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Expression of Heterosis, Gene Action and Relationship among Morpho-physiological and Yield Characters in Sunflower under Different Levels of Water Supply

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ABSTRACT

In order to monitor heterosis, inheritance and interrelationship among morpho-physiological and yield characters in sunflower, half diallel crosses among seven genetically divergent inbred lines were evaluated under adequate water supply, moderate and severe stress. Drought sensitivity index indicated that the parental sunflower genotypes L38 and L990 and the F_1 crosses L38 x L990 and L350 x L460 were more tolerant to water stress, whereas L11 and L235 and the F_1 cross L11 x L990 classified as sensitive one. Cross combination L38 x L350 scored desired and significant heterosis for leaf chlorophyll content at moderate stress; transpiration rate at severe stress; achene yield/plant and achene oil content at adequate water supply and moderate stress. Additive gene action had a great role in controlling transpiration rate, plant height and achene oil content, while dominance was important in controlling achene yield/plant under the three levels of water regimes. The environmental variance had significant effect on gene expression of physiological and yield characters in most cases. Narrow sense heritability was high (>50%) for transpiration rate and low (< 30%) for achene yield/plant under the three levels of water regimes. Significant positive correlations were registered between achene yield/plant and each of leaf water content, transpiration rate, plant height, head diameter and 100-achene weight across three environments. The maximum direct effect on achene yield/plant was accounted for transpiration rate and plant height with values of 12.941% and 12.219%, respectively. The highest indirect effects on achene yield/plant variation were observed for transpiration rate via plant height followed by transpiration rate via 100-achene weight; leaf water content via 100-achene weight with values of 8.442%, 5.530% and 4.579%, respectively across three environments.
Keywords: Sunflower, heterosis, gene action, correlation, path analysis, water stress

INTRODUCTION

Egypt's production of edible vegetable oils has been suffering several problems due to the lower domestic production of oil crops that resulted in failing to meet the needs of domestic consumption (Hassan and Sahfique, 2010). Sunflower (*Helianthus annuus* L.) has become an important oil crop in the world. The total area reached about 24.8 million hectares worldwide with average productivity 1.66 ton/ha. gave total production 41.3 million metric tons. Meanwhile, in Egypt, the total area was about 10000 hectares with average productivity 2.5 ton/ha. gave total production 25 000 tons (FAOSTAT, 2014).

Sunflower breeders have therefore devoted effort to develop superior genotypes for seed yield and adaptation to the different stress factors. Drought was a key factor responsible for yield losses of up to 20% (Reddy *et al*., 2004). High yield is the ultimate objective of any breeding program. However, high yield and drought tolerance are two different mechanisms that are often found to oppose each other. For achieving this purpose, information on the performance of parents, their behavior in hybrid combinations is prerequisite. Therefore, estimate of performance, heterosis, genetic components is essential for identification the promising hybrids tolerant to drought in breeding programs.

The importance of additive and non-additive gene action for seed yield and other related characters have been mentioned by many investigators of them, Goksoy and Turan (2004) indicated that non-additive gene action was accounted the most part of the genetic variation for seed yield and plant height. Neither additive nor non-additive variances were found to be significant for head diameter and 1000- seed weight. However, Ortis *et al*. (2005) indicated the predominant role of additive component for plant height, 1000-seed weight and seed oil content. 1000-seed weight and oil yield were under control of both additive and dominant effects, plant height and oil content were controlled by additive effects, however over dominant effects were detected for seed yield (Ghaffari *et al*., 2011). Also, Burli *et al*. (2001) and Ravi *et al*. (2004) discussed the importance of non-additive gene effects in the expression of seed yield and all contributing characters. Furthermore, Bakheit *et al*. (2010) indicated that the dominance gene action (non-additive gene affects) was more important in controlling plant height, head diameter, 100-achen weight, achene yield/plant and achene oil %.

Utilization of heterosis has allowed sunflower to become one of the major oil seed in many countries of the world. One of approximately 16.5 million hectares of sunflower grown in the major producing countries, 11.5 million hectares are planted to hybrids (Miller, 1998). The introduction of hybrid cultivars produced an increase in yield potential around 25% through exploitation of heterosis (Fernández-Martínez *et al*. 2009). Encheva *et al*., (2015) recorded positive and significant heterosis in the direction of both relative to parental average and relative to better parent for plant height, diameter of head and seed yield per plant.

Yield is a complex character and is a function of several traits and their interaction with environment. It is important to measure the mutual relationship between various plant attributes and determine the characters, on which selection procedure can be based for direct and indirect genetic improvement of crop yield. The estimates of genotypic, phenotypic and environmental correlations among the characters are useful in planning the selection strategies. Since, the relations between leaf chlorophyll content, relative water content, transpiration in particular during water stress, are well described in sunflower (Hirasawa *et al*., 1995; Guidi and Soldatini, 1997; Pankovic *et al*., 1999 and Pourmohammad, 2016). However, only a few papers reported the genetic determinism of these traits of them Hervé *et al*. (2001)

Path coefficient analysis is helpful in partitioning the correlation coefficients into its direct and indirect effects, and many researchers calculated path coefficient analysis of them, Rauf *et al.* (2012), Ardiarini *et al.* (2013) and Iqbal *et al.* (2013). Also, Darvishzadeh *et al.* (2011) found that genotypic correlations manifest that seed yield per plant was positively and significantly associated with head diameter, plant height and achene traits at well-watered condition and with head diameter and chlorophyll content at water-stressed state. Head diameter and number of achene at both conditions and chlorophyll content at water-stressed condition have positive direct effect on seed yield/plant.

The present study was conducted to estimate heterosis, genetic components, correlations and path coefficient analyses for leaf water content, leaf chlorophyll value, transpiration rate, plant height, head diameter, 100-achene weight, achene yield/plant and achene oil content (%) in 7 inbred lines and their F_1 crosses.

MATERIALS AND METHODS

Description of the studied sunflower genotypes

Field experiments were carried out during the two successive seasons 2009 and 2010 at El-Khattara Agriculture Research Stations, Faculty of Agriculture, Zagazig University, Egypt. The experimental materials comprised 7 sunflower inbred lines (L38 and L11 from Egypt and L350, L460, L990, L770 and L235 from Bulgaria). The seeds of all inbred lines were obtained from Oil Research Department, Field Crops Research Institute, Agricultural Research Center (ARC), Ministry of Agriculture and Land Reclamation, Egypt.

Mating system and experimental layout

In 2009 season, the seven inbred lines were crossed in 7 x 7 half diallel to obtain sufficient seed for evaluation in the next season. Each inbred line was sown in 10 rows; each row was 6 meters length, plant to plant and row to row distances were 30 and 50 cm, respectively. In 2010 season, the resultant 21 hybrids were evaluated along with their respective parents under three levels of water regimes (adequate water supply with 7140 m^3, moderate 4760 m^2 and severe stress 2380 m^3/ha.). Quantities of water irrigation were adjusted using a water counter for all irrigation treatments under drip irrigation system. A split plot design with four replicates was used, where the main plots assigned for water regimes and the subplots for sunflower genotypes. The subplot area was 15 m^2 and comprised two rows for each parent and F_1 hybrid. The row length was 5 m, with spacing 50 cm between rows. Three seeds of sunflower genotypes were sown in hills 30 cm apart on 1^{st} June in both seasons. After 21 days from sowing, thinning to one plant/hill was done. All the other cultural practices for growing sunflower were applied as recommended. The soil of the experimental site is sandy in texture and had an average pH of 8.1 and organic matter content of 0.26 %. The average available N, P, K contents were 15.1, 3.2 and 90.5 ppm, respectively.

