

EVALUATION OF SUNFLOWER GENOTYPES FOR YIELD AND PHYSIOLOGICAL TRAITS UNDER WATER STRESS CONDITIONS

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Abstract

Water stress is an important constraint affecting sunflower growth, physiological traits and yield. The present study was conducted to evaluate the mean performance and variability of sunflower genotypes for morphological and physiological traits under contrasting irrigation regimes. The experiment was conducted during the Rabi season of 2023 at the Oilseeds Research Institute, Agriculture Research Center, Tandojam, using 11 sunflower genotypes comprising three lines, two testers and six F1 hybrids. The experiment was laid out in a split-plot design with three replications, with irrigation regimes assigned to main plots and genotypes to sub-plots. Two irrigation treatments, normal irrigation and water stress imposed at the initial and flowering stages, were evaluated. Data were recorded for days to 90% maturity, plant height, number of leaves plant⁻¹, leaf area, head diameter, stem girth, number of seeds head⁻¹, seed index, seed yield, relative water content, chlorophyll content and oil content. Analysis of variance revealed significant differences among genotypes for several morphological and physiological traits, indicating considerable genetic variability. HO-1 × PSF-05 showed superior performance for head diameter, stem girth, seed index and seed yield, whereas HO-1 × Corolla exhibited higher leaf area and number of seeds head⁻¹. PSF-05 showed desirable performance for early maturity and oil content. Genotypic responses varied between normal and water-stressed conditions, particularly for seed index, relative water content and chlorophyll content. The identified superior genotypes may serve as valuable material for developing sunflower cultivars with improved performance under water-limited conditions.

INTRODUCTION

The sunflower, or *Helianthus annuus* L., is an important oilseed crop that is native to North America and belongs to the Asteraceae family. There are 65 different species in the genus *Helianthus* (Andrew et al., 2013). The term "*Helianthus*" comes from the Greek words "helios," which means sun, and "anthos," which means flower. This name reflects the sunflower's unusual habit of following the sun all day long. The *annual Helianthus annuus* is the species in this genus that is most known and its popular name comes from its huge bloom head, which mimics the sun and is a characteristic shared by most annual plants. According to Khaleghizadeh (2011), the sunflower is characterized by its spherical flower heads, wide, coarse-toothed leaves, and thick, hairy stalks. At the base of the structure, the sunflower head has several blooms that develop into seeds (Seghatoleslami et al., 2012). Effective water management is crucial not only for mitigating water deficits but also for optimizing yields within existing water resources. Conventional flood irrigation methods have been associated with significant water loss, reduced crop yields, ecological disruption, widespread salinity, and waterlogging issues (Chen et al. 2023). Such inefficiencies have led to an overall irrigation efficiency of barely up to 30%, rendering these methods impractical for small farms and challenging for common farmers to adopt. Consequently, there is an urgent need to introduce and promote efficient irrigation techniques that not only enhance yields and conserve water but are also cost-effective and user-friendly (Bodner et al., 2015). Production of sunflowers is severely hampered by water stress in many parts of the world, especially in places where growing season rainfall is erratic and unpredictable. Inconsistent water and nutrient absorption can result from such circumstances, which can limit plant growth and development and eventually lower agricultural output and quality (Rauf & Sadaqat, 2008). Optimizing irrigation practices to induce controlled stress during specific stages of plant growth, while

maintaining performance and conserving water, represents a key area of interest for researchers. Additionally, advancements in water management and irrigation techniques can offer valuable solutions for various crops, including sunflowers. The prevailing water scarcity conditions and the adverse impacts of drought stress, there is a growing demand for water-saving techniques that enhance soil water absorption and retention capabilities (Chawla & Balasaheb, 2023).

Material and Methods

The experiment was conducted during the Rabi season of 2023 at the Oilseed Research Institute, Tandojam, Sindh, Pakistan, to evaluate the mean performance and variability of sunflower genotypes under contrasting irrigation regimes. The experiment comprised 11 sunflower genotypes, including three lines (HO-1, Peshawar-93 and Charnika), two testers (Corolla and PSF-05), and six crosses: HO-1 × Corolla, Peshawar-93 × Corolla, Charnika × Corolla, HO-1 × PSF-05, Peshawar-93 × PSF-05 and Charnika × PSF-05.

