The drought was maintained up to the tuberization stage in the year 2015, and it was extended to early tuber bulking in the year 2016. The drought delayed the time to full canopy development by 2–6 days and decreased the growths of shoots in terms of stem length, stem thickness, number of stems, and fresh weight of the shoots. The harvest index was increased in all cultivars due to the decreased shoot growth. The early drought also increased the length of underground stolons. However, the decreases in stem thickness and stem number and the increases in harvest index and stolon length were only significant in the year 2016. Even though the drought did not affect tuberization in early and medium-early cultivars, it decreased early tuber growth by suppressing the longitudinal growth expressed by the ratio of length to width of the tubers. The decrease of tuber growth was observed until the end of the season with the exception of Superior in 2016. In late maturing cultivar, tuber initiation and tuber yield were dependent on the season or length (severity) of the drought. In 2016 when late cultivar, Jayoung, experienced a long drought starting from the emergence of the plants to early tuber bulking, the drought induced earlier tuberization than irrigation treatment, and showed a higher harvest index than in 2015. The early tuberization and tuber bulking due to the long drought induced increased tuber yields. The occurrence of second growth tubers was highly attributed to the maturity of cultivars in both years and the drought in 2016.

1. Introduction

Drought is known as multidimensional stress because it leads to changes in physiological, morphological, ecological, biochemical, and molecular traits of plants (Salehi-Lisar and Bakhshayeshan-Agdam, 2016). In potatoes, as an efficient water user but drought susceptible crop (Monneveux et al., 2013), the morphological, physiological, and yield responses to drought stress have been studied. As morphological parameters to drought stress, growth reductions in stems (Schittenhelma et al., 2006; Albiski et al., 2012), leaves (Jefferies and Mackerron, 1989; Schittenhelma et al., 2006), shoots (Albiski et al., 2012), stolons (Haverkort et al., 1990), and roots (Albiski et al., 2012) have been reported. In vitro (Albiski et al., 2012), field (Jefferies and Mackerron, 1987; Jefferies, 1992a,b; Schittenhelma et al., 2006; Hassanpanah, 2010; Stark et al., 2013) and controlled (Haverkort et al., 1990; Bansal et al., 1991) conditions were used to screen the drought resistance of potato cultivars or lines. Under in vitro conditions, aerial and root growths such as plant length, stem thickness, root number, length and thickness, and plant fresh and dry weights decreased (Albiski et al., 2012). In a study conducted by Jefferies (1995), it was reported that a drought increased root to shoot ratio but made the roots thinner. These responses enabled the plants under drought conditions to exploit soil moisture effectively. Canopy architecture, such as the number of leaves, leaf areas, and stem length were reduced by drought stress in field grown potatoes (Schittenhelma et al., 2006). In particular, the reduced leaf expansion, expressed as leaf area index, and the suppression of branching primarily brought about lower interception of radiation (Jefferies and Mackerron, 1989; Jefferies, 1995).

Aspects of drought-induced physiological and biochemical changes include antioxidant enzymes (Boguszewska et al., 2010; Mahmud et al., 2015), tuber water and pressure potentials (Bethke et al., 2009), proline and soluble sugar (Mahmud et al., 2015), reducing sugars (Kim et al., 1993), and sucrose contents (Bethke et al., 2009). Reactive oxygen species (ROS) were studied as a drought-responsive stress causing

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Table 1
Initial soil test data from sites used to evaluate the effect of early drought stress of potato plants in highland summer crop area, Korea.

Year	pH (1:5)	EC (dS m^{-1})	Av.P_2O_5 (mg kg^{-1})	Ex. Cations ($cmol^+$ kg^{-1})			Org. matter (g kg^{-1})
				K	Ca	Mg	
2015	6.5	0.15	586	0.70	4.7	1.1	29.0
2016	6.6	0.28	619	0.55	8.3	2.2	26.6

oxidative damage in potatoes. Boguszewska et al. (2010) proposed that the cause of poorer properties of potato plants was because of the enhanced production of ROS as well as water shortage itself. Increased activity of peroxidase, superoxide dismutase, and catalase which were known as protecting enzymes against oxidative stress has been reported (Boguszewska et al., 2010; Mahmud et al., 2015). Tuber water and pressure potentials were decreased in response to drought stress, which was enough to prevent further tuber growth (Bethke et al., 2009). More proline and total soluble sugar in leaves (Mahmud et al., 2015) and sucrose in tubers (Bethke et al., 2009) were reported under water stress conditions than in control. According to Kim et al. (1993), drought exposure at the stages of emergence, tuber initiation, and tuber bulking resulted in the increase of reducing sugars in tubers, compared to tubers that were harvested under irrigation. However, the result was reversed when the stress was given at the tuber maturing stage, which showed decreased reducing sugars.

