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# APPRAISAL OF SUNFLOWER (*HELIANTHUS ANNUUS* L.) HYBRIDS FOR MORPHO-PHENOLOGICAL TRAITS UNDER NORMAL AND TERMINAL HEAT STRESS CONDITIONS

**N. AKHTAR[1*], M.A. YOUSAF[1], S. SHAUKAT[2], S. GUL[1], U. SALEEM[1], T. MAHMOOD[3], M. ASIF[4], A. AZIZ[4], and M. ASIF[1]**

[1]Department of Plant Breeding and Genetics, College of Agriculture, University of Sargodha, Sargodha, Pakistan
[2]Department of Plant Breeding and Genetics, Faculty of Agriculture, Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Balochistan, Pakistan
[3]Department of Plant Breeding and Genetics, PMS Arid Agriculture University, Rawalpindi, Pakistan
[4]Department of Agronomy, College of Agriculture, University of Sargodha, Sargodha, Pakistan
*Corresponding author's emails: naeem.uca@gmail.com**,** naeem.siraj@uos.edu.pk
Email addresses of co-authors: uos.boy54321@gmail.com, shadab_uaf@hotmail.com, samrin.gul@uos.edu.pk, usman.saleem@uos.edu.pk, drtalat@uaar.edu.pk, asif.akhtar@uos.edu.pk, ahsan.aziz@uos.edu.pk, masifahmad1122@gmail.com

## SUMMARY

Estimation of genetic diversity is vital in sunflower breeding. Principal component analysis (PCA) is one of the best statistical approaches to study diversity among genotypes by using eigenvalue and PC-1/PC-2 based-biplots. An experiment commenced at the College of Agriculture, University of Sargodha, Pakistan to find out the diversity in 28 sunflower hybrids and select stable hybrids for normal and terminal heat-stress conditions. Growing sunflower hybrids in randomized complete block design had three replications. Under normal condition, sunflower hybrid sowing ensued in February 2019, while to check the effect of terminal stress, growing these hybrids transpired at the end of March 2019. The collected data of seven morpho-phenological traits underwent the principal component analysis, found greater than one for the first three and four PCs under normal conditions. In terminal stress environments, these respectively exposed the presence of ample genetic variation among sunflower hybrids in both environments. Bi-plot analysis signified that SF-18100, SF-18045, and SF-19025 were stable hybrids for most studied traits under normal sowing environment. Meanwhile, the performance of SF-18035 and SF-19010 proved better under the heat-stress environment for studied traits. Hence, these hybrids showed better adaptability under the current scenario of climate change.

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**Keywords:** Sunflower (*H. annuus* L.), diversity, PCA, eigenvalue, genetic variability, phonological traits, biplot

**Key findings:** Heat stress negatively affects sunflower (*H. annuus* L.) crop growth, leading to lower achene yield and oil content. However, the sunflower hybrids SF-18100, SF-18045, SF-19012, and SF-19025 performed better than the rest for achene yield and yield-contributing traits under normal and heat stress environments, making them suitable for sunflower breeding programs and general cultivation.

## INTRODUCTION

Sunflower, originally from North America, is an essential crop among oilseed crops grown in Pakistan. Sunflower seeds are good sources of oil and vitamins (A, D, E, and K). The oil content varies from 34.26% to 39.13% (Hussain *et al*., 2018). In Pakistan, the crop's harvest of 171,000 tons of oil came from an area of 72,439 ha and contributed to 13% of domestic edible oil production (Economic Survey of Pakistan, 2023). Reasons of low sunflower yield in Pakistan are lack of suitable germplasm, unavailability of inputs and modern production techniques, increasing population, climate change, and heat and drought stresses (Farooq *et al*., 2017). At the time of the plant's growth and maturity, temperature change is natural.

Climate change drastically affected agriculture production, and significant yield losses threaten world food security. A rise in temperature of up to 40 °C causes the burning of plants' parts, reducing chlorophyll formation, fruit quality, and quantity. Past studies reported that climate change influenced developing countries more because most of them totally or partially relied on agriculture as a profession for livelihood (Bita and Gerats, 2013). During the plant reproductive stage, long periods of high temperature alter seed development and delay germination, ultimately reducing seedling number. At the initial growth stage, plants are more susceptible to high temperatures. Reduced plant growth causes changes in growth mechanisms (Wollenweber *et al*., 2003; Farooq *et al*., 2017). Hall (2010) observed the drastic effect of heat stress on the shoot, decreasing the length of internodes and ultimately killing plants. Heat stress also decreases achene yield and the biomass of sunflower plants (Khan *et al*., 2017). Heat stress causes changes in the plant's structure at the cellular level, reducing activity (Potters *et al*., 2007). Fruit damage, leaf senescence, and root and shoot damage are evident in high-temperature conditions (Vollenweider and Günthardt-Goerg, 2005).