The experiment was laid out in a split-plot design with three replications. Irrigation regimes were assigned to the main plots, while the 11 genotypes were allocated to the sub-plots. Two irrigation treatments were evaluated: normal irrigation and restricted irrigation, in which irrigation was withheld at the initial and flowering stages. The experiment was conducted under the same agronomic and field management practices, except for the imposed irrigation treatments.

Measurement of morphological and physiological traits

Data were recorded for morphological and physiological traits to assess genotypic performance and variability under the two irrigation regimes.

Days to 90% maturity: The number of days from sowing until approximately 90% of the plants reached maturity was recorded for each genotype.

Plant height (cm): Plant height was measured from the soil surface to the base of the head using a measuring tape. Five randomly selected plants from each genotype in each replication were measured, and their mean was used for statistical analysis.

Number of leaves plant⁻¹: The number of fully developed leaves on five randomly selected plants was counted manually at maturity, and the average number of leaves plant⁻¹ was calculated.

Leaf area: Leaf area was recorded as the total surface area of leaves and expressed in appropriate square units. Measurements were taken from representative plants of each genotype.

Head diameter (cm): Head diameter was measured at maturity using a Vernier caliper. Measurements were taken from five randomly selected plants per genotype in each replication, and the mean was calculated.

Stem girth (cm): Stem girth was measured using a Vernier caliper on the selected plants from each genotype. The mean value for each genotype and replication was used for analysis.

Number of seeds head⁻¹: Mature heads from the tagged plants were harvested separately and threshed. The seeds obtained from individual heads were counted, and the average number of seeds head⁻¹ was calculated for each genotype.

Relative water content (%): Relative water content (RWC) was determined from leaves collected from representative plants under the respective irrigation treatments following the procedure described by Keleri et al. (2022). The trait was expressed as a percentage.

Chlorophyll content: Leaf chlorophyll content was measured using a SPAD chlorophyll meter. Measurements were taken from representative plants of each genotype under the respective irrigation regimes.

Oil content (%): Oil content was determined from a 10-g powdered seed sample using a Soxhlet extraction procedure. The extracted samples were dried, cooled in a desiccator and weighed to determine oil content, which was expressed as a percentage of the original sample weight.

Statistical analysis: The data for all morphological and physiological traits were subjected to analysis of variance (ANOVA) appropriate for the split-plot experimental design following Gomez and Gomez (1984). Genotypic means were compared using an appropriate post-hoc test where significant differences were detected. Variability among genotypes under normal and water-stressed conditions was assessed using the relevant estimates of variation and descriptive statistics. The interaction between irrigation regimes and genotypes was also examined to determine differential genotypic responses to water stress.

Results

Mean squares from ANOVA

The mean squares of analysis of variance revealed that treatment, genotypes, and treatment x genotypes, were significant for all the traits like days to 90% maturity, plant height, number of leaf plant⁻¹, leaf area, head diameter, stem girth, number of seeds head⁻¹, seed index, seed Yield, relative water content, chlorophyll content and oil content whereas, interaction of treatments with genotypes were also significant for traits like seed Index relative water content and chlorophyll content, however non-significant for majority of the traits (Table 1 (a)).

Table 1 (a) Combined ANOVA for yield and oil traits grown under non-stress and water stress condition

Traits	Mean square					Error (b) (D.F.40)
	Replication (D.F.2)	Treatment (D.F.1)	Error (a) (D.F.2)	Genotypes (D.F.10)	TxG (D.F.10)	
Days to 90% maturity	4.13	30.68*	0.409	208.03**	1.54 ^{NS}	1.77
Plant height	17.64	99.41*	8.91	1370.08**	1.01 ^{NS}	5.02
Number of leaf plant ⁻¹	8.28	33.46*	0.46	95.21**	0.16 ^{NS}	1.09
Leaf area	1.68	47.51*	0.65	174.74**	0.21 ^{NS}	2.35
Head diameter	1.69	34.90*	2.18	39.30**	1.10 ^{NS}	1.20
Stem girth	0.32	0.66*	0.01	3.64**	0.00 ^{NS}	0.03
Number of seeds head ⁻¹	259	10973*	519	147980**	378 ^{NS}	700
Seed index	3.379	160.74*	1.470	36.33**	2.376**	0.691
Seed yield	2.129	118.13*	0.30	93.07**	0.90 ^{NS}	3.06
Relative water content	1.68	2596.91*	14.05	174.29**	46.28**	4.48
Chlorophyll Content	0.230	414.00*	1.206	327.04**	13.43**	2.96
Oil content	9.84	37.72*	3.95	19.14**	0.38 ^{NS}	1.45

