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Effect of drought and waterlogging on hydrophilic antioxidants and their activity in potato tubers

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Abstract: Maintaining a strong antioxidant system is essential for preventing drought or waterlogging stresses damage in potato tubers. In the two-year pot experiment, the effect of long-term drought and waterlogging stresses on the content of phenolic acids, ascorbic acid, and antioxidant activity in potato tubers and relative water content of four cultivars was evaluated. Drought stress significantly ($P < 0.05$) decreased relative water content (RWC) in the leaves of all genotypes. The evaluation of the relationship between phenolic acid content and the level of plant stress expressed as RWC showed a negative correlation between RWC and most phenolic acids, but these correlations were not statistically significant, with the exception of L-tyrosine. A significant positive correlation was found between total and individual phenolic acid content and antioxidant activity ($R = 0.657$), confirming the main responsibility for the increase of antioxidant activity. The average tuber yield and weight as well as their average number correlated negatively with total phenolic acids. Drought stress decreased L-ascorbic acid content by reduction of biosynthesis, and its content was positively correlated with decreased RWC, tubers yield, weight, and number. The increase of phenolic antioxidants in potato under stress conditions can be a distinctive marker of cultivar resistance against abiotic stresses.

Keywords: *Solanum tuberosum* L.; long-term abiotic conditions; water stress; vitamin C; climate change

Our changing climate, with more fluctuations in temperature and precipitation levels, is affecting the yield and quality of crops, like potato, one of the most important crops in the world. Drought stress is one of the major yield and quality limiting abiotic stress worldwide. Potato is sensitive to drought due to its shallow root system. When drought occurs in spring and early summer, the quality and quantity of the tubers might be considerably reduced (Bündig et al. 2017). Water stress influences potato growth and production by reducing the amount of productive foliage, by decreasing the rate of photosynthesis per unit of leaf area, and by shortening the vegetative growth period with respect to potato under well-watered conditions. Potato yield under water stress depends on the time, duration, and severity of the stress, as well as on genotype (Hirut et al. 2017). Because a selection for water stress-tolerant genotypes in the field is time-consuming, cost-intensive, and difficult to reproduce, it was proposed that screening genotypes for their response to stress conditions *in vitro* might be an alternative (Bündig et al. 2017).

In living organisms, reactive oxygen species are formed by stress effect, and antioxidants are powerful natural constituents that possess the ability to inhibit oxidative stress and molecular damage. This is the reason that the main phenolic acid contained in potato, especially chlorogenic (3-CQA), crypto-

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chlorogenic (4-CQA), neochlorogenic (5-CQA), and caffeic (CA) acids are important antioxidants acting in abiotic antioxidant stresses (Tošović et al. 2017). Environmental stress such as drought during the tuber development may influence the polyphenol biosynthetic pathway and the expression of the level of polyphenol biosynthetic and regulatory genes among potato genotypes (Kappachery et al. 2013).

Also, L-ascorbic acid (AsA) acts as an antioxidant, which is affected by many factors like abiotic stresses or the use of insecticides (Gugała and Zarzecka 2012). The underwater deficit, the formation of active oxygen species increases, and AsA protect the antioxidant system of cells by controlling their intracellular concentration. Potato is generally considered to be sensitive to drought stress (DS) and waterlogging stress (WLS) that may threaten its sustainable production (Obidiegwu et al. 2015). More tolerant potato cultivars that can withstand fluctuation in water availability and deliver good quality tubers are currently needed. The present study focused on: change of the content of (*i*) phenolic acids; (*ii*) L-ascorbic and L-dehydroascorbic acids; (*iii*) L-tyrosine (an amino acid with antioxidant activity); and (*iv*) antioxidant activity in potato tubers and their relationship to drought and waterlogging stresses.