Sunflower metabolic process based on protein increases vegetative growth and plant yield (Surucu *et al*., 2020). Soare and Chiurciu (2018) reported that yield depends upon the environment on which it grew. Sunflower requires a cool environment for germination and hot for seedling growth. Heat stress has drastic effects on sunflower. Heat stress affects the plant growth, especially the reproductive phase (flowering)—the most critical and sensitive stage to heat stress (Prasad *et al*., 2017). The heat stress influences pollen production and viability of the sunflower, decreasing grain filling and adversely altering seed number, seed weight, oil contents, and yield components (Surucu *et al*., 2020).

High temperature mainly influences the process of photosynthesis and reproductive phases. The plant synthesizes specific stress proteins that are crucial for adoption under heat stress conditions (Mahajan and Tuteja, 2005). In sunflower, the cellular membrane is highly sensitive to abiotic stress, especially high temperatures (Nasrabadi *et al*., 2011). Heat stress also decreases the developmental phase period, leading to a small size and reduced light perception in sunflower, causing yield losses (Amutha *et al*., 2007). Regarding the above discussion, the presented study sought to observe the achene yield performance of sunflower hybrids under normal and heat-stress conditions. The study aimed to evaluate sunflower hybrids for various morpho-phenological traits contributing to yield under normal and terminal heat-stress conditions and search the heat stressed resistant sunflower hybrids for future sunflower breeding programs.

## MATERIALS AND METHODS

The research trials proceeded at the College of Agriculture, University of Sargodha, Pakistan. The experimental material comprised 28 sunflower (*H. annuus* L.) hybrids collected from the National Agriculture Research Center (NARC), Islamabad, Pakistan (Table 1). The performance of these hybrids incurred evaluation under normal and stressed conditions. The experiment consisted of a factorial and randomized complete block design with three replications, using a plot size (3× 5m$^2$) per genotype per replication. Each replication has four rows with a 5m length for each hybrid, while spaces between each plant was at 22 cm, and row-to-row space was 75 cm. For evaluation of hybrids under normal conditions, the hybrid sowing occurred in mid-February 2019. Meanwhile, under terminal heat stress, hybrid growing ensued in late March 2019. Growing the hybrids on raised bed of 75 cm apart helped check the reproductive growth cycle under high temperature (May-June) (Figure 1).

Standard agronomic practices, such as, seedbed preparation, seed rate, irrigation, fertilization, thinning, weed eradication, plant protection measures, and inputs were operational for all the entries from sowing until harvesting. The maturity data recording included days to flower initiation, days to flower completion, plant height (cm), stem circumference (cm), head diameter (cm), days to maturity, 100-achene weight (g), achene yield per plot (kg), and oil contents (%).

**Table 1.** Sunflower hybrids evaluated under normal and heat stress environments.

| Hybrid code | Name of hybrid | Hybrid Code | Name of hybrid | Hybrid code | Name of hybrid | Hybrid code | Name of hybrid |
|---|---|---|---|---|---|---|---|
| G1 | SF-18003 | G8 | SF-18060 | G15 | SF-19003 | G22 | SF-19019 |
| G2 | SF-18005 | G9 | SF-18070 | G16 | SF-19004 | G23 | SF-19021 |
| G3 | SF-18009 | G10 | SF-18080 | G17 | SF-19005 | G24 | SF-19025 |
| G4 | SF-18019 | G11 | SF-18090 | G18 | SF-19008 | G25 | SF-19028 |
| G5 | SF-18020 | G12 | SF-18100 | G19 | SF-19010 | G26 | SF-19030 |
| G6 | SF-18035 | G13 | SF-19001 | G20 | SF-19012 | G27 | SF-19033 |
| G7 | SF-18045 | G14 | SF-19002 | G21 | SF-19015 | G28 | SF-19036 |

