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ORIGINAL ARTICLE

Grouping of Some Potato Cultivars by Water Deficiency Tolerance Based on Their Agro-physiological Characteristics

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A 2-year field experiment was conducted to evaluate the response of potato plants to water deficit. Treatments included 10 potato cultivars were evaluated at the presence of different moisture conditions (30-40 and 60-70% depletion of available soil water). Water deficit increased the activities of peroxidase (POX), ascorbate peroxidase (APX), catalase (CAT), superoxide dismutase (SOD), ion leakage and proline content while decreased chlorophyll pigments, plant dry mass (PDM) and tuber yield (TY) in all cultivars. The extents percent of increases in SOD, POX and CAT activity were greater in tolerant cultivars. The biplot analysis results also showed SOD and POX closely correlated with biomass production of the tolerant cultivars. The highest tuber yields were obtained in Santé under control irrigation and in Spirit under water deficit. The reductions in TY ranged from 55.08 (Born) to 83.42% (Agria). Based on both STI index and biplot analysis Spirit and Agria were respectively identified as the most tolerant and sensitive cultivars to water deficit.

Key words: Water deficit, Chlorophyll pigments, Proline content, ion leakage, antioxidants

Abbreviations: ion leakage (IL), total antioxidant capacity (TAC), peroxidase (POX), catalase (CAT), ascorbate peroxidase (APX), superoxide dismutase (SOD), proline content (Pro), chlorophyll a (Chl a), chlorophyll b (Chl b), total chlorophyll (Chl tot), carotenoid (Car), ratio chl (a/b), ratio Chl tot/car, plant dry mass (PDM), tuber yield (TY) and stress tolerance index (STI).

Potato is considered the world's 4th major crop after rice, wheat and corn in terms of yield (Singh *and* Kaur, 2009). Drought, salinity, low and high temperature are the most important limiting factors among different environmental constraints which induce plant deficit and diminish crop productivity in many parts of the world (Lawlor, 2002). Drought ranks first in limiting crop productivity in the majority of world agricultural fields especially in arid and semi-arid areas (Tas *and* Tas, 2007; Abedi *and* Pakniyat, 2010). Drought due to water deficit impedes many physiological and biochemical aspects of plant growth (Rapacz *et al*., 2010) and also by the changes in chlorophyll contents and components (Nayyar *and* Gupta, 2006; Abedi *and* Pakniyat, 2010). Increasing accumulation of reactive oxygen species (ROS) in plants is a common phenomenon under water deficit (Shi *et al*., 2015; Giraud *et al*., 2008; Boguszewska *et al*., 2010; Finkel *and* Holbrook, 2000). To protect cells against ROS, (Halliwell, 1999) plants develop antioxidant defense system which consists of non-enzymatic antioxidant molecules (Boguszewska *et al*., 2010) and also antioxidant enzymes (Cervilla *et al*., 2007; Mates, 2000; Dewir, 2006). These molecules play important roles to modulate the equilibrium between the production and the elimination of free radicals (Lin *et al*., 2006; Placide *et al*., 2013). Potato is well known as a crop which is highly sensitive to soil drought (Jefferies *and* MacKerron, 1989). Water deficiency may intimidate potato production due to the crop's massive water requirement and its sensitivity to water shortage during the growing season. (Boguszewska *et al*., 2010). Studies have shown that the responses of potato to drought vary among cultivars and some drought-resistant potato cultivars may produce reasonable yields under conditions where grain crops fail, (Iwama *and* Yamaguchi, 2006). In areas where potato is grown under water-limited conditions, understanding plant's drought tolerance or adaptation in these areas is important (Shi *et al*., 2015). Selection for drought tolerance is complicated by the fact that the differences in yield reduction cannot be traced back to one or a few major morphological or physiological components while they are needed to develop an efficient screening technique. Moreover, the ability to maintain a high yield under drought is determined by many characteristics and the importance of each factor varies with time and severity of the deficit (Spitters *and* Schapendonk, 1990). However, little information is available in the literature in terms of the role of antioxidant enzymes in inducing drought tolerance in potato cultivars. On the subject of the strategic importance of the potato crop, climate changes, declining rainfall and the shortage of water resources in the word, this research, was conducted to study the correlation between the activities of antioxidant enzymes with the biochemical and physiological bases of ten cultivated cultivars of potato under drought and non-drought stress conditions.

MATERIALS AND METHODS

Plant material, growing conditions and experimental design

This 2-year field experiment was done in the spring of 2016-2017 and 2017-2018 from (March to June) in the research field of college of agriculture, Isfahan University of Technology located in Esfahan (51 ° 28′ E, 42 ° 33′ N and 1626.2 m above the mean sea level). In this investigation, tubers (50-60 gr) of 10 potato cultivars (Agria, Arinda, Marfona, Banba, Born, Santé, Milva, Satina, jelly and Spirit) were planted on rows with distances (25×75 cm). From the time of planting till carrying out the drought stress treatment (50% of flowering plants), all plants were irrigated normally. After that water deficit was applied for 4 weeks. To determine time of irrigation we used the Automatic system for

measuring and recording humidity and soil temperatures (IDRG SMS-T1).This experiment in a randomized complete block design (2×10) with three replicates (n =3), each block in each replicate contains 16 plants with two levels of irrigation (30-40% and 60-70% depletion of available soil water), treatment was conducted for a split at the flowering stage and cultivars at each level of irrigation and in each block were planted randomly. The available soil water and the volume of irrigation water were calculated based on Askari *and* Ehsanzadeh, (2015). The plants were harvested after four weeks of applying water deficit treatment. Before harvest, the upper fully developed leaves were collected and directly incubated in liquid nitrogen (-196°C) for analysis of antioxidant enzymes, proline content and other physiological traits.

Total antioxidant capacity

The total antioxidant capacity (TAC) was measured based on the modified method of Bettaieb *et al.*, (2011). In this method, the amount of 0.1 g leaf tissue was homogenized using a chilled mortar and pestle in extraction buffer containing 1 ml of alcohol (96%). The extract was centrifuged at 4000 rpm for 5 min at 4oC. The absorbance at 517 nm was done by using a spectrophotometer U-1800 (Hitachi, Japan).

Ion leakage

The percent of ion leakage was measured according to the method of Lutts *et al.*, (1996).

Enzyme extractions and assays

To determine the activity of superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX) and peroxidase enzymes (POX), the amount of 0.1 g of the upper fully developed leaves tissue were collected and homogenized using a chilled mortar and pestle and the mixture was prepared and added to it 1 ml of 100 mM potassium phosphate buffer (pH 7.8), containing 0.5% Triton X-100 and 1% polyvinylpyrrolidone. The extract was centrifuged at 12000 rpm for 30 min at 4°C. The supernatant was used to assay the following antioxidant enzymes.

POX (EC 1.11.1.7): the activity of this enzyme was determined according to the methods of Rao *et al.*, (1996), in 3 ml of 50 mM K-phosphate buffer (pH 7.8), containing 4.51 µl of H_2O_2 (30 %), 3.35 µl Guiacol, and 50 µl of enzyme extract.

APX (EC 1.11.1.11): the activity of this enzyme was determined according to the methods of Nakano *and* Asada, (1981), in 3 ml of 50 mM K-phosphate buffer (pH 7.8), containing 4.51 µl of H_2O_2 (30 %), 100 µl of 5mM ascorbate and 50 µl of enzyme extract.

CAT (EC 1.11.1.6): the activity of this enzyme was determined according to the method of Aebi, (1984), in 3 ml of 50 mM K-phosphate buffer (pH 7.8), containing 4.51 µl of H_2O_2 (30 %) and 50 µl of enzyme extract.

SOD (EC 1.15.1.1): The activity of this enzyme was determined according to the methods of Giannopolitis *and* Ries, (1977), in 1 ml of general phosphate buffer, 33 µl of nitroblue tetrazolium (NBT) and 33 µl of riboflavin (RBV). Protein content was evaluated for all antioxidant enzymes by using bovine serum albumin as the standard Bradford (1976).

Proline content

Proline content was measured by using a spectrophotometer U-1800 (Hitachi, Japan) at a wavelength of 520 nm according to the method described by Bates *et al.* (1973).

