Introduction

Drought is a major abiotic stress affecting the majority of the world’s crop plants. Plants have evolved acclimation and adaptation mechanisms to cope with water deficit, including avoidance, escape from stress, and dehydration tolerance of the protoplast. During water deficit, many physiological and biochemical processes are disturbed. Understanding the multiple mechanisms by which plants respond to water stress is a challenge to enhancing crop drought tolerance (Deikman et al. 2012, Juenger 2013). Modern potato (Solanum tuberosum L.) cultivars are considered sensitive to drought, but they differ in many morphological and physiological responses to water deficit (Anithakumari et al. 2012, Lahlou et al. 2003, Schafleitner et al. 2007, Stark et al. 2013). Under field conditions, drought caused drastic losses in potato tuber yield and/or quality (Lahlou et al. 2003, Stark et al. 2013). Climate change increases the need to identify potato genotypes that exhibit high tolerance to abiotic stresses (Monneveux et al. 2013).

Several methods have been described for screening potato plants for drought tolerance (Anithakumari et al. 2011, Spitters and Schapendonk 1990). Leaf relative water content (RWC) is an important indicator of water status in plants; it reflects the balance between water supply to the leaf tissue and transpiration rate (Lugojan and Ciulca 2011). RWC has been used to evaluate potato cultivars (van Loon 1981, Vasquez-Robinet et al. 2008) and diploid potato progeny (Anithakumari et al. 2011, 2012). However, physiological and agronomic definitions of drought tolerance differ distinctly; the first stipulates that under drought, tolerant plants remain viable and produce viable seeds, while the second requires sufficient plant growth to produce an economically significant yield (Schafleitner et al. 2007). Therefore, in agronomic studies, the extent of the tuber yield decrease is the main criterion for potato resistance to drought (Boguszewska et al. 2010).

The cultivar ‘Katahdin’ is an old ‘North American’ potato that produces a high yield of well-shaped tubers with suitable storage and processing quality (Clark et al. 1931). This cultivar can adapt to a wide range of growing conditions (soil type, climate), is drought tolerant, and can produce good-quality tubers even under hot and dry conditions (Hawkins 1966). ‘Katahdin’ has a high frequency of fertilization even when pollen with a very low viability percentage is applied (Edmundson 1942) and has therefore been cultivated for drought tolerance (Anithakumari et al. 2011, Spitters and Schapendonk 1990). Leaf relative water content (RWC) is an important indicator of water status in plants; it reflects the balance between water supply to the leaf tissue and transpiration rate (Lugojan and Ciulca 2011). RWC has been used to evaluate potato cultivars (van Loon 1981, Vasquez-Robinet et al. 2008) and diploid potato progeny (Anithakumari et al. 2011, 2012). However, physiological and agronomic definitions of drought tolerance differ distinctly; the first stipulates that under drought, tolerant plants remain viable and produce viable seeds, while the second requires sufficient plant growth to produce an economically significant yield (Schafleitner et al. 2007). Therefore, in agronomic studies, the extent of the tuber yield decrease is the main criterion for potato resistance to drought (Boguszewska et al. 2010).

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Note

The effect of drought stress on the leaf relative water content and tuber yield of a half-sib family of ‘Katahdin’-derived potato cultivars

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Drought tolerance in plants is a complex trait involving morphological, physiological, and biochemical mechanisms. Hundreds of genes underlie the response of plants to the stress. For crops, selecting cultivars that can produce economically significant yields under drought is a priority. Potato (Solanum tuberosum L.) is considered a drought sensitive crop, although cultivar-dependent differences in tolerance have been described. Cultivar ‘Katahdin’ possesses many appropriate characteristics and is widely used for breeding purposes worldwide; it also has enhanced tolerance to drought stress. In this study, we evaluated cv. ‘Katahdin’ and a half-sib family of 17 Katahdin-derived cultivars for leaf relative water content (RWC) and tuber yield under drought stress. The yields of cultivars ‘Wauseon’, ‘Katahdin’, ‘Magura’, ‘Calrose’, and ‘Cayuga’ did not significantly decline under drought stress. Among these five, Wauseon exhibited the lowest reduction in both tuber yield and relative water content under water shortage. The data showed that ‘Wauseon’ is the most attractive cultivar for studies of molecular and physiological processes under drought and for potato breeding due to low yield losses that correspond with high RWC values. This cultivar can serve as a reservoir of potentially useful genes to develop cultivars with enhanced tolerance to this abiotic stress.

