Change in antioxidant enzymes activity and some morpho-physiological characteristics of strawberry under long-term salt stress

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Abstract The effects of long term salinity on some morpho-physiological characteristics were studied in strawberry Kurdistan and Queen elisa cultivars. Vegetative and biochemical traits were measured in strawberry cultivars subjected to three levels of salinity including 0, 40 and 80 mM at 20, 40 and 60th days after NaCl addition. Results showed that in both cultivars the dry weight of plant organs decreased in response to NaCl, except of crown weight in cv. Kurdistan. Root to shoot ratio increased due to a greater reduction in above ground biomass under salinity. Strawberry cultivars tended to decrease their stomatal conductance, RWC, proline, soluble carbohydrates and proteins during the different evaluation periods. Compared to the 20th day, peroxidase activity decreased at 80 mM during 40 and 60 days in cv. Queen elisa. On the contrary, ascorbate peroxidase activity elevated until the 40th day and decreased afterwards, in addition application of 40 and 80 mM NaCl increased the ascorbate peroxidase activity of both studied cultivars. Catalase activity increased from 20th until 60th days in cv. Queen elisa, while showed increase in cv. Kurdistan until day 40 and then decreased again at day 60. Application of 40 and 80 mM NaCl resulted in an increase in peroxidase, ascorbate peroxidase

and catalase activities of both cultivars. The Queen elisa cv. showed lower tolerance index (45.88%) compared with cv. Kurdistan (67.97%). Finally, higher salinity resistance of cv. Kurdistan is probably associated with its ability to maintain higher RWC and higher activity of antioxidant enzymes.

Keywords Antioxidant · Growth · Physiology · Salt tolerance index · Salinity

Introduction

Salinity is considered to be one of the most limiting environmental factors for plant growth and productivity in arid and semi-arid regions of the world (Turhan and Eris 2004; Krasensky and Jonak 2012). As a result of salinity stress, some compounds accumulate in plant cells such as osmolytes, plant growth regulators, antioxidants and detoxification enzymes (Mazzucotelli et al. 2008; Munns and Tester 2008). Salinity influences the main processes such as growth, photosynthesis, protein synthesis and lipid metabolism and also has negative effects on enzyme and cell membrane stabilities (Gabr 1999; Khan et al. 2000). Plant response to salinity stress depends on the duration of exposure to salinity conditions (Amor et al. 1999). Changes in cellular components in response to salinity mainly depends on the concentration of salt, duration of salt treatment and plant species. It has been reported that root viability declines in perennial grass with increasing stress duration, while lipid peroxidation increased (Liu et al. 2012). Liu et al. (2012) found that with the salinity duration, root POD and APX activities tend to decrease but still remained higher than control.

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Fragaria × ananassa Duch. is salt-sensitive and salt stress negatively affects the vegetative growth and yield (Garriga et al. 2015). Salinity generally disrupts the strawberry growth and can stimulate the necrosis of the leaf, early senescence and decrease of the photosynthetic leaf area (Yaghubi et al. 2016). Previous reports demonstrated that the responses of strawberry to salinity is different and depends to the degree and duration of salt stress (mild, moderate, severe) and plant developmental stage (Cardeñosa et al. 2015). However, strawberry cultivars showed different responses to salinity stress (Casierre-Posada and Garcia 2005; Turhan and Eris 2005; Keutgen and Pawelzik 2009). In strawberry, vegetative growth, leaf relative water content, amount of chlorophyll, fruit production and fruit quality showed decrease under salinity (Garriga et al. 2015). There are several reports that have demonstrated the adverse effects of salinity on the vegetative growth and development of strawberry (Karlidag et al. 2009; Orsini et al. 2012; Sun et al. 2015). Other studies also have shown differences in salt tolerance among strawberry cultivars (Martinez Barroso and Alvarez 1997; Kepenek and Koyuncu 2002; Orsini et al. 2012; Ferreira et al. 2014). Strawberry is one of the most important small fruits widely used in the world. Strawberry is considered to be a salt-sensitive crop. In most responses to exposure duration in previous studies, change in biochemical components in regards to duration of exposure to salinity stress has not been well studied in strawberry. Therefore, the objectives of this study were to investigate the growth response and biochemical components accumulation of strawberry exposed to different salinity intensity and duration.