Chlorophyll and carotenoids contents

Chlorophyll and carotenoid contents were measured by the method of Lichtenthaler *et al.*, (1987) using the acetone extracts of leaves (0.1 g of leaves per 10 mL of 100% acetone cooled to 2–4°C). The contents of chlorophylls a, b, total chlorophyll and carotenoids were

determined spectrophotometrically at 661.6, 644.8 and 470 nm after extraction.

Plant dry mass

Before harvesting, from each experimental plot consisting of four rows of planting, two lateral rows were considered as margins, and from the two rows in the middle of the plot, with a margin at each end of each row, a total of 4 plants were harvested and the biomass was incubated in the oven for 72 hour at 80 °C then dry matter was weighted.

Yield measurement

At the end of the experiment, from each experimental plot consisting of four rows of planting, two lateral rows were considered as margins, and from the two rows in the middle of the plot, with a margin at each end of each row, a total of 12 plants were harvested and weighed, then the tuber yield was calculated on the basis of tons per hectare.

Stress tolerance index (STI)

This index used to identify cultivars that produce high yield under both drought and non-drought conditions and was calculated according to equation of Fernandez, (1992).

Data analysis

Data were tested and subjected to analysis of variance (ANOVA) by using SAS programs to determine the difference in both treatments and cultivars and based on a randomized complete block design. Comparison of means was performed by using LSD test ($p < 0.01$) and the correlation coefficients between the traits were done by using PROC CORR of SAS. In the other hand, Principle component analysis (PCA) was performed based on the correlation matrix to reduce the multiple dimensions of data space (Johanson *and* Wichern, 2007), and the biplot was drawn using Stat Graphics software.

RESULTS

Treatment (T) of irrigation regimes and cultivar (Cult) except (Chl *tot/car*) led to significant ($p < 0.01$) effects on ion leakage (IL), total antioxidant capacity (TCA), peroxidase activity (POX), ascorbate peroxidase activity (APX), catalase activity (CAT), superoxide dismutase activity (SOD), proline (Pro), chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), total chlorophyll (Chl *tot*), carotenoid (Car), ratio of chlorophyll *a*/*b* (Chl *a*/*b*), plant dry mass (PDM) and tuber yield (TY). Effect of Treatment × cultivar interaction was found significant only for IL, TCA, POX, APX, CAT, SOD, Chl *a*, Car, PDM and TY (Table 2). However, although to increases in mean IL, TCA, POX, APX, CAT, SOD, Pro, Chl *a*/*b*, water deficit led significant decreases in mean Chl *a*, Chl *b*, Chl *tot*, Car, PDM and TY (Table 3).

Plant dry mass and tuber yield

Analysis of variance for PDM and TY of potato cultivars showed significant ($p < 0.01$) interactions between cultivars and irrigation levels (Table 2). Under control irrigation (30-40% depletion of available soil water), the maximum and the minimum values for PDM were obtained in cultivars Agria (261.01 g/plant) and Born (139.93) and for tuber yield were achieved in Santé (21.18 t/ha) and Banba, Jelly (10.4) and Agria (10.93) (Table 4). However, under water stress treatment (60-70% depletion of available soil water), the highest and the lowest values for PDM were obtained in cultivars Agria and Jelly (139.00 g/plant) and Banba (81.40) and for tuber yield were achieved in Spirit and Born (8.29 and 7.97 t/ha, respectively) and Agria and Banba (1.81 and 2.40 t/ha, respectively). PDM and TY were significantly decreased in all cultivars under water deficit treatment. The maximum and the minimum reductions were observed for PDM in cultivars Banba (63.30%) and Spirit (23.70%) and for TY in Agria (83.42%) and Born

(55.08%). STI was calculated to assess drought tolerance of potato cultivars. Based on percentage reduction in tuber yield under 60-70% compared to 30-40% depletion of available soil water, the values of STI for cultivars were 0.744 (Spirit), 0.606 (Born), 0.556 (Santé), 0.534 (Arinda), 0.429 (Marfona), 0.306 (Milva), 0.292 (Satina), 0.161 (Jelly), 0.107 (Banba) and 0.085 (Agria). Higher values of STI corresponds to higher drought tolerance (Fernandez 1992).

Antioxidant enzymes

The interactions between cultivars and irrigation levels were significant ($p < 0.01$) on the activities of antioxidant enzymes POX, APX, CAT and SOD (Table 3). The maximum values for POX, APX, CAT and SOD were obtained under control irrigation in cultivars Jelly (1.06 unit min^{-1} mg^{-1} protein), Satina (0.580), Satina (9.62 unit min^{-1} mg^{-1} protein) and Agria (8.82 unit min^{-1} mg^{-1} protein) and under water stress treatment in Agria and Jelly (1.70 unit min^{-1} mg^{-1} protein), Milva (0.600), Marfona (11.62 unit min^{-1} mg^{-1} protein) and Spirit (15.60), respectively (Table 4). The minimum values for POX, APX, CAT and SOD were obtained under control irrigation in Satina (0.554 unit min^{-1} mg^{-1} protein), Spirit (0.320), Spirit (5.94 unit min^{-1} mg^{-1} protein) and Born (4.37 unit min^{-1} mg^{-1} protein), and under water stress treatment in Banba (0.862), Agria and Spirit (0.44), Agria (7.95) and Santé (9.60), respectively. The highest increase POX activity under water deficit was achieved in Born (166.21%), APX in Jelly (58.68%), CAT in Santé and Born (55.34 and 55.20%) and SOD in Born and Spirit (174.65 and 132.93%) respectively (Table 4). However, the activity of APX and CAT in Satina was decreased by 12.00 and 3.59%, respectively (Table 4).

Total antioxidant capacity

The interactions between cultivars and irrigation levels were significant ($p < 0.01$) on TAC of plants (Table 2). The maximum and the minimum values for TAC were obtained under control irrigation in cultivar Satina (62.17 µg ml^{-1}) and Agria (45.54), and under water stress treatment in Banba (72.60) and Born (65.50). The highest and the lowest increase (Table 4) of TAC under water deficit were obtained in Agria (44.67%) and Satina (8.43%).

Chlorophyll and carotenoid contents

The interactions between cultivars and irrigation levels were significant ($p < 0.01$) on the contents of Chl *a* and Car (Table 2). The maximum values for Chl *a* were obtained under control irrigation in cultivars Banba, Agria and Santé (0.45 mg g^{-1}FW) and Car in cultivars in Agria (0.206 mg g^{-1}FW), and Chl *a* and Car under water stress treatment in Agria (0.343) and (0.152), respectively (Table 4). The minimum values for Chl *a* were obtained under control irrigation in Marfona and Spirit (0.397 and 0.398) and Car in Milva and Satina (0.154 and 0.155), and minimum values for Chl *a* and Car under water stress treatment in Satina (0.277) and (0.100), respectively. The highest decrease of Chl *a* and Car under water deficit were achieved in Satina (34.55%) and Santé (45.46%), respectively (Table 4). However, the interaction effects of cultivars and irrigation levels were not statistically significant for Chl *b*, Chl *tot*, Chl *a*/*b* and Chl *tot/car* in this trait. Regardless of irrigation level, the maximum values (Table 3) of Chl *b* were observed in cultivars Agria (0.381 mg g^{-1}FW), Chl *tot* in Agria (0.779 mg g^{-1}FW), Chl *a*/*b* in Milva (1.89) and Chl *tot/car* in Satina (6.01).

Proline contents

The interactions between cultivars and irrigation levels were not significant ($p < 0.01$) on Pro content in leaves (Table 2). Water deficit (Table 3) was increased

Pro content by about (111.6%). Regardless of irrigation level, the maximum and the minimum values of Pro were observed in cultivars Arinda (6.49 µmol g^{-1} leaf) and in Marfona and Jelly (3.8).

Ion leakage

The interactions between cultivars and irrigation levels were significant ($p < 0.01$) on IL from plant cells (Table 2).The maximum and the minimum amounts (Table 4) of IL under control level of irrigation were obtained in cultivars Agria (53.97%) and Santé (37.98%) and under water stress treatment in Marfona (74.02%) and Spirit and Milva (53.93 and 53.76%, respectively). Ion leakage from plant cells was increased in all cultivars under water stress treatment. However, the maximum and the minimum increases (Table 4) were observed in cultivars Marfona (94.39%) and Agria (8.55%).