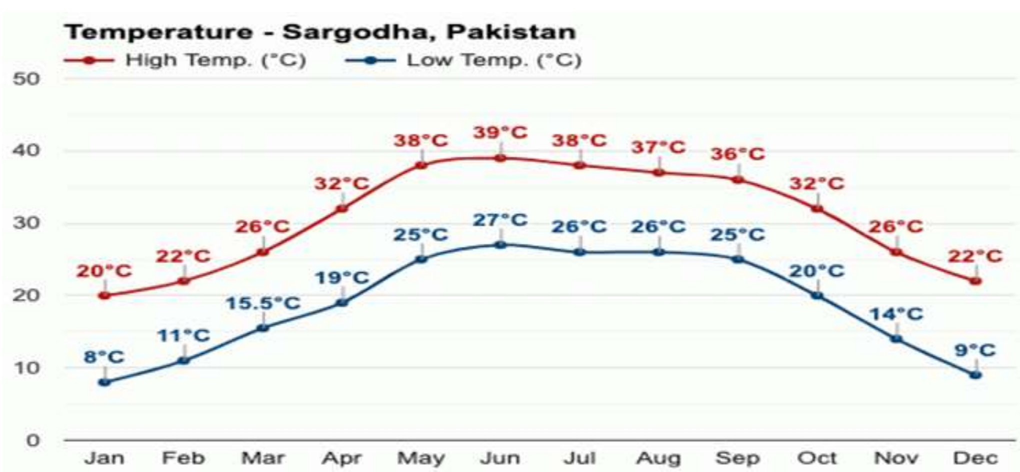


**Figure 1.** Mean temperature during the crop season year-2019.

**Table 2.** Eigenvalues and total variances percentage for principal components under normal environment.

| Principal components | Eigenvalue | Variability (%) | Cumulative (%) |
|---|---|---|---|
| PC1 | 3.648 | 45.604 | 45.604 |
| PC2 | 2.095 | 26.191 | 71.795 |
| PC3 | 1.099 | 13.737 | 85.532 |
| PC4 | 0.537 | 6.707 | 92.239 |
| PC5 | 0.312 | 3.894 | 96.134 |
| PC6 | 0.169 | 2.115 | 98.249 |
| PC7 | 0.098 | 1.224 | 99.473 |
| PC8 | 0.042 | 0.527 | 100.000 |

### Statistical analysis

The numerical data collection of all studied plant traits happened at their proper stage, with means calculated for further analysis. The statistical tool — Principal Component Analysis (PCA) functioned to find out variations among studied parameters and its contribution, as described by Sneath and Sokal (1973). PCA helped to determine interrelationships among utilized characters in the study. PCA continued on two types of data conditions, i.e., normal and terminal heat stressed environments. Two statistical packages, such as, Statistix 8.1 and XLSTAT, aided data analysis.

## RESULTS

### Genotype variation based on PCA

The PCA acquired information about the variation of genotypes grown, applying this information to select sunflower (*H. annuus* L.) hybrids with desirable characteristics under normal and terminal heat-stress environments. PCA distributed the total phenotypic variability into eight principal components in studied sunflower hybrids and plant traits (Table 2). The first three PCs displayed eigenvalues of 3.648, 2.095, and 1.099, indicating high levels of dissimilarity, which exhibited a broad genetic base of sunflower hybrids. These three PCs contributed 85.53% of the total variations, while the contribution of the remaining five PCs was only 14.47%. Among the first three PCs, i.e., PC1, PC2, and PC3, they contributed 45.604%, 26.191%, and 13.737% of the total variations among studied hybrids under normal sowing conditions, respectively.

In the PC1, the most important traits significantly contributing to variations were days to flower initiation, days to flower completion, days to maturity, and 100-achene weight. In the PC2, plant height, head diameter, and seed yield per plot were contributory, while in PC3, only oil contents contributed significantly in total variations and achene yield. Maximum variations in the PC1 appeared in SF-18090, followed by SF-19028 and SF-18009. However, SF-19019, SF-19036, and SF-19001 showed maximum divergence in the PC2. Under PC3, sunflower hybrid SF-19030 gave a maximum contribution to total variability among hybrids.

Similar to optimum conditions, the PCA also displayed total phenotypic variability of studied sunflower hybrids into eight principal components, sown under a terminal heat-stress environment (Table 3). Out of eight principal components, the first three PCs had more than one eigenvalue and represented high levels of dissimilarity in sunflower hybrids. Around 83.397% of the total variations came from these four PCs, while the 16.603% variation emerged from the remaining four PCs. The results of PC1, PC2, PC3, and PC4 exhibited 27.731%, 20.607%, 17.141%, and 14.918% variations, respectively, on an individual component basis.