** = Significant at 1% probability level

* = Significant at 5% probability level

Table 1 (b) ANOVA of sunflower genotypes for yield and physiological traits grown under non-stress and water stress condition

Traits	NON- STRESS			WATER-STRESS		
	Replication (D.F.02)	Genotypes (D.F.10)	Error (D.F.20)	Replication (D.F.02)	Genotypes (D.F.10)	Error (D.F.20)
Days to 90% maturity	3.36	108.82**	1.397	1.18	100.75**	2.14
Plant height(cm)	11.72	684.13**	5.394	14.81	686.95**	4.65
Number of leaf plant ⁻¹	4.0303	49.48**	1.1303	4.72	45.89**	1.06
Leaf area	0.84	91.66**	3.04	1.48	83.29**	1.65
Head diameter(cm)	0.48	23.49**	1.01	3.39	16.92**	1.39
Stem Girth (cm)	0.12	1.84**	0.03	0.21	1.81**	0.02
Number of seeds head ⁻¹	465.5	76629.8**	643.4	312.4	71728.4**	757.2
Seed Index	0.39	16.78**	0.86	4.45	21.92**	0.52
Seed Yield	1.48	46.85**	4.17	0.95	47.12**	1.95
Relative water content (%)	9.90	78.20**	2.24	5.81	142.36**	6.71
Chlorophyll Content %	0.21	133.15**	3.31	1.22	207.32**	2.62
Oil content (%)	0.79	9.15**	1.60	12.99	10.37**	1.30

** = highly significant at 1%

* = significant at 5% probability

NS = non-significant

Separate mean square from ANOVA for yield and oil traits

The mean square of analysis of variance revealed that genotypes, were significant for all the traits like days to 90% maturity, plant height, number of leaf plant⁻¹, leaf area, head diameter, stem girth, number of seeds head⁻¹, seed index, seed Yield, relative water content, chlorophyll content and oil content, under non stress and water stress environment in Table 4.1b.

Mean performance

Tables 4.2 to 4.7 showed the mean performance of the sunflower genotypes grown under non-stress and water-stress.

Days to 90% maturity

The mean performance of females, males and F₁ hybrids exhibited that the Peshawar-93 x corolla took minimum (105.00 and 106.33 days) and (Male) PSF-05 also recorded minimum (105.67 and 104.67 days) for days to 90% maturity. F₁ hybrids Charnika x Corolla took maximum (123.00 and 122.00 days) for days to 90% maturity respectively under both conditions. However, the maximum decrease in 90% maturity days owing to water stressed ascended in F₁ hybrids Charnika x PSF-05 (-2.33 days), female Peshawar-93 (-2.33 days) and HO-1 (-2.00 days) (Table 2).

Plant height (cm)

The minimum reduction was observed in -1.33 in female PSF-05 and F₁ hybrid Peshawar-93 x PSF-05, whereas maximum decrease in plant height was noted in female Peshawar-93 -3.66 and followed by HO-1 and Charnika (3.00 cm). The range of variation in normal irrigation was 123.66 to 168.67 cm and it was 120.00 to 165.33 cm in moisture deficit conditions (Table 2). The minimum plant height was recorded by Peshawar-93 (123.66 and 120.00 cm) followed by F₁ hybrid Peshawar-93 x Corolla (128.33 and 125.67 cm) in non-stress and water stress condition.