Materials and methods

Plant materials and treatments

Experiments were carried out in a polycarbonate greenhouse with natural light and temperature (air temperature ranged between 18 and 30 °C) located in the University of Kurdistan. Two June-bearing (short day) strawberry (*Fragaria × ananassa* Duch.) cultivars were selected for studying their responses to exposure duration to salt stress. The cv. Kurdistan is a cultivar that has long been cultivated in west of Iran (Kurdistan Province) and cv. Queen elisa, has recently been cultivated in this region. Daughter plants of both cultivars were cultivated individually in 6 L plastic pots filled with sand washed profusely with water. Plants were fertigated with 200 mL of modified Hoagland nutrient solution once a day (Hoagland and Arnon 1950). The solution pH was adjusted to 6.0–6.5. The concentrations of

0, 40, and 80 mM NaCl were added to nutrient solution as salinity treatments. To avoid salt accumulation in the pots, every week the pots were drenched with 300 mL of clean water. Experimental time was initiated 30 days after planting by adding NaCl to the nutrient solution and this continued for 60 days. Each treatment was repeated 3 times, including six individual plants in each replicate.

Vegetative parameters assessment

Fully expanded leaves were sampled 20, 40 and 60 days after addition of NaCl to the nutrient solution. Collected leaves were used for biochemical analysis and leaf relative water content (RWC) measurements. Leaf samples were immediately frozen in liquid nitrogen and stored at – 80 °C until analysis. Measurements of morphological parameters were performed at the end of the experiment (60 days after the initiation of salt stress). For evaluation of morphological parameters, six plants from each treatment were randomly selected. In each treatment, the number of leaves, leaf area, dry weight of leaves, roots and crowns, root volume, total biomass, root to shoot ratio and biomass distribution were measured. The root, crown, petiole and leaf were placed in oven at 70 °C for 48 h and then their dry weights were measured. The leaf area (cm²) was measured using a leaf area-meter (Hoddesdon Inc, England). Specific leaf area (SLA, cm² g^{–1}) was determined as the ratio of leaf area to leaf dry weight. Specific leaf weight (SLW, mg per cm²) was determined as the ratio of leaf dry weight to leaf area. Salt tolerance index (STI) is the ratio of the total plant dry weight of the salt treatments to total plant dry weight of the control treatment. The STI was calculated from the following equation: $STI\% = \left(\frac{\text{Total DW salt stress}}{\text{Total DW control}} \right) \times 100$ (El Goumi et al. 2014).

Physiological parameters

The method of Galmés et al. (2007) was used for determination of relative water content (RWC) based on the following equation: $RWC(\%) = [(FW - DW) / (TW - DW)] \times 100$ where FW, TW and DW represent leaf fresh, turgid and dry weight, respectively. Stomatal conductance (g_s) was measured on fully expanded leaves (two leaves per pot) from 11:00 to 13:00 h at photosynthetic active radiation (PAR) > 1000 μmol m^{–2} s^{–1} with a portable prometer system (LP4, Delta T, UK).

The phenol–sulfuric acid method was used for determination of total soluble carbohydrates (Khochert 1987). Total soluble proteins concentration was determined by Bradford method (1976). The content of proline was determined according to spectrophotometry method described by Bates et al. (1973).

Antioxidant enzymes activity assay

For antioxidant enzyme assay, 0.5 g of fresh leaf tissue was added to 5 mL of 50 mM phosphate buffer (pH 7.0) containing 1% PVP and completely homogenized. The homogenized mixture was then centrifuged at 15,000 rpm and 4 °C for 10 min and the supernatant was harvested and stored at – 80 °C until enzyme activity assay.

Peroxidase activity

Peroxidase activity (POD) was determined according to the Hemeda and Klein method (Hemeda and Kelin 1990). For measurement of POD activity, 90 µL 1% guaiacol, 90 µL 0.3% hydrogen peroxide, 780 µL of 50 mMol potassium phosphate buffer (pH 6.6) were mixed in a total volume of 960 µL and reaction started with adding 40 µL crude extract. Activity was determined by the increase in absorbance at 470 nm due to guaiacol oxidation ($E_{0.1\text{cm}}^{1\%} = 0.266 \text{ mM}^{-1} \text{ cm}^{-1}$) during 3 min.