Collected data

Plant height (cm), leaf chlorophyll content, leaf water content (%), transpiration rate, head diameter (cm), 100- achene weigh (g), achene yield/plant (g) and achene oil content (%) were estimated for each sunflower genotype of each replicate under the levels of water regime. At flowering stage, five randomly selected plants were taken from each entry of each replication to estimate leaf chlorophyll content, transpiration rate and leaf water content. Leaf chlorophyll content (SPAD values) was assessed using chlorophyll meter (SPAD - 502, Minolta), measurements were taken from three points of each leaf (upper, middle and lower part). The average of these three readings was considered as SPAD reading of the leaf. Leaf transpiration rate (mg $H_2O/cm^2/h$) was estimated according to the adopted rapid weighing systems (Migahid and Amer, 1950 and Gosev, 1960). Leaf water content (%) was determined according to Turner (1981). At harvest, five guarded plants were taken from each entry of each replication for estimating plant height, head diameter and achene yield/ plant. Drought sensitivity index (DSI) was calculated according to Fischer and Maurer (1978). DSI = $[1 - (Ys / Yp]/SI$, while SI (stress intensity) = $1 - (\bar{Y}s / \bar{Y}p)$. Where, Ys and Yp are the achene yield of a genotype under stress and adequate water supply conditions, respectively, also $\bar{Y}s$ and $\bar{Y}p$ are general mean yield in stress and non-stress conditions, respectively. A sample of 100- filled seeds (at 8% moisture content) was drawn at random from the bulked seeds of 5 plants with an electronic balance. Achene oil content % was determined according to AOAC (1984) using Soxhlet apparatus and diethyl ether as a solvent.

Statistical analysis

The obtained data were analyzed according to Steel and Torrie (1980). Mid-parent $(\overline{M.P.})$ heterosis value was evaluated by using t-test according to Wynne *et al.* (1970). Genetic components and derived parameters were estimated using diallel biometrical approach outlined by Hayman (1954a and b). Genotypic, phenotypic and environmental correlations and path coefficient analyses were computed according to Miller *et al.* (1958). The path coefficient analysis was estimated as outlined by Dewey and Lu (1959). A PC Microsoft Excel and SAS 9.1® Computer program for Windows were used for statistical analysis.

RESULTS AND DISCUSSION

Analysis of variance

Analysis of variance of sunflower genotypes (G) i.e., parents and their F_1 crosses and between the three levels of water regime (W) and (G X W) interaction were computed for leaf water content, leaf chlorophyll content (SPAD), transpiration rate (mg $H_2O/cm^2/h$), plant height (cm), head diameter (cm), 100-achene weight (g), achene yield/plant (g) and achene oil content (%). The results showed highly significant differences between parental sunflower genotypes and their F_1 crosses under the three levels of water supply and (G X W) interaction for the studied characters. This confirms the presence of considerable amount of genetic variability among the genetic materials valid for further biometrical assessments. It is interest to note that, the sunflower genotypes differed in their behavior from adequate water supply, moderate to severe water stress. Significant differences were detected between sunflower parents and their F_1 crosses under different environments for morpho-physiological characters by Herve et al. (2001) and Ibrahim et al. (2003) and for yield contributing characters by Rauf and Sadaqat (2007) and Iqbal et al. (2013).

Mean performance

Physiological characters

The results in Table (1) indicated that highly significant differences were observed between parents and their F_1 crosses under the three levels of water regimes for various physiological characters. The parental sunflower genotypes P_3 (L11) and P_4 (L460) exhibited the highest values for leaf water content, as well as their F_1 crosses P_3 x P_4 and P_4 x P_7 under adequate water supply; P_2 (L350) and P_4 (L460) as well as F_1 crosses P_1 x P_2, P_1 x P_7, P_2 x P_3, P_2 x P_4 , P_2 x P_5, P_3 x P_4, P_3 x P_5 and P_4 x P_7 under moderate as well as P_1 and P_2 and their F_1 crosses P_1 x P_2, P_1 x P_4, P_2 x P_4, P_2 x P_6 and P_4 x P_7 under severe stress. The general mean of leaf water content tended to decrease from 91.00, 82.46 and 68.56 % for adequate water supply, moderate and severe stress, respectively.

Results of leaf chlorophyll content indicated that the highest values were registered by P_1 (L38) and P_4 (L460) as well as F_1 crosses P_1 x P_2, P_1 x P_4, P_2 x P_4, P_3 x P_4 and P_4 x P_6 under adequate water supply; P_1 (L38) , P_4 (L460) as well as F_1 crosses P_1 x P_2, P_1 x P_3, P_1 x P_4, P_2 x P_3, P_3 x P_4 and P_3 x P_7 under moderate as well as P_1 (L38) , P_4 (L460) and P_7 (L235) and F_1 crosses P_1 x P_4, P_2 x P_3, P_2 x P_4, P_3 x P_4, P_4 x P_6 and P_4 x P_7 under severe stress. The general mean of leaf chlorophyll valued 37.61, 38.01and 36.94 under adequate water supply, moderate and severe stress, respectively.

Lower transpiration rates were registered by P_1 (L38) and P_4 (L460) as well as the F_1 crosses P_1 x P_3, P_1 x P_4, P_1 x P_7, P_2 x P_4, P_3 x P_4, P_3 x P_7 and P_4 x P_7 under adequate water supply; P_1 and P_3 as well as the F_1 crosses P_1 x P_2, P_1 x P_3, P_1 x P_7, P_2 x P_7, P_3 x P_7 and P_4 x P_7 under moderate, as well as P_1 and P_7 and the F_1 crosses P_1 x P_6, P_1 x P_7, P_2 x P_7, P_3 x P_6, P_3 x P_7, P_5 x P_7 and P_6 x P_7 under severe stress.

Table 1. Mean performance for physiological characters of sunflower genotypes of half-diallel analysis under three environments.

Character	Leaf water content (%)			Leaf chlorophyll content (SPAD)			Transpiration rate (mg $H_2O/cm^2/h$)		
Water supply	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress
Genotype									
P1 (L38)	87.73	78.05	70.02	41.18	39.03	36.60	0.68	0.32	0.30
P2 (L350)	91.05	89.35	70.53	38.38	36.85	35.43	0.94	0.72	0.45
P3 (L11)	91.40	77.15	66.58	38.20	36.55	35.88	0.86	0.65	0.35
P4 (L460)	90.25	82.10	68.13	40.38	40.85	40.53	0.78	0.70	0.58
P5 (L990)	89.10	80.23	64.88	36.98	34.58	35.45	1.12	0.80	0.40
P6 (L770)	90.18	79.25	64.98	36.98	37.00	35.70	1.08	0.87	0.32
P7 (L235)	91.20	80.63	65.85	38.15	35.73	36.93	0.88	0.57	0.25
P1 x P2	94.60	85.40	72.60	39.45	39.25	37.50	0.90	0.65	0.40
P1 x P3	90.03	80.43	70.25	37.40	39.68	36.83	0.80	0.62	0.36
P1 x P4	91.13	82.23	73.35	38.45	39.05	39.18	0.82	0.68	0.51
P1 x P5	89.98	79.43	69.60	37.95	38.15	35.50	0.98	0.75	0.38
P1 x P6	92.33	79.45	72.28	37.00	38.50	36.05	0.96	0.80	0.35
P1 x P7	87.83	80.53	71.25	36.48	39.03	35.03	0.85	0.52	0.30
P2 x P3	92.00	84.65	69.80	36.80	40.80	38.80	0.92	0.70	0.42
P2 x P4	92.30	86.53	69.15	38.33	38.38	39.35	0.88	0.71	0.54
P2 x P5	90.25	87.58	69.80	36.00	37.00	37.03	1.02	0.78	0.43
P2 x P6	92.53	85.35	70.50	36.98	38.05	36.10	1.05	0.85	0.42
P2 x P7	90.18	83.68	69.48	35.88	39.03	35.30	0.93	0.60	0.35
P3 x P4	92.73	82.30	69.28	39.65	40.00	41.63	0.84	0.70	0.50
P3 x P5	89.60	87.28	66.80	36.18	38.08	36.05	0.99	0.76	0.38
P3 x P6	90.80	85.58	65.98	36.95	36.18	36.73	0.96	0.84	0.34
P3 x P7	89.40	80.53	66.58	36.00	40.95	36.00	0.89	0.65	0.32
P4 x P5	92.68	85.35	67.05	37.03	37.15	37.00	0.95	0.76	0.49
P4 x P6	93.53	81.30	69.95	41.48	37.48	38.98	0.90	0.82	0.45
P4 x P7	93.08	82.30	70.83	36.18	36.15	38.20	0.85	0.62	0.40
P5 x P6	89.20	80.48	61.53	34.98	37.13	36.20	1.00	0.83	0.35
P5 x P7	91.70	81.63	65.38	36.83	37.15	35.10	0.99	0.72	0.32
P6 x P7	91.38	80.30	67.33	36.80	36.50	35.40	1.02	0.77	0.30
Mean	91.00	82.46	68.56	37.61	38.01	36.94	0.92	0.71	0.39
L.S.D $_{0.05}$ (G)	3.42	6.28	3.71	2.10	3.50	3.41	0.08	0.07	0.06
L.S.D $_{0.05}$ (W)		0.87			0.57			0.01	
L.SD $_{0.05}$ (GxW)		4.60			3.04			0.07	