Number of leaf plant⁻¹

In normal environment, the average number of leaf plant⁻¹ was recorded as 26.00 against 23.33 in water stress environment; hence, adverse moisture conditions caused an average decline of -2.00 number of leaf plant⁻¹. Significant genetic dissimilar were shown among genotypes for number of leaf plant⁻¹, which ranged from 26.00 to 12.33 in normal and 24.33 to 11.33 in water stressed environment (Table 4.3). The minimum comparative reductions in number of leaf plant⁻¹ were recorded female Peshawar-93 (-1.00) and male corolla (-1.00). The higher reductions due to water stress were shown for the F₁ hybrid Peshawar-93 x PSF-05 (-2.00), Charnika x PSF-05 (-2.00) and Peshawar-93 x Corolla (-1.67)

Table 2 Mean performance for days to 90% maturity and Plant height of sunflower genotypes grown under non-stress and water stress condition

Genotypes	Days to 90% maturity		D.F.*	Plant height (cm)		D.F*
	Non-stress	Water-stress		Non-stress	Water-stress	
HO-1	115.67	113.67	-2.00	162.00	159.00	-3.00
Peshawar-93	110.00	107.67	-2.33	123.66	120.00	-3.66
Charnika	120.67	118.67	-2.00	155.00	152.00	-3.00
Corolla	109.00	107.33	-1.67	145.00	142.67	-2.33
PSF-05	105.67	104.67	-1.00	155.00	153.67	-1.33
HO-1 x Corolla	112.67	111.33	-1.34	168.67	165.33	-3.34
Peshawar-93 x Corolla	105.00	106.33	1.33	128.33	125.67	-2.66
Charnika x Corolla	123.00	122.00	-1.00	136.67	134.00	-2.67
HO-1 x PSF-05	116.33	115.00	-1.33	158.00	155.67	-2.33
Peshawar-93 x PSF-05	107.67	106.33	-1.34	130.00	128.67	-1.33
Charnika x PSF-05	108.33	106.00	-2.33	153.67	152.33	-1.34
LSD at 5% (T)	0.67			3.16		
LSD at 5% (G)	2.62			2.62		
LSD at 5% (TxG)	4.17			7.03		

Leaf area

The maximum leaf area was recorded in F₁ hybrid HO-1 x PSF-05 (49.00 and 46.67) followed by HO-1 x Corolla (48.67 and 46.33) and female Peshawar-93 (46.00 and 44.33) under non stress and in stress conditions (table 4.3). The leaf area decreased due to stress and average decline of -2.33 and -1.33 was noted under stress environment (Table 3).

Head diameter (cm)

In non-stress condition, the maximum head diameter size was showed in F₁ hybrid HO-1 x PSF-05 (23.00 cm) followed by HO-1 x Corolla (22.33 cm) and female HO-1 (21.67). Almost the same female and F₁ hybrid measured bigger heads in water stress condition also. The head diameter of inbred line and F₁ hybrids in normal conditions varied from 14.33 to 23.00 cm and under stress, it ranged from 14.33 to 21.67 cm. The lower reductions due to moisture insufficiency was observed in female Charnika (-0.00) followed by F₁ hybrid Charnika x Corolla (-1.00 cm) and

Peshawar-93 x Corolla (-1.33 cm), however the average decline was -3.66 cm in head diameter owing to stress conditions (Table 4).

Stem girth (cm)

The stem diameter of inbred line and F₁ hybrids in non-stress varied from 3.13 to 5.27 cm while it was 2.93 to 4.97 cm in genotypes under water stress condition Table 4 Among the (female), (male) and F₁ hybrids, maximum (5.27 and 4.47 cm) stem diameter was observed in HO-1 x Corolla under both normal and drought stress conditions respectively. The higher stem diameter measuring 4.97, 4.97 and 4.83 cm in stress conditions was observed in F₁ hybrids HO-1 x Corolla, HO-1 x PSF-05 and Peshawar-93 x PSF-05 respectively. On an average, stem diameter deteriorated by -0.24 cm due to water stressed conditions (Table 4.4). The minor decline by stress was documented by the genotypes Peshawar-93 (-0.02 cm) followed by HO-1, Charnika (-0.24 cm), whereas higher declines were exhibited in F₁ hybrids Charnika x PSF-05 (-0.24 cm).

