Middle-East Journal of Scientific Research 24 (9): 2807-2815, 2016
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2016.24.09.23882

Effect of Salinity on Some Photosynthetic Parameters of Potato Genotypes

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Abstract: The objective of this study was to examine the effect of salinity stress on some photosynthetic parameters of diploid potato genotypes, determining their heritability and relationship with other traits. Accordingly, ninety four potato genotypes which were progeny from a cross between parents C and E were arranged in a RCBD with five replications out of which three of them were salt treated and the rest were control treatments. A salinity level of 120 mM NaCl was applied to the hydroponic solution. Different growth parameters and some photosynthetic parameters were measured for both the control and salt treatments over time. Photosynthetic parameters were used for analysis in the current paper. ANOVA and correlation analysis were conducted using GenStat statistical software and 5% probability level was used to test the significant differences between genotypes, treatment effects and interactions. Heritability of measured traits was calculated from one-way ANOVA outputs. Leaf area showed a relative reduction of 72% up on salt treatment and the highest heritability value (86%). The chlorophyll content of the upper leaves increased under salt stress condition both after eight and fourteen days (5%) of salt stress period. However, it showed a relative reduction of 11 % after fourteen days of salt stress period for the lower leaves. Nine days after salt stress, maximum quantum efficiency of photosystem-II showed a reduction of 1.48% under salt stress relative to the control. The highest heritability was observed for chlorophyll content of the upper leaf (85%) whereas the lowest was for the lower leaf (60%) fourteen days after salt stress. The heritability of Fv/Fm showed inconsistency up on salt stress treatment and stress period. The highest heritability was observed for the salt treated (61%) and control (55%) condition nine days after salt stress period. This value was reduced to 38% and 41% respectively for the upper and lower leaf under salt treated condition after thirteen days. Under salt treated condition, a strong positive correlation (r = 0.67) was observed between CC of lower leaf and CC of upper leaf, a moderate positive correlation (r = 0.45) between CC of lower leaf and Fv/Fm of lower leaf; and weak correlation with leaf area. In general, the correlation coefficients of chlorophyll content with other measured parameters increased with increasing the stress period in this experiment. Therefore, this parameter may not indicate salt tolerance at early stage of salt stress. The effect of salt stress on the dark adapted Fv/Fm was inconsistent over measurement periods and it revealed weak to moderate correlation with growth parameters and CC. The moderate positive correlation of Fv/Fm of lower leaf measured at the later period of the stress with most growth parameters and CC was shown in the result. This may indicate measuring of this parameter with extended salt stress period to observe whether it is a mechanism for salt tolerance at later period of salt stress.

Key words: Salinity · Photosynthetic parameters · Quantum efficiency · Heritability

INTRODUCTION

Currently, a huge area of land is affected by salinity problem. According to the FAO database, this problem covered more than 6% of the world's total land area. A number of factors are contributing for the buildup of this global problem. Among the factors, irrigation which is widely practiced in the dry land areas raises the water table which brings salts from deeper layers of the soil and concentrates it in the root zone [1, 2]. The concentration of salt in the root zone decreases the osmotic potential of the soil, which interferes with the water uptake of roots. Reduced water uptake decreases stomatal conductance and cell expansion. Moreover, the reduction in stomatal conductance leads to a decrease in CO_2 assimilation and thus, photosynthesis and plant growth [3]. On the other

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hand, the worldwide limited availability of fresh water, forced people to use poor quality water which can also contribute to the problem of salinity [3, 4]. Apart from this, weathering of parental rocks and deposition of oceanic salts carried in wind and rain are other possible causes of salinity [2]. The aforementioned natural processes together with the daily human activities play a significant role in aggravating this global problem. Therefore, the worldwide increase of salinity problem is a challenge to the food supply for the rapidly growing population of the world by reducing the productivity of crops like potato that provide the largest food source around the globe [1-3].

