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Identification of Sunflower *(Helianthus annuus* L.*)* Genotypes Tolerant to Water Stress

Ali Beyhan UÇAK[a]

[a] *Siirt University, Faculty of Agriculture, Department of Biosystem Engineering, Siirt, TURKEY*

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Corresponding Author: Ali Beyhan UÇAK, E-mail: abucak@siirt.edu.tr, Tel: +90 (484) 254 20 57
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ABSTRACT

The present research was carried out to determine water-stress tolerance of linoleic sunflower genotypes (P64LE119, PR63F73, P64LL62) grown under different water stress conditions [no water-stress (I_{100}); mild water-stress (I_{70}); strong water-stress (I_{35})] in the years 2015 and 2016. Variance analyses revealed significant differences between the genotypes ($P<0.01$). As the average of two years, the greatest yield was obtained from no water-stress x genotype interaction (I_{100}xP64LE119) with 4094.66 kg ha^{-1}, the lowest yield was obtained from strong water stress x genotype interaction (I_{35}xPR63F73) with 2487.81 kg ha^{-1}. Again as the average of two years, the greatest chlorophyll content was obtained from no water-stress x genotype interaction (I_{100}xP64LE119) with 49.83 spad, the lowest value was obtained from strong water stress x genotype interaction (I_{35}xPR63F73) with 34.39 spad. The greatest crop water stress index was obtained from strong water stress x genotype interaction (I_{35}xPR63F73) with 0.53, the lowest value was obtained from no water-stress x genotype interaction (I_{100}xP64LE119) with 0.21. The P64LE119 genotype with optimum water use efficiency and prominent with crop water stress index and chlorophyll content both in no water-stress and strong water stress treatments was identified as water stress-resistant and the genotype was considered to have reliable characteristics potentially to be used in further water stress-resistance studies.

Keywords: Sunflower; Water stress; Crop water stress index; Tolerance; Chlorophyll

1. Introduction

Today, agronomists and plant breeders are focused on yields rather than survival of the plants. Breeding programs are mostly implemented to develop high-yield cultivars. However, recent global warming-induced abiotic stressors have negatively influenced agricultural production activities and such impacts compelled the researchers to take new measures against the negative impacts of climate change and resultant global warming. Among the abiotic stressors, water stress, insufficient nutrition, salinity and high temperature are the leading ones (Kozlowski & Pallardy 1997). Recession in plant growth due to deficit moisture within the plant efficient root zone (through the soil profile of 0-90 cm) is defined as water stress. The initial symptoms of water stress realize at stomatal level and stomas close to prevent further moisture loss through transpiration (Flexas & Medrano 2002). Stomal closure reduces CO_2 availability in chloroplasts and negatively influences net photosynthesis rates

(Cornic 2000). Water stress is exerted on plant tissues under drought stress and this reduces photosynthesis rates significantly (Chaves 1991). Neither the soil moisture content nor the atmospheric system can accurately put forth plant inherent water status as much as crop water stress index (Reginato & Howe 1985; Gencoglan & Yazar 1999). Reginato (1983) indicated that daily crop water stress index values varied based on atmospheric demands and soil moisture contents. Water stress is experienced when the plant cover temperature was equal or greater than the air temperature (Walker & Hatfield 1979). Canopy-air temperature difference (Tc-Ta) is a significant indicator of water stress (Jackson & Reginato 1981). Choudhury & Idso (1984) carried out a water stress study on sunflower and reported significant effects of air and dew temperatures on plant cover temperature under high soil moisture conditions. Plant resistance to droughts and water stress are the primary target of plant breeders. For sunflowers, leaf canopy temperatures are the most significant parameters in measuring plant tolerance to water stress under stress conditions (Skoric 2009). Moroni et al (2012) indicated the canopy (leaf-canopy) temperature as the fastest and the most accurate means of measuring water stress and pointed out that this parameter could be used as a selection criterion in breeding studies. Crop water stress index values vary based on plant genotypes, cultivars, environmental and climate conditions (Testi et al 2008). Water stress is among the most important factors restricting plant production activities and may result in significant changes in chlorophyll content and components through hindering photosynthetic activity in plants (Mozaffari et al 1996). The parameters to be used in identification of drought or water stress should be easy, rapid, cheap and repeatable (Kaleem et al 2009; Moroni et al 2012). Oraki et al (2012) reported increased chlorophyll b levels, decreased chlorophyll a and yield levels with increasing water stress levels. Despite the studies about drought (water stress) tolerance of wheat and chickpea plants (Gunes et al 2008), the studies about plant responds to water stress in sunflower are quite limited. For sunflower, efficient selection criteria to be used in distinguishing potential status of the plants against water stress haven't been fully elucidated, yet. That is why in present study (2015-2016), 3 different irrigation treatments (I_{100}, I_{70}, I_{35}) were employed. The present study was conducted under field conditions in 2015 and 2016 to determine water stress resistance of 3 sunflower genotypes (P64LE119, PR63F73, P64LL62) grown under strong water-stress, mild water-stress and no water-stress conditions by using kernel yield, crop water stress index and chlorophyll content values.