Ascorbate peroxidase activity

Ascorbate peroxidase activity (APX) was measured according to the method described by Nakano and Asada (1981). The reaction mixture contained 50 mM potassium phosphate buffer (pH 7.0), 0.1 mM EDTA, 0.5 mM ascorbate and 0.1 mM H_2O_2 , then suitable amount of the enzyme extract was added to mixture. The reaction was initiated by adding H_2O_2 and the decline of absorbance was recorded after every 30 s for 3.0 min at 290 nm.

Catalase activity

Aebi method (1984) was used for measurement of catalase (CAT) activity. CAT activity was recorded by decrease of absorbance at 240 nm for 3 min due to H_2O_2 consumption. The reaction mixture contained 250 µL of 100 mM potassium phosphate buffer (pH 7.0), 250 µL 10 mM H_2O_2 , 494 distilled water and 6.6 µL of enzyme extract in a 1.0 mL volume.

A spectrophotometer UV/VIS T80 + (PG Instruments, UK) was employed for protein, soluble carbohydrate, proline, POD, APX and CAT determination.

Statistical analysis

Statistical analysis was performed with SAS software (SAS Institute Inc. 1990) according to a factorial experiment based on completely randomized design (CRD) with three replicates and six plants in each replication and 18 plants for each treatment. Means comparison carried out by Duncan's test at a significance level of 0.05.

Results and discussion

Vegetative characteristics

Our results showed that both cultivars which have been used in the present experiment were significantly affected by salinity stress. Greater number of leaves were observed in cv. Kurdistan and NaCl noticeably decreased the number of leaves in both cultivars (Table 1). Excessive reduction in the leaf number was observed in treated plants with 80 mM NaCl. Cv. Kurdistan plants had 17 and 45% and cv. Queen elisa had 35 and 81% reduction in the leaf number at 40 and 80 mM NaCl, respectively. The effect of salinity on total leaf area per plant in two strawberry cultivars was similar to that observed in the number of leaves. Thus, leaf area tended to decrease with increasing salinity stress severity. A higher reduction of leaf area was observed in cv. Queen elisa compared to cv. Kurdistan. The reduction in leaf area in cv. Kurdistan ranged between 29 and 35% for 40 and 80 mM NaCl, respectively while in plants of cv. Queen elisa was between 42 and 53%. In general, cv. Kurdistan developed a larger total leaf area per plant and cv. Queen elisa had greater single leaf area (Table 1).

It is well documented that salinity might cause leaf necrosis and accelerate the leaf senescence. In addition, necrosis and senescence of leaf could decrease plant growth and photosynthetic capacity (Saied et al. 2003; Yilmaz and Kina 2008; Khayyat et al. 2009; Karlidag et al. 2011; Garriga et al. 2015). Significant decrease in the leaf number, leaf area, leaf, petiole and roots dry weight that have been observed in the present study is in agreement with the results reported for strawberry in other studies (Turhan and Eris 2007; Keutgen and Pawelzik 2009; Orsini et al. 2012; Garriga et al. 2015). In the present study, salinity mostly decreased the leaf number than the single leaf area in both cultivars which the latter led to the higher reduction in total leaf area. These results are consistent with the results that has been reported in strawberry by Orsini et al. (2012). The salinity induced necrotic leaf area as a consequence of ion toxicity (Munns and Tester 2008; Turhan and Eris 2005), thereby causing premature leaf fall and destruction of leaf tissues. Reduction of leaf area and subsequent reduction in photosynthesis can be the factors that induce the inhibition of cell division and thus, limiting the growth of plant under salinity (Verslues and Zhu 2007).