Potato (*Solanum tuberosum* L.) is a herbaceous perennial plant with harvestable swollen underground stem called tuber. The crop is believed to be originated in the Andean mountain region of South America [5]. In terms of productivity and nutritional value potato is the fourth most important food crop in the world next to the cereals rice, wheat and maize [6, 7]. It also has several health benefits [8]. Potato is grown worldwide under different climatic conditions. China is the first in production followed by the Russian Federation, India and United States of America [7]. The production of potato is affected by a number of biotic and abiotic stresses among which salinity is the major abiotic stresses. Saline soil could be managed by different soil management practices. However, the reclamation of soils affected by this worldwide problem is much expensive. Therefore, the cheapest and environmentally friendly approach to deal with the problem of salinity is to improve salinity tolerance of crops providing the largest food source globally.

Crop plants in general have numerous mechanisms to tolerate salinity stress thorough which several traits are involved. Growth parameters like fresh weight, plant height and leaf area are reported as the most sensitive indicators for the response of plants to salinity stress [9, 10]. Although there are some exceptional species, the decrease in chlorophyll content of leaves in response to salt stress was also reported [11]. Moreover, the incidence of stress on plant leaves causes the damage to photosytem II (PSII), which largely affects the photosynthetic activity of plants. The level of the damage can be determined by measuring the efficiency of PSII using the chlorophyll fluorescence method. This method gives an indication about the tolerance of plants to environmental stress. The theoretically known dark adapted maximum quantum efficiency of PSII (Fv/Fm) value for a normal plant is 0.8 at room temperature [12]. Hence, a decrease in dark adapted Fv/Fm and an increase in the minimal fluorescence (F_0) was reported as an indication of the presence of damage due to environmental stresses [12, 13]. On the other hand, some authors reported no change in maximum quantum efficiency of PII in response to salinity treatment [14] on sugar beet and cabbage. The interaction of salinity with high temperature [15] and high light [16] was also reported. Although several authors reported about the effect of salinity stress in photosynthetic parameters of different crops at different time, information regarding its effect on potato is limited. Hence, the current study aims at:

- Examining the effect of salinity stress on some photosynthetic parameters of diploid potato genotypes, determining their heritability and relationship.

MATERIALS AND METHODS

Plant Material and Experimental Set Up: Ninety four potato genotypes were used in this experiment. The genotypes were progeny from a cross between parents C and E. Planting materials were prepared *in vitro* in MS medium. Axillary shoots taken from each genotype were sterilized and cultured in the media. The cultures were kept under 16 hours photoperiod, 21°C temperature and PPF (Photosynthetic Photon Flux) of 33.75 $\mu molm^{-2}s^{-1}$ supplied by fluorescent light. After two weeks, the plantlets were transferred to hydroponics in greenhouse [17].

The experiment was conducted in an 8 x 8 (64 m^2) greenhouse compartment located at Radix, Unifarm, Wageningen University, latitude 52°N. Potato plantlets were transplanted on 17th June (Replications 1, 2 & 3) and 18th June (Replications 4 & 5), 2009 in small rockwool slabs. It was arranged in a RCBD with five replications out of which three of them were salt treated (replication 1, 3 and 5) and the rest (replication 2 and 4) were control treatments. There were twelve boxes per replication (a total of 60 boxes, 30 boxes per table) filled with nutrient solution where the roots of the potato plants on the trays were submerged. The boxes were arranged perpendicular to the length of the table. Per box, there were 8 genotypes i.e. out of 24 holes per tray that was placed in the hydroponics, 8 were filled with plants. The remaining 16 holes were filled with rockwool slabs to avoid evaporation through the open holes. Therefore, a total of 480 plants were planted including two of the parents.

One of the genotypes (genotype 447), died after some days in replication 3 and 4 and replaced with parent E and C respectively. The growing condition in the greenhouse was 18/15.6°C day/night temperature, 16 hours day length and 60 /80% day/night RH.

The hydroponics was prepared by filling a box with approximately 22 liters of standard nutrient solution on the planting dates (17 and 18 June, 2009). The nutrient solution contains the cations K^+ 7.9, Ca^{2+} 3.9, Mg^{2+} 1.6, NH_4^+ 0.6 and Na^+ 0.4 (mmol/l); the anions NO_3^- 11.0, SO_4^{2-} 2.9, PO_4^{3-} 1.94, HCO_3^- 0.4 and Cl^- 0.3 (mmol/l); the micro nutrients Fe 24, Mn 12, B 9.8, Zn 4.4, Cu 0.7 and Mo 0.3 (µmol/l) and Si 0.02 mmol/l. The nutrient solution had an EC of 2.1 mS/cm and a pH of 5.7[18].