2. Material and Methods

A pre-study was carried out under Siirt conditions in 2014 with two sunflower genotypes (PR63F73, P64LL62) and 4 irrigation treatments (I_{100}, I_{70}, I_{35}, I_0). Correlation analyses revealed that yield positively correlated with chlorophyll content (CC) (86%), water use efficiency (WUE) (74%) and soil moisture content (61%) ($P<0.01$) and negatively correlated with crop water stress index (CWSI) (79%). A negative correlation was also observed between CWSI and soil moisture content (84%) ($P<0.01$). In that pre-study, irrigation treatments were selected as I_{100}, I_{70}, I_{35} and I_0. However, I_0 treatment was not found to be assessable with regard to water-yield relations, thus removed from the study and (I_{35}) treatment was included instead to represent strong water stress conditions. Experiments were conducted under natural field conditions since it is quite hard to transfer the results of the studies carried out under controlled conditions like greenhouses or growth chambers into the practice. Sowing was performed late on 30th of May to shift the negative impacts of precipitations in May. Experiments were carried out over the experimental fields of Siirt Province during the sunflower growing seasons of 2015 and 2016. The research site has an altitude of 894 m and is located on 37° 58' N and 41° 50' E. Linoleic P64LE119, PR63F73, P64LL62 sunflower genotypes were used as the plant material of the study. Long-term and annual climate data of the research site (during sunflower growing seasons) are provided in Table 1.

Table 1- Climate data for the years of 2015 and 2016 and long-term averages (1962-2014)

Years	*Months*	*Mean maximum temperature (°C)*	*Mean temperature (°C)*	*Mean minimum temperature (°C)*	*Mean humidity (%)*	*Mean wind speed ($m\ s^{-1}$)*	*Mean daily sunshine (h)*	*Total precipitation (mm)*
Average 1962-2014	May	25.20	19.40	9.00	49.30	1.00	9.10	36.90
	June	27.20	26.00	17.80	34.90	1.10	11.60	11.50
	July	35.10	30.50	23.40	30.30	1.10	12.30	0.60
	August	34.50	30.30	27.00	29.50	1.00	11.40	2.70
	September	30.00	25.10	14.70	37.40	1.00	10.10	7.00
	October	24.50	17.90	12.70	42.00	1.00	7.20	50.90
2015	May	26.62	19.29	14.52	50.87	1.00	8.70	39.60
	June	26.09	28.16	20.00	35.50	1.10	11.50	10.60
	July	34.13	31.45	24.35	32.69	1.00	12.40	0.10
	August	33.92	31.19	24.23	32.95	1.00	11.30	0.40
	September	31.23	25.43	21.50	39.90	1.10	10.00	9.20
	October	24.30	16.80	11.50	42.30	1.10	7.00	55.10
2016	May	24.69	21.29	14.59	51.77	1.00	9.30	37.70
	June	28.19	28.41	20.25	34.40	1.10	12.00	9.30
	July	36.24	33.19	25.35	29.69	1.00	12.50	0.10
	August	35.92	32.45	24.73	29.95	1.00	11.50	0.00
	September	32.23	27.43	21.65	36.79	1.10	10.00	12.20
	October	21.10	19.70	12.00	44.20	1.00	7.30	69.20

Soil samples were taken before sowing from 0-90 cm soil profile (from three depth segments as 0-30, 30-60 and 60-90 cm). Soil moisture content at field capacity (33 kPa) was determined in accordance with Klute (1986) and bulk density with Blake & Hartge (1986). Disturbed samples were subjected to organic matter, texture and permanent wilting point analyses. Water holding capacity at permanent wilting point (1500 kPa) was determined in accordance with Klute (1986). Soil physico-chemical characteristics are provided in Table 2.