In the case of PC1, the most important traits significantly contributing to the variations were head diameter, plant height, days to flower initiation, and days to maturity. In the PC2, days to flower initiation, achene yield per plot, and oil contents, while in PC3, the 100-

**Table 3.** Eigenvalues and cumulative variances of sunflower hybrids for principal components under heat stress environment.

| Principal components | Eigenvalue | Variability (%) | Cumulative (%) |
|---|---|---|---|
| PC1 | 2.219 | 27.731 | 27.731 |
| PC2 | 1.649 | 20.607 | 48.338 |
| PC3 | 1.371 | 17.141 | 65.479 |
| PC4 | 1.193 | 14.918 | 80.397 |
| PC5 | 0.561 | 7.014 | 87.410 |
| PC6 | 0.408 | 5.100 | 92.511 |
| PC7 | 0.349 | 4.366 | 96.876 |
| PC8 | 0.250 | 3.124 | 100.000 |

achene weight contributed meaningfully to create a variation. Regarding the share of sunflower hybrids in creating total genetic variation, planted in a heat-stress environment, sunflower hybrids SF-19015, SF-19005, and SF-18003 gave maximum shares in PC1, while SF-18060 and SF-19033 showed maximum divergence in PC2. Similarly, in PC3, SF-18009 and SF-19001 hybrids displayed the highest variation share in total variability among sunflower hybrids.

**Biplot description**

The biplot analysis indicated that SF-18090 and SF-18100 performed better to create variations for studied phenological traits, i.e., days to flower initiation, days to flower completion, and days to maturity. Likewise, sunflower hybrids SF-19036, SF-19033, and SF-19028 created maximum variations in head diameter, achene yield per plot, and plant height among studied hybrids under normal conditions (Figure 2). Similarly, SF-19005 and SF-19003 were superior for 100-achene weight. The biplot depicted that SF-19015 and SF-18025 were the stable hybrids for most studied traits under the normal sowing environment.

The biplot analysis under terminal heat-stress conditions implied that sunflower hybrids SF-19036, SF-19004, SF-19030, and SF-19033 performed better than other hybrids under observation to create variation for days to flower initiation and days to flower completion. The results revealed that these hybrids are early maturing and have tolerance against heat stress (Figure 3). The sunflower hybrids SF-18019, SF-18080, and SF-19015 displayed variations for plant height, head diameter, and days to maturity. It was also evident that sunflower hybrids SF-19019, SF-19001, and SF-19012 were stable hybrids for most studied traits under the terminal heat-stress environment. The discussion on the performance of sunflower hybrids for various traits under normal and heat stressed environments follows below.

**Days to flower initiation**

Sunflower hybrids for days to flower initiation under normal and terminal heat-stress environments appear in Figure 4. A report stated that sunflower SF-19030, followed by SF-19033 and SF-19036, performed better under the terminal heat-stress condition. Meanwhile, SF-18090 performed well in normal environments for days to flower initiation. However, overall hybrids SF-18005 and SF-19025 performed best in both environments (Figure 4).

**Days to flower completion**

Early flower completion leads to early maturity in sunflowers. It has been notable that flowering and reproduction phases are highly sensitive to heat stress, causing reduction in yield and quality in sunflower crops. Regarding sunflower hybrid performance in heat stress environment, it was apparent that SF-19015 and SF-19021 performed better than other hybrids under terminal heat-stress conditions, and SF-18090 and SF-18100 performed well in normal sowing environments (Figure 5).