A salinity level of 120 mM NaCl was selected to observe the response of genotypes. The treatment was started after thirteen days of adaptation time (transplanting); on 30 June 2009 (for replication 1 & 3). On this date the control treatment (replication 2) was refreshed with the standard nutrient solution while 60 mM of NaCl was added to the standard nutrient solution and applied to replications 1 & 3 after removing the previous media (the standard nutrient solution filled on the planting date). This procedure was in order to reduce the shocking effect of salt on the plants up on applying 120 mM NaCl at once. On the next date (1 July 2009) 120 mM NaCl was added to the standard nutrient solution and applied to the boxes of replications 1 & 3 after removing the previous media with the 60 mM NaCl. On 1st July 2009 the media of replication 4 was refreshed and 60 mM NaCl was applied to replication 5. On the next day (2 July 2009) 120 mM NaCl was applied to the boxes of replication 5 after changing the previous media of 60 mM NaCl. The growing media (hydroponic solution) of all replications was refreshed for the second time on 8 July 2009 with the respective treatments i.e. with 120 mM NaCl for the salt treated boxes (replications 1, 3 & 5) and with standard nutrient solutions for the control treatments (replications 2 & 4).

Measured Parameters: In this experiment, different growth parameters, number of leaves, some photosynthetic parameters (leaf area, chlorophyll content and chlorophyll fluorescence) were measured for both the control and salt treatments over time. Chlorophyll content was measured using Chlorophyll Meter (SPAD-502) zero and eight days after salt treatment by taking the average of three leaves counted from the upper matured third leaf basipetally. After fourteen days of salt treatment, chlorophyll content was measured by taking the average of three leaves separately for the upper leaves counted from the third leaf to the base and the lower leaf. Chlorophyll fluorescence was measured using OS-30_P Chlorophyll Fluorometer. Measuring light was switched on to measure the initial or minimal level of fluorescence (F_0). Then the dark adapted maximal fluorescence (F_m) was measured by applying a saturated flash of light according to [13]. At the same time the Maximum quantum efficiency of Photosystem-II (F_v/F_m) value was saved in the fluorometer and loaded to a computer. This value can also be calculated using the formula:

Maximum quantum efficiency of PII $(F_v/F_m) = (F_m - F_0)/ F_m$

Where:
$F_{v=}$ the variable fluorescence which is the difference between F_m & F_0
$F_{m=}$ the maximal fluorescence
$F_{0=}$ the minimal fluorescence

These parameters were measured one day after salt treatment by taking the average of two upper leaves counting from the third mature leaves, nine days after salt treatment by taking the average of the third and fifth leaves counted from the top and thirteen days after salt treatment by taking the upper (third leaf from the top) and lower leaf separately. In all cases chlorophyll fluorescence measurements were done after 20 minutes of dark adaptation with a small clip.

The genotypes were then harvested on 16th (replication 1&2), 17th and 18th (Replication 3, 5 and part of replication 4) and 20 (the remaining boxes of replication 4) July 2009. After carefully removing the plants out of the hydroponics, the root was gently cleaned to separate it from the rockwool. After drying the water left on the roots with tissue, growth parameters were measured. Then, Leaf area was measured using leaf area meter (LI-COR model 3100). In this experiment, leaf area, chlorophyll content and Fv/Fm was considered for analysis.

Statistical Analysis: Analysis of variance (ANOVA) and correlation analysis were conducted using GenStat statistical software (11th edition). One-way ANOVA was carried out for the salt treated and control treatments to observe the presence of genotypic differences. Heritability of measured traits was calculated from one-way ANOVA outputs to determine the percentage variation due to the genetic factor. Two-way ANOVA was carried out to examine the interaction between genotype

and treatment. In both cases (one-way and two-way ANOVA), 5% probability level ($P = 0.05$) was used to test the significant differences between genotypes, treatment effects and interactions.

RESULTS

Overall genotypes showed the highest relative reduction in leaf area and different responses to salinity stress for the Chlorophyll content of upper and lower leaves. Moreover, different responses were observed for the Maximum quantum efficiency of photosystem-II (Fv/Fm) of upper and lower leaves for the measurement periods.