Experimental soils were classified as brown forest soil with low electrical conductivity and salinity, low phosphorus content, high potassium content and medium level organic matter content and lime levels were not posing any problems for plant growth.

Table 2- Some physical and chemical soil characteristics of the research site

Properties	*Soil layer (cm)*		
	0-30	*30-60*	*60-90*
Clay (%)	62.00	58.00	55.00
Silt (%)	20.00	25.00	32.00
Sand (%)	18.00	17.00	13.00
Texture	Clay	Clay	Clay
Field capacity (Pw_{fc})	33.52	36.04	35.38
Permanent wilting point (Pwp)	24.44	26.08	25.57
Bulk density ($g\ cm^{-3}$)	1.42	1.39	1.41
pH ($1.25\ sw^{-1}$)	7.50	7.66	7.91
Electrical conductivity ($dS\ m^{-1}$)	1.55	1.77	1.75
Organic matter (%)	3.09	2.06	1.80
$CaCO_3$ (%)	6.40	1.90	1.90

Irrigation water quality parameters were determined in accordance with the method specified by Tuzuner (1990). Irrigation water quality class was C_2S_1 with an average EC value of 0.34 $dS\ m^{-1}$ and a pH value of 7.21. Experiments were conducted in randomized blocks-split plots experimental design with 3 replications with genotypes (P64

LE119, PR63 F73 and P64 LL62) on main plots and irrigation treatments (I_{100}, I_{70} and I_{35}) on sub-plots.

Irrigation program was scheduled as to have irrigations once a week. Treatments were selected as no water-stress treatment (I_{100}) in which 100% of depleted moisture was supplied, mild water-stress treatment (I_{70}) in which 70% of depleted moisture was supplied and strong water-stress treatment (I_{35}) in which 35% of depleted water was supplied. Therefore, one full irrigation and two deficit irrigation treatments were created.

Drip irrigation was used to perform irrigations. A lateral line (20 mm and 4 atm operational pressure, 0.33 m apart 4 L h^{-1} drippers) was placed along each plant row. Soil infiltration rate was measured as 7 mm h^{-1}. Deep percolation and surface runoff were not considered. Each plot has a size of 6x2.8 m (16.8 m^2) with 4 plant rows with 70 cm row spacing and 30 cm on-row plant spacing. A buffer zone of 2 m was placed between the experimental plots as to prevent interactions.

All of the phosphorus fertilizer (pure 90 kg ha^{-1} P_2O_5) and one third of nitrogen (280 kg ha^{-1} N) were supplied at sowing. Rest of the nitrogen was given when the plants were 40-50 cm tall.

Gravimetric moisture content of each layer (0-30, 30-60 and 60-90) was converted into depth with Equation 1.

$$d = \frac{(Pw_{FC} - Pw_{AW}) \times As \times D}{100} \tag{1}$$

Where; *d*, soil moisture content in depth (mm); Pw_{FC} is field capacity (%); Pw_{AW} is moisture content of each layer (%); As is bulk density (g cm^{-3}); *D* is layer depth (mm). Volume of water to be applied was calculated by using the following Equation 2.

$$d_{T(0-90)} = d_{(0-30)} + d_{(30-60)} + d_{(60-90)} \tag{2}$$

Where; $d_{T(0-90)}$ is soil moisture at 0-90 cm soil profile (mm); $d_{(0-30)}$ is soil moisture at 0-30 cm soil profile (mm); $d_{(30-60)}$ is soil moisture at 30-60 cm soil profile (mm); $d_{(60-90)}$ is soil moisture at 60-90 cm soil profile (mm).

Volume of water to be applied to each plot was calculated by Equation 3.

$$V = d_T \times A \times U_0 \times P \tag{3}$$

Where; *V* is volume of water to be applied (L); *A* is plot size (m^2); U_0 is deficit ratio (%) and *P* is cover ratio (%).

Plant canopy width was divided by row spacing to get cover ratios (CR). The ratio was taken as 0.30 and 0.80 for cover ratios of 30% and 80%. The principles specified in Gungor et al (2006) were employed to find out the amount of water to be used in each plot.

Water budget method was used to calculate monthly and seasonal evapotranspiration values (Sahin et al 2007). Water use efficiency (WUE) values were calculated by using Equation 4 (Scott 2000).

$$WUE = \frac{Y}{ET_a} \tag{4}$$

Where; *WUE* is water use efficiency (kg da mm^{-1}); *Y* is yield; ET_a is evapotranspiration (mm).