MATERIAL AND METHODS

Plant material. Four cultivars of potatoes are characterised in Table 1. Potato plants were grown in partially controlled temperature and humidity conditions of the greenhouse of the Department of Botany and Plant Physiology, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague. Potato plants were grown in 5 L pots in the substrate Hawita baltisches Trysubstrat (dispensing 45 025, pH value 5.8 $CaCl_2$, white peat 70%, black peat 30%, structure fine, HAWITA Gruppe GmbH, Vechta, Germany). 2 g of NPK 8-24-24 fertiliser was added to the pot before starting the experiment. In each pot, one plant of potato was grown. The experiment was performed in four replicates for each year (a total of eight replicates; in both years 2017 and 2018, the same experimental conditions were ensured). The pots were placed in the greenhouse according to the Latin square method. Plants were grown under the natural light mode, where the length of the day was 13 h and dark 11 h. The temperature mode was set at 22 °C by day and 17 °C by night at 70% air relative humidity. The experimental scheme included three variants of the experiment; the first variant consisted of irrigated control, the second variant represented the water deficit, and the third variant the permanent waterlogging. The control plants were irrigated with distilled water at regular three-day intervals, where the amount of water was 450 mL per pot. In the second variant, the water deficit was induced by the method of gradual natural drying out of the substrate. In the third variant, the plants and the substrate were kept in anoxia by placing the pots in a bath with water. Plant stress in the second and third variants of the experiment was induced in the development phase BBCH 109. Plants of all experimental variants were twice fertilised with 3% NPK 8-24-24 solution in 450 mL water for watering in the developmental stages 406 and 703 BBCH. In the nutrient solution, 2.40 g of N, 3.14 g of P, and 5.98 g of K in pure nutrients were added. Tuber sampling was carried out in the developmental step according to the BBCH scale 909 (harvested product, 71 days of stress).

Determination of phenolic acids. Approximately 15 g of freshly cut potatoes were poured with 50 mL

Table 1. Characteristics of analysed potato cultivars

Cultivar	Origin of tubers/year	Maturity	Skin color	Flesh color	Shape of tubers	Origin	Resistance to biotic stress
Laura	Austria 1998	medium-early	red	dark yellow	oval	Saskia × MPI 49 540 2	medium-high
Marabel	Germany 1993	early to medium-early	yellow	yellow	oval	Nena × MA 75 304 2	high
Milva	Germany 2002	medium-early to early	yellow	yellow	oval to tear drop	Nena × Dunja	medium-high
Valfi	Czech Republic 2005	medium-early to medium-late	blue-violet	blue-violet marbled	round to oval	clone selection from British Columbia Blue heritage cultivar	medium-less

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of methanol and homogenised for one minute using a blender. The sample was then filtered into a 100 mL volumetric flask, rinsed with sufficient solvent, and filled with methanol to the mark. The aliquot was diluted 1:1 with deionised water, then transferred *via* a 0.45 µm PVDF microfilter to a vial and subjected to HPLC-DAD analysis. Chromatographic separation was performed using a chromatograph Ultimate 3000 HPLC System (Thermo Fisher Scientific, Inc., Waltham, USA) equipped with a quaternary pump, autosampler, column heater, and diode array detector. The analytical column used was Omnispher C18, 250 × 4.6 mm, 5 µm (Agilent, Inc., Santa Clara, USA) and pre-column: Microsorb C18, 300A, 4.6 × 10 mm, 5 µm (Agilent, Inc., Santa Clara, USA). Mobile phases A 0.1% acetic acid in the water, and B: 0.1% acetic acid in acetonitrile were used in linear gradient mode.

Determination of L-ascorbic acid (AsA) and L-dehydroascorbic acid (DHAsA). A slightly modified method, according to Mazurek and Jamroz (2015), was used. In brief, approximately 15 g of freshly cut potatoes were homogenised with 50 mL of 3% HPO_3 for one minute using a blender. The sample was then filtered, first through the filter paper, and then through a 0.45 µm PVDF microfilter into a beaker. For the determination of AsA, part of the extract was diluted 1:1 with 3% HPO_3 and directly analysed by HPLC-DAD. 5 mL of the remaining extract was transferred into a 10 mL volumetric flask, and 1 mL of 100 mmol TCEP (tris-(2-carboxyethyl) phosphine hydrochloride) was added. The volumetric flask was filled to a volume of 10 mL with HPO_3. The extract was then transferred into the plastic falcon tube and shaken for 20 min on a shaker (GFL 3006, Burgwedel, Germany). After 20 min reduction, part of the extract was transferred to a vial and analysed on HPLC-DAD. DHAsA content was calculated from the difference between total AsA after the reduction of the extract (all vitamin in the form of AsA) and the AsA of the extract.