Effect of Salinity on Leaf Area: After sixteen days of salt stress treatment, genotype and treatment showed significant ($P < 0.001$) interaction effect on leaf area (Table 1) and other growth parameters (data not shown). Moreover, genotypes showed significant ($P < 0.001$) differences in leaf area. Leaf area showed a reduction of 71.9% relative to the control. The result of this study also revealed the highest heritability value (85.9%) of this parameter under salt stress condition (Table 1).

Effect of Salinity on Chlorophyll Content: Genotype and treatment showed significant ($P < 0.001$) interaction effect on the chlorophyll content of the upper leaves both after eight and fourteen days of salt stress. The interaction effect of genotype and treatment on the chlorophyll content of the lower leaf was also significant ($P = 0.005$) after fourteen days of salt stress period (Table 1).

Relative to the control, the chlorophyll content of the upper leaves increased under salt stress condition both after eight and fourteen days of salt stress period. The increase in chlorophyll content was 5.1% and 4.6% after eight and fourteen days of salt stress period respectively (Table 1). After fourteen days of salt stress period, the chlorophyll content of the lower leaves showed a reduction of 11.1% relative to the control.

Effect of Salinity on the Maximum Quantum Efficiency of PII: Genotype and treatment showed significant interaction effect on the maximum quantum efficiency of PII (Fv/Fm) of the upper leaves (3^{rd} & 4^{th} leaves counted from the top) one day after salt stress ($P < 0.001$), 3^{rd} & 5^{th} leaves ($P = 0.002$) nine days after salt stress period (Table 2). Thirteen days after salt stress period, genotype and treatment showed no significant ($P = 0.098$) interaction effect on the Fv/Fm of the upper (3^{rd}) leaf; and lower leaf ($P = 0.365$). Moreover, genotypes showed significant ($P < 0.001$) differences in Fv/Fm of both the upper and lower leaves after thirteen days of salt stress, however the treatment effect was not significant ($P = 0.818$; $P = 0.138$ for the upper and lower leaves respectively). Even though the interaction between genotype and treatment was not always significant and treatment effect was not significant, Fv/Fm slightly decreased after nine and thirteen days of salt stress. Fv/Fm measured one day after salt stress showed lower values than normal both for the control and salt treated conditions with higher values under salt stress. Nine days after salt stress, Fv/Fm showed a reduction of 1.48% under salt stress relative to the control (Table 2).

Heritability of Parameters

Chlorophyll Content: Genotypes showed significant ($P < 0.001$) differences in chlorophyll content zero, eight and fourteen days after salt stress both under control and salt treated condition. Heritability of chlorophyll content increased with salt treatment and with an increase of the stress period from eight to fourteen days for the upper leaf. However, heritability decreased with salt treatment for the lower leaf after fourteen days of salt stress. The highest heritability was observed for chlorophyll content of the upper leaf (85.4%) whereas the lowest was for the lower leaf (59.8%) fourteen days after salt stress (Table 3).

Maximum Quantum Efficiency of PII (Fv/Fm): Genotypes showed significant ($P = 0.01$) differences in the maximum quantum efficiency of PII under control condition, but the differences were not significant ($P = 0.451$) under salt stress after one day of salt treatment (Table 3). Nine days after salt stress, genotypes showed significant differences ($P < 0.001$) in Fv/Fm of both the control and salt stress condition. Thirteen days after salt stress, genotypes showed significant differences in Fv/Fm of the upper ($P = 0.003$) and lower leaf ($P < 0.001$) under salt stress condition, however the differences between genotypes were not significant under control condition for both the upper ($P = 0.539$) and lower ($P = 0.109$) leaves (Table 3).

The heritability of Fv/Fm showed inconsistency up on salt stress treatment and stress period. The highest heritability was observed for the salt treated (61.1%) and control (54.5%) condition nine days after salt stress period. After thirteen days of growth period negative heritability value (~0) was observed under control condition. On the other hand, the result of the current study revealed heritability values of 38.4% and 41.2% respectively for the Fv/Fm of upper and lower leaf under salt treated condition at same growth period (Table 3).

