International Journal of Agricultural and Natural Sciences
E-ISSN: 2651-3617 18(2): 229-241, 2025
doi:10.5281/zenodo.17011691
Research Article

IDENTIFICATION OF POTENTIAL SUNFLOWER GENOTYPES FOR YIELD AND OIL TRAITS FOR LOW WATER STRESS CONDITIONS

Rukhsar Samoon[1*], Wajid Ali Jatoi [1], Aweesha Bughio[1] , Shah Nawaz Mari[1], Inam Ali Jatoi[1], Nabeela Khokhar[1], Zubair Ahmed[1], Reema Vistro[2], Mehmooda Buriro[3]

[1]*Sindh Agriculture University, Faculty of Crop Production, Department of Plant Breeding and Genetics, Tandojam, Pakistan*
[2]*Cotton research institute ARC Tandojam*
[3]*Sindh Agriculture University, Faculty of Crop Production, Department of Agronomy, Tandojam, Pakistan*

**Corresponding Author:*
E-mail: rukhsarsamoon69@gmail.com

(Received 15th May 2025; accepted 22nd July 2025)

ABSTRACT. The present studies were conducted during the spring season 2024 at the experimental area of Oilseeds Research Institute, Agriculture Research Center, Tandojam, for determining the effect of low water stress for yield and oil traits of sunflower (*Helianthus annus* L.) genotypes, there were six genotypes, including, LD 1003, YK 221, YK A91, YK A 90, YK A92, GP-606 were investigated. The experimental design was a split-plot design with two treatments (T1=control conditions) and (T2=single irrigation), and three replications, while nine parameters were recorded. The mean squares from ANOVA expressed that all genotypes were significant for days to 90% maturity, plant height, number of seeds head^{-1}, stem girth, head mass, protein content (%), oil content (%), oleic acid (%) and linoleic acid (%) at P<0.01. Among all genotypes, Yk a91 showed the maximum performance compared to the rest of the genotypes. YK a91 shows highest performance for PH, NSH, SG and HM and minimum for DTM, OC and LA in Low stress conditions, In water stress same genotype YK a91 has maximum performance for plant height, no. of seeds head^{-1}, stem girth, head mass, protein content and oil content and have minimum days to 90% maturity, and minimum linoleic acid were recorded. The correlation coefficient, regression & coefficient of determination analyses under Low stress and water stress, head mass gave a positive association with its contributing traits. Heritability in a broad sense was estimated that high heritability was observed for all the studied traits. Genotype YK A91 shows the highest performance in water stress conditions.

Keywords: *Water stress, correlation, regression, heritability, sunflower genotypes*

INTRODUCTION

The sunflower (*Helianthus annuus* L.) is an annual self-incompatible insect-pollinated plant that is a member of the Asteraceae family. 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 that helps them to grow. The most common type of sunflower is *H. annuus* L. Over 70 species of *Helianthus* are known globally [1]. 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. They have special quality traits called heliotropism where the young flower heads face east in the morning and track the path of the sun throughout the day this is referred to as phototropism or solar tracking [2]. It became increasingly popular among oilseeds, and its cultivation area is progressively expanding due to its short growing season, light insensitivity, and adaptability. It represents a promising oilseed crop due to its faster seed multiplication rate, drought tolerance, good quality of oil, and production of more oil per unit area, and it is a source of linoleic acid [3]. Furthermore, water stress is a very serious climatic factor that decreases sunflower yield. It requires an understanding of the phenotypic characteristics that can restore the performance under water stress conditions and an understanding of the complicated physiological and genetic pathways involved under stress conditions. One of the most chief goals of plant breeders is to enhance drought tolerance and water productivity in plants for such regions. One of the main concerns for plant breeders shortly is to boost crop plants' resistance to water stress while also improving their ability to use water efficiently [4]. From a genetic and natural perspective, sunflower is a field crop that is susceptible to drought [5]. The insufficient water supply is becoming a serious matter from time to time, which affects plant growth and development.

Drought may have a significant but adverse impact on the production of food in light of the facts. Water scarcity is a key abiotic stress that reduces yield in almost all crop plants, especially in arid and semi-arid areas of the world [6]. The correlation of sunflowers refers to the relationship between different aspects of sunflowers, such as their growth, morphology, ecological significance, and economic value. They have been cultivated for various purposes, including oil production, ornamental value, and as a food source for humans and wildlife. Furthermore, correlation also assesses the progressive and undesirable properties of characteristics on achene yields. To overcome the high number of breeding lines, breeders always utilize well-organized approaches [7-8]. Since correlation reduces the likelihood of ambiguity, predictions made using correlation analysis are probably quite close to reality. Several researchers have identified various forms of association between oil content and grain production [9]. The level of the relationship among yield components is described by regression analysis. However, correlation to explicate yield relationships only is generally preferred by sunflower researchers [10-11]. The regression analysis determines the relationship between seed yield and other agronomic traits. Regression analysis gives information about the relevant plant traits based on maximum variation in seed yield [12]. The different multiple regression models are used to determine the appreciate selection criteria. The results of their studies were shown to be changeable, exposed to the population and environmental circumstances in which selection was practiced, considering the relevance of correlation and regression analysis [13]. An increase in local oilseed production is crucial for saving a significant amount of foreign exchange. Developing high-yielding oilseed varieties/hybrids that can adapt to our climatic conditions is the only viable solution.