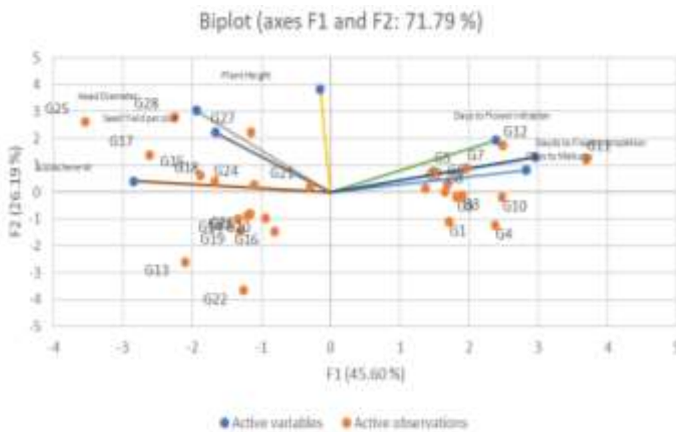


**Figure 2.** PCA biplot for 28 sunflower hybrids under normal sowing condition.

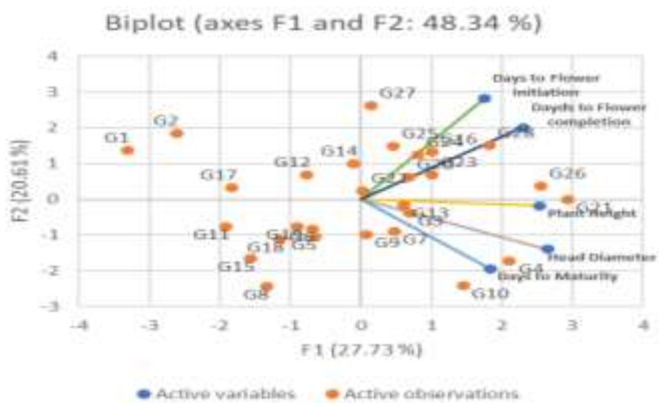


**Figure 3.** PCA biplot for 28 sunflower hybrids under terminal heat stress sowing condition.

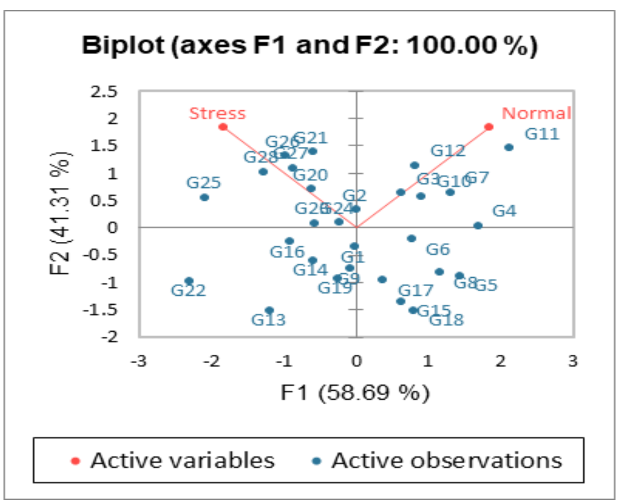


**Figure 4.** Hybrids performance for days to flower initiation under normal and heat stress environments.

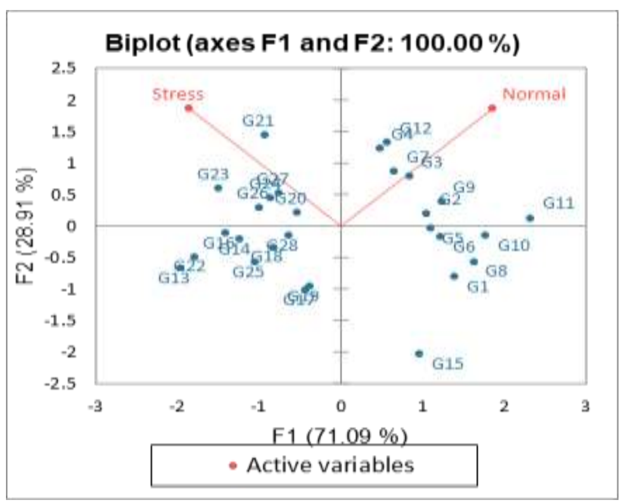


**Figure 5.** Hybrids performance for days to flower completion under normal and heat stress environments.

Overall, the sunflower hybrid SF-19012 performed excellently in both environments for days to flower completion.

**Plant height**

The results of plant height trait displayed that sunflower hybrids SF-18080, followed by SF-19015, are better performing under the terminal heat-stress environment, whereas, SF-19036 and SF-19028 performed well in a normal sowing season (Figure 6). However, overall, the SF-18070 was outstanding in both environments for plant height.

**Head diameter**

Head diameter is an influential yield-contributing trait in sunflower crops, which directly affect the sunflower achene yield. Generally, it is typical that the heat stress condition reduces head diameter and achene yield in sunflowers. The results of head diameter exhibited that sunflower hybrid SF-18019, followed by SF-19030, performed better than other hybrids under the terminal heat-stress environment, while the hybrids SF-19028 and SF-19005 performed well in a normal environment (Figure 7). Overall, the hybrids SF-19025 and SF-18100 performed best in both environments for head diameter. It indicates that the studied sunflower hybrids have a strong genetic makeup.