Table 3 Mean performance for to number of leaf plant⁻¹ and leaf area of sunflower genotypes grown under non-stress and water stress condition

Genotypes	Number of leaf plant ⁻¹		D.F.*	Leaf area		D.F.*
	Non-stress	Water-stress		Non-stress	Water-stress	
HO-1	16.00	14.67	-1.33	42.33	40.67	-1.66
Peshawar-93	12.33	11.33	-1.00	46.00	44.33	-1.67
Charnika	19.67	18.33	-1.34	35.00	33.33	-1.67
Corolla	21.33	20.33	-1.00	44.00	42.67	-1.33
PSF-025	22.00	20.67	-1.33	36.67	35.33	-1.34
HO-1 x Corolla	26.00	24.33	-1.67	48.67	46.33	-2.34
Peshawar-93 x Corolla	23.00	21.67	-1.33	42.00	40.67	-1.33
Charnika x Corolla	18.00	16.67	-1.33	45.67	44.00	-1.67
HO-1 x PSF-025	16.00	14.67	-1.33	49.00	46.67	-2.33
Peshawar-93 x PSF-025	19.00	17.00	-2.00	47.00	45.00	-2.00
Charnika x PSF-025	24.33	22.33	-2.00	33.00	31.67	-1.33
LSD at 5% (T)	0.72			0.85		
LSD at 5% (G)	2.06			3.01		
LSD at 5% (TxG)	3.28			4.80		

Table 4 Mean performance for head diameter and stem girth of sunflower genotypes grown under non-stress and water stress condition

Genotypes	Head diameter		D.F.*	Stem girth		D.F.*
	Non-stress	Water-stress		Non-stress	Water-stress	
HO-1	21.67	20.33	-1.34	4.97	4.77	-0.2
Peshawar-93	17.67	16.33	-1.34	4.03	3.93	-0.1
Charnika	14.33	14.33	0.00	3.13	2.93	-0.2
Corolla	16.67	15.33	-1.34	3.40	3.17	-0.23
PSF-025	19.67	18.00	-1.67	4.83	4.67	-0.16
HO-1 x Corolla	22.33	18.67	-3.66	5.27	4.97	-0.3
Peshawar-93 x Corolla	18.00	16.67	-1.33	4.07	3.90	-0.17
Charnika x Corolla	16.33	15.33	-1.00	3.60	3.40	-0.2
HO-1 x PSF-025	23.00	21.67	-1.33	5.17	4.97	-0.2
Peshawar-93 x PSF-025	20.67	19.33	-1.34	5.03	4.83	-0.2
Charnika x PSF-025	17.00	15.33	-1.67	3.67	3.43	-0.24
LSD at 5% (T)	1.56			0.13		
LSD at 5% (G)	2.16			0.35		
LSD at 5% (TxG)	3.44			0.56		

Number of seeds head⁻¹

The number of seeds head⁻¹ ranged between 698.67 to 1158.33 in non-stress condition and

676.33 to 1135.00 in water stress Table 4.5. Whereas minimum decrease in number of seeds head⁻¹ was counted in F₁ hybrids Charnika x

Corolla (-3.67) and maximum in (female) HO-1 (-70.00) followed by F₁ hybrids Peshawar-93 x PSF-05 (-35.00) under water stress environment. The maximum number of seeds head⁻¹ were observed in F₁ 234789 hybrids HO-1 x PSF-05 (1158.33 and 1135.00), followed by the F₁ hybrids HO-1 x Corolla and (male) PSF-05 (1129.33 and 1109.33) and (1055.33 and 1030.67) under both environment Table 5).

Seed yield

In normal irrigation, the maximum seed yield was noted in F₁ hybrids charnika x PSF-025 (72.00 and 69.67) followed by HO-1 x Corolla (70.33 and 68.33), female charnika (69.33 and 66.67%) and male parent PSF-025 (68.00 and 65.00,) under both environments. The seed yield of inbreed lines and F₁ hybrids in non-stress conditions varied from 60.10 to 72.00 and under stress, it ranged from 57.33 to 69.67. The lower reductions due to

water shortage were noted in male parent corolla (-1.34) and F₁ hybrids HO-1 x Corolla (-2.00) followed by HO-1 x PSF-05 and Charnika x PSF-05 (-2.33 and -2.33) in (Table 5).