Among oilseed crops, oilseed sunflower is the preferred source of oil for domestic consumption and cooking worldwide [14]. It is considered an important oil crop globally, with an annual production of 20 to 25 million hectares [15]. Sunflower was introduced to Pakistan in the 1960s due to its superior qualities compared to other oilseed crops. Sunflower oil is highly regarded for its light color, mild flavor, low levels of saturated fatty acids, and ability to withstand high cooking temperatures. In addition to its advantages as a premium oil, sunflower can also be used as birdseed, livestock feed, and more [16].

MATERIALS AND METHODS

During the spring growing season of 2024, the experiment carried out in a split-plot design with three replications and two treatments, a total of four irrigations were applied (T1=control conditions) on stages i.e. 20-25 days after sowing, near to flowering with nitrogen, after maturation of head, and 4th before maturation. While (Treatment-II were given between germination and flowering (single irrigation) at the experimental area of the Oilseeds Research Institute, Tandojam. The space between plant to plant was about 09 inches, and row to row was about 2.5 ft; however, plot size was 3 x 5 (m). To identify potential sunflower genotypes for yield and oil traits, six sunflower genotypes i.e. LD-1003, Yk-221, Yk-a91, Yk-a90, Yk-a92, and GP-606, were used for the following parameters.

Days to 90% maturity

The data were recorded when heads 90% mature from the date of sowing days was recorded by observing plants.

Plant height (cm)

The index plants were measured in centimeters and recorded as plant height.

Number of seeds head^{-1}

After harvesting, the heads were manually threshed to count the seeds per head in the laboratory.

Stem girth (cm)

The stem girth was measured with the help of vernier caliper in centimeters from index plants.

Head mass (g)

The harvested head was put in the laboratory and heads were measured on electronic balance and recorded data in grams.

Protein content (%)

The samples were digested using a modified Kjeldahl method, in which nitrogen was converted into NH4-N, and the digestion was determined using 40% NaOH and 0.1 NHCL standard.

Oil content (%)

Oil content % was recorded by extracting the oil from the 100g seed of each selected head of each variety.

Oleic acid content (%)

It is calculated according to procedures adopted by Shamshad et al. (2016).

Linoleic acid content (%)

It is calculated according to procedures adopted by Shamshad et al. (2016).

Statistical analysis

The data were analyzed using analysis of variance, following the method described by Gomez & Gomez (1984). Mean differences were compared using the least significant differences test (LSD). Heritability was estimated using the approach suggested by Allard (1960), while the correlation coefficient between different traits was computed according to Snedecor and Cochran (1980). Additionally, regression analysis was performed as recommended by Galton (1886).

RESULTS AND DISCUSSION

Analysis of Variance

The mean squares from ANOVA (Table 1) expressed that genotypes were significant for all study traits at ($P<0.01$). These results suggested that genotypes performed differently over the stress conditions for yield and oil traits. Similar results were obtained by [12] they also observed significant variation.

Table 1a. *Combined mean square from ANOVA for yield and oil traits of sunflower under Low stress and water stress*

Traits	Mean square					
	Replication (D.F.2)	**Treatment (D.F.1)**	**Error (a) (D.F.2)**	**Genotypes (D.F.5)**	**T x G (D.F.5)**	**Error (b) (D.F.20)**
Days to 90% maturity	2.52	506.25**	1.08	257.56**	15.78**	3.57
Plant height	11.08	6346.78**	17.69	2316.00**	188.24**	4.72
No. of seeds head^{-1}	29.00	177241**	105.00	142401**	10377**	145
Stem girth	0.00	11.61**	0.01	5.90**	1.08**	0.03
Head mass	0.38	182.92**	0.17	62.77**	7.17**	0.43
Protein content	0.58	177.77**	2.86	26.66**	3.91**	0.82
Oil content	7.58	26.69 **	6.02	8-.58**	94.76**	0.70
Oleic acid	0.19	160.44**	0.86	47.37**	6.71**	0.69
Linoleic acid	0.04	375.00**	2.51	183.95**	6.94**	1.07

**, * Denotes significance at 1% and 5% probability respectively.

Table 1b. *Mean square from ANOVA for yield and oil traits of sunflower under non-stress and water stress*

Traits	LOW STRESS			WATER-STRESS		
	Replication (D.F.2)	**Genotypes (D.F.5)**	**Error (D.F.10)**	**Replication (D.F.02)**	**Genotypes (D.F.5)**	**Error (D.F.)**
Days to 90% maturity	0.72	182.75**	1.32	2.88	90.58**	5.82
Plant height	2.72	1767.12**	4.46	26.05	737.12**	4.98
No. of seeds head^{-1}	15.00	101259**	126.00	119.4	51518.7**	164.1
Stem girth	0.001	5.52**	0.06	0.00	1.46**	0.01
Head mass	0.02	45.48**	0.20	0.54	24.45**	0.67
Protein content	2.72	20.48**	0.72	0.72	10.08**	0.92
Oil content	7.38	162.22**	1.18	6.22	13.12**	0.22
Oleic acid	0.38	27.95**	0.58	0.66	26.13**	0.80
Linoleic acid	1.05	117.19**	0.65	1.50	73.70**	1.50

Mean performance of sunflower genotypes

Days to 90% maturity

Days to 90% maturity decreased on average by 7.50 days under water stress, whereas the minimum decrease was observed in GP-606 and the maximum was observed in LD-1003 for days to 90% maturity. Other researchers, like [13], also observed a reduction in days to 90% maturity under a stressful environment.