Determination of L-Tyrosine (L-Tyr). 0.5 g of lyophilised potato tubers (Lyovac GT2, Steris, Inc., Hurth, Germany) was weighed into a 15 mL falcon tube and then 5 mL of extraction mixture methanol/water (1:1) was added. The mixture was shaken for 30 min on a shaker (150 rpm, GFL 3006, Burgwedel, Germany). Subsequently, the samples were centrifuged (5810R, Eppendorf, Ltd., Hamburg, Germany) at 8 228 rcf for 5 min. The supernatant was diluted 100 times with water, then filtered through a nylon microfilter (0.45 µm) and analysed on LC-ESI-MS/MS. A liquid chromatograph (UltiMate 3000 RS, Thermo Fisher Scientific, Inc., USA) coupled with mass detector (A 3200 QTRAP quadrupole mass spectrometer, AB Sciex, Inc., Danaher, USA) was used to analyse L-Tyr. Chromatography was provided on the analytical column: ZORBAX SB-C18, 3.0 × 150 mm, 5 µm (Agilent Inc., Santa Clara, USA) with gradient elution of the mobile phase.

Determination of antioxidant activity (AA). DPPH (2,2-diphenyl-1-picrylhydrazyl) spectrophotometric method was used (Helios Gamma UV-Vis Spectrophotometer, Thermo Fisher Scientific, Inc., USA) at wavelength λ = 515 nm. The results are given in µg of ascorbic acid per g DM (dry matter) potato tubers.

Determination of relative water content (RWC). Leaf fresh weight samples were weighed (FW), then were submerged in distilled water for 3 h and weighed (TW), and finally was dried at 70 °C for 48 h and weighed again (DW). RWC was calculated according to Dhopte and Manuel (2002):

$$RWC = (FW - DW/TW - DW) \times 100$$

where: FW – fresh weight; DW – dry weight; TW – turgor weight of leaf samples.

Dry matter (DM) determination. Approximately 30 g of chopped potato tubers were dried at 105 °C to constant weight (48 h). The dry weight was determined from the difference in weight between fresh and dry samples.

Statistical analysis. All samples were analysed in three replicates. Data were processed by Chromeleon (Thermo Fisher Scientific, Inc., Waltham, USA), Analyst ® Software 1.7 (AB SCIEX, Ltd., Framingham, USA), Excel (Microsoft, Redmond, USA) and Statistica software (ver. 12; StatSoft, Inc., Tulsa, USA). The influence of cultivar, DS/WLS, and their interactions on the phenolic acids, AsA, DHAsA, L-Tyr, AA, RWC, the yield of tubers, tuber weight, and the number of tubers were evaluated by factorial ANOVA ($P < 0.05$) and Tukey post hoc *HSD* (honestly significant difference) test. The Pearson correlation coefficient at the significance level of $P < 0.05$ was used to evaluate the relationship between the tested parameters.

RESULTS AND DISCUSSION

Effect of DS and WLS on RWC. DS and WLS significantly affected RWC in all genotypes ($P < 0.05$) (Table 2). Valfi and Marabel cultivars showed higher RWC values under DS when compared with Milva and Laura cultivars. In the case of WLS, cvs. Milva and Valfi

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Table 2. Content of analysed acids (phenolic acids, L-tyrosine and total vitamin C), antioxidant activity, leaf RWC, average tuber yield and weight and number of tubers in four potato cultivars under drought and waterlogging stress compared with control