The general mean of transpiration rate appeared to be decreased with increasing water stress and valued 0.92, 0.71 and 0.39 mg $H_2O/cm^2/h$ under adequate water supply, moderate and severe stress, respectively. The interaction between sunflower genotypes and water supply treatments was significant, hereby the studied materials are effected by water stress applications

Some sunflower genotypes showed relative stability from environment to another i.e. P_2 (L350) and the F_1 crosses P_2 x P_5 and P_3 x P_5 for leaf water content from

7140 to 4760 m^3 water supply; P_2, P_3, P_4, and P_7, as well as the F_1 crosses P_2 x P_3, P_2 x P_4, P_2 x P_5, P_3 x P_6, P_4 x P_5, P_4 x P_6 and P_4 x P_4 for leaf chlorophyll content as well as P_1 and their F_1 cross P_1 x P_4 for transpiration rate from 4760 to 2380 m^3. Therefore, these genotypes are more tolerant to water stress. The grand mean of both characters tended to decrease from adequate water supply, moderate to severe stress. This result could be due to drought acclimation affected the partitioning of water between the apoplastic and symplastic fractions (Maury *et al*. 2006), they also found differential responses of three sunflower genotypes to water stress for leaf water parameters i.e., predawn leaf water potential, photosynthetic rate and stomatal conductance.

Yield and its attributes

The results in Tables (2 and 3) indicated that, P_1 (L38) and P_3 (L11) were the shortest ones among the studied parents, as well as their F_1 crosses P_1 x P_3 and P_1 x P_4 . On the other hand, P_5 (L990) and P_6 (L770) were the tallest ones, as well as their F_1 crosses P_2 x P_5, P_2 x P_6, P_4 x P_5 and P_5 x P_6. This trend was hold true under the three levels of water supply. Plant height tended to decrease from 137.87 to 123.92 and 103.34cm under 7140 m^3, 4760 m^3 and 2380 m^3, respectively, as a result of water stress effect on elongation of cells.

Parental sunflower genotypes P_4 (L460), P_5 (L990) and P_6 (L770) gave broader heads which transmitted to their F_1 progenies P_2 x P_4 , P_2 x P_5, P_2 x P_6, P_3 x P_6, P_5 x P_6 and P_6 x P_7 under the three environments. Otherwise, P_1 and P_2 as well as their F_1 crosses P_1 x P_2, P_1 x P_3, P_1 x P_6 and P_2 x P_7 were narrow in head diameter among the studied sunflower genotypes. The value of head diameter tended to decrease from 19.8 to 16.36 and 14.21cm, for adequate water supply, moderate to severe stress, respectively.

Sunflower inbreds P_5 (L990) and P_6 (L770) gave the heaviest 100-achene weight, as well as the F_1 crosses P_2 x P_6, P_3 x P_5, P_4 x P_5, P_4 x P_6, P_5 x P_6 and P_6 x P_7 rather than the studied genotypes under the three environments.

Table 2. Mean performance for morphological characters of sunflower genotypes of half-diallel analysis under three environments

Character	Plant height (cm)			Head diameter (cm)			100-achene weight (g)		
Water supply / Genotype	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress
P1 (L38)	79.95	68.38	60.50	15.80	13.28	12.38	9.35	7.48	5.38
P2 (L350)	130.88	119.28	98.53	16.68	13.50	12.70	10.40	9.23	6.00
P3 (L11)	114.85	100.63	91.98	18.69	16.78	12.98	8.53	7.65	6.20
P4 (L460)	120.23	117.75	96.98	19.28	15.30	14.03	8.25	7.28	7.00
P5 (L990)	150.55	129.48	112.20	19.03	17.00	15.13	8.85	8.03	8.23
P6 (L770)	148.63	138.45	104.73	18.88	16.70	15.08	8.95	7.80	7.30
P7 (L235)	141.00	128.20	105.08	18.25	15.33	13.95	8.15	7.63	7.08
P1 x P2	134.83	126.93	91.10	17.80	15.93	12.58	11.08	8.35	6.38
P1 x P3	115.30	106.25	100.40	19.13	16.03	12.55	8.88	8.43	6.85
P1 x P4	115.18	102.88	92.20	18.73	17.10	14.65	8.70	8.33	7.85
P1 x P5	142.85	130.38	100.55	18.30	15.03	13.23	9.98	8.90	7.48
P1 x P6	142.08	117.23	83.55	17.45	14.60	12.90	9.78	9.33	7.78
P1 x P7	142.75	133.00	106.63	19.33	15.28	13.98	9.45	8.10	7.60
P2 x P3	134.23	127.18	96.95	18.75	16.33	15.28	10.03	9.13	6.70
P2 x P4	126.55	121.00	101.43	21.30	17.10	14.85	10.70	8.85	7.28
P2 x P5	152.00	134.75	111.58	20.68	16.55	14.95	10.48	10.00	6.88
P2 x P6	155.13	137.43	117.31	22.33	17.45	14.75	11.33	9.10	6.75
P2 x P7	150.10	125.34	112.25	17.83	14.70	13.40	8.70	8.98	7.30
P3 x P4	125.68	114.28	98.38	20.83	16.23	14.38	9.78	8.25	6.68
P3 x P5	140.83	134.28	115.45	21.43	17.53	14.58	10.43	9.13	6.73
P3 x P6	136.60	131.13	111.90	22.50	16.90	13.33	8.75	7.25	6.50
P3 x P7	147.70	125.50	113.90	19.58	16.10	14.15	8.83	8.25	6.68
P4 x P5	153.45	128.65	110.55	21.18	18.00	15.65	9.08	8.28	7.15
P4 x P6	149.30	136.23	113.60	21.75	16.73	15.98	9.05	7.95	6.90
P4 x P7	155.95	136.28	109.10	21.18	16.85	14.68	8.88	7.08	6.98
P5 x P6	156.60	133.78	112.00	23.43	19.13	15.50	9.60	8.88	7.38
P5 x P7	149.75	130.75	112.93	21.90	18.33	14.63	9.23	7.05	6.05
P6 x P7	147.45	134.43	111.68	22.38	18.30	15.83	9.60	7.80	7.25
Mean	137.87	123.92	103.34	19.80	16.36	14.21	9.46	8.30	6.94
L.S.D $_{0.05}$ (G)	12.58	12.32	11.00	1.86	1.80	1.44	0.86	1.20	1.34
L.S.D $_{0.05}$ (W)		2.24			0.32			0.22	
L.S.D $_{0.05}$ (G x W)		11.86			1.69			1.14	

The best genotypes had high performance for achene yield/plant were P_4 (L460) followed by P_7 (L235) and P_6 (L770) along with the F_1 crosses P_1 x P_3, P_1 x P_6, P_2 x P_4, P_2 x P_5, P_4 x P_5 and P_4 x P_6 under adequate water supply; P_4 and P_5 as well as the F_1 crosses P_1 x P_2, P_1 x P_6 and P_4 x P_5 under moderate, as well as P_4 and P_5 and the F_1 crosses P_1 x P_6 and P_4 x P_6 under severe stress (Table 3). These results coupled with heterotic effects, where these crosses displayed positive and significant heterosis. Achene yield/plant tended to decrease by decreasing water supply from 7140 to 4760 and 2380 m^2/ha. with values of 80.05, 67.46 and 54.56 g, respectively.