Plant height

The plant height decreased on average by (-26.55 cm) under water stress conditions. YK-221 showed minimum under stress environment, and YK-A91 showed maximum reduction in plant height as compared to other genotypes. Further, the genotype Yk A91 was also observed to be a taller plant in water stress conditions, followed by GP-606, which exhibited plant height. From the present research, it is suggested that medium-tall plants should be preferred as compared to taller plants. Other researchers like [14], they also reported a similar type of results.

No. of seeds head^{-1}

The no. of seed head^{-1} on average by (-140.34) under water stress conditions, while lower reduction in seed head=1 was noted in Yk-221. The highest NSH were detected in Yk A91 followed by LD 1003. Water stress causes a significant reduction in no. of seeds head=1. However, the above cited genotype reduced lower no. of seeds head=1 such types of genotypes should be selected for further breeding. Other researchers like [15] also noted similar results.

Table 2. *Mean performance for days to 90% maturity, plant height and number of seeds head^{-1} of sunflower genotypes grown under Low stress and water stress environments*

	Days to 90% maturity			Plant height (cm)			No. of seeds head^{-1}		
Genotypes	**Low stress**	**Water-stress**	**D.F.***	**Low stress**	**Water-stress**	**D.F.***	**Low stress**	**Water-stress**	**D.F.***
LD-1003	121.33	108.00	-13.33	162.33	137.00	-25.33	982.00	716.67	-265.33
Yk-221	105.00	97.33	-7.67	145.67	132.00	-13.67	733.33	690.00	-43.33
Yk-A91	111.33	103.67	-7.66	189.67	145.00	-44.67	1017.67	833.33	-184.34
Yk-A 90	108.00	103.00	-5	122.00	102.33	-20.33	643.67	496.67	-147
Yk-A92	117.33	110.00	-7.33	140.00	118.33	-21.67	856.67	708.33	-148.34
GP-606	100.33	96.33	-4.00	172.00	137.67	-34.33	563.00	509.33	-53.67
Mean	110.55	103.05	-7.5	155.27	128.72	-26.55	799.39	659.05	-140.34
LSD at 5% (T)		1.49			6.04			14.72	
LSD at 5% (G)		3.43			3.94			21.87	
LSD at 5% (TxG)		5.67			6.52			36.16	

Stem girth (SG)

The stem girth decreased on average by (-1.13 cm) under water stress conditions. Genotype Yk A91 gave maximum stem girth, followed by LD 1003, respectively. Our results agree with [16] their results showed that a smaller reduction in stem girth was observed in different genotypes of sunflower under water stress conditions.

Head mass

The head mass decreased on average by (-6.69 cm) under water stress conditions. while minimum reduction was observed in LD-1003 and maximum was given by Yk-A92. The present findings suggested that the above genotype, which showed the minimum reduction, performed well under water stress conditions as compared to rest of the genotypes. Similar results were obtained by [17] who also observed that water stress also reduced the head mass, although some genotypes showed a smaller reduction and others showed maximum reduction in head mass.

Protein content

The Protein content decreased on average by (-4.45%) under water stress conditions. The genotype LD 1003 has the highest protein content, followed by genotype Yk 221. Whereas GP-606 exhibited minimum protein content comparing the rest of the genotypes. Our results agree with [18].

Table 3. *Mean performance for stem girth, head mass and protein content of sunflower genotypes grown under Low stress and water-stress environment*

Genotypes	Stem girth			Head mass			Protein content		
	Low stress	Water-stress	D.F*	Low stress	Water-stress	D.F*	Low stress	Water-stress	D.F*
LD-1003	45.1	41.39	-2.43	45.1	41.39	-3.71	24	17.00	-7
Yk-221	43.3	38.21	-0.87	43.3	38.21	-5.09	23.33	20.00	-3.33
Yk-A91	50.36	42.9	-1.97	50.36	42.9	-7.46	22.00	17.00	-5
Yk-A 90	42.1	35.1	-0.47	42.1	35.1	-7	18.00	15.00	-3
Yk-A92	48.78	39.15	-0.53	48.78	39.15	-9.63	22.00	16.67	-5.33
GP-606	39.34	32.1	-0.59	39.34	32.1	-7.24	18.00	15.00	-3
Mean	44.83	38.14	-1.13	44.83	38.14	-6.69	21.22	16.77	-4.45
LSD at 5% (T)		0.03			0.6			2.42	
LSD at 5% (G)		0.35			1.2			1.64	
LSD at 5% (TxG)		0.59			1.98			2.72	

Oil content

The oil content is varied from -1.33 to -7.00% due to water stress conditions, although the genotype LD-1003 showed the minimum reduction in oil content, while the maximum was given by Yk-A90 for oil content. These results suggested that water stress also caused a reduction in oil content. However, genotype LD-1003 reduced the minimum reduction and sustained stress; such a genotype should be preferred for further study. Other researchers like [19] their results are similar to our findings.