Relationship between the traits

Correlation coefficients between different traits were calculated and are presented in Table (5). Under control conditions (30-40% depletion of available soil water), IL was highly and positively correlated with SOD enzyme. Also, TAC was negatively correlated with Chl *b* and Chl *a*/*b.* Chl *tot/car* was highly and positively correlated with APX and CAT enzymes. Car was negatively correlated with Chl *a*/*b* and Chl *tot/car.* Meanwhile, the positive correlation among chlorophyll pigments was observed. At the same time, under drought conditions (60-70% depletion of available soil water), POX was positively correlated with SOD, Car and PDM. Also, IL was negatively correlated with PDM. Meanwhile, a positive correlation was achieved between TY and STI.

Biplot analysis

Principle component analysis (PCA) revealed that the first and second components explained more than 60.8 and 61.4 % of the variation in 30-40 and 60-70% depletion of available soil water, respectively (Table 6). Under 30-40% depletion of available soil water, PC1 had higher correlation with Chl *a*, Chl *b*, Chl *tot* and Car. As higher values of these characteristics may show higher photosynthetic capacity, PC1 was named "photosynthetic capacity" under control conditions. Also PC1 had higher correlation with the activity of POX enzyme. PC2 had higher correlation with IL, TAC, POX APX, CAT, SOD and PDM. Therefore, higher values of these traits indicated higher PDM of the varieties. As a result, PC2 could be called "antioxidative potential and plant dry mass production". To classify the cultivars based on PCA, the biplot of PC1 and PC2 was constructed (Fig. 1a). As a result, cultivars Agria, Banba, Santé and Satina were found to have high photosynthetic capacity and PDM but Spirit, Santé, Born, Arinda and Marfona were found to have high Pro and yield production. In other hand, cultivars Agria had high potential of SOD and CAT activities. Also, Satina had high potential of APX and CAT activities under 30-40% depletion of available soil water. Under 60-70% depletion of available soil water, PC1 had negative correlations with Chl *a*, Chl *b*, Chl *tot*, Car, PDM and positive correlations with APX and CAT activities. Therefore, selection based on high PC1 values can lead to sensitive cultivars with low photosynthetic capacity. On the other hand, PC2 was positively correlated with POX, SOD, Pro, TY and STI. Therefore, cultivars with high PC2 are suitable for drought stress conditions. According to the biplot analysis of PC1 and PC2 (Fig. 1b), cultivars Agira had high PC1 but low PC1 and Banba had low PC1 and PC2. In the contrary, cultivars Spirit, Arinda, Marfona, Santé and Born had high PC2 and were hence identified as preferable cultivars for 60-70% depletion of available soil water.

Table 1. Physical and chemical properties of the experimental soil.

pH	EC (dSm^{-1})	Organic carbon %	Available K ($mg\ kg^{-1}$)	Available P ($mg\ kg^{-1}$)	Total N ($mg\ kg^{-1}$)	Tissue of soil	Organic content %
7.6	3.56	0.73	457.9	44.9	375	clay laom	1.25

Table 2 Analysis of variance for different traits of ten potato cultivars (Cult) evaluated at two levels of irrigation regime treatments (T) and in 3 replicates (R) in 2 years (Y).

Source of variation	*df*	Mean square														
		IL	TAC	POX	APX	CAT	SOD	Pro	Chl *a*	Chl *b*	Chl *tot*	Car	Chl (*a*/*b*)	Chl *tot*/*car*	PDM	TY
Y	1	12750.2**	22.36^{ns}	0.617**	3.60**	1011.8**	2466.9**	342.73**	0.064**	0.724**	0.393**	0.303**	12.13**	680.6**	0.00001^{ns}	87.84**
Y (R)	4	10.61	28.68	0.005	0.002	0.95	0.465	0.676	0.0003	0.0003	0.001	0.0001	0.0308	1.55	44.66	1.19
T	1	10713.7**	4748.9**	11.69**	0.427**	158.52**	926.85**	339.89**	0.449**	0.456**	2.10**	0.115**	1.30**	0.223^{ns}	251403.6**	2947.5**
Y × T	1	133.6^{ns}	51.95^{ns}	0.358**	0.012^{ns}	45.93**	190.0**	7.45*	0.071**	0.049**	0.023^{ns}	0.020**	2.11**	0.956^{ns}	0.00001^{ns}	346.8**
Y × T (R)	4	83.88	16.43	0.008	0.004	0.94	1.21	0.669	0.001	0.002	0.004	0.0001	0.029	0.168	7.36	0.861
Cult	9	147.5**	124.69**	0.419**	0.029**	9.45**	23.41**	7.53**	0.004**	0.029**	0.062**	0.003**	0.323**	0.897^{ns}	8201.9**	115.4**
Y × cult	9	96.37**	14.13^{ns}	0.091**	0.012**	4.49**	15.68**	3.92**	0.003**	0.01**	0.004^{ns}	0.0003**	0.142**	1.61**	0.00001^{ns}	26.84**
T × cult	9	240.97**	44.01**	0.187**	0.018**	6.08**	9.26**	0.430^{ns}	0.002**	0.001^{ns}	0.005^{ns}	0.0005**	0.053^{ns}	0.885^{ns}	4912.9**	20.55**
Y × T × cult	9	94.56**	20.31^{ns}	0.145**	0.016**	7.89**	4.87**	1.79**	0.002**	0.002^{ns}	0.008**	0.001**	0.069^{ns}	0.902^{ns}	0.00001^{ns}	23.74**
Error	72	28.86	13.07	0.012	0.0023	1.26	1.47	0.312	0.0003	0.002	0.003	0.0001	0.041	0.471	53.20	0.905

** Significant at $P < 0.01$, ^{ns} non-significant, respectively. Freedom degree (*df*), ion leakage (IL), total antioxidant capacity (TAC), peroxidase (POX), catalase (CAT), ascorbate peroxidase (APX), superoxide dismutase (SOD), proline content (Pro), chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), total chlorophyll (Chl *tot*), carotenoid (Car), ratio chl (*a*/*b*), ratio Chl *tot*/*car*, plant dry mass (PDM) and tuber yield (TY).

Table 3 Mean comparison for different traits of ten potato cultivars evaluated at two levels of irrigation regime in 2 years.