Correlation Between Parameters: Correlation analysis was done based on measurements of chlorophyll content and plant height zero days after salt stress and chlorophyll fluorescence one day after salt stress. The maximum quantum efficiency of photosystem-II (Fv/Fm) and plant height showed a moderate positive correlation (r = 0.34) under control condition. However, the correlation between these parameters was weak under salt stress. Chlorophyll content and Fv/Fm showed weak correlation both under control and salt stress condition (Table 4).

Based on correlation analysis done on measurements of plant height, chlorophyll content and Chlorophyll Fluorescence after seven, eight & nine days of salt stress respectively, weak but, positive correlations were observed between CC and plant height, Fv/Fm and plant height, CC and Fv/Fm (Table 5). Moreover, a moderate positive correlation (r = 0.35) was observed between Fv/Fm and plant height under salt treated condition. Although, correlations between these parameters were weak to moderate, correlation coefficients were more under salt treated than control condition (Table 5).

Table 1: Effect of salinity on chlorophyll content measured after different days of salt stress treatment. Values are analyzed for the averages of three leaves per genotype for both upper and lower leaves.

		Control		Salt treated		Two-way ANOVA *P*- value				
Days after treatment	Leaf measured	Mean[1]	Range	Mean	Range	G[2]	T[3]	G * T[4]	Relative reduction (%)	C.V(%)
0	Upper	41.1	32.2-53.9	40.1	30.2-49.8	< 0.001	ns[5]	ns	2.2	6.6
8	Upper	43.1	34.4-53.9	45.3	37.8-54.8	< 0.001	ns	< 0.001	-5.1	7.3
14	Upper	43.6	31.8-50.1	45.6	27.8-57.4	< 0.001	0.015	< 0.001	-4.6	6.7
14	Lower	41.4	27.5-50.9	36.8	22.3-47.4	< 0.001	0.004	0.005	11.1	10.5
At harvest	Leaf area	399	9.2-1007.9	112	1.2-250.3	<0.001	0.006	<0.001	71.9	36.6

[1] Mean values are averages of 94 genotypes over 2 & 3 replications for the control and salt treated conditions respectively.
[2] Genotype, [3] Treatment, [4] Genotype by treatment interaction, [5] Non-significant.

Table 2: Effect of salinity on maximum quantum efficiency of PII (Fv/Fm) measured after different days of salt stress treatment. Values are analyzed based on the averages of two leaves per genotype and single leaf for thirteen days after salt stress.

		Control		Salt treated		Two-way ANOVA *P*- value				
Days after treatment	Leaf measured	Mean[2]	Range	Mean	Range	G	T	G * T	Relative reduction (%)	C.V (%)
1	3rd & 4th	0.660	0.412-0.774	0.714	0.624-0.793	<0.001	0.031	<0.001	-8.18	10.9
9	3rd & 5th	0.810	0.729-0.835	0.798	0.682-0.827	<0.001	ns[3]	0.002	1.48	2.3
13	3rd	0.761	0.717-0.794	0.760	0.661-0.792	<0.001	ns	ns	0.13	3.7
13	Lower[1]	0.775	0.687-0.813	0.752	0.667-0.806	<0.001	ns	ns	2.97	4.1

[1] The lower undamaged leaf.
[2] Mean values are averages of 94 genotypes over 2 & 3 replications for the control and salt treated conditions respectively.
[3] Non significant.

Table 3: Heritability of parameters measured after different days of salt treatment under control and salt treated conditions. Values are calculated from one-way ANOVA outputs.

Parameters	Days after treatment	Treatment	V_g[1]	V_e[2]	H (%)[3]	*P*-value
Chlorophyll content	0	Control	15.17	3.29	82.2	<0.001
		Salt	11.91	2.48	82.8	<0.001
	8	Control	7.28	3.40	68.1	<0.001
		Salt	11.39	4.07	73.7	<0.001
Upper leaf	14	Control	7.78	4.09	65.5	<0.001
		Salt	25.26	4.32	85.4	<0.001
Lower leaf	14	Control	13.21	5.82	69.4	<0.001
		Salt	12.06	8.09	59.8	<0.001
Fv/Fm	1	Control	0.3E-2	0.5E-2	39.1	0.01
		Salt	0.2E-4	0.1E-2	1.84	ns[4]
	9	Control	0.7E-4	0.6E-4	54.5	<0.001
		Salt	0.2E-3	0.1E-3	61.1	<0.001
Upper leaf	13	Control	-0.6E-5	0.3E-3	-0.02	ns
		Salt	0.2E-3	0.3E-3	38.4	0.003
Lower leaf	13	Control	0.8E-4	0.3E-3	22.9	ns
		Salt	0.3E-3	0.4E-4	46.2	<0.001
Leaf area (cm²)		Control	2641.5	8995	74.6	<0.001
		Salt	2593.3	427	85.9	<0.001