**Days to maturity**

The number of days taken to maturity is an important phenological parameter, which determines the early or late maturity of sunflower hybrids. The hybrids SF-19010 and SF-18019 performed better than other hybrids for the number of days to maturity under the terminal heat-stress condition. However, the hybrids SF-18080, SF-18090, and SF-18100 were better performers in normal sowing conditions (Figure 8). The sunflower hybrid SF-18035 gave enhanced performance in both environments.

**100-achene weight**

A hundred achene weight is a yield-contributing trait in sunflowers, and the higher the achene weight, the higher is the achene yield. Under terminal stress conditions, normally, 100-achene weight decreases along with a reduction in head size. Under normal and terminal heat-stress conditions, the sunflower hybrids SF-18009 and SF-18019 performed well and gained higher 100-achene weight than other hybrids under heat stress environments, while the SF-19028 gave a good yield under a normal sowing environment. However, the SF-19033 and SF-19030 performed better in both environments (Figure 9).

**Achene yield per plot**

The estimation of 28 sunflower hybrids for achene yield per plot proceeded under normal and terminal heat-stress environments, which indicated that SF-19033, SF-18005, and SF-19004 have maximum yields per plot under terminal heat-stress conditions (Figure 10). In contrast, SF-19036 and SF-19030 gained the maximum achene yield per plot in a normal sowing environment. Overall, sunflower hybrids SF-19003 and SF-19012 gave good achene yield in both environments.

**Oil content**

Oil content is the primary product of the sunflower achene, determining the existence of hybrids in the market. Base on this concept, the results of oil contents concluded that achenes of SF-18005, followed by SF-18070 and SF-19004, attained good oil contents under the heat-stress environment. Under normal sowing conditions, hybrids SF-19033, SF-18035, and SF-18045 gave good oil contents in their achenes. Regarding overall performance, hybrids SF-18003 and SF-19012 performed better for the oil content parameter in both environments (Figure 11).