In the both cultivars, total dry weight of plants decreased when NaCl concentration in the growing medium was increased. Kurdistan cv. plants showed 31 and 32% reduction in total dry weight at 40 and 80 mM NaCl, respectively. Cv. Queen elisa showed higher total dry weight decline compared to cv. Kurdistan in response to 40 and 80 mM NaCl (42 and 56% reduction, respectively)

Table 1 Effects of salinity treatments on morphological traits across two strawberry cultivars

Treatments	Cultivar	Leaf number	Leaf area (cm ² plant ⁻¹)	Single leaf area (cm ² leaf ⁻¹)	SLA (cm ² g ⁻¹)	SLW (mg cm ⁻²)
Kurdistan	Control	*21.83 ^a	822.20 ^a	41.49 ^{bc}	111.90 ^{ab}	8.937 ^{bc}
	40 mM NaCl	18.17 ^b	585.80 ^b	36.35 ^c	114.50 ^{ab}	8.74 ^{bc}
	80 mM NaCl	12.00 ^c	537.00 ^b	36.46 ^c	115.00 ^{ab}	8.70 ^{bc}
Queen elisa	Control	9.00 ^c	492.40 ^b	55.20 ^a	105.80 ^{bc}	9.47 ^{ab}
	40 mM NaCl	5.83 ^d	286.70 ^c	49.86 ^{ab}	99.61 ^c	10.09 ^a
	80 mM NaCl	1.67 ^e	230.80 ^c	49.24 ^{ab}	116.70 ^a	8.58 ^c
Significance	Cultivar (C)	**	**	**	*	*
	Salinity (S)	**	**	NS	*	*
	C × S	NS	NS	NS	NS	NS

Values with different superscripts within the same column show significant differences at $P < 0.05$ level between treatments (Duncan's multiple range test). NS, (), (**) are non-significant or significant at $P < 0.05$ or 0.01 respectively

(Table 1). The dry weight of plant tissues decreased in response to 40 and 80 mM NaCl in both cultivars, except of crown dry weight in cv. Kurdistan (Fig. 1a).

Increased levels of salt around roots can interfere with the absorption of mineral nutrients by plant roots. Reduction of mineral absorption can cause membrane damage and metabolic disorder including photosynthesis, which consequently reduce the growth rate (Hasanuzzaman et al. 2013; Jamali and Eshghi 2015). In this study, higher reduction in shoot (27% in Kurdistan and 57% in Queen elisa) and root (40% in Kurdistan and 55% in Queen elisa) dry weight in higher concentration of salt (80 mM) was observed in cv. Queen elisa plants. Keutgen and Pawelzik (2009) and Garriga et al. (2015) showed that higher reduction in root and shoot dry weight is an important marker to detect salt-sensitive plants. According to salinity tolerance index, cv. Queen elisa showed lower tolerance index (45.88%) compared to cv. Kurdistan (67.97%) (Fig. 1b). Total dry weight was also highest in the Kurdistan cultivar, whereas lowest dry mass was observed in cv. Queen elisa. Consistent with this it has been shown that sensitive cultivar under salinity condition produced less dry

weight than tolerant cultivar and growth is one of the most important agricultural indices of salinity tolerance (Munns 2002; Kusvuran et al. 2007; Talei and Valdiani 2013).

Increase in the ratio of root to shoot due to salinity stress in the present study is related to greater reduction in above ground biomass (Table 2) rather than an increase in root biomass in cv. Queen elisa, while root to shoot ratio remained stable in cv. Kurdistan (Table 2). Changes in the root/shoot biomass ratio, may affect plant response to stresses (Fleta-Soriano and Munné-Bosch 2016). The results of the present study showed that root had higher tolerance to salinity stress compared to shoot. This response can be explained by the fact that roots are more tolerant than leaves against salinity (Munns and Tester 2008). Yoon et al. (2009), showed that root dry weight of soybean was not decreased under salinity, hence it seems that tissue susceptibility to salinity stress is varied between different plant species.