Drought, as one of the abiotic stresses, also has severe and adverse effects on tuber growth and yield (Levy et al., 2013). The number of tubers (Mackerron and Jefferies, 1986; Jefferies and Mackerron, 1989; Haverkort et al., 1990; Jefferies, 1992b; Schittenhelma et al., 2006), accumulation of dry matter, dry matter concentration (Jefferies and Mackerron, 1987, 1989; Jefferies, 1992b), and harvest index (Jefferies and Mackerron, 1989) were reported. These are all important factors that limit the potato's yield and quality. The number of tubers, total dry matter production, and yields was reduced, but tuber dry matter concentration, harvest index and reducing sugars were increased. Mackerron and Jefferies (1986) reported a reduction in the number of tubers when a drought occurred before the onset of tuber initiation. In long-term field experiments, Haverkort et al. (1990) explained the seasonal variability in the number of tubers per plant in relation to precipitation during the first 40 days after planting. They inferred that less than 60 mm of rainfall during the period might lead to differences in the number of tubers per plant.

Since potato plants are sensitive to relatively small changes in soil moisture (Curwen, 1993), a narrow range of soil water content throughout the growing season is needed for maximum yield and quality (Stark et al., 2013). When the level of available soil water drops below 60–65%, the soil moisture becomes critical and a water deficiency develops in potato plants in most soils (Curwen, 1993). The first response is a closure of leaf stomata as a defense against further water loss. The prolonged stress causes darker leaves and wilting due to the loss of internal water pressure in plant cells (Harris, 1982; Curwen, 1993).

Recently, many regions of the world, including Korea, have been experiencing the drought stress in potato production. Limited rainfall during the spring season has been a major increasing constraint for potato production. Kim et al. (1993) reported that yield reduction was significant when potato plants were exposed to water stress in tuber bulking and/or in the stage of emergence depending on the cultivars. Hence, in recent years, there has been an increasing concern of producers regarding the growing of potatoes with enough water supply in the spring. Advances in irrigation science and the development of drought-resistant cultivars have been needed as useful options for growing potatoes during periods of drought. However, reports on canopy development and the morphological growth patterns of shoots and tubers that were affected by the length and/or severity of drought were not enough. In particular, considering the maturity of tubers, information on the responses of potato cultivars to drought stress has been limited. This study evaluated the effects of early drought stress and its time period on canopy development and tuber growth of three potato cultivars with different maturities.

2. Materials and methods

A two-year field experiment was conducted to determine the effect of early drought stress on potato (*Solanum tuberosum* L.) cultivars with different maturities. The three cultivars included Chubaek (Cho et al., 2001), Superior (Rieman, 1962) and Jayoung (Park et al., 2009). These three cultivars represent a very wide range of seasonal maturing patterns. Chubaek is a very early maturing cultivar that exhibits rapid growth, while Superior is a medium-early cultivar, and Jayoung is a late maturing cultivar that produces strong stems. All the experiments were conducted at the Highland Agriculture Research Institute (37°69′N, 128°74′E, and 800 m elevation), which is located in Daegwallyeong, Pyeongchang. Virus-free seed tubers were sourced from the same screen house each year and were stored, sprouted, and cut under the same conditions. The seed tubers were hand-planted on April 29, 2015 and 2016 using cone-shaped dibbles at 10-cm depths into a Samgag coarse loamy soil (mixed, mesic family of Typic Dystudepts) with 16–21% field capacity and 3–5% wilting points. Before the planting, the physical and chemical properties of the soil were analyzed from air-dried samples collected from the 10 cm depth. The soil texture was determined as 66–71% sand, 21–24% silt and 7.6–9.3% clay with 26–29 g kg^{-1} of organic matter, 6.5–6.6 pH, 0.15–0.28 dS m^{-1} EC, 0.5–0.7 $cmol^+$ kg^{-1} K, 4.7–8.3 $cmol^+$ kg^{-1} Ca, and 1.1–2.2 $cmol^+$ kg^{-1} Mg (Table 1). The weather conditions during the growing season were monitored by the Korea Meteorological Administration (KMA, 2015–2016), which is located adjacent to the experimental site. The average temperatures, daily sunshine hours, and precipitation data recorded were 17.5–18.0 °C, 7.5–8.6 h and 545–786 mm, respectively (Table 2).

In both years, the experimental design was a split-plot with three replications. The drought and irrigation treatment served as the main plot. Each main plot had 3 cultivar subplots, that were 3 m (4 rows) wide and 5 m long, with a planting distance of 0.25 m at the density of 5.33 plants m^{-2}. Each main plot contained 240 plants, with 80 plants

Table 2
Mean air temperature, daily sunshine hours, and monthly rainfall during growing season in the years of study.

Meteorological factor	Year	Month				
		May	June	July	Aug.	Mean (total)
Temperature (°C)	2015	14.7	16.1	19.0	20.0	17.5
	2016	14.0	17.2	20.1	20.5	18.0
	mean	14.4	16.7	19.6	20.3	17.8
Sunshine hours	2015	10.6	7.3	5.3	6.9	7.5
	2016	10.4	9.3	6.6	8.2	8.6
	mean	10.5	8.3	6.0	7.6	8.1
Rainfall (mm)	2015	13	88	136	308	545 [a]
	2016	47	57	421	260	786
	mean	30	73	279	284	666

[a] Total rainfall from May to August.