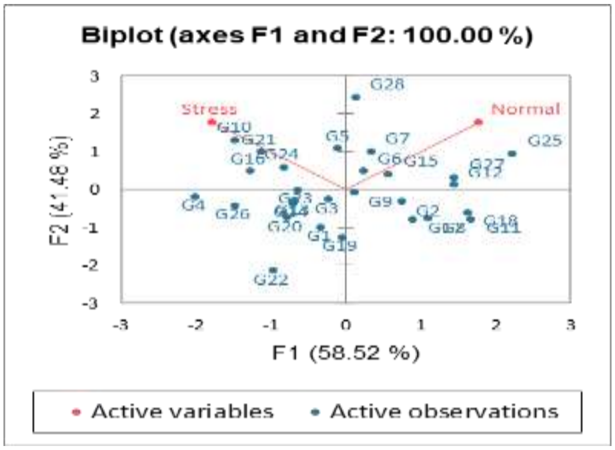


**Figure 6.** Hybrids performance for plant height under normal and heat stress environments.

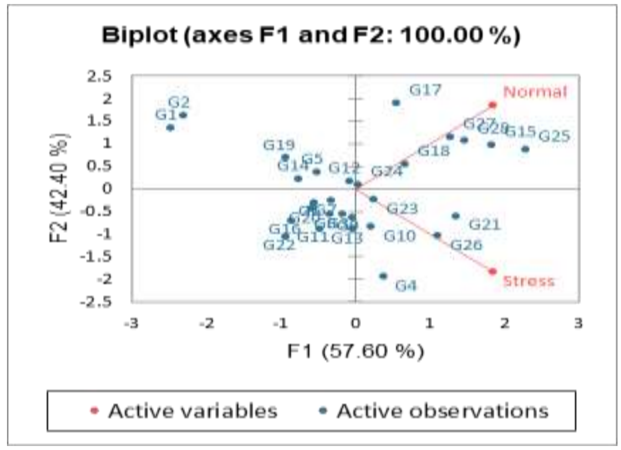


**Figure 7.** Hybrids performance for head diameter under normal and heat stress environments.

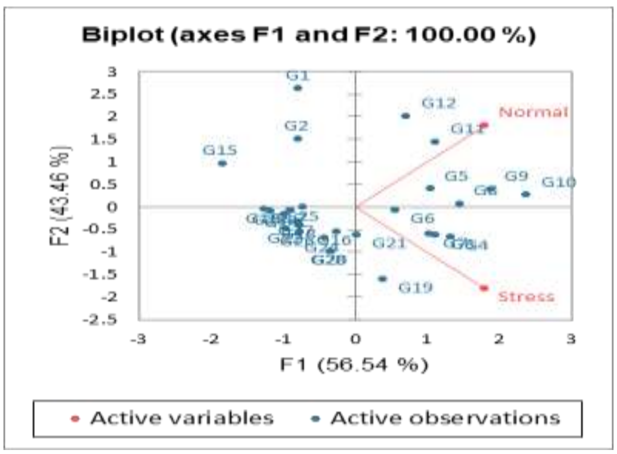


**Figure 8.** Hybrids performance for number of days to maturity under normal and heat stress environments.

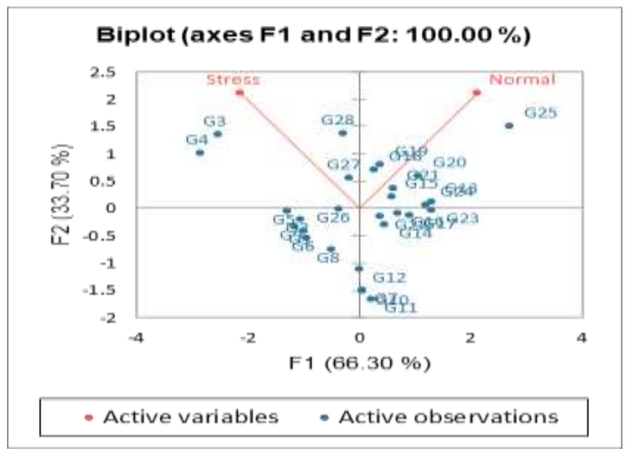


**Figure 9**. Hybrids performance for 100-achene weight under normal and heat stress environments.

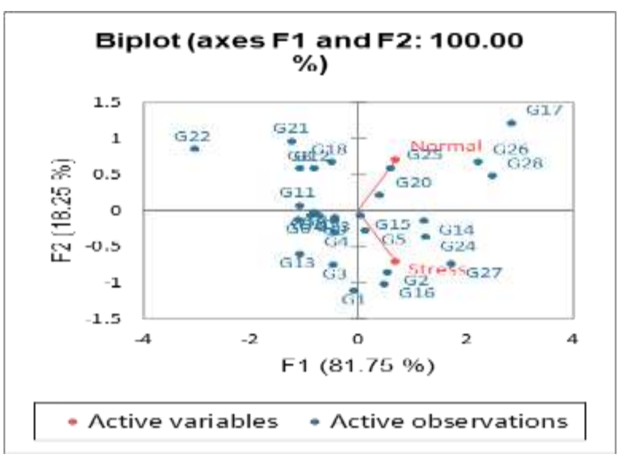


**Figure 10.** Hybrids performance for achene yield weight under normal and heat stress environments.

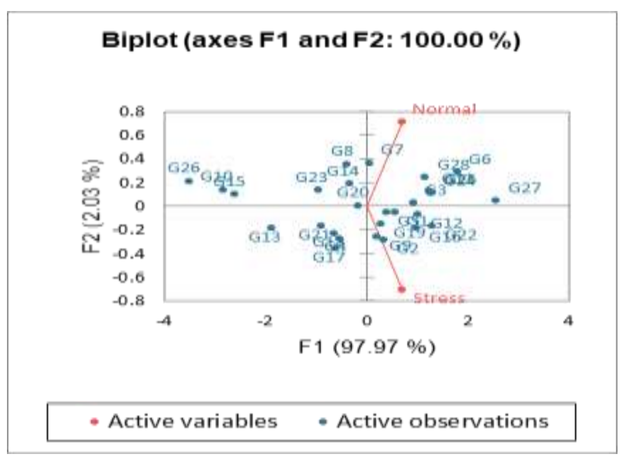


**Figure 11.** Hybrids performance for oil content under normal and heat stress environments.

## DISCUSSION

Biotic and abiotic stresses are major crop yield limiting factors worldwide. Among them, heat stress is a serious threat of the current era and a main hazard, limiting crop yields (Hall, 2010). Heat stress is a function of the magnitude and rate of temperature increase, as well as the duration of exposure to the raised temperature. An increase of ambient temperatures due to heat stress is causing climate change, which ultimately reduces crop productivity and disturbs cropping pattern. Thus, crop resilience is necessary against different environmental stresses. Crops with higher plasticity from emergence to their maturity are more resilient against different environmental stressed conditions.