A significant decrease in length and root volume of cv. Queen elisa occurred at 80 mM NaCl (Table 2). However, unlike the morphological variables addressed above, length and volume of roots in cv. Kurdistan did not change under

Fig. 1 Organs dry weight changes (a) and salt tolerance index (b) of two strawberry cultivars subjected to three levels of salt stress (0, 40 and 80 mM NaCl) after 60 days. Means followed by a different letter are significantly different at $P < 0.05$ by Duncan's test

Table 2 Effects of salinity treatments on morphological traits across two strawberry cultivars

Treatments	Cultivar	Root volume (cm ³)	Root length (cm)	Root to shoot ratio	Total dry weight (g plant ⁻¹)	Shoot dry weight (g)
Kurdistan	Control	*25.44 ^a	45.92 ^a	0.79 ^b	21.34 ^a	11.91 ^a
	40 mM NaCl	22.78 ^{ab}	43.92 ^a	0.70 ^b	14.79 ^{bc}	8.76 ^b
	80 mM NaCl	18.72 ^{abc}	43.58 ^a	0.66 ^b	14.36 ^{bc}	8.68 ^b
Queen elisa	Control	22.39 ^{ab}	38.08 ^a	1.22 ^a	18.29 ^{ab}	8.22 ^b
	40 mM NaCl	15.11 ^{bc}	35.25 ^a	0.81 ^b	10.65 ^{cd}	5.94 ^c
	80 mM NaCl	13.33 ^c	17.83 ^b	1.32 ^a	8.08 ^d	3.50 ^d
Significance	Cultivar (C)	*	**	**	**	**
	Salinity (S)	*	*	*	**	**
	C × S	NS	NS	*	NS	NS

Values with different superscripts within the same column show significant differences at $P < 0.05$ level between treatments (Duncan's multiple range test). NS, (), (**) are non-significant or significant at $P < 0.05$ or 0.01 respectively

salinity treatments. Reduction in root length and root volume under salinity has been reported (Shahzad et al. 2012). Increasing of salinity decreases the density and length of roots, and in parallel decreased the root surface area (Robin et al. 2016). Reduction of root growth by NaCl could be related to changes in accumulation of auxin because salinity inhibits auxin gene expression in primary root tips (Contreras-Cornejo et al. 2014).

SLA and SLW remained unaltered in both control plants and treated plants at 40 and 80 mM NaCl, in Kurdistan cv. the SLW decreased by approximately 9.5% in plants treated with 80 mM of NaCl in cv. Queen elisa (Table 1). Our results indicate that Queen elisa cv. generally showed stronger growth limitation under severe salinity conditions. On the other hand, SLA increased in cv. Queen elisa in response to 80 mM NaCl, which indicates the formation of thinner leaves, a higher area per unit of dry weight and higher reduction of leaf dry weight compared to leaf area in responses to severe salt stress in this cultivar. Our findings are in agreement with previous results demonstrating the effects of NaCl stress on SLA. Tedeschi et al. (2011) and Hernández et al. (2014) found an increase in SLA in melon grown under salt stress.

Stomatal conductance (g_s) and relative water content (RWC)

In general, the two strawberry cultivars showed tendency to decrease their stomatal conductance (g_s) during the evaluation periods, independent of treatment and cultivars (Fig. 2a). Stomatal conductance was reduced from 20th to 40th day in all treatments, while between 40th and 60th days, significant reduction was observed only in cv. Queen

elisa plants exposed to 80 mM salinity. Stomatal conductance decreased in 40 and 80 mM NaCl compared to the control at all times, while differences between 40 and 80 mM salinity treatments were significant just at 60th day of experiment in cv. Queen elisa. After 20 days, g_s was 15 and 27% lower than control plants in cv. Kurdistan exposed to 40 and 80 mM NaCl, while 25 and 25% reduction in stomatal conductance was observed in cv. Queen elisa plants which were treated with 40 and 80 mM NaCl after 20 days. Similar reduction patterns in g_s in the two cultivars in control plants during 20–60 days, revealed some possible limitations of stomatal measurements that could have been affected by many variables, including light conditions (Eisinger et al. 2000) and abiotic stress. Our data showed that decrease of stomatal conductance during the experimental period might limit the photosynthetic capacity, and might protect plants against rapid dehydration. Stomatal closure has beneficial effects due to reduced transpiration under salinity stress to conserve water. Lower transpiration rates are related to the higher resistance of plants to salinity (Maggio et al. 2006) and activate antioxidant enzyme activity for protecting plants against oxidative stress, particularly 40 days after salinity application. Stomatal closure can activate a cascade of stress signals which can influence the plant growth (Maggio et al. 2002; Ruggiero et al. 2004; Orisini et al. 2012) for protecting plants against abiotic stresses including salinity.