Key Words: RWC parameter, Katahdin, Solanum tuberosum, tuber yield, water deficit.

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used as the male or female parent in breeding of more than 200 potato cultivars worldwide (Potato Pedigree Database, www.plantbreeding.wur.nl/potatopedigree). Here, we report the variation in leaf RWC and tuber yield of a family of ‘Katahdin’-derived half-sib potato cultivars in response to water deficit.

Materials and Methods

Plant material

‘Katahdin’ and 17 ‘Katahdin’-derived potato cultivars were received from the potato collection at the Plant Breeding and Acclimatization Institute, National Research Institute, Bonin, Poland. Cultivars were released by potato breeding companies in the United States of America (cvs ‘Calrose’, ‘Cayuga’, ‘Katahdin’, ‘Pontiac’, ‘Sebago’, ‘Seneca’, ‘Sequoia’, ‘Wauseon’, ‘Yampa’), The Netherlands (‘Ari’, ‘Urgenta’, ‘Humalda’), Romania (‘Carpatin’, ‘Magura’), Poland (‘Dalila’), Soviet Union (‘Ermak’), Yugoslavia (‘Igor’), and Great Britain (‘Ulster Supreme’).

Evaluation of leaf relative water content

Two experiments were conducted in 2013–2014. Potato plants were grown in 15 cm diameter pots filled with soil in a greenhouse until they were 30–35 cm tall. For each cultivar, five plants of equal size were transferred to a growing chamber (16 h, 23°C day; 8 h, 15°C night; light intensity above the canopy 4,000 lux). The RWC (fresh weight – dry weight)/(turgid weight – dry weight) × 100 (Pieczynski et al. 2013) was evaluated before the drought treatment (control; turgid plants) and after 3 weeks without watering (drought). Results were expressed as RWC after 3 weeks without watering in relation to the control according to the formula: (RWC of plants after drought treatment) × 100%/ (RWC of control plants) and calculated as an average from the 2 years. All statistical analyses were performed using Statistica version 8 software (StatSoft, Poland).

Yield analysis

Twenty-five cut tuber pieces of each cultivar were planted into pots and maintained in the greenhouse conditions for 4 weeks. After this period, 18 plants of equal height of each cv. were transferred into a tent. A drip irrigation system was used to control of watering. The ground in the tent was lined with black foil to prevent water entry. Plants were planted in cylindrical plastic bags (26 cm height, ~25 cm diameter) filled with soil. A capillary watering system was used to ensure that each plant received the same amount of water. In the experiment, two treatments were performed: drought stress and watered control. Each treatment had a randomized complete block design with three blocks (replications) and three plants per block. In total, 18 plants per cultivar (2 treatments, 3 blocks per treatment, and 3 plants per block) were tested in each experiment.

For the first 4 weeks, all plants in both treatments were watered equally. Afterwards, half of the tested plants (drought stress treatment) went unwatered for the next 4 weeks, while the other half (control treatment) was still irrigated optimally. After this period, both treatments were again irrigated equally until the foliage began to die naturally. The tubers from each plant were harvested and weighed individually. For each replicate, the mean tuber yield per plant was calculated. To assess the influence of treatment and cultivar on tuber yield, a two-way analysis of variance (ANOVA) was applied. For each cultivar, planned comparisons (contrasts) between tuber yields of plants subjected to drought stress and control treatments were calculated. For each tested cultivar, the relative decrease in tuber yield after water stress was also calculated according to the formula: 100 × [(mean value of tuber yield per control plant) – (mean value of tuber yield per drought-treatment plant)]/(mean value of tuber yield per control plant) (Boguszewska et al. 2010, with modification). Correlation coefficients (r) between RWC and relative decrease in tuber yield were calculated.