Seed index

The F₁ hybrid Charnika x PSF-05 (-1.00), HO-1 x Corolla (-1.67) and Charnika x Corolla (-2.00) showed smaller reductions in drought conditions against other inbreed lines and F₁ hybrid under evaluation. The upper edge in seed index (45.00 and 41.00) was showed by the F₁ hybrid Peshawar-93 x Corolla followed by Charnika x Corolla (44.00 and 42.00) and (female) HO-1 (43.00 and 38.00) under non stress and in water stress conditions. The maximum reduction was observed female HO-1 (-5.00) and followed by PSF-05 (-4.33) and Charnika (-3.67) in Table 6).

Table 5 Mean performance for number of seeds head⁻¹ and seed index of sunflower genotypes grown under non-stress and water stress condition

Genotypes	Number of seeds head ⁻¹		D.F.*	Seed yield		D.F*
	Non-stress	Water-stress		Non-stress	Water-stress	
HO-1	1046.67	976.67	-70.00	64.33	61.00	-3.33
Peshawar-93	821.33	809.33	-12.00	66.33	62.00	-4.33
Charnika	698.67	676.33	-22.34	69.33	66.67	-2.66
Corolla	805.33	785.33	-20.00	61.67	60.33	-1.34
PSF-025	1055.33	1030.67	-24.66	68.00	65.00	-3.00
HO-1 x Corolla	1129.33	1109.33	-20.00	70.33	68.33	-2.00
Peshawar-93 x Corolla	1008.00	987.00	-21.00	63.67	61.33	-2.34
Charnika x Corolla	798.67	786.00	-3.67	60.10	57.33	-2.77
HO-1 x PSF-025	1158.33	1135.00	-23.33	61.00	58.67	-2.33
Peshawar-93 x PSF-025	1088.33	1053.33	-35.00	65.00	62.00	-3.00
Charnika x PSF-025	834.33	811.67	-22.66	72.00	69.67	-2.33
LSD at 5% (T)	24.16			0.58		
LSD at 5% (G)	52.09			3.44		
				5.49		
LSD at 5% (TxG)	83.02					

Relative water content (%)

In normal irrigation, the maximum relative water content (%) was noted in Charnika x Corolla (91.00 and 80.67%) followed by HO-1 x Corolla (90.67 and 77.00 %) and Corolla (76.67 and 66.33 %,) under both environments. The relative water content % of inbred lines and F₁ hybrids in non-

stress conditions varied from 76.67 to 91.00 % and under stress, it ranged from 62.00 to 84.00%. The lower reductions due to water shortage were noted in F₁ hybrids HO-1 x PSF-05(-7.00) followed by Charnika x PSF-05 (8.33%) and male Corolla (-8.34) in (Table 6).

Table 6 Mean performance for seed yield and relative water content of sunflower genotypes grown under non-stress and water stress condition

Genotypes	Seed index		D.F.*	Relative water content (%)		D.F.*
	Non-stress	Water-stress		Non-stress	Water-stress	
HO-1	43.00	38.00	-5.00	80.33	62.00	-18.33
Peshawar-93	40.33	37.33	-3.00	85.33	69.67	-15.66
Charnika	40.00	36.33	-3.67	88.33	62.67	-25.66
Corolla	39.00	36.33	-2.67	76.67	68.33	-8.34
PSF-025	40.33	36.00	-4.33	83.00	71.33	-11.67
HO-1 x Corolla	42.00	40.33	-1.67	90.67	77.00	-13.67
Peshawar-93 x Corolla	45.00	41.00	-4.00	86.33	76.00	-10.33
Charnika x Corolla	44.00	42.00	-2.00	91.00	80.67	-10.33
HO-1 x PSF-025	46.00	41.67	-4.33	91.00	84.00	-7.00
Peshawar-93 x PSF-025	41.67	39.00	-2.67	83.00	74.33	-8.67
Charnika x PSF-025	45.00	44.00	-1.00	78.33	70.00	-8.33
LSD at 5% (T)	1.28			3.97		
LSD at 5% (G)	1.63			4.16		
LSD at 5% (TxG)	2.60			6.64		

Chlorophyll content (%)

The chlorophyll content decreased due to water stress and average decline of -13.33 was showed under stress environment (Table 4.7). The higher chlorophyll content was observed in F₁ hybrids Charnika x PSF-05 (61.00 and 59.33), and female Corolla (54.33 and 50.23) Peshawar-93 x PSF-05

(54.00 and 49.67) in normal condition and water stress condition.