Plant water consumptions were calculated by using Equation 5 (Sahin et al 2007).

$$ET_a = P + I - R_f - D_p \pm \Delta S \tag{5}$$

Where; ET_a is evapotranspiration (mm); *P* is precipitation (mm); *I* is amount of irrigation water (mm); R_f is surface flow (mm); D_p is deep percolation (mm); ΔS is the change in soil moisture (mm).

Change in CWSI and CC values of P64LE119, PR63F73, P64LL62 sunflower genotypes grown under I_{100}, I_{70} and I_{35} irrigation treatments were determined in one week intervals. CWSI and CC measurements were performed along the diagonals of each plot in four corners in three replications from the leaves close to head.

CWSI values were calculated by using Equation 6 as recommended by Idso (1982).

$$CWSI = \frac{\left[\left(T_c - T_a\right) - LL\right]}{UL - LL} \tag{6}$$

Where; $CWSI$ is crop water stress index; T_c is canopy temperature (°C); T_a is air temperature (°C); LL is lower limit of water stress; UL is upper limit of water stress.

The lower limit (LL) at which plants did not experience any water stresses was calculated by the equation provided by Idso (1982) and using regression analyses between canopy-air temperature and vapor pressure deficit (VPD, kPa) (Equation 7);

$$T_c - T_a = (a - b) \times VPD \tag{7}$$

Where; a is intermediate section value (°C); b is slope of the line (kPa °C^{-1}); VPD is vapor pressure deficit (kPa).

Vapor pressure deficit was calculated with basic psychrometric equations (Alderfasi & Nielsen 2001). These equations are provided below;

$$e_w = 0.61078 \exp\left[\frac{17.27\, T_w}{237.3 + T_w}\right] \tag{8}$$

$$e_a = e_w - \left[AP \times \left(T_a - T_w\right)\right] \tag{9}$$

Where; e_w is saturated vapor pressure at wet-bulb temperature (kPa); e_a is actual vapor pressure at air temperature (kPa); T_w is wet-bulb temperature (°C); A is psychrometric constant (kPa °C^{-1}); P is barometric pressure (kPa).

Psychrometric constant (A) was calculated from the following equation;

$$A = \left[0.00066\left(1 + 00115\, T_w\right)\right] \tag{10}$$

Saturated vapor pressure was calculated by using the following equation;

$$e_a \times T_a = 0.61078 \exp\left[\frac{17.27\, T_a}{237.3 + T_a}\right] \tag{11}$$

Vapor pressure deficit (VPD) was calculated as the difference of saturated vapor pressure at dry-bulb temperature from the actual vapor pressure at the same temperature;

$$VPD = \left[(e_a \times T_a) - e_a\right] \tag{12}$$

Where; e_a x T_a is saturated vapor pressure at dry-bulb temperature (kPa).

The upper limit (UL) at which plants experienced full-water stress was calculated by using the equations recommended by Idso et al (1981);

$$T_c - T_a = \left(a - b\right) \times VPG \tag{13}$$

$$VPG = \left[\left(e_a \times T_a\right) - e_a \times \left(T_a + a\right)\right] \tag{14}$$

Where; a and b are lower limits (LL) at which there are no water stress; VPG is slope of negative atmospheric vapor pressure required for the training of zero canopy-air vapor pressure.

CC of the genotypes was measured with a portable chlorophyll meter. Measurements were initiated when the plant cover ratio of the plots reached to 80% and performed throughout the growing season before and after the irrigations from the same plant and same leaves. Measurements were performed in days with clear sky and between 12$^{:00}$-14$^{:00}$ hours when the change in sun-ray angles the least. Chlorophyll-meter measurements were taken from the leaves just beneath the sunflower head, the device was oriented over the leaf as not to create a shade over it and 3 subsequent measurements (a total of 12 readings) were taken along the diagonal of the plot. CC increases as the value approaches to 1 and decreases as the value approaches to 0.

Harvest was performed when the seed moisture content decreased to 10% to determine the yields. Side rows and 0.5 m space at top and bottom of inner two rows were omitted as to consider side effects.

Analysis of variance (ANOVA) was performed in accordance with randomized blocks-split plots experimental design. Significant treatments were then subjected to LSD (Least Significant Difference) multiple comparison tests. Correlation analyses were carried out to identify the relationships between the traits. The directions of the relationships (positive or negative) were determined. Analyses were carried out with JUMP 5.0.1a statistical software (Der & Everitt 2002).