Furthermore, the parental sunflower genotypes P_1 (L38) followed by P_5 (L990) and P_7 (L235) gave the highest achene oil content and their F_1 crosses P_1 xP_3, P_1 xP_5, P_1 x P_7, P_3 xP_5 and P_5 x P_7. The value of achene oil content showed relative stable under the three levels of water supply in parental sunflower genotypes P_2 (L350) and P_7 (L235) and the F_1 crosses P_2 xP_3, P_2 xP_4, P_3 xP_5, P_3 xP_7, P_5 x P_7 and P_6 xP_7. This result could be discussed on the basis that achene oil content was more heritable character and less influenced by the environmental conditions.

These results could be discussed with reference to the connection between transpiration efficiency and plant growth accompanied by changes in plant growth characteristics and the effect of drought stress on partitioning of current assimilates between reproductive and non-reproductive organs as indicated by Virgona *et al.* (1990). Similar observation was also confirmed by Darvishzadeh *et al.* (2011), Ardiarini *et al.* (2013) and Iqbal *et al.* (2013). Also, Ibrahim *et al.* (2003) detected significant variation between sunflower genotypes in chlorophyll content and yield attributes. They added that Fodac cultivar was superior in chlorophyll content, plant height, head diameter, 100-achene weight, seed yield/ plant and oil yield/plant compared with Erflor and Malbar.

Drought sensitivity index (DSI)

Drought sensitivity index(DSI) as regards of achene yield/plant was estimated for determining tolerance of sunflower genotypes to water stress (Table 3). Genotypes with DSI values less than 1.0 are more tolerant to water stress, while those with values above 1.0 are sensitive one. Therefore under severe stress, P_1 (L38) and P_5 (L990) and the F_1 crosses P_1 xP_5, P_1 xP_6, P_1 xP_7, P_2 xP_7, P_3 xP_4, P_3 xP_5, P_5 x P_7 and P_6 x P_7 exhibited DSI less than unity, hence these genotypes were considered as more tolerant to severe stress. Particularly, parental genotypes P_1 (L38) and P_5 (L990) and their F_1 cross P_1 x P_5 gave the smallest and desirable DSI with values 0.63, 0.68 and 0.79, respectively. On the other side, sunflower cross P_2 xP_5 exhibited DSI value more than 1.0 (1.32), it is classified as sensitive to water stress. Moreover, for moderate stress, P_1 (L38), P_2 (L350), P_4 (L460), P_5 (L990) and P_6 (L770) and the F_1 crosses P_1 xP_2, P_1 xP_3, P_1 xP_6, P_1 xP_7, P_2 xP_6, P_3 xP_4, P_3 xP_5 and P_5 xP_6 had DSI less than unity, hence these genotypes were considered as more tolerant to moderate stress. Furthermore, the remaining genotypes attained DSI values near 1.0 and considered as moderate tolerant to water stress. These findings are in close agreement with those of Rauf and Sadqat (2007).

Table 3. Achene yield / plant , achene oil % and drought susceptibility index (DSI) of sunflower genotypes under three environments

Character	Achene yield /plant (g)					Achene oil content (%)		
Water supply Genotype	Adequate water supply	Moderate stress	Severe stress	(DSI) Moderate stress	(DSI) Severe Stress	Adequate water supply	Moderate stress	Severe stress
P1 (L38)	50.33	43.80	40.28	0.82	0.63	36.10	35.40	34.90
P2 (L350)	76.78	67.23	48.73	0.79	1.15	23.40	23.10	23.00
P3 (L11)	74.85	62.80	53.18	1.02	0.91	29.50	27.90	27.10
P4 (L460)	85.73	74.68	55.10	0.82	1.12	25.40	24.80	24.50
P5 (L990)	79.10	75.63	61.85	0.28	0.68	30.50	29.50	28.80
P6 (L770)	80.20	68.05	53.28	0.96	1.05	27.40	26.20	25.60
P7 (L235)	81.30	61.40	51.13	1.56	1.17	30.40	29.80	29.10
P1 x P2	81.55	75.50	54.93	0.47	1.03	32.50	31.20	30.40
P1 x P3	84.15	73.40	52.93	0.81	1.17	35.20	33.50	32.60
P1 x P4	79.83	67.53	54.53	0.98	1.00	32.10	30.10	28.53
P1 x P5	64.48	51.83	48.20	1.25	0.79	36.40	35.40	34.10
P1 x P6	84.50	76.45	60.43	0.61	0.89	30.50	29.20	27.20
P1 x P7	77.73	67.30	56.55	0.85	0.86	38.30	34.40	32.20
P2 x P3	83.23	68.40	59.30	1.13	0.90	28.40	27.00	28.40
P2 x P4	83.95	69.20	53.90	1.12	1.12	26.80	26.10	25.20
P2 x P5	97.10	68.15	56.25	1.90	1.32	28.60	27.50	25.60
P2 x P6	77.93	72.33	51.45	0.46	1.07	28.80	25.40	24.20
P2 x P7	77.18	62.03	55.73	1.25	0.87	31.20	29.00	28.80
P3 x P4	78.78	69.58	58.40	0.74	0.81	29.90	27.40	26.10
P3 x P5	77.80	68.23	55.90	0.78	0.88	31.20	29.10	29.20
P3 x P6	74.80	63.50	52.15	0.96	0.95	29.40	27.80	28.30
P3 x P7	82.03	62.63	54.55	1.50	1.05	30.30	30.00	29.50
P4 x P5	87.60	75.70	55.95	0.86	1.13	30.30	29.90	28.00
P4 x P6	93.80	70.58	60.58	1.57	1.11	26.70	25.00	24.60
P4 x P7	81.85	67.45	53.38	1.12	1.09	30.40	29.10	27.30
P5 x P6	82.70	73.25	51.78	0.73	1.17	31.10	30.20	28.00
P5 x P7	80.70	67.23	57.88	1.06	0.89	30.60	29.10	30.10
P6 x P7	81.58	64.95	59.55	1.30	0.85	29.80	29.60	28.60
Mean	80.05	67.46	54.56			30.40	29.03	28.21
L.S.D $_{0.05}$ (G)	13.94	10.94	10.81			0.91	1.17	1.39
L.S.D $_{0.05}$ (W)		2.24					0.22	
L.S.D $_{0.05}$ (G x W)		11.86					1.16	

Heterosis

Physiological characters

Results presented in Table (4) show heterosis as percentage of mid-parents for leaf water content, leaf chlorophyll content and transpiration rate. Cross combinations P_1 x P_2, P_1 x P_6, P_4 x P_5 and P_4 x P_6 gave significant positive heterotic effects for leaf water content at adequate water supply. Meanwhile, no significant positive heterosis was found among all crosses at both moderate and severe stress treatments. Also, significant positive heterosis was found for leaf chlorophyll content in the F_1 crosses P_1 x P_2 and P_4 x P_6 at adequate water supply; P_1 x P_3 , P_2 x P_3 , P_2 x P_7 and P_3 x P_7 at moderate and P_2 x P_3 and P_3 x P_4 at severe drought stress.

On the other hand, desirable significantly negative heterosis has been registered for transpiration rate by only one cross (P_5 x P_6) at adequate water supply; P_1 xP_7, P_2 xP_3, P_2 xP_4, P_2 xP_5, P_2 xP_7, P_3 xP_4, P_3 xP_5, P_3 xP_7, P_5 x P_6 and P_5 xP_7 at moderate and all crosses at severe stress. These results were desired for the breeder where the genotypes, which maintain high levels of leaf water content with high ability to reduce transpiration rate might be considered as tolerant to water stress. Hervé *et al*. (2001) found that the mean values of recombinant inbred lines were intermediate between the two parents for leaf chlorophyll concentration, net photosynthesis, internal CO_2 concentration and transpiration. Some recombinant inbred lines had more extreme values than the parents showing a transgressive segregation.

Yield and its attributes

Results presented in Tables (5 and 6) clear showed negative and highly significant heterosis of mid-parents for plant height in the cross (P_5 x P_6) only at moderate water stress, as well as P_1 xP_6 , P_2 xP_3 , P_2 xP_4 , P_2 x P_5, P_5 xP_6 , P_5 xP_7 and P_6 xP_7 at severe stress. This result might be due to accumulation of decreasing alleles controlling short plants. Otherwise, positive and highly significant heterosis were recorded for plant height in 14 out of 21cross ranging from 7.43% for (P_2 x P_5) to 22.61% for (P_1 xP_7) at adequate water supply; 7 out of 21cross varied from 8.85% for (P_4 x P_7) to 21.75% for (P_1 x P_7) at moderate and 2 out of 21cross valued 13.24% for (P_1 x P_7) and 14.38% for (P_1 x P_3) at severe stress.