Traits	IL %	TAC (µg ml^{-1})	POX (unit min^{-1} mg^{-1} protein)	APX (unit min^{-1} mg^{-1} protein)	CAT (unit min^{-1} mg^{-1} protein)	SOD (unit min^{-1} mg^{-1} protein)	Pro (µmol g^{-1} leaf)	
Irrigation regime								
Control	42.52 ^{b}	55.03 ^{b}	0.694 ^{b}	0.393 ^{b}	7.53 ^{b}	6.29 ^{b}	3.02 ^{b}	
drought	61.41 ^{a}	67.61 ^{a}	1.32 ^{a}	0.512 ^{a}	9.83 ^{a}	11.85 ^{a}	6.39 ^{a}	
LSD$_{(0.05)}$	4.64	2.05	0.047	0.034	0.491	0.557	0.415	
cult								
Agria	56.27 ^{a}	55.70 ^{e}	1.26 ^{b}	0.402 ^{fg}	7.63 ^{c}	11.15 ^{a}	5.31 ^{b}	
Arinda	55.92 ^{a}	59.26 ^{cd}	0.856 ^{ef}	0.477 ^{bc}	9.17 ^{ab}	7.65 ^{e}	6.49 ^{a}	
Marfona	56.05 ^{a}	61.61 ^{bc}	0.945 ^{de}	0.411 ^{efg}	9.89 ^{a}	8.73 ^{cd}	3.78 ^{e}	
Banba	54.05 ^{ab}	65.73 ^{a}	0.775 ^{f}	0.466 ^{bcd}	9.36 ^{ab}	8.34 ^{de}	4.27 ^{d}	
Born	50.16 ^{bcd}	58.61 ^{de}	1.05 ^{c}	0.453 ^{cd}	7.67 ^{c}	8.19 ^{de}	4.57 ^{cd}	
Santé	49.98 ^{bcd}	63.69 ^{ab}	0.906 ^{de}	0.435 ^{def}	8.68 ^{b}	7.39 ^{e}	4.69 ^{cd}	
Milva	48.20 ^{d}	60.68 ^{cd}	0.880 ^{de}	0.503 ^{b}	8.70 ^{b}	8.17 ^{de}	4.53 ^{cd}	
Satina	53.01 ^{abc}	64.79 ^{a}	0.956 ^{d}	0.545 ^{a}	9.45 ^{ab}	9.69 ^{bc}	4.70 ^{cd}	
Jelly	48.79 ^{cd}	64.09 ^{ab}	1.37 ^{a}	0.447 ^{cde}	9.02 ^{ab}	10.28 ^{ab}	3.75 ^{e}	
Spirit	47.18 ^{d}	59.06 ^{cd}	1.06 ^{c}	0.382 ^{g}	7.23 ^{c}	11.15 ^{a}	4.98 ^{bc}	
LSD$_{(0.05)}$	4.37	2.94	0.089	0.039	0.913	0.987	0.45	
Traits Irrigation regime	Chl *a* (mg g^{-1} leaf)	Chl *b* (mg g^{-1} leaf)	Chl *tot* (mg g^{-1} leaf)	Car (mg g^{-1} leaf)	chl (*a*/*b*)	Chl *tot*/*car*	PDM (g/plant)	TY (t ha^{-1})
Control	0.427 ^{a}	0.316 ^{a}	0.743 ^{a}	0.175 ^{a}	1.53 ^{b}	5.44 ^{a}	201.02 ^{a}	15.28 ^{a}
drought	0.305 ^{b}	0.192 ^{b}	0.497 ^{b}	0.113 ^{b}	1.74 ^{a}	5.53 ^{a}	109.48 ^{b}	5.37 ^{b}
LSD$_{(0.05)}$	0.012	0.023	0.033	0.005	0.087	0.21	1.37	0.470
Agria	0.398 ^{a}	0.381 ^{a}	0.779 ^{a}	0.179 ^{a}	1.25 ^{d}	5.14	199.75 ^{a}	6.37 ^{f}
Arinda	0.355 ^{de}	0.244 ^{c}	0.599 ^{cde}	0.132 ^{e}	1.63 ^{bc}	5.89	120.14 ^{f}	12.74 ^{c}
Marfona	0.345 ^{e}	0.227 ^{cd}	0.572 ^{de}	0.136 ^{de}	1.66 ^{bc}	5.31	149.4 ^{de}	10.98 ^{d}
Banba	0.385 ^{ab}	0.255 ^{bc}	0.640 ^{bc}	0.143 ^{cd}	1.72 ^{b}	5.55	151.49 ^{d}	6.39 ^{f}
Born	0.385 ^{ab}	0.282 ^{b}	0.667 ^{b}	0.156 ^{b}	1.55 ^{c}	5.52	115.64 ^{f}	12.86 ^{c}
Santé	0.376 ^{bc}	0.252 ^{bc}	0.628 ^{bc}	0.149 ^{bc}	1.65 ^{bc}	5.25	180.34 ^{b}	13.65 ^{b}
Milva	0.361 ^{cd}	0.202 ^{d}	0.563 ^{e}	0.132 ^{e}	1.89 ^{a}	5.46	145.39 ^{e}	9.24 ^{e}
Satina	0.349 ^{de}	0.225 ^{cd}	0.574 ^{de}	0.127 ^{e}	1.68 ^{bc}	6.01	172.35 ^{c}	9.38 ^{e}
Jelly	0.358 ^{de}	0.247 ^{bc}	0.605 ^{cd}	0.143 ^{cd}	1.57 ^{bc}	5.33	170.67 ^{c}	7.00 ^{f}
Spirit	0.345 ^{de}	0.224 ^{cd}	0.569 ^{de}	0.143 ^{cd}	1.72 ^{ab}	5.43	147.30 ^{de}	14.63 ^{a}
LSD$_{(0.05)}$	0.015	0.036	0.046	0.009	0.164	0.558	5.94	0.774

Mean followed by the same letter in each column are not significant different according LSD test (probability level of 5 %). ion leakage (IL), total antioxidant capacity (TAC), peroxidase (POX), catalase (CAT), ascorbate peroxidase (APX), superoxide dismutase (SOD), proline content (Pro), chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), total chlorophyll (Chl *tot*), carotenoid (Car), ratio chl (*a*/*b*), ratio Chl *tot*/*car*, plant dry mass (PDM) and tuber yield (TY).

Table 4 Mean comparisons of interaction effects of irrigation regime treatment × cultivar on different traits of potato.

Traits	IL %		TAC (µg ml^{-1})		POX (unit min^{-1} mg^{-1} protein)		APX (unit min^{-1} mg^{-1} protein)		CAT (unit min^{-1} mg^{-1} protein)	
Cultivar	control	drought	control	drought	control	drought	control	drought	control	drought
Agria	53.97^{f}	58.59^{def}	45.54^{i}	65.87^{cd}	0.825^{f}	1.70^{a}	0.358^{g-j}	0.445^{ef}	7.31^{ghi}	7.95^{f-i}
Arinda	45.16^{g}	66.68^{bc}	52.86^{gh}	65.66^{cd}	0.646^{gh}	1.07^{e}	0.432^{bcd}	0.523^{cd}	8.82^{def}	9.53^{bcd}
Marfona	38.08^{h}	74.02^{a}	56.48^{fg}	66.74^{bc}	0.679^{gh}	1.21^{d}	0.322^{ij}	0.501^{cd}	8.16^{e-h}	11.62^{a}
Banba	40.38^{gh}	67.73^{b}	58.86^{ef}	72.60^{a}	0.688^{g}	0.862^{f}	0.399^{fgh}	0.534^{bcd}	7.93^{f-i}	10.79^{ab}
Born	39.98^{gh}	60.35^{de}	51.72^{h}	65.50^{cd}	0.572^{gh}	1.52^{b}	0.376^{ghi}	0.530^{bcd}	6.01^{j}	9.33^{cde}
Santé	37.98^{h}	61.99^{bcd}	57.02^{fg}	70.37^{ab}	0.665^{gh}	1.15^{de}	0.387^{gh}	0.484^{de}	6.80^{ij}	10.56^{abc}
Milva	42.65^{gh}	53.76^{f}	54.30^{gh}	67.07^{bc}	0.634^{gh}	1.13^{de}	0.406^{fg}	0.600^{a}	7.11^{hij}	10.29^{bc}
Satina	44.51^{g}	61.51^{cde}	62.17^{de}	67.41^{bc}	0.554^{h}	1.36^{c}	0.580^{ab}	0.511^{cd}	9.62^{bcd}	9.28^{cde}
Jelly	42.02^{gh}	55.58^{ef}	59.20^{ef}	69.00^{abc}	1.06^{gh}	1.69^{a}	0.346^{hij}	0.549^{abc}	7.62^{f-i}	10.42^{abc}
Spirit	40.43^{gh}	53.93^{f}	52.20^{h}	65.94^{cd}	0.618^{gh}	1.50^{b}	0.320^{j}	0.444^{ef}	5.94^{j}	8.53^{d-g}
LSD$_{(0.05)}$	6.18		4.16		0.126		0.055		1.29	
Traits	SOD (unit min^{-1} mg^{-1} protein)		Chl *a* (mg g^{-1} leaf)		Car (mg g^{-1} leaf)		PDM (g)		TY (t ha^{-1})	
Cultivar	control	drought	control	drought	control	drought	control	drought	control	drought
Agria	8.82^{fg}	13.48^{b}	0.454^{a}	0.343^{f}	0.206^{a}	0.152^{g}	261.01^{a}	138.50^{g}	10.93^{f}	1.81^{l}
Arinda	5.39^{ijk}	9.90^{ef}	0.424^{cd}	0.287^{hi}	0.163^{efg}	0.102^{j}	156.58^{f}	83.69^{lm}	18.88^{b}	6.60^{h}
Marfona	6.00^{ij}	11.46^{cd}	0.397^{e}	0.293^{hi}	0.165^{ef}	0.107^{ij}	206.26^{c}	92.56^{k}	15.52^{d}	6.46^{hi}
Banba	6.55^{hij}	10.13^{def}	0.455^{a}	0.316^{g}	0.181^{cd}	0.105^{i}	221.64^{b}	81.36^{m}	10.39^{f}	2.40^{l}
Born	4.37^{k}	12.01^{c}	0.433^{bc}	0.336^{f}	0.185^{bc}	0.128^{h}	139.93^{g}	91.35^{kl}	17.75^{c}	7.97^{g}
Santé	5.18^{jk}	9.60^{ef}	0.452^{ab}	0.301^{gh}	0.193^{b}	0.105^{ij}	258.78^{a}	101.91^{j}	21.18^{a}	6.13^{hi}
Milva	5.55^{ijk}	10.80^{cde}	0.406^{de}	0.316^{g}	0.154^{fg}	0.111^{ij}	175.94^{d}	114.84^{i}	12.99^{e}	5.50^{ij}
Satina	7.70^{gh}	11.68^{c}	0.423^{cd}	0.277^{i}	0.155^{fg}	0.100^{j}	220.68^{b}	124.03^{h}	13.83^{e}	4.94^{j}
Jelly	6.70^{hi}	13.87^{b}	0.430^{c}	0.287^{hi}	0.172^{de}	0.115^{i}	202.33^{c}	139.01^{g}	10.38^{f}	3.62^{k}
Spirit	6.70^{hi}	15.60^{a}	0.398^{e}	0.294^{hi}	0.178^{cd}	0.109^{ij}	167.07^{e}	127.53^{h}	20.98^{a}	8.29^{g}
LSD$_{(0.05)}$	1.39		0.02		0.012		8.40		1.10	