[1] Genetic variance.
[2] Environmental variance.
[3] Heritability.
[4] Non significant.

Table 4: Correlation between parameters measured zero and one day after salt stress.

	Control			Salt treated		
Parameters	Plant height	CC	Fv/Fm	Plant height	CC	Fv/Fm
Plant height [1]	-			-		
CC[1]	-0.03	-		-0.02	-	
Fv/Fm[2]	0.34	-0.10	-	0.08	0.09	-

[1] Measured zero days after salt treatment.

[2] Measured one day after salt treatment.

Table 5: Correlation between parameters measured seven, eight and nine days after salt stress.

	Control			Salt treated		
Parameters	Plant height	CC	Fv/Fm	Plant height	CC	Fv/Fm
Plant height [1]	-			-		
CC[2]	0.19	-		0.23	-	
Fv/Fm[3]	0.24	0.19	-	0.35	0.26	-

[1] Measured seven days after salt treatment.

[2] Measured eight days after salt treatment.

[3] Measured eight days after salt treatment.

Correlation Between Photosynthetic Parameters at Later Period of Stress: Correlation analysis was conducted for CC and Fv/Fm measured fourteen and thirteen days after salt stress respectively & leaf area at harvest. The results were presented for the control and salt treated condition separately.

Control: For potato genotypes grown under control condition, chlorophyll content (CC) of the lower leaf showed moderate positive correlation with CC of upper leaf (r = 0.48) and weak correlation with Fv/Fm of lower leaf and leaf area. Furthermore, an almost no correlation was observed with Fv/Fm of upper leaf. CC of upper leaf showed weak and no correlation with Fv/Fm and leaf area respectively (Table 6). Fv/Fm of lower leaf showed a moderate positive correlation (r = 0.36) with Fv/Fm of upper leaf.

Salt Treated: For potato genotypes grown under salt treated condition, a strong positive correlation (r = 0.67) was observed between CC of lower leaf and CC of upper leaf. Moreover, a moderate positive correlation (r = 0.45) was observed between CC of lower leaf and Fv/Fm of lower leaf; and weak correlation with leaf area (r = 0.24). A moderate positive correlation was observed between CC of upper leaf and Fv/Fm of upper leaf (r = 0.38). Furthermore, Fv/Fm of lower leaf showed a moderate positive correlation with Fv/Fm of upper leaf (r= 0.49) and leaf area (r = 0.35).

Table 6: Correlation between parameters measured at harvest under control condition. Chlorophyll content and Chlorophyll fluorescence were measured fourteen and thirteen days after salt stress respectively.

	CC lower L[1]	CC upper L	Fv/Fm lower	Fv/Fm upper	Leaf area	Root DW[2]	Root FW[3]	Root Length	Root /Shoot	Shoot DW	Shoot FW	Shoot length
CC lower L	-											
CC upper L	**0.48**	-										
Fv/Fm lower	0.23	-0.15	-									
Fv/Fm upper	0.02	-0.12	**0.36**	-								
Leaf area	0.18	-0.05	0.09	-0.22	-							
Root DW	0.21	0.09	0.12	-0.12	**0.82**	-						
Root FW	0.19	0.09	0.11	-0.05	**0.78**	**0.94**	-					
Root Length	0.19	0.02	**0.34**	-0.06	**0.63**	**0.59**	**0.63**	-				
Root/Shoot	-0.28	0.05	**-0.39**	0.02	**-0.38**	-0.06	-0.10	**-0.51**	-			
Shoot DW	0.27	0.08	0.17	-0.18	**0.92**	**0.81**	**0.79**	**0.69**	**-0.49**	-		
Shoot FW	0.22	0.12	0.11	-0.24	**0.93**	**0.79**	**0.75**	**0.62**	**-0.38**	**0.93**	-	
Shoot length	**0.31**	0.18	0.22	-0.23	**0.57**	**0.44**	**0.39**	**0.44**	**-0.49**	**0.65**	**0.69**	-

[1] Leaf.