In the absence of salinity stress, 40 and 80 mM NaCl higher reduction in RWC of Queen elisa cv. was observed, whereas the amount of RWC in Kurdistan cv. slightly decreased after 60 days. The RWC decreased with increase of NaCl concentration in both strawberry cultivars and in all the studied time points (Fig. 2b). Greater reduction of

Fig. 2 Evolution of stomatal conductance (g_s) (a) and leaf relative water content (RWC) (b) of leaves of two strawberry cultivars subjected to three levels of salt stress (0, 40 and 80 mM NaCl) during 20, 40 and 60 days. Bars on each data point indicate standard error

RWC (%38) was observed in Queen elisa cv. when salt was applied for 60 days. The results showed greater water loss experienced by these plants upon salinization. Cv. Kurdistan showed lower reduction in RWC (%7 after 60 days) compared to control when salinity intensity increased. Upon salinization, water loss was slightly affected in cv. Kurdistan plants, whereas a substantial decrease was observed in cv. Queen elisa in all the salinity levels studied in our experiment. Based on the findings of the present study, stable RWC of cv. Kurdistan could not correlate just with the reduction of stomatal conductance, because similar g_s reduction was observed in both cultivars and higher decline of RWC was obtained in cv. Queen elisa. This difference might relate to the capability of cv. Kurdistan for water absorption. Cv. Kurdistan had stable root length and volume in response to different salt concentrations, while cv. Queen elisa showed severe reduction in root length and volume (Table 1). Significant decrease of RWC due to salt stress observed in the present study during 20 to 60 day period is in agreement with the report of Garriga et al. (2015) in strawberries cvs.

Proline and total soluble carbohydrates

A higher amount of proline was obtained at 20th day, then decreased at day 40 and 60. Significant differences between day 40 and 60 in cv. Kurdistan were observed only in 80 mM, while the amount of proline in cv. Queen elisa from 40th day to 60th day increased in plants treated with 40 mM NaCl, and decreased in 80 mM. However, significant differences among treatments were detected at all times after the start of the experiment in both cultivars. The leaf proline content of the two strawberry cultivars grown under different levels of salt (0, 40, or 80 mM NaCl) tended to increase by increasing of NaCl concentrations, but decreased at 80 mM at day 60 in cv. Queen elisa (Fig. 3a). Soluble carbohydrates were stable in all studied treatments and time points in cv. Kurdistan, while first increased at day 40 and then decreased on day 60 day in cv. Queen elisa

especially at 80 mM NaCl (Fig. 3b). Lowest amount of soluble carbohydrates was observed in Queen elisa at 80 mM and 60th day.

Under abiotic stress conditions, plants accumulate several organic osmolytes to make higher osmotic adjustment and to maintain a suitable gradient for flow of water from soil to roots (Slama et al. 2007). The significant increase in proline concentration due to salt stress in the present study have been reported in strawberry cvs. Camarosa and Chandler (Turhan and Eris 2009), cvs. Camarosa and *Fragaria chiloensis* (Garriga et al. 2015) and cvs. Kurdistan and Paros (Yaghubi et al. 2016). Similar to the present research, Unal et al. (2014) revealed that the amount of proline decreased with increase in the exposure time of salinity. Qurishi et al. (2013) reported that proline accumulates under low salinity (40 mM) and decreased by increase of salinity. It seems that proline accumulates under mild and moderate stresses, but formation of excessive activated oxygen species might limit its accumulation (Qureshi et al. 2005). Salt stress leads to the greater production of reactive oxygen in plants which are highly reactive and toxic, and cause damage to proteins, lipid peroxidation, and carbohydrates decomposition. On the other hand, salinity leads to accelerated senescence of leaves (Ondrášek et al. 2006). This effect over a long period reduces leaf area, photosynthetic capacity and plant growth, and eventually leads to a reduction in carbohydrate production. Accumulation of proline and soluble carbohydrates under stress can protect the cell by balancing of cytosol osmotic strength with that of vacuole and external environment (Sairam et al. 2002). A direct consequence of higher osmolyte concentrations at 80 mM on the 60th day in cv. Kurdistan is the maintenance of higher RWC and antioxidant enzymes activity under this condition.