3. Results and Discussion

Seven irrigations were performed in all irrigation treatments. Irrigation water applied in 2015 and 2016 was measured as 550.80 and 624.46 mm in no water-stress treatments and as 216.20 and 245.09 mm in strong water-stress treatments. Seasonal plant water consumptions varied between 626.30-696.66 mm in no water-stress treatments and between 291.70-317.29 mm in strong water-stress treatments (Table 3). Higher ET_a values of strong water-stress treatments were because plants continued to benefit from the residual moisture in soil from the winter precipitations even after termination of irrigations. Water consumptions of the same plant genotypes may vary based on climate and regions and such values may even vary within the same region. Relevant differences might be due to the differences in plant genotypes, climate parameters, soil properties, method of irrigation and irrigation schedules.

The variations in yield and physiological characteristics of sunflower genotypes with irrigation water quantities are provided in Table 3, correlation coefficients between yield and other parameters are provided in Table 4. Significant differences were observed in yield, CWSI, CC and WUE values of the genotypes (P<0.01) and such differences were then subjected to LSD test (grouping) (Table 3). In the first year of experiments, the greatest yield in strong water-stress treatments (2657.67 kg ha^{-1}) was obtained from I_{35}xP64LE119 interaction with a low CWSI (0.31) and CC (37.13 spad) value and the lowest yield (2597.63 kg ha^{-1}) was obtained from I_{35}xPR63F73 interaction with a high CWSI (0.49) and a low CC (34.73 spad) value. The greatest yield in no water-stress treatments (4214.66 kg ha^{-1}) of the first year was obtained from I_{100}xP64LE119 interaction with a low CWSI (0.19) and a high CC (50.33 spad) values and the lowest yield (3914.65 kg ha^{-1}) was obtained from I_{100}xPR63F73 interaction with a high CWSI (0.26) and a low CC (46.25 spad) value. Genotypes also had significant impacts on yields (P<0.01). The greatest yield (3519.0 kg ha^{-1}) was obtained from P64LE119 genotype and the lowest yield (3398.0 kg ha^{-1}) was obtained from PR63F73 genotype. In the second year of experiments, the greatest yield (2685.66 kg ha^{-1}) in strong water-stress treatments was obtained from I_{35}xP64LE119 interaction with a low CWSI (0.37) and a high CC (36.11 spad) value and the lowest yield (2378.00 kg ha^{-1}) was obtained from I_{35}xPR63F73 interaction with a high CWSI (0.56) and a low CC (34.04) value. The greatest yield (3974.66 kg ha^{-1}) in no water-stress treatments of the second year was obtained from I_{100}xP64LE119 interaction with a low CWSI (0.22) and a high CC (49.32 spad) value and the lowest yield (3800.0 kg ha^{-1}) was obtained from I_{100}xPR63F73 interaction with a high CWSI (0.28) and a low CC (45.76) value. Variance analyses revealed that genotypes had significant effects on yields also in the second year of the experiments (P<0.01). Similar to the first year, the greatest yield (3393.33 kg ha^{-1}) was observed in P64LE119 genotype and the least (3225.88 kg ha^{-1}) in PR63F73 genotype. The other genotype (P64LL62) was placed in between these two genotypes in both years. As to conclude, significant interactions were observed between irrigation treatments and genotypes. Complying with the present findings, Kassab et al (2012) also reported significant interactions between irrigation treatments and genotypes. Water deficits in flowering period may cause considerable yield losses (Ali & Shui 2009). In addition, Afkari (2010), Kassab et al (2012) showed that water deficits significantly reduced plant heights, number of seeds per head, leaf area index and leaf relative water content of sunflower. Current findings comply with the results of Ali & Shui (2009), Afkari (2010) and Kassab et al (2012). However, Alahdadi et al (2011) reported substantial yield losses at short-term water deficits. Moisture deficiencies may negatively influence plant regeneration since sunflower is quite sensitive to drought stress during pollination period (Hajhassani-Asl et al 2009). Zaeifizade & Goliov (2009) showed that deficit moisture levels from budding to the end of flowering had devastating impacts on yields. In addition, Chimenti et al (2002) indicated flowering and seed maturity stages as the sensitive stages of sunflower to water-stress. Current results are in line with the findings of Hajhassani-Asl et al (2009), Zaeifizade & Goliov

(2009) and Chimenti et al (2002). Darvishzadeh et al (2010) carried out a selection study for water stress resistance of sunflower genotypes and reported that relevant genotypes exhibited similar performances both under water stress conditions and optimum conditions. Therefore in present study, the genotype P64LE119 with similar yield performance under both strong water-stress and no water-stress conditions were found to be prominent. Then, it was determined that this genotype could be used in studies to be carried out for the resistance or tolerance of sunflower genotypes to water stress and other abiotic stress factors.

