Breeding Science 66: 328–331 (2016)
doi:10.1270/jsbbs.66.328

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

Dorota Soltys-Kalina*, Jarosław Plich, Danuta Strzelczyk-Żyta, Jadwiga Śliwka and Waldemar Marczewski

Plant Breeding and Acclimatization Institute, National Research Institute, Młochów Research Center, Platanowa 19, 05-831 Młochów, Poland

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 as 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.

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 evaluative 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

---

Communicated by H. Ezura
Received May 25, 2015. Accepted December 17, 2015.
*Corresponding author (e-mail: d.soltys@ihar.edu.pl)

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).

Fig. 1. Response of cultivars Katahdin (left) and Wauseon (right) after 3 weeks of drought treatment.

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 *at 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 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 limited by the volume of plastic bags, in which plants were grown. Among tested potato cultivars no large differences in plant architecture or canopy size were observed. As these cultivars belongs 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').

Table 1. Relative water content (RWC) and relative yield decreased after drought stress in a half-sib family of 'Katahdin'-derived potato cultivars

Cultivar	Maturity[1]	Relative Yield Decrease (%)	Relative Yield Decrease P-value	RWC[2] (%, ±SD)
Wauseon	Late	13.3^{ns}	0.550	81.0 ± 5.5
Katahdin	Late	20.4^{ns}	0.110	79.2 ± 5.0
Magura	Mid-late	21.7^{ns}	0.110	77.4 ± 3.4
Calrose	Late	25.3^{ns}	0.100	79.5 ± 9.9
Seneca	Late	27.2	0.040	66.7 ± 7.2
Ulster Supreme	Late	31.5	0.008	82.3 ± 6.9
Sequoia	Late	71.6	<0.001	76.2 ± 8.2
Cayuga	Mid-early	23.9^{ns}	0.080	77.9 ± 7.0
Ermak	Mid-early	28.9	0.030	73.5 ± 9.7
Sebago	Mid-early	29.3	0.049	86.7 ± 7.8
Urgenta	Early	35.2	0.003	85.7 ± 11.0
Yampa	Mid-early	35.4	0.019	80.5 ± 10.5
Pontiac	Mid-early	38.9	<0.001	77.3 ± 10.3
Humalda	First early	42.5	<0.001	74.9 ± 6.1
Dalila	First early	44.2	<0.001	74.6 ± 9.3
Igor	Early	51.2	<0.001	76.5 ± 7.3
Ari	Mid-early	53.1	<0.001	92.0^{ns} ± 6.6
Carpatin	Mid-early	63.0	<0.001	64.4 ± 5.8

[1] based on The European Cultivated Potato Database and Department of Potato Protection and Seed Science at Bonin—Potato Gene Bank.
[2] RWC measured after 3 weeks without watering in relation to control (turgid plants).
^{ns} – not statistically significant in relation to control (*Planned comparison tests*).

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.

Literature Cited

Anithakumari, A.M., O. Dolstra, B. Vosman, R.G.F. Visser and C.G. van der Linden (2011) In vitro screening and QTL analysis for drought tolerance in diploid potato. Euphytica 181: 357–369.

Anithakumari, A.M., K.N. Nataraja, R.G.F. Visser and C.G. van der Linden (2012) Genetic dissection of drought tolerance and recovery potential by quantitative trait locus mapping of a diploid potato population. Mol. Breed. 30: 1413–1429.

Boguszewska, D., M. Grudkowska and B. Zagdańska (2010) Drought-responsive antioxidant enzymes in potato (*Solanum tuberosum* L.). Potato Res. 53: 373–382.

Clark, C.F., W. Stuart and F.J. Stevenson (1931) The Katahdin potato: a new variety. Am. Potato J. 8: 121–125.

Deblonde, P.M.K., A.J. Haverkort and J.-F. Ledent (1999) Responses of early and late potato cultivars to moderate drought conditions: agronomic parameters and carbon isotope discrimination. Eur. J.

Agron. 11: 91–105.

Deblonde, P.M.K. and J.F. Ledent (2001) Effects of moderate drought conditions on green leaf number, stem height, leaf length and tuber yield of potato cultivars. Eur. J. Agron. 14: 31–41.