Measured parameter	Cv. Laura			Cv. Marabel			Cv. Milva			Cv. Valfi		
	C	DS	WLS	C	DS	WLS	C	DS	WLS	C	DS	WLS
TPA (µg/g DM)	1 690^{f}	1 550^{ef}	1 746^{fg}	286.7^{a}	1 105de	597.8^{abcd}	497.6^{ab}	343.3^{a}	501.2^{abc}	1 051^{cde}	2 280^{g}	1 049^{bcde}
5-CQA (µg/g DM)	50.4^{f}	31.5^{cde}	< LOD	5.0^{ab}	32.3^{de}	6.8^{ab}	14.6^{abc}	17.7^{bcd}	0.0^{a}	110.1^{g}	97.3^{g}	39.6^{ef}
3-CQA (µg/g DM)	1 398^{e}	1 371de	1 594^{ef}	213.9^{a}	912.6^{cde}	533.2^{abc}	419.4^{ab}	252.3^{a}	447.7^{abc}	793.5^{bc}	1 897^{f}	883.4^{bc}
4-CQA (µg/g DM)	161.3^{de}	84.8^{bc}	71.0^{abc}	16.5^{a}	95.5^{c}	25.4^{ab}	26.8^{ab}	30.1^{ab}	15.5^{a}	104.0^{cd}	168.5^{e}	79.8^{bc}
CA (µg/g DM)	78.1^{b}	56.6^{ab}	80.9^{b}	49.3^{a}	55.2^{ab}	29.5^{a}	34.2^{a}	31.5^{a}	29.8^{a}	42.9^{a}	109.2^{c}	46.0^{a}
SA (µg/g DM)	2.20	< LOD	< LOD	< LOD	7.27	< LOD	< LOD	6.12	9.24	< LOD	8.01	< LOD
FA (µg/g DM)	< LOD	< LOD	< LOD	2.88	2.24	< LOD	2.57	5.69	< LOD	< LOD	< LOD	< LOD
L-Tyr (µg/g DM)	1 293^{f}	1 000^{e}	1 843^{g}	603.3^{cd}	503.3^{b}	486.7^{b}	676.7^{d}	310.8^{a}	566.7^{bc}	980.0^{e}	920.0^{e}	1 380^{f}
Total vitamin C (µg/g DM)	1 295^{fg}	777.0^{ab}	1 092^{def}	899.0^{bcd}	1 004^{cde}	1 507^{g}	972.3^{bcde}	809.0^{abc}	1 127^{ef}	631.7^{a}	845.0^{abc}	967.0^{bcde}
AA (µg AsA/g DM)	313.0^{bcd}	384.4^{de}	339.7^{cd}	168.9^{ab}	229.8^{abcd}	94.9^{a}	204.8^{abc}	155.2^{ab}	165.4^{ab}	685.7^{f}	855.0^{g}	544.4^{ef}
RWC (%)	86.6^{d}	67.8^{a}	85.6^{d}	88.8^{e}	73.5^{b}	85.1^{d}	85.5^{d}	72.7^{b}	90.4^{f}	88.8^{e}	78.9^{c}	87.3^{e}
Av. yield of tubers (g)	1 341^{ef}	411^{bcd}	372^{bc}	1 176^{def}	294^{ab}	2 435^{g}	1 577^{f}	720^{d}	190^{a}	1 349^{ef}	339^{abc}	941de
Av. tuber weight (g)	22.4^{cd}	7.9^{a}	10.6^{ab}	19.9^{c}	7.5^{a}	32.9^{e}	19.0^{c}	12.6^{b}	8.3^{a}	24.1^{d}	10.9^{ab}	24.8^{d}
Number of tubers	60de	52^{d}	35^{bc}	59de	39^{bc}	74^{ef}	83^{f}	57^{d}	23^{a}	56^{d}	31^{b}	38^{bc}

C – control; DS – drought stress; WLS – waterlogging stress; TPA – total phenolic acids content; 5-CQA – neochlorogenic acid; 3-CQA – chlorogenic acid; 4-CQA – cryptochlorogenic acid; CA – caffeic acid; SA – sinapic acid; FA – ferulic acid; L-Tyr – L-tyrosine; AA – antioxidant activity; RWC – relative water content; LOD – limit of detection. Different letters in lines mean that the values are statistically significant at $P < 0.05$

had higher values of RWC compared to cvs. Laura and Marabel. Leaf RWC is one of the best growth/biochemical indices revealing the stress intensity. Plants that have higher yields under drought stress should have high RWC. Mentioned cultivars, which are classified as high and medium yielding genotypes in the condition of DS and WLS, should be of high RWC.