Oil content (%)

The F₁ hybrid Charnika x PSF-05 (-2.33) was observed maximum reduction whereas minimum reduction was showed F₁ hybrid Charnika x PSF-05 (-0.67) in (Table 4.7). The maximum oil

content was recorded in PSF-05 (42.08, 40.67%), followed by HO-1 x PSF-05 (41.67, 39.67%) and HO-1 40.67, 39.62%) under non stress and water stress environments respectively. The genetic

variation of 36.67 to 42.08% and 34.67 to 40.670% was recorded in oil content of genotypes in normal and in stress conditions correspondingly.

Table 7 Mean performance for chlorophyll content and oil content of sunflower genotypes grown under non-stress and water stress condition

Genotypes	Chlorophyll content %		D.F.*	Oil content (%)		D.F*
	Non-stress	Water-stress		Non-stress	Water-stress	
HO-1	44.00	38.00	-6.00	40.67	39.62	-1.05
Peshawar-93	39.67	35.67	-4.00	39.00	37.67	-1.33
Charnika	41.00	35.67	-5.33	37.00	35.33	-1.67
Corolla	54.33	50.23	-4.1	38.00	37.00	-1.00
PSF-025	48.33	45.00	-3.33	42.08	40.67	-1.41
HO-1 x Corolla	44.33	31.00	-13.33	39.61	37.77	-1.84
Peshawar-93 x Corolla	43.00	38.33	-4.67	38.33	36.00	-2.33
Charnika x Corolla	47.00	43.67	-3.33	36.67	34.67	-2.00
HO-1 x PSF-025	53.00	48.00	-5.00	41.67	39.67	-2.00
Peshawar-93 x PSF-025	54.00	49.67	-4.33	39.00	37.67	-1.33
Charnika x PSF-025	61.00	59.33	-1.67	38.67	38.00	-0.67
LSD at 5% (T)	1.16			2.10		
LSD at 5% (G)	3.39			2.37		
LSD at 5% (TxG)	5.40			3.78		

Discussion

Results from the analysis of variance (ANOVA) showed that all traits, including days to 90% maturity, plant height, number of leaves per plant, leaf area, head diameter, stem girth, number of seeds per head, seed index, seed yield, relative water content, chlorophyll content, and oil content, were significantly influenced by treatment, genotypes, and their interactions. For seed index, relative water content, and chlorophyll content, the interaction between treatments and genotypes was significant; however, it was not significant for the majority of other variables. Significant genotype and treatment effects were noted in the investigations conducted by Boero et al. (2023); Baloch et al. (2018) and Mackay et al. (2021), which showed similar findings, were significant for all the traits like days to 90% maturity, plant height, number of leaf plant⁻¹, leaf

area, head diameter, stem girth, number of seeds head⁻¹, seed index, seed Yield, relative water content, chlorophyll content and oil content, under non stress and water stress environment in Table 1.b. The mean performance of females, males and F₁ hybrids exhibited that the Peshawar-93 x corolla took minimum (and (Male) PSF-025 also recorded minimum for days to 90% maturity. F₁ hybrids Charnika x Corolla took maximum for days to 90% maturity respectively under both conditions. However, the maximum decrease in 90% maturity days owing to water stressed ascended in F₁ hybrids Charnika x PSF-025, female Peshawar-93 and HO-1 (Table 2). The minimum reduction was observed in in female PSF-05 and F1 hybrid Peshawar-93 x PSF-05, whereas maximum decrease in plant height was noted in female Peshawar and followed by HO-1 and Charnika (Table 2). The minimum plant