Climate vulnerability also threatens food security systems of Pakistan. Based on these facts, the presented study transpired to evaluate 28 sunflower hybrids under normal and terminal heat-stress sowing environments and observe the fitness of these hybrids for general cultivation with minimum loss of achene yield. The principal component analysis (PCA) aided to select sunflower hybrids with desirable characteristics under normal and heat-stress conditions (Nasrabadi *et al*., 2011; Masvodza *et al*., 2015). Under normal sowing condition, PCA distributed the total variability for fitness of hybrids into eight components. The first three PCs showed high level of dissimilarity (85%), which indicated a broad genetic base of these hybrids for yield performance. Among these three PCs, phenological traits, such as, days to flower initiation, days to flower completion, and days to maturity played a significant role in genetic variability among hybrids for achene yield and distinguished them as early and late maturing.

These plant traits proved excellent for developing early-maturing sunflower hybrids and should be options in selecting parental inbred lines for hybridization. Similarly, yield-contributing attributes like 100-achene weight, plant height, head diameter, and oil contents significantly improve achene yield in the studied hybrids (Prasad *et al*., 2017; Soare and Chiurciu, 2018). Thus, the sunflower hybrid SF-18090, followed by SF-19028, SF-18009, SF-19019, SF-19036, and SF-19001, proved superior for cultivation under a normal sowing condition. They could be suitable for general cultivation under recommended sowing seasons in various environments.

For the terminal heat-stress environment, PCA also distributed the total variability of studied sunflower hybrids into eight PCs, in which, the first four PCs contributed 83.4% of the total variations among sunflower hybrids for studied plant traits. Among these PCs, the plant traits of PC1 (days to flower initiation, head diameter, plant height, and days to plant maturity) contributed 27.73% in total variation, implying as the most important attributes for selecting hybrids in heat-stress environments. Other plant traits, days to flower initiation and oil contents, are crucial to enhancing achene yield in the heat-stress environment. Thus, the study suggested that these traits should remain under consideration during selecting sunflower hybrids in heat-stress conditions, as these traits create tolerance in sunflower plants against heat stress (Farooq *et al*., 2017, Buriro *et al.,* 2015; Barrios *et al.,* 2017). Sunflower hybrids SF-19015, SF-19005, SF-18003, SF-18060, and SF-19033 performed better than the other hybrids and gave good achene yield in terminal heat-stress environment. This may be due to the presence of heat-tolerant genes in their genetic makeup, making them candidate hybrids for general cultivation in climate changing areas. These hybrids can be beneficial as germplasm for breeding heat-resistant sunflowers in the near future.

About the trait wise performance of sunflower hybrids under normal and terminal heat-stress environments, it was evident that sunflower hybrids SF-19015, SF-19033, SF-19036, SF-18005, and SF-18019 performed better than the rest in terminal heat-stress environment for most studied traits. Similarly, hybrids SF-19036, SF-19028, SF-19033, SF-18090, and SF-19030 performed well for achene yield and other yield-contributing traits under the normal sowing condition. The results of the study revealed that heat stress directly affects the morpho-phenological traits of the sunflower plant. However, the most adverse effects occur at the anthesis stage, causing pollen grain abortion, low achene setting, and less grain filling, ultimately resulting in reduced achene yield in sunflowers (Kaleri *et al*., 2023). Therefore, sunflower hybridization, selection, and evaluation of newly developed hybrids is a continuous struggle to ensure food security in existing climate change (Bakht *et al.,* 2010; Hwang *et al.,* 2014; Kalyar *et al.,* 2014; Khan *et al.,* 2017; Yousaf *et al.,* 2022).

## CONCLUSIONS

Heat stress adversely influences the growth and development of sunflower, resulting in reduced achene yield and its oil content. Based on the results, the study concluded that sunflower hybrids SF-18090, SF-19030, and SF-19036 were more stable under a normal environment, while SF-19033, SF-18005, and SF-18019 performed well under a heat-stress environment for most studied traits. However, sunflower hybrids SF-19012 and SF-19025 gave better performance under both environments for studied traits.

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