Oleic acid

Genotype Yk A92 has the maximum oleic acid, followed by genotype. Whereas, GP-606 has a minimum oleic acid %, as compared to other genotypes [20] they also observed a smaller reduction in traits; thus, our results are in confirmation with these researchers.

Linoleic acid

The Yk 221 showed the highest linoleic acid followed by Yk A92. The minimum linoleic acid is observed in GP-606 in water-stress conditions. Our results are conformity with other researchers like [21] they also observed similar type of results.

Table 4 *Mean performance oil content, oleic acid, and linoleic acid of sunflower genotypes grown under Low stress and water stress*

Genotypes	Oil content			Oleic acid			Linoleic acid		
	Low stress	Water-stress	D.F.*	Low stress	Water-stress	D.F.*	Low stress	Water-stress	D.F.*
LD-1003	38.33	37.00	-1.33	30.33	24.00	-6.33	81.4	74.00	-7.4
Yk-221	39.67	35.00	-4.67	32.67	25.67	-7	86.00	80.00	-6
Yk-A91	38.00	35.33	-2.67	34	31.00	-3	71.67	67.00	-4.67
Yk-A 90	38.00	31.00	-7	28.67	26.33	-2.34	76.67	71.00	-6.67
Yk-A92	41.33	35.00	-6.33	35.67	31.00	-4.67	84.33	74.00	-10.33
GP-606	38.00	33.00	-5	28	26.00	-2	71.67	67.00	-4.67
Mean	38.88	34.38	-4.5	31.55	27.33	-4.33	78.62	72.16	-6.46
LSD at 5% (T)		3.52			1.33			2.27	
LSD at 5% (G)		1.52			1.51			1.88	
LSD at 5% (TxG)		2.52			2.5			3.11	

Correlation Coefficient (r), Regression (b) & Coefficient of Determination (r^2) for various traits in sunflower under Low stress and water stress

Head mass V/S Days to 90% maturity

Under Low stress the correlation coefficient between days to 90% maturity (DTM) and head mass was positively significant which advocated that upturn in days to 90% maturity resulted increase in head mass by (b =0.31) which proposed that an increase in days to 90% maturity was associated with increased head mass, indicating considerable variation among these traits. [22] they also reported similar results.

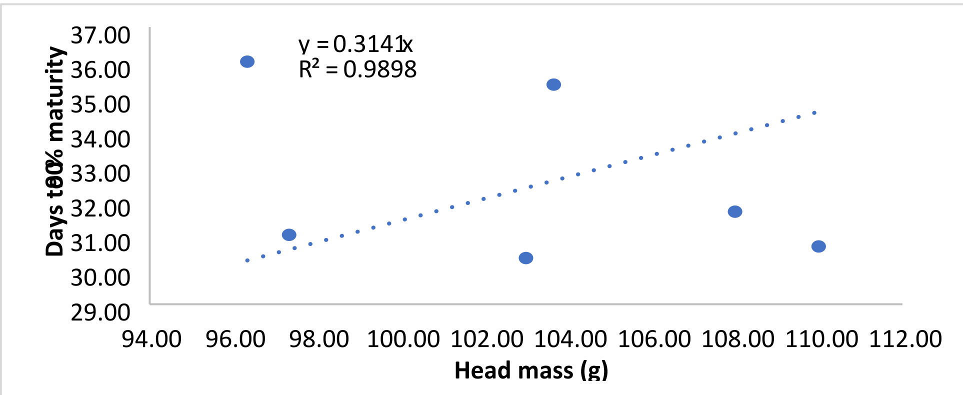

Fig. (1a) *Relationship of days to 90% maturity with head mass of sunflower genotypes grown in Low stress*

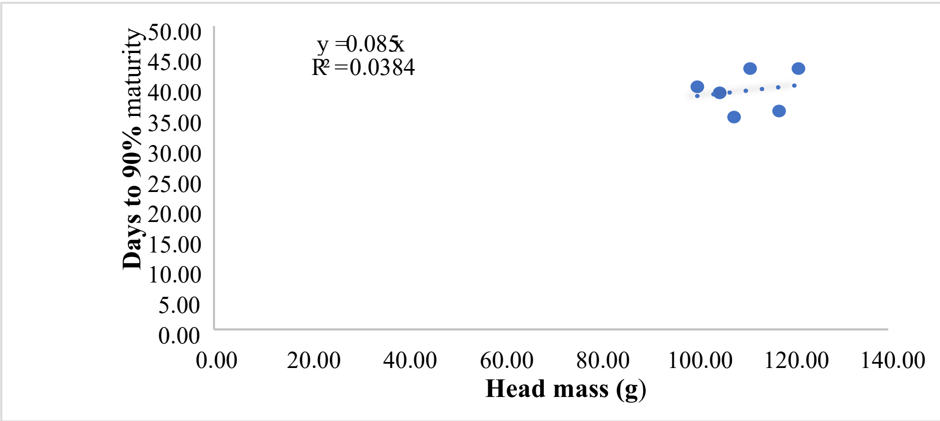

Fig. (1b) Relationship of days to 90% maturity with a head mass of sunflower genotypes grown in water stress