In the first year of experiments, the greatest CC (37.13 spad) in strong water-stress treatments was obtained from I_{35}xP64LE119 interaction and the lowest value (34.73 spad) was obtained from I_{35}xPR63F73 interaction. The greatest CC (50.33 spad) in no water-stress treatments of the first year was obtained from I_{100}xP64LE119 interaction and the lowest value (46.25 spad) was obtained from I_{100}xPR63F73 interaction. Variance analyses revealed that genotypes had also significant effects on CC values. The greatest CC (44.15) was observed in P64LE119 genotype and the lowest value (40.17 spad) was observed in PR63F73 genotype. In the second year of experiments, the greatest CC (36.11) in strong water-stress treatments was seen in I_{35}xP64LE119 interaction and the lowest value (34.04) was observed in I_{35}xPR63F73 interaction. In no water-stress treatments of the second year, the greatest CC (49.32) was seen in I_{100}xP64LE119 interaction and the lowest value (45.76) was observed in I_{100}xPR63F73 interaction. Variance analyses revealed also for the second year that genotypes had significant effects on CC values with the greatest value (42.93) in P64LE119 genotype and the lowest value (39.70 spad) in PR63F73 genotype. The decrease in CC values was low in drought-resistant genotypes and high in sensitive genotypes (Table 3). Plants have different resistances to stress conditions and even different genotypes of the same plant may have different resistance levels (Win et al 2011) Robert et al (2016) reported decreased chlorophyll a, b and total chlorophyll contents in sunflowers under water stress. Several other researchers also reported decreased leaf chlorophyll contents under water stress conditions (Demirtas & Kirnak 2009; Zlatev et al 2010). It was also reported in previous studies that CC values might vary based on plant genotypes, cultivars, environmental and climate conditions (Testi et al 2008). Present findings comply with those earlier results.

In the first year of experiments, the greatest CWSI (0.49) in strong water-stress treatments was seen in I_{35}xPR63F73 interaction and the lowest (0.31) was observed in I_{35}xP64LE119 interaction. In no water-stress treatments of the first year, the greatest CWSI (0.26) was seen in I_{100}xPR63F73 interaction and the lowest (0.19) was observed in I_{100}xP64LE119 interaction. Variance analyses revealed that genotypes also had significant effects on CWSI values with the greatest value (0.40) in PR63F73 genotype and the lowest value (0.26) in P64LE119 genotype. In the second of experiments, the greatest CWSI (0.56) in strong water-stress treatments was observed in I_{35}xPR63F73 interaction and the lowest value (0.37) was seen in I_{35}xP64LE119 interaction. In no water-stress treatments of the second year, the greatest CWSI (0.28) was observed in I_{100}xPR63F73 interaction and the lowest value (0.22) was seen in I_{100}xP64LE119 interaction. Variance analyses again revealed that genotypes had significant effects on CWSI values with the greatest value (0.43) in PR63F73 genotype and the lowest value (0.29) in P64LE119 genotype. CWSI values of the second year were relatively higher than the CWSI values of the first year (Table 3). Drier conditions of the second year as compared to the first year increased evapotranspiration, thus CWSI values were found to be higher in the second year. Decreased CC and higher CWSI values were reported for water stress treatments (Moran et al 1994). Thusly, Khayatnezhad et al (2011) reported decreased chlorophyll contents and then reduced yields with water stress treatments in maize. Current findings comply with those earlier findings. P64LE119 with high yield, CC and low CWSI values were identified as resistant and the others were identified as sensitive.