[2] Dry weights.

[3] Fresh weights.

Table 7: Correlation between parameters measured at harvest under salt stress condition. Chlorophyll content and Chlorophyll fluorescence were measured fourteen and thirteen days after salt stress respectively.

	CC lower L[1]	CC upper L	Fv/Fm lower	Fv/Fm upper	Leaf area	Root DW[2]	Root FW[3]	Root Length	Root /Shoot	Shoot DW	Shoot FW	Shoot length
CC lower L	-											
CC upper L	**0.67**	-										
Fv/Fm lower	**0.45**	0.28	-									
Fv/Fm upper	0.28	**0.38**	**0.49**	-								
Leaf area	0.24	0.18	**0.39**	0.25	-							
Root DW	0.26	**0.31**	**0.35**	0.25	**0.78**	-						
Root FW	0.26	0.29	**0.38**	0.28	**0.76**	**0.97**	-					
Root Length	**0.39**	**0.39**	**0.48**	**0.35**	**0.67**	**0.67**	**0.71**	-				
Root/Shoot	-0.29	-0.28	**-0.30**	**-0.41**	**-0.35**	-0.02	-0.03	**-0.34**	-			
Shoot DW	0.29	0.29	**0.35**	0.26	**0.94**	**0.85**	**0.83**	**0.67**	**-0.32**	-		
Shoot FW	**0.32**	**0.30**	**0.37**	0.25	**0.94**	**0.80**	**0.78**	**0.68**	**-0.40**	**0.97**	-	
Shoot length	**0.46**	**0.48**	**0.39**	**0.38**	**0.56**	**0.49**	**0.51**	**0.55**	**-0.46**	**0.62**	**0.65**	-

[1] Leaf.

[2] Dry weights.

[3] Fresh weights.

DISCUSSIONS

The aim of this study was to examine the effect of salinity stress on some photosynthetic parameters of diploid potato genotypes, their heritability and association. Accordingly ninety four diploid potato genotypes, which are progenies from a cross between C and E parents were examined based on some photosynthetic parameters under hydroponics condition. Hydroponics was chosen to study the response of the genotypes to salt stress because it provides a uniform salinity environment and reduces the interaction with other environmental factors.

The results of the current study revealed significant interaction effect of genotype and treatment on leaf area (Table 1). Furthermore, the effect of salinity in reducing leaf area is greater than its effect on the total number of living leaves (data not shown). Similarly [9, 16] were reported this parameter as the most sensitive indicator for salinity stress. Thus, maintaining high leaf area is more important than number of leaves for salinity tolerance, since the correlation between leaf area and growth parameters is strong, but weak correlations were observed between total number of living leaves and growth parameters (data not shown).

In the current experiment chlorophyll content was measured three times during the experimental period i.e. zero days, eight days and fourteen days after salt stress treatment. Zero and eight days after salt stress CC was measured for the upper leaves only but, fourteen days after stress CC was measured for the upper and lower leaves separately. Accordingly the interaction effect of genotype and treatment on CC of upper leaves was significant both eight and fourteen days after salt stress; and the CC of lower leaves after fourteen days of salt stress. Chlorophyll content of upper leaves showed an increase of 5.1% after eight days and 4.6% after fourteen days of salt stress relative to the control (Table 1). This result is not in agreement with those of [15, 17] who reported the decrease in chlorophyll content due to salt stress on soya bean and faba bean plants. However, the current study revealed that the increase in CC of upper leaves decreased from 5.1% to 4.6% when the stress period was extended from eight to fourteen days. This may indicate that the decrease in CC of the upper leaves might be observed after the stress period was extended which can also be observed from the significant treatment effects after fourteen days of salt stress (Table 1). On the other hand, the chlorophyll content of lower leaves showed a reduction of 11.1% relative to the control (Table 1). This indicates that salinity stress may speed up the senescence of lower leaves. Although separations between upper and lower leaves were not shown in their report, this result agrees with the results of [15] on soya bean and [17] on fib bean.