Head mass V/S Plant height

Plant height (PH) and head mass (HM) were positively significant, that indicated an increase in plant height increases in head mass. These traits showed moderate variation so selection should be more effective for the further improvement between these traits. Our results are similar with other researchers like [23]

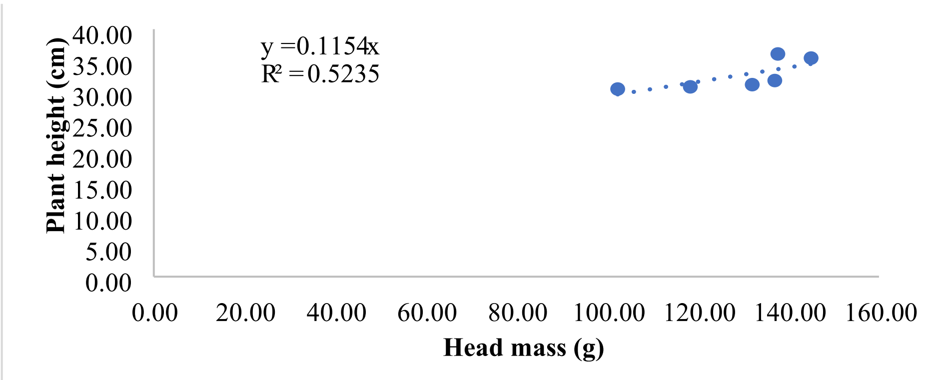

***Figure (2a)** Relationship of plant height with head mass of sunflower genotypes grown in Low stress*

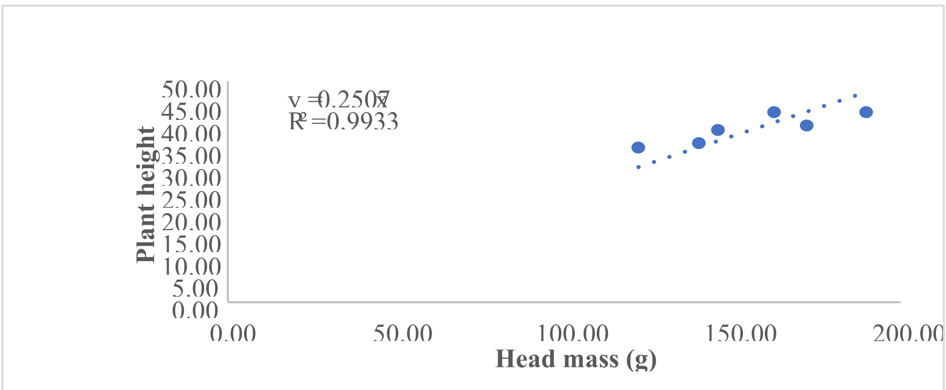

***Figure (2b)** Relationship of plant height with head mass of sunflower genotypes grown in water stress*

Head mass V/S no of seeds plant^{-1}

The no. of seeds plant^{-1} (NSP) and head mass (HM) was significant and positive that indicated that an increase in NSP will increase HM while analysis of regression that shows an increase in no. of seeds plant^{-1} will increase in HM. These traits established poor associations due to low variation in both environments. [24] They observed the same type of results.