Table 3- Changes in yield and physiological properties of sunflower genotypes

Treatments	*Yield (kg ha^{-1})***	*CWSI***	*Chlorophyll content (spad)***	*Irrigation water (mm)*	*ETa (mm)*	*WUE (kg da^{-1}-mm)***
2015 (First year)						
Irrigation treatments						
I_{100} (FI)	4071.00 a	0.21 c	48.36 a	550.80	626.30	0.65 c
I_{70} (DI)	3683.22 b	0.38 b	42.64 b	402.81	478.34	0.77 b
I_{35} (DI)	2625.33 c	0.42 a	36.11 c	216.20	291.70	0.90 a
Average	3459.85	0.34	42.37	389.94	465.44	0.77
LSD (0.05)	1.79	0.008	1.25			0.050
Varieties						
P64LE119	3519.00 a	0.26 c	44.15 a	364.37	439.87	0.80 a
P64LL62	3462.55 b	0.36 b	42.79 b	374.18	449.68	0.77 b
PR63F73	3398.00 c	0.40 a	40.17 c	383.68	459.18	0.74 c
Average	3459.85	0.34	42.37	374.07	449.57	0.77
LSD (0.05)	0.80	0.007	0.76			0,018
Varieties x irrigation treatments						
I_{100}xP64LE119	4214.66 a	0.19 h	50.33 a	526.69	602.09	0.70 d
I_{100}xP64LL62	4083.64 b	0.21 g	48.51 b	552.75	628.25	0.65 e
I_{100}xPR63F73	3914.65 c	0.26 f	46.25 c	576.94	652.44	0.60 f
I_{70}x 64LE119	3684.66 d	0.28 e	44.99 c	390.91	466.41	0.79 c
I_{70}x P64LL62	3683.33 d	0.43 c	43.39 d	409.15	484.65	0.76 c
I_{70}xPR63F73	3681.63 e	0.45 b	39.55 e	402.63	478.13	0.77 c
I_{35}x P64LE119	2657.67 f	0.31 d	37.13 f	207.23	282.73	0.94 a
I_{35X}P64LL62	2620.64 g	0.46 b	36.48 f	209.35	284.85	0.92 a
I_{35}xPR63F73	2597.63 h	0.49 a	34.73 g	225.72	301.22	0.87 b
Average	3459.85	0.34	42.37	389.04	464.53	0.78
LSD (0.05)	1.37	0.013	1.30			0.030
2016 (Second year)						
Irrigation treatments						
I_{100} (FI)	3901.33	0.24 c	47.69 a	624.46	696.66	0.56 c
I_{70} (DI)	3505.11	0.40 b	41.57 b	442.66	514.86	0.68 b
I_{35}	2538.33	0.47 a	34.86 c	245.09	317.29	0.80 a
Average	3314.92	0.37	41.38	437.40	509.60	0.68
LSD (0.05)	ns	0.017	1.72			0.005
Varieties						
P64LE119	3393.33 a	0.29 c	42.93	399.09	471.29	0.72 a
P64LL62	3325.55 b	0.39 b	41.50	416.85	489.05	0.68 b
PR63F73	3225.88 c	0.43 a	39.70	431.84	504.04	0.64 c
Average	3314.92	0.37	41.38	415.92	488.12	0.68
LSD (0.05)	48.5	0.012	ns			0.170
Varieties x irrigation treatments						
I_{100}xP64LE119	3974.66 a	0.22 h	49.32 a	601.47	673.67	0.59 e
I_{100}xP64LL62	3929.33 a	0.24 g	47.99 b	629.46	701.66	0.56 ef
I_{100}xPR63F73	3800.00 b	0.28 f	45.76 c	644.78	716.98	0.53 f
I_{70}x P64LE119	3519.67 c	0.30 e	43.36 d	430.61	502.81	0.70 cd
I_{70}x P64LL62	3499.66 c	0.44 c	42.05 e	442.46	514.66	0.68 d
I_{70}xPR63F73	3496.00 c	0.46 b	39.30 f	449.59	521.79	0.67 d
I_{35}x P64LE119	2685.66 d	0.37 d	36.11 g	232.98	305.18	0.88 a
I_{35X}P64LL62	2551.33 e	0.48 b	34.45 h	238.94	311.14	0.82 b
I_{35}xPR63F73	2378.00 f	0.56 a	34.04 h	253.55	325.75	0.73 c
Average	3314.92	0.37	41.38	435.98	508.18	0.68
LSD (0.05)	84.00	0.020	1.02			0.041

**, significant at P≤0.05 and P≤0.01; ns, not significant; means in the same column with the same letter are not significantly different