Significant or highly significant positive mid-parent heterosis have been recorded for head diameter by the cross combinations (P_1 x P_3, P_1 xP_7, P_2 xP_4, P_2 xP_5, P_2 x P_6, P_3 xP_4, P_3 x P_5, P_3 xP_6, P_4 x P_6, P_4 x P_7, P_5 x P_6 and P_6 xP_7) at adequate water supply; (P_1 xP_4) at moderate water stress. Also, 100-achene weight exhibited significant positive heterosis for eight crosses (P_1 x P_2 , P_1 xP_5 , P_2 xP_4 , P_2 xP_5, P_2 xP_6 , P_3 xP_4 , P_3 x P_5 and P_6 xP_7) at adequate water supply only.

Table 4. Heterosis over mid-parent (M.P.) for physiological characters of sunflower crosses of half-diallel analysis in three environments.

Character	Leaf water content (%)			Leaf chlorophyll content (SPAD)			Transpiration rate (mg $H_2O/cm^2/h$)		
Water supply / Genotype	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress
P1 x P2	5.51**	-3.67	-8.99**	4.97*	6.43	3.97	10.00**	-7.69	-41.25**
P1 x P3	0.51	-2.50	-9.82**	0.00	7.81*	1.60	3.75	-7.26	-45.07**
P1 x P4	2.35	-3.27	-6.24**	-0.10	0.83	1.56	10.98**	-1.47	-23.53**
P1 x P5	1.74	-5.73	-9.63**	3.06	6.72	-1.48	8.16*	1.33	-42.11**
P1 x P6	3.66*	-5.08	-5.64*	0.57	4.42	-0.28	8.33*	3.13	-44.93**
P1 x P7	-1.86	-4.53	-7.77**	-2.47	7.34	-4.96	8.24*	-20.19**	-55.00**
P2 x P3	0.84	0.65	-12.91**	-0.03	11.80**	8.12*	2.17	-13.57**	-53.57**
P2 x P4	1.79	-0.06	-15.09**	1.11	0.62	3.49	2.27	-15.49**	-40.74**
P2 x P5	0.19	2.21	-11.69**	-0.56	5.41	4.29	-0.98	-11.54**	-55.81**
P2 x P6	2.07	0.23	-10.66**	2.10	4.83	1.49	3.81	-6.47	-50.00**
P2 x P7	-1.05	-2.58	-12.92**	-2.54	8.84*	-2.48	2.15	-25.83**	-70.00**
P3 x P4	2.05	-5.41	-15.14**	3.85	4.09	8.23*	2.38	-11.43**	-44.00**
P3 x P5	-0.73	1.68	-16.97**	-0.69	7.49	1.07	0.00	-9.21*	-65.79**
P3 x P6	0.01	0.29	-18.51**	1.42	-0.73	2.55	-1.04	-2.67	-73.53**
P3 x P7	-2.13	-6.81*	-18.10**	-2.81	12.58**	-1.11	2.25	-10.00**	-73.44**
P4 x P5	3.24*	0.13	-15.68**	-4.66	-1.08	-2.67	0.00	-3.95	-21.65**
P4 x P6	3.54*	-4.24	-10.95**	6.57*	-3.44	2.21	-3.33	-0.61	-22.22**
P4 x P7	2.52	-3.81	-10.20**	-8.74*	-5.46	-1.37	2.35	-8.87	-28.75**
P5 x P6	-0.49	-4.60	-25.21**	-3.54	2.42	1.73	-10.00**	-19.88**	-105.71**
P5 x P7	1.69	-3.97	-18.51**	0.07	4.21	-3.10	-1.01	-17.36**	-114.06**
P6 x P7	0.75	-6.35	-15.87**	-0.34	2.16	-2.58	3.92	-7.14	-121.67**

***,** Significant at P=0.05 and P=0.01, respectively**

Achene yield/plant revealed significantly positive heterosis in five crosses at adequate water supply, *i.e.*, P_1 x P_2, P_1 xP_3, P_1 xP_6, P_1 xP_7 and P_2 x P_5 ranging from -2.03% for (P_4 xP_7) to 25.62% for (P_1 xP_3), as well as four crosses at moderate, i.e., P_1 xP_2, P_1 xP_3, P_1 xP_6 and P_1 x P_7 varied from -12.52% for (P_3 xP_6) to 22.94% for (P_1 x P_3), but no significant heterosis was recorded for seed yield/plant at severe stress (Table 6), reinforcing the effect of water deficit on gene expression of yield character. For achene oil content, significant heterosis was detected in 17 out of 21cross ranging from -4.10% for (P_1 xP_6) to 13.78% for (P_2 xP_7) at adequate water supply; 12 out of 21cross ranging from -6.68% for (P_1 xP_6) to 8.28% for (P_2 xP_7) at moderate and four out of 21cross varied from -13.42% for (P_1 xP_6) to 11.09% for (P_2 xP_3) at severe water stress.

Hence, on the basis of the obtained results, it could be concluded that the cross combination (P_1 x P_2) showed desired heterosis for leaf water content, leaf chlorophyll content and 100-achene weight at adequate water supply, transpiration rate at severe stress; achene yield/plant and achene oil content at both adequate water supply and moderate stress. Also the cross combination (P_1 x P_3) showed significant positive heterosis for leaf chlorophyll content at moderate, head diameter at adequate water supply, achene yield/plant and achene oil content at both adequate water supply and moderate water stress conditions.

It is interest to note that the sunflower cross (P_1 x P_6) produced the maximum value of heterosis for achene yield/plant under adequate water supply (22.77%) and moderate (22.58%) level with DSI value less than 1.0 and had significantly negative heterosis for plant height (-10.52%) and transpiration rate (-44.93%) at severe stress, therefore it could be considered the promising one and classified as tolerant to water stress. The present study suggested that the abovementioned crosses would be promising sources for commercial exploration of heterosis.

Table 5 . Heterosis over mid-parent (M.P.) for morphological characters of sunflower crosses of half-diallel analysis under three environments.

Character	Plant height (cm)			Head diameter (cm)			100-achene weight (g)		
Water supply / Genotype	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress
P1 x P2	21.82**	21.52**	2.04	8.78	8.01	-13.32**	10.84**	-11.23	-20.39*
P1 x P3	15.52**	15.02**	14.38**	9.84*	-1.64	-14.64**	-0.70	-0.89	-13.50
P1 x P4	13.10**	3.91	4.05	6.34	9.06*	-1.79	-1.15	0.15	-4.14
P1 x P5	19.32**	19.68**	4.45	4.85	-9.15*	-16.92**	8.77*	2.39	-17.56*
P1 x P6	19.56**	6.85	-10.52**	0.64	-11.30*	-19.67**	6.39	8.04	-7.07
P1 x P7	22.61**	21.75**	13.24**	11.90**	-1.88	-6.44	7.41	-4.78	-8.06
P2 x P3	8.47*	8.98*	-14.93**	5.70	-2.45	2.95	5.61	1.10	-23.88**
P2 x P4	0.79	-2.74	-12.32**	15.61**	6.51	-3.37	12.85**	0.14	-19.59*
P2 x P5	7.43*	3.40	-8.93*	13.66**	-1.74	-6.35	8.11*	7.88	-35.45**
P2 x P6	9.91**	2.01	-0.42	20.38**	4.37	-7.63	14.57**	0.00	-31.11**
P2 x P7	9.44**	-3.35	-5.10	2.03	-8.84	-14.27**	-6.61	-0.42	-19.69**
P3 x P4	6.48	-1.77	-7.66	8.85*	-4.74	-13.78**	14.19**	4.24	-16.29
P3 x P5	5.77	9.02*	1.67	11.99**	-1.82	-15.99**	16.67**	9.32	-24.54**
P3 x P6	3.56	3.41	1.89	16.53**	-4.70	-26.69**	0.14	-12.59	-21.73**
P3 x P7	13.39**	3.17	3.46	5.65	-5.63	-15.33**	5.52	2.12	-16.85
P4 x P5	11.77**	2.95	-5.12	9.56*	-0.76	-9.90*	5.79	1.66	-15.21
P4 x P6	9.96**	5.06	0.99	12.30**	-7.55	-7.51	4.97	-0.94	-12.68
P4 x P7	16.25**	8.85*	-3.25	11.39**	-2.67	-13.20**	7.61	-12.19	-9.86
P5 x P6	4.48	-8.02*	-13.96**	19.10**	6.60	-10.00**	7.29	6.20	-9.49
P5 x P7	2.65	-6.60	-13.18**	14.90**	6.28	-12.74**	7.86	-16.84*	-31.61**
P6 x P7	1.79	-2.97	-13.59**	17.04**	6.56	-3.71	10.94**	-6.25	-10.52

*,** Significant at P=0.05 and P=0.01, respectively

Table 6. Heterosis over mid-parent (M.P.) for achene yield/head and achene oil content (%) of sunflower crosses of half-diallel analysis under three environments.