Effect of DS and WLS on yield, weight, and potato tubers number. The quality parameters of potato tubers were greatly influenced by stress conditions. DS and WLS significantly reduced yield, weight, and the number of tubers for all genotypes, with one exception of the cv. Marabel grew under WLS (Table 2).

Phenolic acid profile and quantity in potato cultivars affected by DS and WLS. The effect of DS and WLS on the content of phenolic acids in potato tubers of cvs. Laura, Milva, Marabel, Valfi was evaluated (Table 2). The highest total phenolic acid content was characteristic for cvs. Laura and Valfi; lower levels were found in cvs. Milva and Marabel. It has been shown that DS increased significantly phenolic acid content in cvs. Valfi and Marabel, while WLS was characterised by an insignificant increase in all cultivars as compared with control. Between individual phenolic acids, the most represented was 3-CQA. In lesser amounts were contained 4-CQA, 5-CQA, and CA. Sinapic (SA) and ferulic (FA) acids were contained only in minor concentrations or were under LOD. The evaluation of the relationship between phenolic acid content and the level of plant stress expressed as RWC showed a negative correlation between RWC and most phenolic acids, but these correlations were not statistically significant (Table 3). A significant correlation was found between tuber quality parameters and phenolic acid content. The average tuber yield, as well as their average number correlated negatively with total phenolic acids ($R = –0.366$; $R = –0.406$), 3-CQA ($R = –0.382$; $R = –0.417$), CA ($R = –0.379$; $R = –0.388$) and SA ($R = –0.593$; $R = –0.591$).

Hydroxy amino acid L-tyrosine decreased in all cultivars under DS. WLS caused an L-Tyr increase in cvs. Laura and Valfi, while a decrease in cvs. Milva and Marabel has been observed (Table 2). On average of all cultivars as compared with control (888.4 µg/g DM), WLS caused an increase (1 070 µg/g DM), whereas

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Table 3. Correlation analysis between tested variables

Variable	TPA	3-CQA	4-CQA	5-CQA	CA	SA	FA	L-Tyr	Vitamin C
Antioxidant activity	0.657*	0.612*	0.685*	0.852*	0.564*	0.036	–0.401	0.587*	–0.496*
Relative water content	–0.228	–0.238	–0.170	–0.042	–0.140	–0.243	–0.338	–0.387*	0.310
Average yield of tubers	–0.366*	–0.382*	–0.216	–0.034	–0.379*	–0.593*	–0.017	–0.203	0.428*
Average tuber weight	–0.265	–0.291	–0.091	0.106	–0.293	–0.601*	–0.175	–0.158	0.378*
Number of tubers	–0.406*	–0.417*	–0.266	–0.121	–0.388*	–0.591*	0.326	–0.066	0.161

*$P < 0.05$. TPA – total phenolic acids content; 3-CQA – chlorogenic acid; 4-CQA – cryptochlorogenic acid; 5-CQA – neochlorogenic acid; CA – caffeic acid; SA – sinapic acid; FA – ferulic acid; L-Tyr – L-tyrosine

DS a decrease of L-Tyr content (683.4 μg/g DM). Like other phenolic acids, L-Tyr showed a moderate inverse relationship between its content and RWC (R = –0.387; Table 3).

AsA and DHAsA contents in potato cultivars affected by DS and WLS. On average of all cultivars, the DS decreased total vitamin C (AsA + DHAsA) in comparison with control, and on the contrary, WLS increased it. DS decreased vitamin C content in cv. Laura, and conversely, WLS enhanced total vitamin C content in Valfi, Milva, and Marabel cultivars (Figure 1). DHAsA expressed as a percentage of total vitamin C ranged between 7.91% (cv. Marabel, WLS) and 16.06% (cv. Milva, WLS). When evaluating the relationship between vitamin C content, the RWC value, and the quality of potato tubers, a different trend was found to that of phenolic acids. The vitamin C content correlated positively with RWC (R = 0.310), but even in this case, the determined dependence was not statistically significant. A significant positive correlation was found between vitamin C and average tuber yield (R = 0.428) as well as between vitamin C and average tuber weight (R = 0.378).