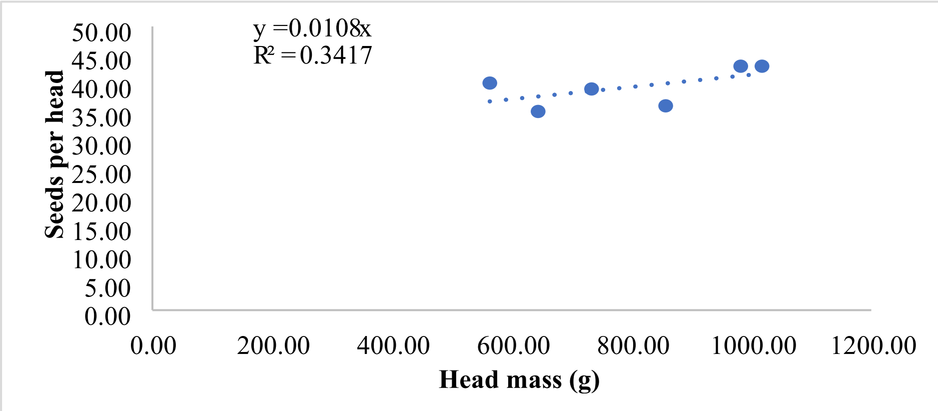

***Fig. (3a)** Relationship of seeds per head with head mass of sunflower genotypes grown in Low stress*

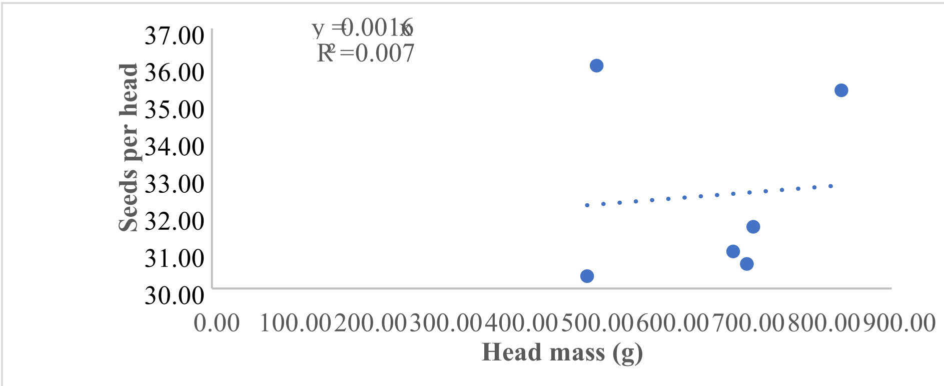

***Figure (3b)** Relationship of seeds head-1 with head mass of sunflower genotypes grown in water stress*

Head mass V/S Stem girth

Stem girth (SG) and head mass (HM) was significant and positive that indicated an increase in SG will increase HM although analysis of regression shows that if SG increases then HM would increase. Such findings suggested that selection should be more effective for further improvement in these traits. [25] They also reported similar type of findings.

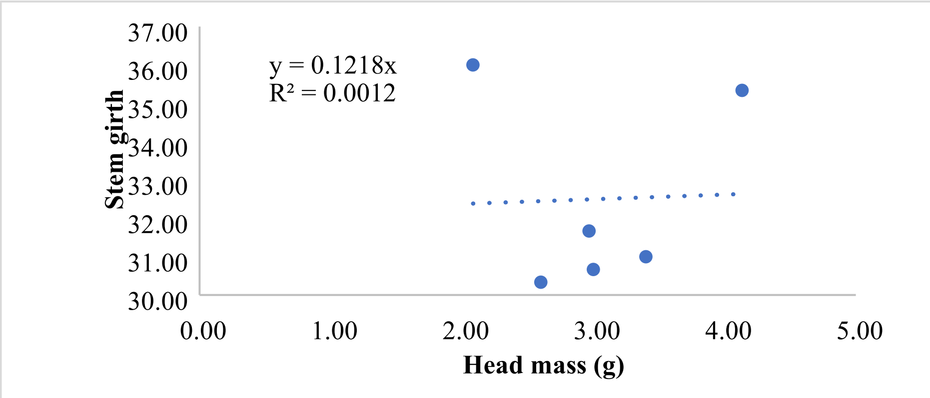

Fig. (4a) *Relationship of stem girth with head mass of sunflower genotypes grown in Low stress*

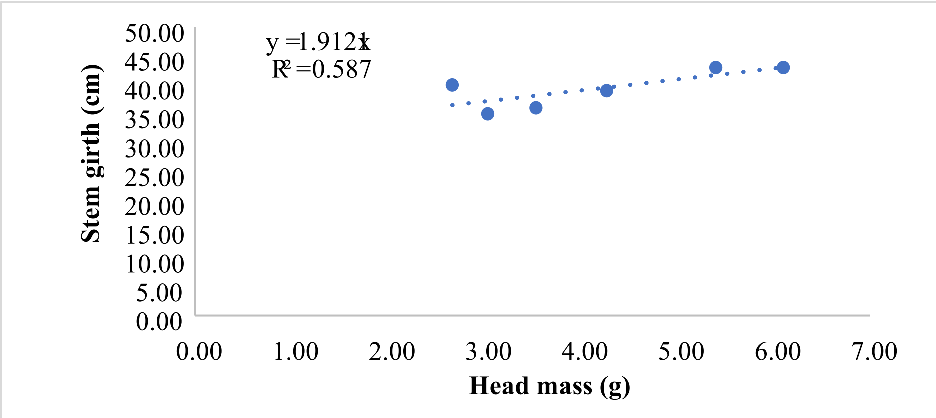

Figure (4b) *Relationship of stem girth with head mass of sunflower genotypes grown in water stress*

Head mass V/S Oleic acid

Oleic acid (OA) and head mass (HM) was positive significant that indicated an increase in OA would increase HM while analysis of regression indicated that if OA increases then HM would increase. [26] They also reported similar type of findings.

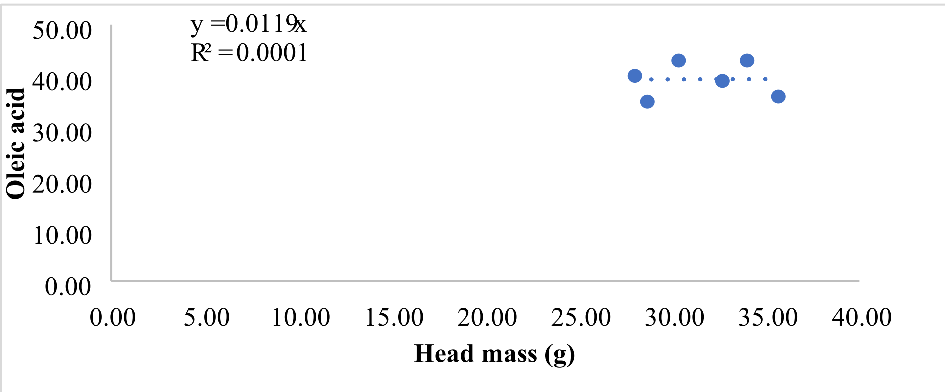

Fig. (5a) *Relationship of oleic acid with head mass of sunflower genotypes grown in Low stress*