In this study chlorophyll fluorescence was measured three times during the salt stress period i.e. one and nine days after salt stress for the upper leaves and thirteen days after salt stress for both the upper and lower leaves. The maximum quantum efficiency of PII (dark adapted Fv/Fm) was used for analysis. Accordingly, significant interaction effects of genotype and treatment on Fv/Fm of upper leaves were observed one and nine days after salt stress (Table 2). One day after salt stress, the Fv/Fm values showed higher mean value under salt stress than control condition and wide range was observed for the

control than salt treated which lowered the average value of the control. However, this result is unexpected compared to the previously published reports by [12, 13] about the decrease in dark adapted Fv/Fm due to environmental stress. Nine days after salt stress dark adapted Fv/Fm of upper leaves showed slight reduction (1.48%) relative to the control. After thirteen days of salt stress non significant genotype & treatment interaction and treatment effects on Fv/Fm of both upper and lower leaves were observed (Table 2). Overall, the mean dark adapted Fv/Fm for the control and salt treated condition showed lower values than the theoretically known value (0.8) for a normal plant except for the control condition after nine days of salt stress. However, there were still some genotypes which showed same values as normal plant both under control and salt treated condition which can be seen from the range of this parameter (Table 2). Although results were inconsistent and slight reduction in the Fv/Fm at leaf level was observed sometimes, the higher reduction in leaf area (71.9%) due to salt stress (Table 1) indicates the reduction in the photosynthesis of the whole plant, which adversely affects the growth of the potato genotypes. Moreover, the mean Fv/Fm of both the control and salt treated condition measured one day after salt stress was lower than the values after nine and thirteen days of salt stress (Table). This might be because of the high temperature inside the greenhouse on one day (July 1 & 2, 2009) after salt stress compared to the other dates (Temperature data available). Similar to this explanation, the interaction of salinity with high temperature was already reported by [15] on soya bean. In general, the effect of salinity on Fv/Fm of leaves is not consistent over the measurements done during the stress period, which makes it difficult to draw conclusions about it.

Heritability of Measured Traits: In the current study, significant ($P < 0.001$) differences in chlorophyll contents between genotypes were observed both under control and salt treated condition (Tables 3). Heritability of chlorophyll content ranged from 65.5% to 82.2% under control and 59.8% to 85.4 under salt treated condition indicating that the variation in this trait is more genetically controlled than it is environmentally controlled. Although this parameter showed high heritability values, it showed weak to moderate positive correlation with most growth parameters (data not shown) and Fv/Fm under salt stress condition (Table 6). Consequently, the author suggests the measurement of this parameter (CC) at later period of stress to observe whether it is a mechanism for salt tolerance in potato or not.

Genotypes showed significant differences in Fv/Fm one and nine days after salt treatment for the control; and nine days and thirteen days after salt stress for salt treated condition (Table 6). The heritability of this parameter ranged from 0% to 54.5% under control and 2% to 61.1% under salt stress. The negative heritability value which was reported so far on table 3 was approximated to zero according to [18]. Although inconsistent heritability values were observed over stress period and treatment effects, Fv/Fm of the lower leaf showed moderate positive correlation with the measured growth parameters except root/shoot dry weight ratio (Table 7). Moreover, Fv/Fm had moderate positive correlation with the CC of lower leaf. This may give an indication about the relation between this parameter and salt tolerance at later period of salt stress.

CONCLUSION

In general, the correlation coefficients of chlorophyll content with other measured parameters increased with increasing the stress period in this experiment. Therefore, this parameter may not indicate salt tolerance at early stage of salt stress. The effect of salt stress on the dark adapted Fv/Fm was inconsistent over measurement periods. Mostly, lower average values than a normal plant were observed for this parameter under control and salt treated condition. Although genotypic differences were observed in some cases and there were some genotypes with normal values, this parameter showed low heritability, weak to moderate correlation with growth parameters and CC. Moderate positive correlation of Fv/Fm of lower leaf measured at the later period of the stress with most growth parameters and CC was shown in the result. This may indicate measuring of this parameter with extended salt stress period to observe whether it is a mechanism for salt tolerance at later period of salt stress.

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