Effect of DS and WLS on AA. Low AA was found in cvs. Marabel and Milva, which differed significantly from cvs. Laura and Valfi with higher AA levels (Table 2). On average of all cultivars, DS caused a significant increase of AA and, conversely, WLS a decrease as compared with the control. A high positive correlation was determined between the majority of individual and total phenolic acid and antioxidant activity (Table 3). Interestingly, a negative correlation was found between vitamin C and antioxidant activity (R = –0.496). These results show that phenolic acids are mainly responsible for the antioxidant activity of potato tubers under stress.

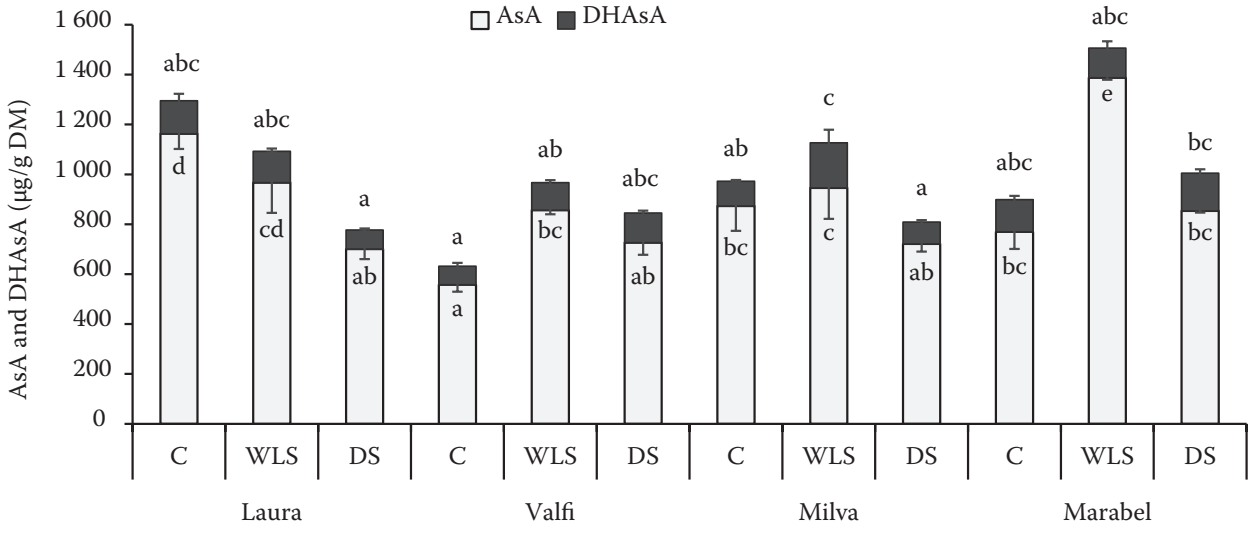

Figure 1. Effect of drought and waterlogging stress on L-ascorbic acid (AsA) and L-dehydroascorbic acid (DHAsA) content. Columns with different letters are significantly different ($P < 0.05$). Letters and error bars above columns are for DHAsA, letters and error bars in white columns are for AsA. DM – dry matter