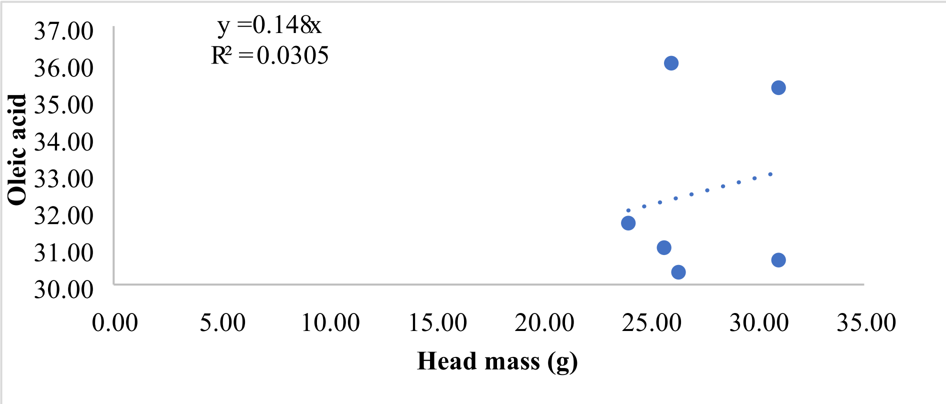

***Fig. (5b)** Relationship of oleic acid with head mass of sunflower genotypes grown in water stress*

Heritability estimates in broad sense (h^2 b.s. %) for sunflower genotypes

The heritability for yield and oil traits showed high heritability under both the environment for all the parameters [27] the results suggested that these traits were less affected by environment and selection should be more effective for the further improvement in these characters. Other researchers like [21] also estimated high heritability for yield and oil traits.

***Table 5.** Heritability estimate in broad sense (h2 b.s. %) for sunflower genotypes*

Traits	LOW STRESS			STRESS		
	Genotypic Variance (σ^2g)	Phenotypic Variance (σ^2p)	Heritability (H^2)	Genotypic Variance (σ^2g)	Phenotypic Variance (σ^2p)	Heritability (H^2)
Days to 90% maturity	181.43	183.19	99.03	88.64	96.40	92.33
Plant height	1765.63	1771.58	99.66	735.52	741.90	99.14
No.of seeds head^{-1}	101217	101385	99.83	51464	51682.81	99.57
Stem girth	5.50	5.58	98.56	1.45	1.47	99.31
Head mass	45.41	45.68	99.40	24.22	25.12	96.39
Protein content	20.24	21.20	95.47	9.77	11.00	88.24
Oil content	161.82	163.40	99.21	13.04	13.34	92.80
Oleic acid	27.75	28.53	97.26	25.86	26.93	95.98
Linoleic acid	116.97	117.84	99.26	73.20	75.20	97.34

CONCLUSION

In this study, among the genotypes YK A91 showed maximum performance as compared to the rest of genotypes in both conditions. Correlation coefficient, regression & coefficient of determination analyses showed positive and significant associations between head mass and its contributing traits. According to heritability in a broad sense, all the traits under study showed high heritability.

REFERENCES

[1] Petraru, A., Ursachi, F. and Amariei, S. (2021): Nutritional characteristics assessment of sunflower seeds, oil and cake. Perspective of using sunflower oilcakes as a functional ingredient. Plants 10(11): 2487.

[2] Saeed, M. Q., Khalid, M. N. and Amjad, I. (2020): A jaunt through sunflower: from its origin to the different breeding approaches for its improvement. Bulletin of Biological and Allied Sciences Research 1: 17.

[3] Li, Z., Xiang, F., Huang, X., Liang, M., Ma, S., Gafurov, K., et al. (2024): Properties and characterization of sunflower seeds from different varieties of edible and oil sunflower seeds. Foods 13(8): 1188.

[4] Saremi-Rad, A. and Mostafavi, K. (2020): Genetic diversity study of sunflower (Helianthus annuus L.) genotypes for agro-morphological traits under normal and drought stress conditions. Plant Productions 43(2): 227–240.

[5] Tyagi, V., Dhillon, S. K., Kaushik, P. and Kaur, G. (2018): Characterization for drought tolerance and physiological efficiency in novel cytoplasmic male sterile sources of sunflower (Helianthus annuus L.). Agronomy 8(10): 232.

[6] Fernández-Martínez, J. M., Pérez-Vich, B. and Velasco, L. (2010): Sunflower. In: Oil Crops. pp. 155–232.

[7] Abdikan, S., Sekertekin, A., Narin, O. G., Delen, A. and Sanli, F. B. A. (2023): Comparative analysis of SLR, MLR, ANN, XGBoost and CNN for crop height estimation of sunflower using Sentinel-1 and Sentinel-2. Advances in Space Research 71(7): 3045–3059.

[8] Cui, X., Han, W., Zhang, H., Cui, J., Ma, W., Zhang, L. and Li, G. (2023): Estimating soil salinity under sunflower cover in the Hetao Irrigation District based on unmanned aerial vehicle remote sensing. Land Degradation & Development 34(1): 84–97.