Total soluble proteins

Total soluble proteins tended to decrease during the evaluation period under salinity treatments in both cultivars

Fig. 3 Evolution of proline (a) and total soluble carbohydrates (b) of leaves of two strawberry cultivars subjected to three levels of salt stress (0, 40 and 80 mM NaCl) during 20, 40 and 60 days. Bars on each data point indicate standard error

(Fig. 4a). Plants grown under control treatment (0 mM) kept similar soluble proteins during the experiment period. The soluble proteins decreased with increase of NaCl concentration in the root medium, these differences were significant at the end of the experiment especially in the cv. Queen elisa at 80 mM. Soluble proteins are metabolites and their concentrations are reduced by salt stress. Therefore, it is apparent that accumulation of toxic ions such as Na and Cl is the main cause of protein reduction under salinity. Lower reduction of protein levels in plants of cv. Kurdistan could be due to its greater adaptability to NaCl stress conditions. In addition, these results demonstrated that by increasing duration of salinity, the reduction in the amount of proteins was more higher, especially in cv. Queen elisa. Protein content might be reduced by protease enzymes, increasing free radicals production and decreasing protein synthesis under salinity (Ranjan et al. 2001). Under salt stress, production of free radicals increases in plant cell and consequently leads to decomposition of proteins (Makale et al. 1999). In agreement with this, similar results have been reported in strawberry (Gulen et al. 2006) and mulberry (Agastian et al. 2000) plants grown under salinity.

Antioxidant enzyme activity

Antioxidant enzyme analysis is most customary way to study plant response to an environmental stresses. Antioxidant enzymes were measured in the present during salt treatments. As shown in Figs. 4b and 5a, b, significant increases of antioxidant activity was observed due to increase of NaCl concentrations. Decrease of POD activity was observed at 80 mM during day 40 and 60 in cv. Queen elisa compared to the 20th day, while POD activity increased at 40 mM from 20th until 60th day. POD activity of cv. Kurdistan decreased in 40th day compared to 20th day, then increased at 60th day at 40 and 80 mM NaCl. The application of 40 and 80 mM NaCl caused an increase in POD activity in both cultivars, except of 80 mM after 60 days in cv. Queen elisa. Under severe salt stress (80 mM) in 60th day POD activity of cv. Kurdistan was higher than cv. Queen elisa (Fig. 4b).

APX activity increased until the 40th day and then decreased in both cultivars. APX activity increased with increasing of salinity stress severity. The application of 40 and 80 mM NaCl caused an increase in APX activity in both cultivars. Highest APX activity was obtained at 80 mM at 40th day and then significantly reduced in both

Fig. 4 Evolution of protein (a) and peroxidase activity (POD) (b) of leaves of two strawberry cultivars subjected to three levels of salt stress (0, 40 and 80 mM NaCl) during 20, 40 and 60 days. Bars on each data point indicate standard error

Fig. 5 Evolution of ascorbic peroxidase (APX) (a) and catalase (CAT) (b) activity of leaves of two strawberry cultivars subjected to three levels of salt stress (0, 40 and 80 mM NaCl) during 20, 40 and 60 days. Bars on each data point indicate standard error

cultivars (Fig. 5a). After 60 days with 80 mM NaCl the highest APX activity was observed in cv. Kurdistan compared to cv. Queen elisa at 80 mM NaCl.

CAT activity in cv. Kurdistan increased from day 20 to day 40 and decreased again at day 60, whereas CAT activity increased from 20th until 60th day in cv. Queen elisa. At 20th day of experiment, the CAT activity increased by increasing NaCl concentrations up to 80 mM in cv. Queen elisa, while was stable in cv. Kurdistan. Conversely, at day 40, the CAT activity increased by increasing NaCl levels up to 80 mM in cv. Kurdistan, but increased up to 40 mM then started to decrease in 80 mM in cv. Queen elisa. The application of 40 mM NaCl at 60th day caused an increase in the CAT activity, while started to decrease with application of 80 mM NaCl in both cultivars.