Results and Discussion

Ideally, potato cultivars should be drought tolerant with a high yield potential under drought stress; currently, drought is a major limiting factor in potato cultivation, making irrigation necessary. However, potato crop plants can adapt to water stress in various ways, e.g., through higher assimilate partitioning to tubers, larger tubers, or more tubers (Deblonde et al. 2001). Many agro-physiological parameters related to drought tolerance have been established, such as leaf area index, leaf area duration, chlorophyll content, and decrease in water supply (Deblonde et al. 1999, Khan et al. 2015, Lahlou et al. 2003). A fast screening tool would be

Fig. 1. Response of cultivars Katahdin (left) and Wauseon (right) after 3 weeks of drought treatment.
helpful in selecting valuable genotypes with defined growth strategies that translate to drought tolerance and are suitable for experiments and/or breeding.

In potato, tolerance to drought is a very complex trait (Anithakumari et al. 2011, 2012). About 2000 differentially expressed genes were revealed in potato in response to water deficit (Watkinson et al. 2006). For quantitative traits, the phenotype is controlled by genes derived from both parents. In the present study, we identified different RWC and tuber yield responses in the half-sib family of ‘Katahdin’-derived potato cultivars under drought stress. The 3-week drought treatment decreased the leaf water content of the 18 cultivars in relation to control (Table 1). RWCs of 17 cultivars ranged from 64.4% to 86.7% in relation to the control, while cv. ‘Ari’ had an RWC of 92%, which was not statistically different to that of the control. Correlation of RWC in relation to control between years was significant ($r = 0.47$), with the highest variability in cv. ‘Carpatin’ (2013, 57%; 2014, 72%). Six cultivars (‘Yampa’, ‘Wauseon’, ‘Ulster Supreme’, ‘Urgenta’, ‘Sebago’, and ‘Ari’) had RWC more than 80% that of the control. The lowest RWC in relation to control was in cultivars ‘Carpatin’ (64.4%) and ‘Seneca’ (66.7%). According to ANOVA, the factors ‘cultivar’ and ‘treatment’ significantly affected tuber yield in this experiment ($p < 0.001$). Planned comparisons showed that mean tuber yields of plants subjected to drought stress and of control plants differed significantly for 13 tested cultivars, but for five (‘Wauseon’, ‘Katahdin’, ‘Magura’, ‘Calrose’, and ‘Cayuga’) the differences were statistically insignificant. Among those five cultivars, ‘Wauseon’ had the lowest decrease of RWC and tuber yield in relation to control after water deficit (Table 1). The correlations between RWC and relative yield decrease were statistically significant but low ($r = -0.18$).

Plant drought tolerance is often related with their morphological traits (Tuberosa 2012). Enhanced drought tolerance was observed in potato cultivars with steam-type of canopy, producing larger foliage biomass (Schittenhelm et al. 2006). Also late maturing potato genotypes, with greater and deeper root systems, are more drought tolerant (Iwama 2008). In our tent experiment, root growth of all cultivars was observed. Among test potato cultivars no large differences in plant architecture or canopy size were observed. As these cultivars belong to various maturity groups, some variation in flowering and senescence time was observed, but the differences were small (data not shown). However, among the five most drought-tolerant cvs with the lowest yield decrease, three (Wauseon, Calrose and Katahdin) were late maturing, one was mid-late (Magura), and one mid-early (Cayuga). However, late maturity cannot be the main determinant of drought tolerance, since yield decrease another late maturing cultivar—Sequoia 71.6%, and was the highest among all examined cultivars.

Considering the RWC and tuber yield decrease together, we classified the 18 cultivars into four groups: type A, high RWC with low yield losses (e.g., cv. ‘Wauseon’); type B, high RWC with high yield losses (e.g., ‘Ari’); type C, low RWC with high yield losses (e.g., ‘Sequoia’ and ‘Carpatin’); and type D, low RWC with low yield losses (e.g., ‘Ermak’ and ‘Seneca’).

The various responses of the potato cultivars to drought observed in this study may reflect the influence of genetic factors of cv. ‘Katahdin’ and the other parent used in the crosses. The results indicate that ‘Wauseon’ (Fig. 1) is the most attractive potato cultivar among examined cultivars for genetic, molecular-physiological, and breeding studies to improve drought tolerance in potato.

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