Character	Achene yield /plant (g)			Achene oil content (%)		
Water supply / Genotype	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress
P1 x P2	22.07**	22.15**	9.83	8.46**	5.13**	2.80
P1 x P3	25.62**	22.94**	2.22	6.82**	4.48**	3.07
P1 x P4	14.78	7.44	3.32	4.21**	-1.16	-6.19**
P1 x P5	-0.37	-21.51**	-16.36	8.52**	7.34**	4.84*
P1 x P6	22.77**	22.58**	14.27	-4.10**	-6.68**	-13.42**
P1 x P7	15.33*	16.99*	10.30	13.19**	4.22**	-1.24
P2 x P3	8.91	-2.03	-9.57	6.87**	5.00**	11.09**
P2 x P4	3.22	-9.43	-22.33**	8.96**	7.66**	4.96*
P2 x P5	19.73**	-11.81	-23.22**	5.77**	3.82*	-1.95
P2 x P6	-0.72	-0.12	-26.38**	11.81**	2.36	-1.24
P2 x P7	-2.41	-11.39	-14.76	13.78**	8.28**	8.85**
P3 x P4	-1.92	-7.46	-11.26	8.19**	0.91	-3.45
P3 x P5	1.06	-10.27	-22.27**	3.85**	-1.37	0.17
P3 x P6	-3.64	-12.52	-22.84**	3.23*	-0.18	2.65
P3 x P7	4.82	-8.78	-15.47	1.16	1.17	0.68
P4 x P5	5.92	-6.57	-31.88**	7.76**	8.19**	3.21
P4 x P6	11.55	-8.94	-14.73	1.12	-3.20	-3.66
P4 x P7	-2.03	-9.06	-28.20**	8.22**	5.15**	0.18
P5 x P6	3.69	-0.44	-27.84**	6.91**	6.13**	-0.18
P5 x P7	0.62	-4.50	-12.51	0.49	-3.61*	1.00
P6 x P7	1.01	-9.01	-10.26	3.02*	3.38*	1.22

*,** Significant at P=0.05 and P=0.01, respectively

The magnitude of heterosis differed from adequate water supply, moderate to severe stress and tended to decrease with increasing water stress. Some crosses like P_2 x P_5 for achene yield/plant, plant height, 100-achene weight and achene oil content gave positive and highly significant heterosis under adequate water supply, but showed negative and insignificant heterosis at moderate level, as well as, negative and highly significant heterosis at severe water stress. Positive and negative heterosis over mid-parents were detected herein, may be due to the effect of environments on gene expression. Different magnitudes of heterosis for seed yield and various sunflower characters has also been registered by Gill *et al*. (1998), and Habib *et al*. (2007) and Bakhiet *et al*. (2010).

Genetic components and heritability

Physiological characters

Data presented in Table (7) indicated that the genetic components of variance and their derived parameters were fluctuated from adequate water supply, moderate to severe drought stress, since the dominance genetic variance was significant and accounted the main type controlling the inheritance of leaf water content under adequate water supply, resulting in an average degree of dominance $(H_1/D)^{0.5}$ was more than unity. Hereby, pedigree method might be exploited and superior genotypes could be identified from its phenotypic expression and selected in F_2. On the otherwise, the additive genetic component was the prevailed type controlling leaf water content under moderate; leaf chlorophyll content under moderate and severe stress and transpiration rate under severe stress condition, resulting in an average degree of dominance $(H_1/D)^{0.5}$ was less than unity. In this connection, Hervé et al. (2001) revealed that additive gene action was more pronounced in controlling leaf chlorophyll concentration, net photosynthesis, internal CO_2 concentration and transpiration rather than the environmental variance.

Furthermore, both additive (D) and dominance (H_1 and H_2) genetic components were significant and involved in the inheritance of transpiration rate under moderate stress, with the predominant of additive gene action in controlling transpiration rate.

The covariance of additive and dominance gene effects in the parents (F value) was positive and significant for transpiration rate under adequate water supply and moderate stress, indicating that increasing alleles were more frequent than the decreasing ones in the parental populations. Whereas, in the remaining cases, the F values didn't reach the level of significance.

The overall dominance effects of heterozygous loci (h^2) were positive and significant for leaf water content under the three levels of water regimes; transpiration rate under moderate and severe stress as well as leaf chlorophyll content under adequate water supply, hereby dominance was mainly attributable to heterozygous loci and seemed to be acting in positive direction. The environmental variance had significant effect on gene expression of physiological characters in most cases, explaining the changes in the genetic components and their derived parameters from condition to another.

The proportion of genes with positive and negative effects in the parents ($H_2/4H_1$) was near to its maximum value (0.25) for leaf water content under moderate stress and leaf chlorophyll content under adequate water supply. Whereas, the ($H_2/4H_1$) was less than its maximum value (0.25) for the remaining physiological characters under different levels of water regimes,

The proportion of dominance to recessive genes in the parents (KD/KR) was more than unity for leaf water content and leaf chlorophyll content under moderate stress; transpiration rate under normal and moderate water stress, showing an excess of dominant alleles in the parental populations. On the other wise, excess of recessive alleles have been detected for leaf water content and leaf chlorophyll content under both adequate water supply and severe stress as well as transpiration rate under severe stress only.

Narrow sense heritability ($T_{(n)}$) which reflect the fixable type of gene action transmissible from the parents to the progeny was high (>50%) for transpiration rate under the three levels of water regimes; leaf water content and leaf chlorophyll content under severe water stress. However, moderate narrow sense heritability have been registered for leaf water content under moderate water stress and leaf chlorophyll content under adequate water supply. Whereas, low narrow sense heritability was recorded for leaf water content under adequate water supply and leaf chlorophyll content under moderate water stress.

Table 7. Genetic components for physiological characters of sunflower genotypes of half-diallel analysis under three environments.

Character	Leaf water content (%)			Leaf chlorophyll content (SPAD)			Transpiration rate (mg $H_2O/cm^2/h$)		
Water supply	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress
Genetic parameters									
D	0.06	11.36**	3.71*	2.02**	2.81*	1.71**	0.024**	0.032**	0.012**
H_1	6.09*	4.80	7.62	5.16*	4.70	0.84	0.004	0.013**	0.0002
H_2	4.99*	4.36	6.66	4.73*	2.78	0.11	0.003	0.008**	0.0002
F	-0.41	1.03	-6.79	-0.04	2.81	-2.21	0.010**	0.016**	-0.006
h^2	3.17*	9.30*	7.76**	4.92**	2.43	-0.28	0.001	0.010**	0.001**
E	1.69**	5.01**	1.69**	0.56	1.57**	1.55**	0.001**	0.001	0.0004**
Derived parameters									
$[H_1/D]^{0.5}$	10.18	0.65	1.43	1.60	1.29	0.70	0.41	0.64	0.14
$[H_2/4H_1]$	0.20	0.23	0.22	0.23	0.15	0.03	0.16	0.15	0.22
$[h^2/H_2]$	0.64	2.13	1.16	1.04	0.87	-2.66	0.45	1.26	3.00
[KD / KR]	0.49	1.15	0.22	0.99	2.26	0.04	3.32	2.33	0.67
$T_{(n)}$	21.13	46.88	63.08	41.70	29.70	59.67	83.68	79.96	92.99

***,** Significant at P=0.05 and P=0.01, respectively**

Yield and its attributes

Data presented in Tables (8 and 9) indicated that the genetic components of variance and their derived parameters were fluctuated from condition to another, since the dominance genetic variance was significant and accounted the main type controlling the inheritance of head diameter, 100-achene weight and achene yield/plant under all environments, resulting in an average degree of dominance $(H_1/D)^{0.5}$ was more than unity.