Long-term salt stress altered the antioxidants enzyme activity in strawberry leaf. The activities of POD, APX and CAT decreased at higher salinity concentration at day 60. The differences in activity of antioxidant enzyme under salinity can be related to exposure time and salt concentration (Kim et al. 2005, Jin et al. 2009). There are some reports that indicate antioxidant enzyme activities declined under salt stress (Abogadallah et al. 2010, Hafsi et al. 2010, Noreen et al. 2010, Yang et al. 2010). A previous study showed that APX activities decreased at higher salinity concentrations (Sairam et al. 2005), because a strong osmotic stress was produced by long-term salt stress on the 60th day, severe reduction in protein content seems to be due to more toxic effects of salts which lead to a reduction of antioxidant enzyme activity. The decrease in the antioxidant enzymes activity at prolonged salinity was probably due to the harmful effect of overproduction of ROS as ROS derivatives could inhibit the protein synthesis (Hu et al. 2012). A great deal of research has been reported that the induction of the cellular antioxidant machinery is important for the protection against salt stress (Mittova et al. 2004; Tuteja 2007). In accordance with our findings, Keutgen and Pawelzik (2009) and Gulen et al. (2006) also

found a significant increase in antioxidant enzyme activity under saline conditions compared with control.

Based on this study, different responses of the two cultivars to salinity illustrate a correlation between the resistance and activity levels of antioxidant enzymes. Lower susceptibility of cv. Kurdistan to salt stress might be associated with higher POD and APX activities at 80 mM on the 60th day. Activity of antioxidant enzymes under salt stress have been demonstrated as physiological traits that may differentiate salt tolerant and salt sensitive cultivars (Turhan et al. 2008). It is apparent that CAT did not contribute to the tolerance in strawberry in this study because at 80 mM on the 60th day, higher CAT activity observed in cv. Queen elisa while no increase in biomass or leaf area was observed in this conditions.

Conclusion

Vegetative characteristics of the two strawberry cultivars grown under different levels of NaCl (0, 40, or 80 mM) decreased by increasing the NaCl concentration. Significant decrease of leaf number, leaf area, leaf, petiole and roots dry weight have been observed in the present study. Both strawberry cultivars showed stomatal conductance (gs), RWC, proline, soluble carbohydrate and soluble proteins reduction during the evaluation periods. This reduction was remarkable when strawberry plants were treated with 80 mM NaCl for 60 days. Lower decline in leaf area, leaf number, biomass, RWC and soluble proteins were observed in cv. Kurdistan compared to cv. Queen elisa under salinity may be related to higher antioxidant enzyme activity for capturing of reactive oxygen species (ROS) in this cultivar. Cv. Kurdistan had higher ability to water absorption and maintain RWC and higher salt tolerance index at 80 mM after 60 days.

A higher amount of proline was obtained on the 20th day, then decreased on day 40 and 60. Amount of proline in

both strawberry cultivars tended to increase by increasing of NaCl concentrations in all studied time points, but decreased at 80 mM on day 60 in cv. Queen elisa. Soluble carbohydrates content did not change in all studied treatments and time points in cv. Kurdistan, whereas first increased 20th to 40th day and then decreased at 60th day in cv. Queen elisa. stomatal conductance and RWC decreased during the evaluation periods, independent of treatment and cultivars and NaCl caused reduction of gs and RWC in all studied time points. A significant reduction in POD and APX activities coincided with the higher reduction in protein content at 80 mM NaCl at the end of the experiment in cv. Queen elisa, therefore it seems that NaCl made adverse effects on this cultivar in comparison with cv. Kurdistan. In general terms, the two cultivars tended to decrease their RWC, gs and biochemical traits in response to prolonged salinity stress. Ultimately, intensity and duration of salinity-stress and the type of cultivars can all impact the selection of salinity tolerance level in strawberry.

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