Mean followed by the same letter in each column are not significant different according LSD test (probability level of 5 %). ion leakage (IL), total antioxidant capacity (TAC), peroxidase (POX), catalase (CAT), ascorbate peroxidase (APX), superoxide dismutase (SOD), chlorophyll *a* (Chl *a*), carotenoid (Car), plant dry mass (PDM) and tuber yield (TY).

Table 5 Correlation coefficients of different traits evaluated at two levels of irrigation regime in control (below diagonal) and water deficit (above diagonal).

Characters	IL	TAC	POX	APX	CAT	SOD	Pro	Chl *a*	Chl *b*	Chl *tot*	car	Chl (*a*/*b*)	Chl *tot*/*car*	PDM	TY	STI
IL	**1**	0.19 ns	-0.54 ns	-0.06 ns	0.55 ns	-0.56 ns	-0.02 ns	-0.17 ns	-0.09 ns	-0.15 ns	-0.31 ns	0.01 ns	-0.23 ns	-0.72 **	-0.03 ns	-0.04 ns
TAC	**-0.56** ns	**1**	-0.49 ns	0.22 ns	0.55 ns	-0.41 ns	-0.33 ns	-0.11 ns	-0.19 ns	-0.18 ns	-0.37 ns	0.16 ns	-0.04 ns	-0.22 ns	-0.49 ns	-0.42 ns
POX	**0.25** ns	**-0.01** ns	**1**	-0.37 ns	-0.58 ns	0.81 **	-0.11 ns	0.18 ns	0.51 ns	0.47 ns	0.66 *	-0.61 ns	-0.03 ns	0.78 **	-0.03 ns	-0.04 ns
APX	**0.20** ns	**0.48** ns	**-0.42** ns	**1**	0.52 ns	-0.45 ns	-0.35 ns	-0.07 ns	-0.44 ns	-0.36 ns	-0.32 ns	0.49 ns	-0.43 ns	-0.26 ns	-0.05 ns	-0.26 ns
CAT	**0.24** ns	**0.51** ns	**-0.01** ns	**0.69** *	**1**	-0.54 ns	-0.61 ns	-0.32 ns	-0.54 ns	-0.53 ns	-0.56 ns	0.50 ns	-0.53 ns	-0.51 ns	0.01 ns	-0.10 ns
SOD	**0.71** *	**-0.11** ns	**0.35** ns	**0.16** ns	**0.34** ns	**1**	-0.11 ns	0.03 ns	0.23 ns	0.22 ns	0.42 ns	-0.29 ns	0.31 ns	0.74 **	0.07 ns	0.08 ns
Pro	**0.44** ns	**-0.58** ns	**0.35** ns	**0.16** ns	**0.02** ns	**-0.15** ns	**1**	-0.06 ns	0.22 ns	0.14 ns	0.02 ns	-0.22 ns	0.45 ns	-0.07 ns	0.04 ns	0.19 ns
Chl *a*	**0.32** ns	**-0.08** ns	**0.26** ns	**0.13** ns	**0.01** ns	**0.18** ns	**0.05** ns	**1**	0.70 *	0.83**	0.81**	-0.40 ns	-0.22 ns	-0.03 ns	-0.26 ns	-0.21 ns
Chl *b*	**0.61** ns	**-0.64** *	**0.26** ns	**-0.22** ns	**-0.22** ns	**0.38** ns	**0.24** ns	**0.69** *	**1**	0.97**	0.92**	-0.92**	-0.19ns	0.33 ns	-0.56 ns	-0.45 ns
Chl *tot*	**0.54** ns	**-0.50** ns	**0.30** ns	**-0.14** ns	**-0.18** ns	**0.31** ns	**0.19** ns	**0.84** **	**0.97****	**1**	0.95**	-0.82**	-0.19 ns	0.28 ns	-0.51 ns	-0.42 ns
car	**0.28** ns	**-0.56** ns	**0.26** ns	**-0.46** ns	**-0.53** ns	**0.21** ns	**0.07** ns	**0.68** *	**0.88****	**0.88****	**1**	-0.77 **	-0.24 ns	0.42 ns	-0.36 ns	-0.31 ns
chl (*a*/*b*)	**-0.45** ns	**0.71** *	**-0.26** ns	**0.40** ns	**0.32** ns	**-0.18** ns	**-0.29** ns	**-0.39** ns	**-0.89****	**-0.81****	**-0.78****	**1**	0.15 ns	-0.41 ns	0.58 ns	0.48 ns
Chl *tot*/*car*	**-0.03** ns	**0.45** ns	**-0.31** ns	**0.72** **	**0.72** **	**-0.26** ns	**0.27** ns	**-0.15** ns	**-0.41** ns	**-0.36** ns	**-0.72****	**0.40**ns	**1**	0.11 ns	0.21 ns	0.31 ns
PDM	**0.29** ns	**0.11** ns	**0.32** ns	**0.08** ns	**0.22** ns	**0.58** ns	**-0.31** ns	**0.57** ns	**0.39** ns	**0.49** ns	**0.47** ns	**-0.18** ns	**-0.40** ns	**1**	-0.29 ns	-0.28 ns
TY	**-0.43** ns	**-0.15** ns	**-0.54** ns	**-0.11** ns	**-0.36** ns	**-0.54** ns	**0.45** ns	**-0.28** ns	**-0.16** ns	**-0.19** ns	**0.05** ns	**-0.10** ns	**-0.05** ns	**-0.32** ns	**1**	0.96 **
STI	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1**

Ion leakage (IL), total antioxidant capacity (TAC), peroxidase (POX), catalase (CAT), ascorbate peroxidase (APX), superoxide dismutase (SOD), proline content (Pro), chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), total chlorophyll (Chl *tot*), carotenoid (Car), ratio chl (*a*/*b*), ratio Chl *tot*/*car*, plant dry mass (PDM), tuber yield (TY) and stress tolerance index (STI). ns non-significant, * significant at 5 % level of probability and ** significant at 1 % level of probability, respectively.

Table 6 Principle component loading for the traits measured on ten potato cultivars evaluated at two levels of irrigation regime.