Significant correlations were observed between yield and CWSI and between yield and CC values ($P<0.01$). The correlation coefficients (r) for the relationships of yield with CC, CWSI and WUE are presented in Table 4a and b respectively for the years 2015 and 2016. Each year was assessed in itself to see the year-based variations in correlation and regression between the investigated traits. Significant correlations were observed between the investigated traits in 2015 ($P<0.01$). There was an increasing correlation between CC and yield ($r= 0.925^{**}$). The regression analysis between these two parameters revealed a linear relationship as of Yield= -1253.00 + 111.00 x (CC). In this relation, 1 spad increase in CC corresponds to 1.142 kg increase in yield. Coefficient of determination was observed as $R^2= 86\%$. In other words, the change in yield was 86% influenced by CC. There was decreasing correlation between CWSI and yield ($r= -0.664^{**}$). The regression analysis between these two parameters revealed a negative linear relationship as of Yield= 4809.31 - 3887.77 x CWSI. In this relationship, 1 unit increase in CWSI corresponds to 0.921 kg decrease in yield. Coefficient of determination was identified as $R^2= 44.6\%$.

Table 4- The correlation coefficients between yield and other parameters

a (2015)	*Yield*	*WUE*	*CWSI*	*CC*
Yield		-0.782^{**}	-0.664^{**}	0.925^{**}
WUE	-0.782^{**}		0.594^{**}	-0.794^{**}
CWSI	-0.664^{**}	0.594^{**}		-0.837^{**}
CC	0.925^{**}	-0.794^{**}	-0.837^{**}	
b (2016)	*Yield*	*WUE*	*CWSI*	*CC*
Yield		-0.825^{**}	-0.797^{**}	0.953^{**}
WUE	-0.825^{**}		0.577^{**}	-0.821^{**}
CWSI	-0.797^{**}	0.577^{**}		-0.879^{**}
CC	0.953^{**}	-0.821^{**}	-0.879^{**}	

**, $P<0.01$; WUE, water use efficiency; CWSI, crop water stress index; CC, chlorophyll content

Significant correlations were also observed between all parameters in 2016 ($P<0.01$). There was a highly positive correlation between CC and yield ($r= 0.953^{**}$). The regression analysis between these two parameters revealed a linear relationship as of Yield= -926.12 + 102.65 x CC. In this relationship, 1 spad increase in CC corresponds to 0.823 kg increase in yield. Coefficient of determination was identified as $R^2= 90\%$. In other words, the change in yield was 90% influenced by CC. There was a decreasing correlation between CWSI and yield ($r= -0.797^{**}$). The regression analysis between these two parameters revealed a linear relationship as of Yield= 4840.49 - 4071.49 x CWSI. In this relationship, 1 unit increase in CWSI corresponds to 0.769 kg decrease in yield. Coefficient of determination was identified as $R^2= 63.9\%$. In other words, the change in yield was 63.9% influenced by CWSI.

4. Conclusions

As the average of two years, the greatest yield was obtained from I_{100}xP64LE119 interaction (4094.66 kg ha^{-1}) and the lowest yield was obtained from I_{35}xPR63F73 interaction (2487.81 kg ha^{-1}). The greatest CC was observed in I_{100}xP64LE119 interaction (49.83 spad) and the lowest value was seen in I_{35}xPR63F73 interaction (34.39 spad). The greatest CWSI was observed in I_{35}xPR63F73 interaction (0.53) and the lowest CWSI was observed in I_{100}xP64LE119 interaction (0.21). There was an inverse relationship between irrigation water and CWSI and a direct relationship between irrigation water and CC. CWSI values decreased and CC values increased with increasing irrigation water quantities. However, such increase or decreases were not constant and varied based on genotypes even in no water-stress treatments. The greatest WUE (0.76 kg da mm^{-1}) was observed in P64LE119 genotype and it was placed in group A. The lowest WUE (0.71 kg da mm^{-1}) was observed in PR63F73 genotype and it was placed in group C. Therefore, the genotype P64LE119 was found to be prominent both in strong water-stress and no water-stress treatments and optimally converted applied irrigation water into the yield. The water stress-induced reduction in CC was low in water stress-resistant genotypes and high in sensitive genotypes.

In brief, in strong water-stress and no water-stress treatments of the experimental years, yield, CWSI and CC values of P64LE119 genotype were above the averages. Therefore, P64LE119 genotype was identified as water stress-resistant and can be used in further studies to be carried out for resistance to abiotic stress factors.

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