[9] Lakshman, S. S., Chakraborty, N. R., Debnath, S. and Kant, A. (2021): Genetic variability, character association and divergence studies in sunflower (Helianthus annuus L.) for improvement in oil yield. African Journal of Biological Sciences 3(1): 129–145.

[10] Kaya, Y., Evci, G., Durak, S., Pekcan, V. and Gucer, T. (2009): Yield components affecting seed yield and their relationships in sunflower (Helianthus annuus L.). Pakistan Journal of Botany 41(5): 2261–2269.

[11] Pandya, M. M., Patel, P. B. and Narwade, A. V. (2016): A study on correlation and path analysis for seed yield and yield components in sunflower [Helianthus annuus (L.)]. Electronic Journal of Plant Breeding 7(1): 177–183.

[12] Abro, T. F., Oad, P. K., Sootaher, J. K., Menghwar, K. K., Soomro, T. A., Shaikh, A. A., et al. (2022): Genetic variability and character association between grain yield and oil content traits in sunflower (Helianthus annuus L.). International Journal of Biology and Biotechnology 17(4): 701–706.

[13] Kaleri, M. H., Jatoi, W. A., Baloch, M., Chachar, Q., Mari, S. N., Abro, T. F. and Fatima, N. (2023): Evaluation of sunflower genotypes for yield and quality parameters under well-water-stressed and non-stressed environments. Egyptian Journal of Agronomy 45(1): 45–63.

[14] Hussain, M. M., Rauf, S., Noor, M., Bibi, A., Ortiz, R. and Dahlberg, J. (2023): Evaluation of introgressed lines of sunflower (Helianthus annuus L.) under contrasting water treatments. Agriculture 13(6): 1250.

[15] Krstić, M., Mladenov, V., Ćuk, N., Ovuka, J., Gvozdenac, S., Krstić, J. and Miklič, V. (2022): Agro-morphological traits of inbred sunflower lines and their genetic assessment. Contemporary Agriculture 71(1–2): 87–95.

[16] Yousaf, M. A., Akhtar, N., Gul, S., Saleem, U., Mahmood, T., Aziz, A. and Raza, N. (2022): Genotype by environment interaction and association of yield contributing traits in sunflower genotypes under the environmental condition of Sargodha, Pakistan. Helia 45(76): 55–70.

[17] Rigon, C. A. G., Rigon, J. P. G. and Capuani, S. (2014): Correlation and path analysis as an indirect selection criterion for sunflower achene productivity. Bioscience Journal 30: 768–773.

[18] Boero, A., Ramírez, F., Oklestkova, J., Vigliocco, A., Strnad, M., Alemano, S. and Andrade, A. (2023): A differential phytohormone profile in the aerial part and roots as a response to water stress underlying morphophysiological and biochemical changes in two inbred sunflower lines at early growth stage. Journal of Plant Growth Regulation 42(11): 7083–7095.

[19] Meena, H. P. and Sujatha, M. (2022): Sunflower breeding. In: Fundamentals of Field Crop Breeding. Springer Nature, Singapore. pp. 971–1008.

[20] Ebeed, H. T., Hassan, N. M., Keshta, M. M. and Hassanin, O. S. (2019): Comparative analysis of seed yield and biochemical attributes in different sunflower genotypes under different levels of irrigation and salinity. Egyptian Journal of Botany 59(2): 339–355.

[21] Anuradha, B., Manivannan, N., Sasikala, R., Harish, S. and Senthivelu, M. (2023): Genetic variability and association studies in BC3F1 population of sunflower (Helianthus annuus L.). Electronic Journal of Plant Breeding 14(3): 923–927.

[22] Sipio, W. D., Sahar, W. A., Abro, T. F., Keerio, J. M., Sipio, N., Unar, I. H., et al. (2024): Correlation and regression analysis in different genotypes of sunflower (Helianthus annuus L.). Pakistan Journal of Biotechnology 21(1): 172–177.

[23] Babar, A., Memon, S., Soomro, Z. A., Bhutto, L. A., Memon, S. A. and Memon, A. (2023): Efficacy of different quantitative characters in sunflower genotypes (Helianthus annuus L.) under Tandojam climate conditions. Pure and Applied Biology 12(2): 1214–1223.

[24] Debaeke, P., Casadebaig, P., Flenet, F. and Langlade, N. (2017): Sunflower crop and climate change: vulnerability, adaptation, and mitigation potential from case-studies in Europe. OCL – Oilseeds and Fats, Crops and Lipids 24(1): 15.

[25] Chambó, E. D., De Oliveira, N. E., Garcia, R. C., Ruvolo-Takasusuki, C. C. and De Toledo, V. D. A. A. (2017): Phenotypic correlation and path analysis in sunflower genotypes and pollination influence on estimates. Open Biological Sciences Journal 3(1): 9–15.

[26] Ghaffari, M., Gholizadeh, A., Rauf, S. and Shariati, F. (2023): Drought-stress induced changes of fatty acid composition affecting sunflower grain yield and oil quality. Food Science & Nutrition 11(12): 7718–7731.

[27] Rahim, A. Y. (2024): Correlation analysis of achene yield in sunflower (Helianthus annuus L.) to study genetic variability. In: Proceedings of the International Anatolian Agriculture, Food, Environment and Biology Congress. p. 596.