Characters	30-40% depletion of available soil water		60-70% depletion of available soil water	
	PC1	PC2	PC1	PC2
IL %	0.239	0.255	0.167	-0.228
TAC (µg ml^{-1})	-0.278	0.250	0.146	-0.309
POX (unit min^{-1} mg^{-1} protein)	0.170	0.166	-0.307	0.180
APX (unit min^{-1} mg^{-1} protein)	-0.165	0.347	0.192	-0.206
CAT (unit min^{-1} mg^{-1} protein)	-0.147	0.445	0.297	-0.277
SOD (unit min^{-1} mg^{-1} protein)	0.176	0.366	-0.231	0.291
Pro (µmol g^{-1} leaf)	0.063	-0.145	-0.073	0.177
Chl *a* (mg g^{-1} leaf)	0.269	0.194	-0.239	-0.192
Chl *b* (mg g^{-1} leaf)	0.391	0.0329	-0.360	-0.176
Chl *tot* (mg g^{-1} leaf)	0.381	0.076	-0.353	-0.183
Car (mg g^{-1} leaf)	0.384	-0.110	-0.370	-0.101
chl (*a*/*b*)	-0.349	0.123	0.340	0.140
chl *tot*/*car*	-0.259	0.203	0.002	0.342
PDM (g)	0.202	0.305	-0.253	0.150
TY (t ha^{-1})	-0.073	-0.406	0.167	0.387
STI	-	-	0.133	0.405
Eigenvalue	5.91	3.22	6.33	3.50
Percent of variation	39.38	21.46	39.59	21.85
Cumulative percentage	39.38	60.83	39.59	61.44

DISCUSSION

In arid and semi-arid regions, drought stress is the most important limiting factor for growth and production of different crops in many parts of the world including Iran (Hojati *et al*., 2011). The type of observed reactions of plants in response to drought stress depends on severity and duration of the stress, genotype, plant growth stage and the other factors causing the stress (Sairam *and* Saxena, 2000; Mensah *et al*., 2006). By way of potato is a drought sensitive plant compared to the other field crops (Monneveux *et al*., 2014). In the present study, under control irrigation regime, among ten evaluated cultivars, the maximum TY was obtained for Santé (21.18 t/ha) followed by Spirit (20.98), Arinda (18.88), Born (17.75) and Marfona (15.52) (Table 4). These cultivars may, therefore, be appropriate for cultivation in areas where water is not limited for crop production. Potato tuber yield was significantly reduced at 60-70% depletion of available soil water as compared to the control. Water deficit reduce crop production in different ways including reduction in light absorption by decreasing leaf area, reducing stomata conductivity and carbon dioxide absorption and lowering the efficiency of light absorption which directly affects photosynthetic production (Hur, 1991).

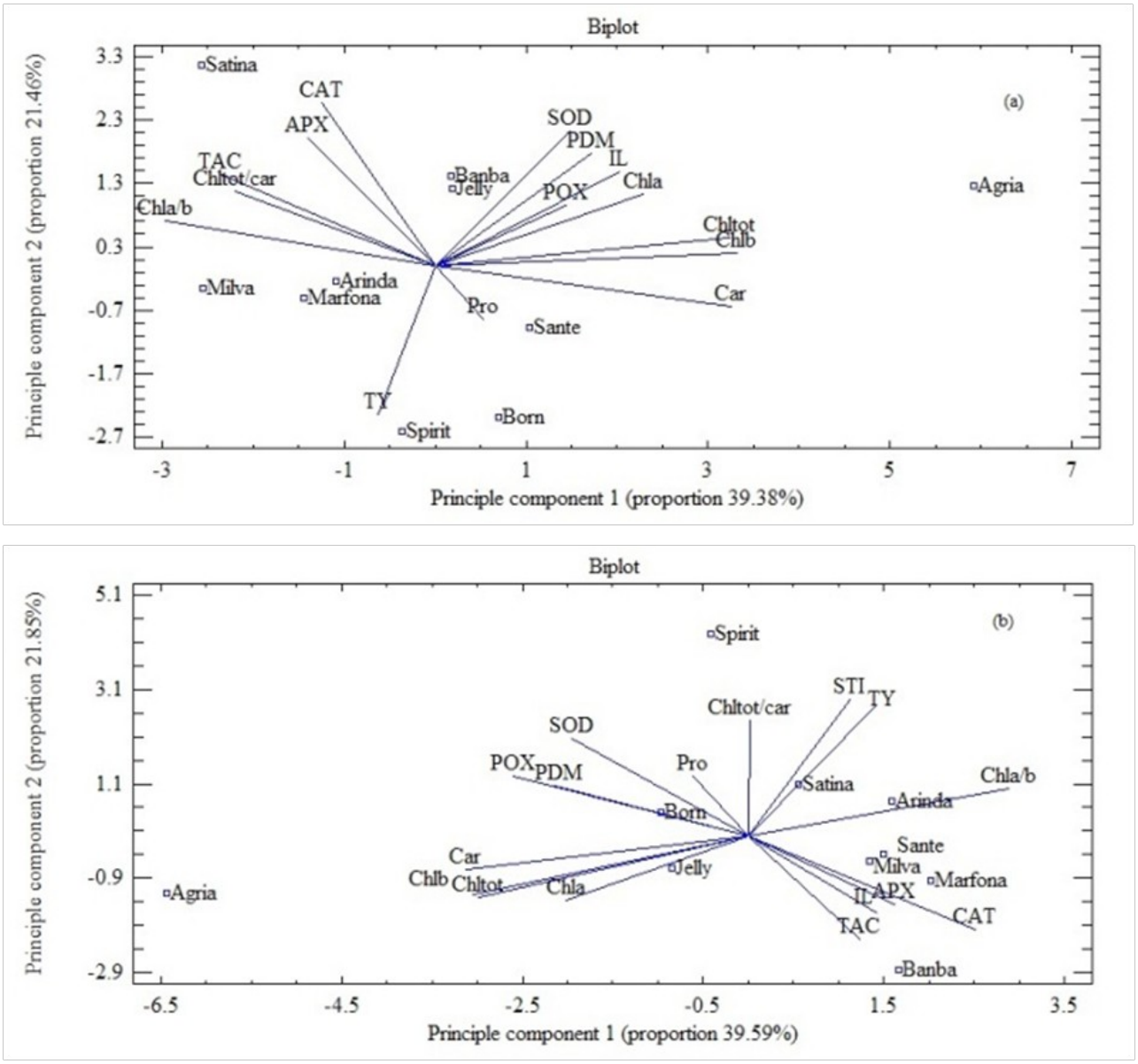

Figure 1. The biplot display of the traits measured on ten potato cultivars evaluated at two levels of irrigation regime, control (a) and water deficit (b) in 2 years. ion leakage (IL), total antioxidant capacity (TAC), peroxidase (POX), catalase (CAT), ascorbate peroxidase (APX), superoxide dismutase (SOD), proline content (Pro), chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), total chlorophyll (Chl *tot*), carotenoid (Car), ratio chl (*a*/*b*), ratio Chl *tot*/*car*, plant dry mass (PDM), tuber yield (TY) and stress tolerance index (STI).

There were significant variation among potato cultivars in response to water deficit, so that under water deficit treatment, the reductions (Table 4) in TY ranged from 55.08 (Born) to 83.42% (Agria) and also the decreases in PDM ranged from 23.67 (Spirit) to 63.29% (Banba). In line with our results, in the studies of Boguszewska *et al*., (2010) and Hijmans, (2003), TY and PDM of potato cultivars were decreased under water deficit conditions. Based on calculated stress tolerance index (values recorded in result section under tuber yield), the most susceptible cultivars to drought stress were Agria, followed by Banba, Jelly, Satina, Milva, Marfona, Arinda, Santé, Born and Spirit. For that reason, Spirit, Born, Santé and Agria, Banba, Jelly were the

most tolerant and sensitive cultivars in terms of tuber production, respectively. However, Hassanpanah, (2010), reported that the tolerant cultivars had higher and marketable tuber yield compared to sensitive cultivars. Water deficit, like other abiotic stresses, causes oxidative stress which can lead to the production of ROS in plant tissues (Mittler *et al*., 2004). Positive correlations have been reported between the activity of antioxidant enzymes and plant resistance to stress condition (Kholova *et al*., 2011). In current study, potato cultivars responded differently to water stress in terms of antioxidant enzyme activities. This shows that different potato cultivars have distinct drought stress thresholds and in fact they possess various adaptive mechanisms to regulate their redox status. The activities of POX, APX, CAT and SOD were increased in most cases in response to water deficit (Table 3 and 4). Similar to our findings, some other studies have documented raised activity of antioxidant enzymes under water deficit, as in the study of Shi *et al*., (2015); Lu *et al*., (2010) and Wegener *and* Jansen, (2013), In our study, there were even significant reductions in the activity of APX in cultivar Satina and that of CAT non-significant reduction in Satina. The extent increases of SOD activity in tolerant cultivars Born (174.65%), Spirit (132.93%) and those of POX in tolerant cultivars Born (166.21%) and Spirit (143.41%). Also, those of CAT in Santé (55.34%), Born (55.20%) and Spirit (43.63%) were in general significantly greater as compared to the other tested cultivars (Table 4). Similar to the findings of Boguszewska *et al*., (2010) and Shi *et al*., (2015), our biplot results also showed SOD and POX the most antioxidant enzymes which closely correlated with biomass production of the tolerant cultivars of Spirit and Born. These results, therefore, may indicate that the activation of SOD and POX could possess contribution in the tolerance of potato cultivars to water deficit. Similar to the findings Bettaieb *et al*., (2011), we observed that water deficit was accompanied by significantly increase in the TAC of potato plants based on DPPH assay. In fact, DPPH a stable radical absorbs at 517 nm and upon reduction by an antioxidant species through the donation of hydrogen, forming the reduced DPPH-H. The change in color (from purely to yellow) provides an easy and rapid way to evaluate the antiradical activities of extracts. So, DPPH can be used as a board screen to identify the ranges of antioxidant activity (Brand-Williams *et al*., 1995).