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Drought stress is one of the major abiotic stresses, which induces the production of different kinds of ROS including both free radicals such as superoxide (O_2^-), hydroxyl radicals (OH^-), perhydroxyl radical (HO_2^-) and alkoxy radical (RO^-) and non-radical (molecular) forms, that is, singlet oxygen ($^1O_2$), and hydrogen peroxide (H_2O_2). Drought stress decreased RWC, the average yield of tubers, average tuber weight, or the number of tubers. On the other hand, the content of phenolic acids increased, and their effect increased the antioxidant activity. Vitamin C content decreased due to drought (cvs. Laura and Milva), and this trend was reflected in accordance with RWC, yield, and weight of tubers and their number. Seminario et al. (2017) observed a similar decrease in L-ascorbic acid biosynthesis due to water scarcity for soybean. In the process of L-ascorbic acid biosynthesis, mainly regulators of the pathway correlated with the decline in AsA are applied, such as VTC1 genes correlated with the decrease in AsA biosynthesis (conversion of D-mannose-1-P to GDP-D-mannose). Analysed cultivars exposed to DS or WLS have developed different strategies to avoid or tolerate stress effects. Production of phenolic acids (or polyphenols) in potato tubers is one of the strategies used of plant species of adverse environments to avoid the oxidative damage caused by DS or WLS. DS increased significantly phenolic acid content in cvs. Valfi and Marabel, while WLS caused an insignificant increase of these compounds related to AA. The most represented 3-CQA increased significantly in cvs. Valfi and Marabel, whereas an opposite trend was recorded in cvs. Milva and Laura. The different responses of potato cultivars could be related to their tolerance to DS or WLS. Also in yellow-fleshed potato and two purple breeding clones, differences in soluble phenol levels between the genotypes after exposure of DS were reported (Wegener et al. 2015). Maintaining a strong antioxidant system is essential for preventing drought-induced stress. In the present experiment, cvs. Marabel and Valfi were characterised by the highest hydroxycinnamic acid levels and by high AA under DS. DS can induce higher hydroxycinnamic phenolic accumulation and antioxidant activity due to the upregulation of the phenolic acid biosynthetic pathway, similarly, as was shown in the anthocyanin biosynthesis (González-Villagra et al. 2018). In our study, a high correlation (R = 0.657) between phenolic hydroxycinnamic acids and AA was found, likewise in the study of González-Villagra et al. (2018) between total phenols and antioxidant activity (R = 0.706). This increase confirms the role of non-enzymatic or enzymatic antioxidants in response to stress. Boaretto et al. (2014) confirmed that an efficient antioxidant system response under DS was associated with drought-tolerant resistant cultivars. Mild drought stress significantly increased phenolic acids and flavonoids in *Festuca* (Fariaszewska et al. 2017). Thus, the antioxidant effect of phenolic acids can relate to their dominant representation in potatoes. Ma et al. (2014) evaluated the accumulation of flavonoids related to phenolic acids in wheat, and they believe that the expression of genes in response to stress is genotype-dependent. DS enhanced catalase, ascorbate peroxidase, and peroxidase activities in wheat that responded differently to DS levels and injury (Song et al. 2017). DS in our study resulted in a decrease of L-Tyr in all examined cultivars. Significant increase of L-Tyr hydroxylase and L-DOPA decarboxylase activities measured in potato leaves cv. Desirée under DS (Świędrych et al. 2004) led to the next hydroxylation of L-Tyr to L-dihydroxy phenylalanine (L-DOPA) and subsequent decarboxylation to catecholamine biosynthesis. Hydroxylation of L-Tyr with one hydroxyl group to L-DOPA with two hydroxyl groups can lead to better antioxidant properties. Different responses of cultivars to WLS (cvs. Milva and Marabel decreased L-Tyr, cvs. Laura and Valfi increased L-Tyr) could be dependent on different enzyme activities in the shikimate and aromatic acid biosynthesis pathways based on genotype, where a number of alternative cross-regulated biosynthesis routes and transcription factors regulating the expression genes encoding enzymes are present.

DS reduced the total vitamin C level in cvs. Laura and Milva, while WLS increased it in cv. Marabel and cv. Valfi (Figure 1). Insignificant AsA decrease was recorded in three potato yellow- and purple-fleshed cultivars (Wegener et al. 2015). The drought stress was applied as detailed by Wegener and Jansen (2013) and specified for 2010/11 years. Analogously as in other antioxidants, biosynthesis of AsA can be affected by a mutation in the gene encoding the last enzyme of ascorbate biosynthesis. The non-enzymatic antioxidants AsA and glutathione and their oxidised forms DHAsA and glutathione disulphide and the enzymes continuously recycling them in the ascorbate-glutathione cycle may discriminate between drought- and waterlogging-sensitive and tolerant cultivars (Zagorchev et al. 2016).

In conclusion, obtained results revealed that both investigated stresses generally increased total and individual phenolic acid content and antioxidant activity. Drought stress decreased relative water

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content, tuber yield, weight, and the number of tubers and decreased AsA content. It seems that in response to abiotic stresses, the key role plays cultivars with individual-specific genetic features. Results given in this study suggest that the changes between potato response of phenolic acid content and antioxidant activity can be useful markers for resolution between drought- and waterlogging-tolerant and sensitive cultivars.

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