height was recorded by Peshawar-93 followed by F₁ hybrid Peshawar-93 x Corolla in non-stress and water stress condition. The minimum comparative reductions in number of leaf plant⁻¹ were recorded female Peshawar-93 and male corolla, they reported similar types of mean performance for males, females and their F₁ hybrids Bano et al (2017); Chawla et al. (2023); Chen et al. (2023). The higher reductions due to water stress were shown for the F₁ hybrid Peshawar-93 x PSF-025, Charnika x PSF-025 and Peshawar-93 x Corolla. The maximum leaf area was recorded in F₁ hybrid HO-1 x PSF-025 and) followed by HO-1 x Corolla and female Peshawar-93 under non stress and in stress conditions (table 4.3). In non-stress condition, the maximum head diameter size was showed in F₁ hybrid HO-1 x PSF-025 followed by HO-1 x Corolla and female HO-1. Almost the same female and F₁ hybrid measured bigger heads in water stress condition also. The lower reductions due to moisture insufficiency were observed in female Charnika followed by F₁ hybrid Charnika x Corolla and Peshawar-93 x Corolla, however the average decline was -3.66 cm in head diameter owing to stress conditions. Among the (female), (male) and F₁ hybrids, maximum stem diameter was observed in HO-1 x Corolla under both normal and drought stress conditions respectively. The higher stem diameter in stress conditions was observed in F₁ hybrids HO-1 x Corolla, HO-1 x PSF-025 and Peshawar-93 x PSF-025 respectively. The minor decline by stress was documented by the genotypes Peshawar-93 followed by HO-1, Charnika, whereas higher declines were exhibited in F₁ hybrids Charnika x PSF-025. The maximum number of seeds head⁻¹ were observed in F₁ hybrids HO-1 x PSF-025, followed by the F₁ hybrids HO-1 x Corolla and (male) PSF-025 under both environments. Other researchers like Saeed et al. (2022); Siahbidi et al. (2022) and Rajper et al. (2018), reported that in normal irrigation, the maximum Seed yield was noted in F₁ hybrids charnika x PSF-025 followed by HO-1 x Corolla, female charnika and male parent PSF-025 under both environments. The seed yield of inbreed lines and F₁ hybrids in non-

stress conditions varied from 60.10 to 72.00 and under stress, it ranged from 57.33 to 69.67. The lower reductions due to water shortage were noted in male parent corolla and F₁ hybrids HO-1 x Corolla followed by HO-1 x PSF-025 and Charnika x PSF-025 in (Table 5). In normal irrigation, the maximum relative water content (%) was noted in Charnika x Corolla followed by HO-1 x Corolla and Corolla under both environments. The relative water content % of inbreed lines and F₁ hybrids in non-stress conditions varied from 76.67 to 91.00 % and under stress, it ranged from 62.00 to 84.00%. The lower reductions due to water shortage were noted in F₁ hybrids HO-1 x PSF-025 (-followed by Charnika x PSF-025 and male Corolla in (Table 6). The chlorophyll content decreased due to water stress and average decline of -13.33 was showed under stress environment (Table 4.7). The higher chlorophyll content was observed in F₁ hybrids Charnika x PSF-025, and female Corolla Peshawar-93 x PSF-025 in normal condition and water stress condition. The F₁ hybrid Charnika x PSF-025 was observed maximum reduction whereas minimum reduction was showed F₁ hybrid Charnika x PSF-025 in (Table 7). The maximum oil content was recorded in PSF-025, followed by HO-1 x PSF-025 and HO-1 under non stress and water stress environments respectively. The genetic variation of 36.67 to 42.08% and 34.67 to 40.670% was recorded in oil content of genotypes in normal and in stress conditions correspondingly.

Conclusion

The mean squares from ANOVA showed that genotypes, parents, females, males and females x males were significant for all the traits like days to 90% maturity, plant height, number of leaf plant⁻¹, leaf area, head diameter, stem girth, number of seeds head⁻¹, seed index, seed Yield, relative water content, chlorophyll content and oil content whereas, interaction of treatments with genotypes were also significant for traits like seed Index relative water content and chlorophyll content, however non-significant for majority of the traits.

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