Ion leakage was increased in all tested potato cultivars under water deficit condition. Similarly, Lu *et al*., (2010) pointed out that the cell membrane was degraded under drought condition and led to increase IL from damaged cells. Lu *et al*., (2010) also reported increased IL in potato cultivars under water deficit condition. In the current study, the extent of increases in IL was greater in cultivars Marfona (94.39%) and Banba (67.74%) that were identified as semi-sensitive and sensitive in terms of the reduction in biomass accumulation under water deficit (Table 4). This may, therefore, verify the use of this trait as an important index for cultivar selection under drought stress. Moreover, significant negative correlation found between IL and PDM under stress condition indicated the role of the cell membrane damage in retarding plant growth under imposed water stress.

The content of carotenoids was decreased in all tested potato cultivars under water stress and the reductions varied among cultivars ranged from 26.17 to 45.46% (Table 4). These decreases were varied among cultivars. On the other hand, a positive correlation was observed between Car content and POX activity under water deficit. Since the activity of this enzyme was also positively correlated with biomass production, it seems that under water deficit, carotenoids have positive effects

on POX motivated radical scavenging capacity as revealed by the existence of significant positive relationship between these enzymes and carotenoid content of plants (Table 5). However, carotenoids are pigments which play a main role in the protection of plants against photo-oxidative processes. They are involved in protecting the photosynthetic apparatus by quenching single oxygen and other harmful free radicals which are synthesized during photosynthesis (Collins, 2001). Noctor *et al*., (1998) confirmed that carotenoids could directly detoxify superoxide and hydroxyl radicals and thus contribute to non-enzymatic ROS scavenging.

Proline has shown to be related to the adaptation of plants to stress by osmotic regulation, increasing antioxidant activity, removing ROS and stabilizing membranes (Rudoplh *et al*., 1986; Shannon, 1997). However, the extent of proline accumulation in response to stress differs widely among plant species and genotypes (Pinhero *et al*., 2000). In the present study, water deficit increased proline content in all tested cultivars but to different extents. The highest increases were observed in Arinda that showed tolerant and the lowest in Marfona and Jelly that showed semi-sensitive and sensitive to water deficit (Table 3). By the same token, in the study of Schafleitner *et al*., (2007), proline accumulation under water stress was primarily occurred in sensitive potato cultivars. These results may indicate that in this study proline accumulation did not necessarily lead to increased resistance of potato cultivars to drought stress. However, some researchers reported positive correlations between increasing content of proline and the plant tolerance to water deficit (Rudoplh *et al*., 1986). On the other hand, in some other works, there have been no correlations or even negative correlations between proline accumulation and the tolerance to water stress (Pinhero *et al*., 2000). These findings and ours indicate that in some situations, the stress-induced raise of proline may be considered as an effect of stress rather than an adapting mechanism.

Chlorophyll content is one of the key factors in determining the rate of photosynthesis and dry matter accumulation (Juan *et al*., 2005). In this study, water stress decreased the contents of Chl *a*, Chl *b* and Chl *tot* and Car but increased the Chl *a*/*b* ratio. Similarly, Anosheh *et al*., (2012); Gholami-Zali and Ehsanzadeh, (2018) observed reductions in the content of chlorophyll pigments in wheat and fennel under water stress. Cultivars varied in their response to drought stress, so that the reductions (Table 4) in Chl *a* ranged from 22.27 (Milva) to 34.55% (Satina) and Car from 26.17 (Agria) to 45.46% (Santé). Meanwhile, water deficit decreased Chl *b* and Chl *tot* by about 39.2 and 33.1%, respectively and increased Chl *a*/*b* by about 13.7% (Table 3). Consistent with the present study, many researchers reported increased ratio of Chlorophyll *a*/*b* which can to account for by faster damage to Chl *b* compared to Chl *a* under drought stress conditions (Ebrahimiyan *et al*., 2013). Overall, based on the biplot analysis, under water deficit treatment, the biomass production of sensitive cultivars Agria and Jelly was closely related to chlorophyll content, but this related did not observed for TY production. This is indicating that the potential of these cultivars was spend for vegetative growth of plants. In the contrary, potential of tolerant cultivars was used up for TY production (Fig. 1b).

CONCLUSION

In this study we have been able to gather evidence that water deficit increased total antioxidant capacity, the activity of antioxidant enzymes POX, APX, CAT and SOD, ion leakage and proline content. But decreased chlorophyll, carotenoids content, biomass and tuber yield of potato cultivars. Although a prolonged drought is potent to harmfully affect the potato agro-physiological

characteristics. However, SOD, POX and CAT activities showed to be related to stress tolerance of potato as the extents of increases in the activities of these enzymes were greater in tolerant cultivars. Instead, there was no correlation between the proline accumulation and the tolerance of potato cultivars to water deficit. Highest increases of ion leakage in semi-sensitive and sensitive cultivars under water stress may confirm this trait as an important index to be used in selection and improvement of potato cultivars for water limited areas.

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REFERENCES

Abedi T. and Pakniyat H. (2010) Antioxidant enzyme changes in response to drought deficit in ten cultivars of oilseed rape (Brassica napus L.). *Czech. J. Genet. Plant Breed*., **46**, 27-34.

Aebi H. (1984) Isolation, purification, characterization, and assay of antioxygenic enzymes: catalase in vitro. *Meth. in Enzymol.*, **105**, 121-126.

Anosheh H.P., Emam Y., Ashraf M. and Foolad M.R. (2012) Exogenous application of salicylic acid and chlormequat chloride alleviates negative effects of drought stress in wheat. *Advan. Stud. in Biol.*, **4**, 501-520.

Askari E. and Ehsanzadeh P. (2015) Drought stress mitigation by foliar application of salicylic acid and their interactive effects on physiological characteristics of fennel (Foeniculum vulgare Mill.) genotypes. *Acta Physiol. Plant.*, **37**, 1-14.

Bates L.S., Waldren P.R. and Teare D.I. (1973) Rapid determination of free proline for water deficit studies. *Plant and Soil,* **39**, 205-208.

Bettaieb I., Knioua S., Hamrouni I., Limam F. and Marzouk B. (2011) Water deficit impact on fatty acid and essential oil composition and antioxidant activities of Cumin (Cuminum cyminum L.) aerial parts. *J. Agric. Food Chem*., **59**, 328-334.

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

Bradford M.M. (1976) A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein- dye binding. *Anal. Biochem.*, **72**, 248-254.

Brand-Williams W., Cuvelier M.E. and Berset C. (1995) Use of free radical method to evaluate antioxidant activity. *Lebens Wissens Technol.*, **28**, 25-30.

Cervilla, L.M., Blasco B., Rios J.J., Romero L. and Ruiz J. (2007) Oxidative deficit and antioxidants in tomato (solanum lycopersicum) plants subjected to boron toxicity. *Annal. of Bot.*, **100**, 747-756.

Collins A. (2001) Carotenoids and genomic stability. *Mut. Res.*, **475**, 1-28.

Dewir Y.H., Chakrabarty D., Ali M.B., Hahn E.J. and Paek K.Y. (2006) Lipid peroxidation and antioxidant enzyme activities of Euphorbia millii hyperhydric shoots. *Environ. Exp. Bot.*, **58**, 93-99.