Both additive (D) and dominance (H_1 and H_2) genetic components were significant and involved in the inheritance of plant height, achene yield/plant, achene oil content under the three levels of water regimes; and head diameter under moderate and sever stress as well as 100-

achene weight under severe stress, with the predominant of additive gene action in controlling plant height and achene oil content. Whereas, dominance gene action was the prevailed type governing head diameter and achene yield/plant under the three levels of water regimes.

The covariance of additive and dominance gene effects in the parents (F value) was positive and significant for plant height and achene yield/plant under the three levels of water regimes, indicating that increasing alleles were more frequent than the decreasing ones in the parental populations. Whereas, F value was negative and significant for head diameter under adequate water supply, as well as, 100- achene weight under both adequate water supply and moderate water stress, but in the remaining cases, the F value didn't reach the level of significance.

The overall dominance effects of heterozygous loci (h^2) were positive and significant for plant height, head diameter, achene yield/plant under the three levels of water regimes as well as 100-achene weight and achene oil content under adequate water supply and moderate water stress. The environmental variance was significant for yield contributing characters in most cases and achene oil content under moderate stress only. Whereas, it was insignificant under adequate water supply and severe stress conditions for that character, revealing that achene oil content was more heritable character and less influenced by the environmental fluctuations

The proportion of genes with positive and negative effects in the parents ($H_2/4H_1$) was near to its maximum value (0.25) for plant height under severe stress as well as achene oil content under both adequate water supply and moderate stress. The ($H_2/4H_1$) was less than its maximum value (0.25) for the remaining yield contributing characters under different levels of water regimes.

Table 8. Genetic components for morphological characters of sunflower genotypes of half- diallel analysis under three environments.

Character Water supply	Plant height (cm)			Head diameter (cm)			100-achene weight (g)		
	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress
Genetic parameters									
D	586.40**	536.93**	267.61**	1.29	1.98**	0.96**	0.50**	0.23*	0.63**
H_1	341.61**	359.86**	159.04**	6.88**	3.34**	1.64**	1.26**	0.97**	0.98**
H_2	292.37**	276.62**	150.72**	6.22**	3.19**	1.46**	1.27**	0.93**	0.52
F	271.53**	400.81**	97.19**	-2.43	0.31	-0.31	-0.29	-0.34	1.01**
h^2	655.78**	444.93**	295.68**	15.10**	4.49**	1.02**	1.42**	0.90**	0.08
E	20.14*	19.55	16.41*	0.46	0.40**	0.26**	0.10**	0.18**	0.27**
Derived parameters									
$[H_1/D]^{0.5}$	0.76	0.82	0.77	2.31	1.30	1.30	1.59	2.04	1.25
$[H_2/4H_1]$	0.21	0.19	0.24	0.23	0.24	0.22	0.25	0.24	0.13
$[h^2/H_2]$	2.24	1.61	1.96	2.43	1.41	0.69	1.12	0.97	0.15
[KD / KR]	1.87	2.68	1.62	0.42	1.13	0.78	0.69	0.47	4.57
$T_{(n)}$	66.13	55.29	62.30	52.12	43.29	53.72	48.66	42.83	9.89

***,** Significant at P=0.05 and P=0.01, respectively**

Table 9. Genetic components for achene yield/head and achene oil content (%) characters of sunflower genotypes of half-diallel analysis under three environments.

Character Water supply	Achene yield /plant (g)			Achene oil content (%)		
	Adequate water supply	Moderate stress	Severe stress	Adequate water supply	Moderate stress	Severe stress
Genetic parameters						
D	109.53**	99.46**	28.78**	16.60**	15.90**	14.98**
H_1	155.19**	167.82*	44.30	8.33**	4.75**	5.76*
H_2	133.59**	119.31	31.57	7.74**	4.64**	4.82**
F	99.02*	130.96	40.10	0.02	-0.11	1.63
h^2	97.47**	29.51	29.18*	10.70**	4.29**	1.97
E	25.32**	15.16	14.32**	0.36	0.38*	0.35
Derived parameters						
$[H_1/D]^{0.5}$	1.19	1.30	1.24	0.71	0.55	0.62
$[H_2/4H_1]$	0.22	0.18	0.18	0.23	0.24	0.21
$[h^2/H_2]$	0.73	0.25	0.92	1.38	0.92	0.41
[KD / KR]	2.22	3.06	3.56	1.00	0.99	1.19
$T_{(n)}$	21.48	15.90	3.07	78.90	84.01	82.14

***,** Significant at P=0.05 and P=0.01, respectively**

The proportion of dominance to recessive genes in the parents (KD/KR) was around the unity for achene oil content, while it was more than unity for achene yield / plant and plant height under different levels of water supply. On the other wise, excess of recessive alleles have been detected for head diameter under the three levels of water regimes as well as 100-achene weight under both adequate water supply and moderate stress.

Narrow sense heritability was high (>50%) for plant height, and achene oil content under various levels of water regimes and head diameter under adequate water supply and severe water stress. Moderate narrow sense heritability have been registered for head diameter under moderate water regime; 100-achene weight under adequate water supply and moderate water regime. Whereas, low narrow sense heritability was recorded for

100-achene weight under severe water stress and achene yield/plant under the three levels of water regimes.

Therefore, selection for the aforementioned characters must extended for late segregating generations. Hervé *et al.* (2001) indicated that the traits related to photosynthetic activity and water status are genotype dependent in sunflower. Narrow sense heritability was low for relative water content (0.22), moderate for transpiration (0.40), and high for chlorophyll concentration (0.57). However, Ortis *et al.* (2005) indicated the predominant role of additive component for plant height, 1000-seed weight and seed oil content. Thus, hybrid breeding method could be used aiming to improve these characters. On the other hand, Ghaffari *et al.* (2011) indicated that 1000-seed weight, and oil yield were under control of both additive and dominance effects, plant height and oil content were controlled by additive effects, however over dominance effects were detected for seed yield.

Phenotypic, genotypic and environmental correlation coefficients

Phenotypic, genotypic and environmental correlation coefficients were used to determine the most effective characters which played an important role in the final yield across the three environments (Table 10). Positive and significant correlations were registered between achene yield/plant and each of leaf water content, transpiration rate, plant height, head diameter and 100-achene weight. These results are hold true at both phenotypic and genotypic levels, except for leaf water content which showed significant correlation at genotypic level only. Whereas, significantly negative genotypic and phenotypic correlations were recorded between achene oil content and achene yield/plant. Therefore, increasing values of achene oil content resulted in decreasing achene yield/plant.

Positive and highly significant environmental correlation was observed between 100-achene weight and achene yield/plant. This result could be discussed on the basis that both characters having the same environmental requirements. Moreover, positive and highly significant interrelationship was recorded between leaf water content with each of leaf chlorophyll content, transpiration rate and 100-achene weight, and between transpiration rate with each of plant height, head diameter and 100-achene weight, as well as, between plant height and both head diameter and 100-achene weight at both genotypic and phenotypic levels in most cases. Hereby, increasing value of one character led to increase the another associated character. On the contrary, negative and highly significant association was registered between leaf water content with achene oil content and between leaf chlorophyll content with each of transpiration rate, plant height and head diameter as well as, between transpiration rate, plant height, head diameter on one hand with achene oil content, on the other hand. These results are in agreement with a few exceptions with those recorded by Darvishzadeh *et al.* (2011), Rauf *et al.* (2012) , Ardiarini *et al.* (2013) and Iqbal *et al.* (2013).

Table 10. Genotypic (G) , phenotypic (P) and environmental (e) correlation coefficients of various metric traits of sunflower genotypes across three environments.