Deikman, J., M. Petracek and J.E. Heard (2012) Drought tolerance through biotechnology: improving translation from the laboratory to farmers' fields. Curr. Opin. Biotechnol. 23: 243–250.

Edmundson, W.C. (1942) Comparison of Katahdin potato pollen produced in the field and in the greenhouse. Am. Potato J. 19: 12–15.

Hawkins, A. (1966) Potato varieties—the past as a key to the future in Connecticut. Am. Potato J. 43: 253–256.

Iwama, K. (2008) Physiology of the potato: new insights into root system and repercussions for crop management. Potato Res. 51: 333–353.

Juenger, T.E. (2013) Natural variation and genetic constraints on drought tolerance. Curr. Opin. Plant Biol. 16: 274–281.

Khan, M.A., D. Saravia, S. Munive, F. Lozano, E. Farfan., R. Eyzaguirre and M. Bonierbale (2015) Multiple QTLs linked to agro-morphological and physiological traits related to drought tolerance in potato. Plant Mol. Biol. Rep. 33: 1286–1298.

Lahlou, O., S. Ouattar and J.-F. Ledent (2003) The effect of drought and cultivar on growth parameters, yield and yield components of potato. Agronomie 23: 257–268.

Lugojan, C. and S. Ciulca (2011) Evaluation of relative water content in winter wheat. J. Hortic. Fores. Biotechnol. 15: 173–177.

Monneveux, P., D.A. Ramírez and M.-T. Pino (2013) Drought tolerance in potato (*S. tuberosum* L.): Can we learn from drought tolerance research in cereals? Plant Sci. 205–206: 76–86.

Pieczynski, M., W. Marczewski, J. Hennig, J. Dolata, D. Bielewicz, P. Piontek, A. Wyrzykowska, D. Krusiewicz, D. Strzelczyk-Zyta, D. Konopka-Postupolska *et al.* (2013) Down-regulation of CBP80 gene expression as a strategy to engineer a drought-tolerant potato. Plant Biotechnol. J. 11: 459–469.

Schafleitner, R., R.O.G. Rosales, A. Gaudin, C.A.A. Aliaga, G.N. Martinez, L.R.T. Marca, L.A. Bolivar, F.M. Delgado, R. Simon and M. Bonierbale (2007) Capturing candidate drought tolerance traits in two native Andean potato clones by transcription profiling of field grown plants under water stress. Plant Physiol. Biochem. 45: 673–690.

Schittenhelm, S., H. Sourell and F.-J. Löpmeier (2006) Drought resistance of potato cultivars with contrasting canopy architecture. Eur. J. Agron. 24: 193–202.

Spitters, C.J.T. and A.H.C.M. Schapendonk (1990) Evaluation of breeding strategies for drought tolerance in potato by means of crop growth simulation. Plant Soil 123: 193–203.

Stark, J.C., S.L. Love, B.A. King, J.M. Marshall, W.H. Bohl and T. Salaiz (2013) Potato cultivar response to seasonal drought patterns. Am. J. Potato Res. 90: 207–216.

Tuberosa, R. (2012) Phenotyping for drought tolerance of crops in the genomics era. Front. Physiol. 3: 347.

van Loon, C.D. (1981) The effects of water stress on potato growth, development, and yield. Am. Potato J. 58: 51–69.

Vasquez-Robinet, C., S.P. Mane, A.V. Ulanov, J.I. Watkinson, V.K. Stromberg, D. De Koeyer, R. Schafleitner, D.B. Willmot, M. Bonierbale, H. Bohnert *et al.* (2008) Physiological and molecular adaptations to drought in Andean potato genotypes. J. Exp. Bot. 59: 2109–2123.

Watkinson, J.I., L. Hendricks, A.A. Sioson, C. Vasquez-Robinet, V. Stromberg, L.S. Heath, M. Schuler, H.J. Bohnert, M. Bonierbale and R. Grene (2006) Accessions of *Solanum tuberosum* ssp. *andigena* show differences in photosynthetic recovery after drought stress as reflected in gene expression profiles. Plant Sci. 171: 745–758.