Ebrahimiyan M., Majidi M.M., Mirlohi A. and Noroozi A. (2013) Physiological traits related to drought tolerance in tall fescue. *Euphy*., **190**, 401-414.

Finkel T. and Holbrook N.J. (2000) Oxidants, oxidative deficit and the biology of ageing. *Nature*, **408**, 239-247.

Fernandez G.C.J. (1992) Effective selection criteria for assessing stress tolerance. In: Kuo C.G. (Eds.), Proceedings of the international symposium on adaptation of vegetables and other food crops in temperature and water stress, Publication, Tainan, Taiwan.

Gholami-Zali A and Ehsanzadeh P. (2018) Exogenously applied proline as a tool to enhance water use efficiency: Case of fennel. Agric. Water Manag., 197, 138-146.

Giannopolitis C.N. and Ries S.K. (1977) Superoxide dismutase: occurrence in higher plants. *Plant Physiol.*, **59**, 309-314.

Giraud E., Ho L.H. andClifton R. (2008) The absence of alternative Oxidase 1a in arabidopsis results in

acute sensitivity to combined light and drought deficit. *Plant Physiol.*, **147**, 595-610.

Halliwell B. (1999) Antioxidant defense mechanism from the beginning to the end. *Free Radical Res.*, **31**, 261-272.

Hijmans R.J. (2001) Global distribution of the potato crop. *Amer. J. Potato Res.*, **78**, 403-412.

Hojati M., Modarres-Sanavy S.M.A., Karimi M. and Ghanati F. (2011) Responses of growth and antioxidant systems in Carthamus tinctorius L. under water deficit deficit. *Acta Physiol. Plant.*, **33**, 105-112.

Hassanpanah D. (2010) Evaluation of potato cultivars for resistance against water deficit under in vivo conditions. *Potato Res.*, **53**, 383-392.

Hur S.N. (1991) Effect of osmo-conditioning on the productivity of Italian ryegrass and sorghum under suboptimal conditions. *Korean J. Ani. Sci.*, **33**, 101-105.

Iwama K. and Yamaguchi J. (2006) Abiotic deficit. In: Handbook of potato production, improvement and post-harvest management, Gopal J. and Khurana Paul S.M. (Eds.). Food Product Press, New York.

Jefferies R.A and MacKerron D.K.L. (1989) Radiation interception and growth of irrigated and droughted potato (Solanum tuberosum). *Field Crops Res*., **22**, 101-112.

Johanson R.A. and Wichern D.W. (2007) Applied multivariate statistical analysis. Prentice Hall Inter, Inc, New Jersey.

Juan M., Rivero R.M., Romero L. and Ruiz J.M. (2005) Evaluation of some nutritional and biochemical indicators in selecting salt resistant tomato cultivars. *Environ. Exp. Bot.*, **54**, 193-201.

Kholova J., Hash C.T., Kocova M. and Vadez V. (2011) Does a terminal drought tolerance QTL contribute to differences in ROS scavenging enzymes and photosynthetic pigments in pearl millet exposed to drought? *Environ. Exp. Bot.*, **71**, 99-106.

Lawlor D.W. (2002) Limitation to photosynthesis in water-deficited leaves: stomata vs. metabolism and the role of ATP. *Ann. Bot.*, **89**, 871-885.

Lichtenthaler H.K. (1987) Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. *Meth. Enzymol.*, **148**, 350-382.

Lin K.H., Tsou C.C., Hwang S.Y., Chen L.F.O. and Lo H.F. (2006) Paclobutrazol pre-treatment enhanced flooding tolerance of sweet potato. *J. Plant Physiol.*, **163**, 750-760.

Lu Y.Y., Deng X.P. and Kwak S.S. (2010) Over expression of CuZn superoxide dismutase (CuZnSOD) and ascorbate peroxidase (APX) in transgenic sweet potato enhances tolerance and recovery from drought deficit. *Afri. J. Biotechnol.*, **9**, 8378-8391.

Lutts S., Kinet J.M. and Bouharmon J. (1996) NaCl induced senescence in leave of rice (Oryza sativa L.) cultivars differing in salinity resistance. *Ann. Bot.*, **78**, 389-398.

Mates J.M. (2000) Effects of antioxidant enzymes in the molecular control of reactive oxygen species toxicology. *Toxicol*., **153**, 83-104.

Mensah J.K., Obadoni B.O., Eruotor P.G. and Onome-Irieguna F. (2006) Simulated flooding and drought effects on germination, growth and yield parameters of sesame (Sesomum indicum L.). *Afri. J. Biotechnol.*, **13**, 1249-1253.

Mittler R., Vanderauwera S., Gollery M. and Breusegem F.V. (2004) Reactive oxygen gene network of plants. *Trend. Plant Sci.*, **9**, 490-498.

Monneveux P., Ramirez D.A., Awais-Khan M., Raymundo R.M., Loayza H. and Quiroz R. (2014) Drought and heat tolerance evaluation in potato (Solanum tuberosum L.). *Potato Res.*, **57**, 225-247.

Nakano Y. and Asada K. (1981) Hydrogen peroxide is scavenged by ascorbate-specific peroxidase in spinach Chloroplasts. *Plant and Cell Physiol.*, **22**, 867-880.

Nayyar H. and Gupta D. (2006) Differential sensitivity of C3 and C4 plants to water deficit deficit: Association with oxidative deficit and antioxidants. *Environ. Exp. Bot.*, **58**, 106-113.

Noctor G. and Foyer C.H. (1998) Ascorbate and glutathione: keeping active oxygen under control. *Annu. Rev. of Plant Physiol. and Plant Molecul Biol.,* **49**, 249-279.

Pinhero R.G., Pao M.V., Palyath G., Murr D.P. and Fletcher R.A. (2000) Changes in the activities of antioxidant enzymes and their relationship to genetic and paclobutrazol induced chilling tolerance of maize seedlings. *J. Plant Physiol.*, **114**, 695-704.

Placide R., Shimelis H., Laing M. and Gahakwa D. (2013) Physiological mechanisms and conventional breeding of sweet potato (Ipomoea batatas L. Lam.) to drought-tolerance. *Afri. J. Agric. Res.*, **8,** 1837-1846.

Rao M.V., Paliyath G. and Ormod D.P. (1996) Ultraviolet-B radiation and ozone- induced biochemical changes in the antioxidant enzymes of Arabidopsis thaliana. *Plant Physiol.*, **110**, 125-136.

Rapacz M., Kosćielniak J., Jurczyk B., Adamska A. and Wojcik M. (2010) Different patterns of physiological and molecular response to drought in seedlings of malt- and feed-type barleys (Hordeum vulgare). *J. Agron. Crop Sci.*, **196**, 9-19.

Rudoplh A.S., Crowe J.H. and Crowe L.M. (1986) Effects of three stabilizing agents-proline, betaine, and trehalose on membrane phospholipids. *Arch. Biochem. Biophys.*, **245**, 134-143.

Sairam R.K. and Saxena D.C. (2000) Oxidative deficit and antioxidants in wheat genotypes: possible mechanism of water deficit tolerance. *J. Agron. Crop Sci.*, **184**, 55-61.

Schafleitner R., Gaudin A., Rosales R.O.G., Aliaga C.A.A. and Bonierbale M. (2007) Proline accumulation and real time PCR expression analysis of genes encoding enzymes of proline metabolism in relation to drought tolerance in Andean potato. *Acta Physiol. Plant.*, **29**, 19-26.

Shannon M.C. (1997) Adaption of plants to salinity. *Advan. in Agron.*, **60**, 75-120.

Shi S., Fan M., Iwama K., Li F., Zhang Z. and Jia L. (2015) Physiological basis of drought tolerance in potato grown under long term water deficiency. Inter. *J. Plant Prod.*, **9**, 305-320

Singh J. and Kaur L. (2009) Advances in potato chemistry and technology. In Bradshaw J.E. and Ramsay G. (Ed.), Potato Origin and ProductionAcademic Press is an imprint of Elsevier. USA. pp. 1-26.

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

Tas S. and Tas B. (2007) Some physiological responses of drought deficit in wheat genotypes with different ploidity in Turkiye. *World J. Agric. Sci.*, **3**, 178-183.

Wegener C.B. and Jansen G. (2013) Antioxidants in different potato genotypes: effect of drought and wounding deficit. *Agricul*., **3**, 131-146.