Characters		Leaf chlorophyll content (%)	Transpiration rate	Plant height (cm)	Head diameter	100- achene weight (g)	Achene oil content (%)	Achene yield/ plant
Leaf water content (%)	rg	0.452**	0.236*	0.055	-0.070	0.615**	-0.405**	0.381**
	rp	0.166	0.171	0.064	-0.100	0.219*	-0.259*	0.179
	re	-0.063	0.082	0.112	-0.168	-0.139	0.102	-0.002
Leaf chlorophyll content	rg	1	-0.255*	-0.589**	-0.256*	-0.142	-0.144	-0.019
	rp	1	-0.181	-0.414**	-0.190	-0.085	-0.085	0.041
	re	1	-0.090	-0.191	-0.117	-0.035	0.071	0.092
Transpiration rate	rg		1	0.668**	0.601**	0.576**	-0.617**	0.674**
	rp		1	0.584**	0.506**	0.366**	-0.569**	0.476**
	re		1	0.061	0.092	-0.029	-0.097	0.148
Plant height	rg			1	0.679**	0.340**	-0.307**	0.653**
	rp			1	0.566**	0.239*	-0.279**	0.414**
	re			1	0.055	0.065	0.068	-0.044
Head diameter	rg				1	0.097	-0.291**	0.577**
	rp				1	0.101	-0.249*	0.378**
	re				1	0.121	0.047	0.067
100-achene weight	rg					1	-0.117	0.311**
	rp					1	-0.071	0.298**
	re					1	0.085	0.285**
Achene oil content (%)	rg						1	-0.563**
	rp						1	-0.390**
	re						1	-0.007

***,** Significant at P=0.05 and P=0.01, respectively**

Path coefficient analysis

Maximum direct effect on achene yield/plant was accounted for transpiration rate and plant height with values of 12.941% and 12.219%. Whereas, moderate direct effects were recorded by both 100-achene weight and leaf water content with values of 7.128 and 7.779 %. Moreover, the other remaining three characters i.e., leaf chlorophyll content, achene oil content and head diameter were less contribution as exhibited 1.917, 0.438 and 0.081%, respectively. The highest indirect effects on achene yield/plant variation were observed for transpiration rate via plant height followed by transpiration rate via 100-achene weight, leaf water content via 100-achene weight, plant height via 100-achen and leaf chlorophyll content via plant height with values of 8.442, 5.530, 4.579, 3.181 and 2.858, respectively (Table 11).

According to the total contribution of the studied characters on achene yield/plant variation, it could be arranged as follows, transpiration rate (22.778 %) plant height (20.413%), 100-achene weight (13.939%), leaf water content (12.796%), leaf chlorophyll content (4.997%), achene oil content (2.571%) and then head diameter (0.871%). Generally, it could be concluded that the studied characters accounted for 78.365% of the achene yield/plant variation , however the residual effect was 21.635%. Hence, the results obtained from correlation and path analyses revealed the importance of transpiration rate, plant height, 100-achene weight and leaf water content as selection criteria for improvement of sunflower yield. Hence, the results obtained from correlation and path analyses revealed the importance of transpiration rate, plant height, 100-achene weight and leaf water content as selection criteria for improvement of sunflower yield. Similar results were registered by Rauf *et al.* (2012), Ardiarini *et al.* (2013) and Iqbal *et al.* (2013). Also, Darvishzadeh *et al.* (2011) indicated that genotypic correlations manifest that seed yield per plant was positively and significantly associated with head diameter, plant height, number of leaf and achene traits under well-watered condition. While, under the water-stressed state, head weight, head diameter, number of achene and chlorophyll content showed positive and significant correlation with seed yield per plant. Head diameter and number of achene under both conditions and chlorophyll content under water-stressed condition have positive direct effect on seed yield/plant.

Table 11. Direct and indirect effect of various metric traits of sunflower genotypes on achene yield/ plant across three environments

S.O.V.	CD	RI %	Total contribution on achene yield/plant
Leaf water content % (X_1)	0.07779	7.779	12.796
Leaf chlorophyll content (X_2)	0.01917	1.917	4.997
Transpiration rate (X_3)	0.12941	12.941	22.778
Plant height (X_4)	0.12219	12.219	20.413
Head diameter (X_5)	0.00081	0.081	0.871
100-achene weight (X_6)	0.07128	7.128	13.939
Achene oil content % (X_7)	0.00438	0.438	2.571
X_1 x X_2	0.01746	1.746	
X_1 x X_3	0.02367	2.367	
X_1 x X_4	0.00537	0.537	
X_1 x X_5	0.00056	0.056	
X_1 x X_6	0.04579	4.579	
X_1 x X_7	0.00748	0.748	
X_2 x X_3	0.01270	1.270	
X_2 x X_4	0.02858	2.858	
X_2 x X_5	0.00101	0.101	
X_2 x X_6	0.00525	0.525	
X_2 x X_7	0.00132	0.132	
X_3 x X_4	0.08422	8.422	
X_3 x X_5	0.00615	0.615	
X_3 x X_6	0.05530	5.530	
X_3 x X_7	0.01470	1.470	
X_4 x X_5	0.00678	0.678	
X_4 x X_6	0.03181	3.181	
X_4 x X_7	0.00713	0.713	
X_5 x X_6	0.00074	0.074	
X_5 x X_7	0.00055	0.055	
X_6 x X_7	0.00207	0.207	
R^2	0.78365	78.365	78.365
Residual	0.21635	21.635	21.635
Total	1.00000	100	100.000

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تعبير قوة الهجين والفعل الجيني والعلاقة بين الصفات المورفو- فسيولوجية والمحصول فى دوار الشمس تحت مستويات مختلفة من الإمداد المائي

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لتقدير قوة الهجين وطبيعة التوارث والعلاقة التبادلية للصفات المورفو-فسيولوجية مع المحصول فى دوار الشمس، تم تقييم الهجن النصف تبادلية بين سبع سلالات تحت ثلاث معاملات للإمداد المائي: كافي، متوسط وإجهاد قاسى . أظهر دليل الحساسية للجفاف أن الآباء L38 و L990 والهجن L38 X L990 و L350 x L460 كانت الأكثر تحملاً للإجهاد المائي، بينما كانت السلالات L11 و L235 و الهجين L11 x L990 الأكثر حساسية للجفاف. وأعطى الهجين L38 x L350 قيماً مرغوبة ومعنوية لقوة الهجين لصفات محتوى كلوروفيل الورقة تحت الاجهاد المتوسط ، معدل النتح تحت الاجهاد الشديد، محصول البذور / النبات ونسبة الزيت بالبذور تحت كل من الإمداد الكافي للمياه و الإجهاد المتوسط. وظهر أهمية الفعل المضيف للجين في وراثة صفات معدل النتح ، إرتفاع النبات ومحتوى الزيت بالبذور ، بينما كان الفعل السيادي للجين هو المتحكم في وراثة محصول البذور/ النبات تحت الثلاث مستويات من الامداد المائي. أثر التباين البيئي معنوياً على التعبير الجيني للصفات الفسيولوجية وصفات المحصول عند معظم حالات الإمداد المائي. سجل معامل التوريث بالمعنى الخاص قيماً مرتفعة (> ٥٠%) لصفة معدل النتح وقيماً منخفضة (< ٥٠%) لمحصول البذور / النبات تحت الثلاث مستويات

للإمداد المائي. وسجلت قيماً موجبة ومعنوية لمعاملات الإرتباط بين محصول البذور / النبات مع كلٍ من محتوى الماء النسبى بالورقة ، معدل النتح، إرتفاع النبات، قطر القرص ووزن ١٠٠ بذرة. وكان أكبر تأثير مباشر على محصول البذور / النبات راجعاً لصفات معدل النتح ، وإرتفاع النبات (١٢.٩٤١ و ١٢.٢١٩% ، على التوالي). بينما كانت أعلى التأثيرات غير المباشرة على محصول البذور / النبات لصفتي معدل النتح وارتفاع النبات ، يليهما معدل النتح ووزن ١٠٠ بذرة و محتوى الماء بالورقة ووزن ١٠٠ بذرة (٨.٤٤%، ٥.٥٣٠% و ٤.٥٧٩% على التوالي).