Pak. j. sci. ind. res. Ser. B: biol. sci. 2025 **68B**(2) 138-157

Combining Ability Analysis of Sunflower Genotypes for Yield Traits Under Adverse Environment

Majid Hussain Kaleri[a], Wajid Ali Jatoi*[a], Muhammad Mithal Lund[f], Shahnaz Memon[b], Shireen Naz Rind[b], Samreen Khanzada[b], Muhammad Siddique Depar[c], Muhammad Rafique Rind[b], Hafeez Ali Bhatti[d] and Muhammad Kashif Shahzad Sarwar[e]

[a]Department of Plant Breeding and Genetics, Sindh Agriculture University, Tandojam, Pakistan
[b]Agriculture Research Center, Tandojam, Pakistan
[c]Arid Zone Research Center, Umar Kot, Pakistan
[d]Department of Biotechnology, Sindh Agriculture University, Tandojam, Pakistan
[e]Cotton Research Station, Ayub Agricultural Research Institute Faisalabad, Pakistan
[f]Sindh Agriculture University, Tandojam, Pakistan

(received December 9, 2022; revised October 19, 2023; accepted October 30, 2023)

Abstract. Five CMS lines *viz*. HO.1, Mehran, Thatta, PSF-025 and SH-3915 were crossed with three restorer male inbreds UC-666, Peshawr-93 and B-2 in a line × tester mating design. 15 F_1 crosses were developed for genetic assessment. All eight characters including agronomic were studied in non-stress and water stress treatments. The genetic analysis indicated significant differences between treatments, inbred parents, F_1 hybrids and parents versus hybrids for agronomic traits. Line × tester revealed the prominence of specific combing ability and involvement of dominant genes. The predominance of dominant genes were involved in advocating the traits considered because of higher ratio σ^2D/σ^2A and degree of dominance $(\sigma^2D/ \sigma^2A)^{½}$ exceeded over unity in both the environments with few exceptions under stress condition. These results demonstrated the preponderance of dominant gene action, thus indicated the feasibility of hybrid sunflower developments. The variation due general combining ability GCA (σ^2A) and specific combining ability SCA (σ^2D) and degree of dominance $(\sigma^2D/ \sigma^2A)^{½}$ being higher than unity for different traits indicated that σ^2 SCA variances were far greater than σ^2GCA indicating entire characters under study were predominantly advocated by dominant genes in both the environments. General combining ability of lines and testers indicated that lines, were good combiners for early maturity and seed yield were regarded as best general combiners, thus these inbreds may be crossed to produce prolific hybrids. Specific combining ability and heterotic estimates are essential genetic parameters presenting worth of F_1 hybrid expansion. The hybrids like Thatta × UC-666, Mehran × Peshawar-93 and Ho.1 × B-2, on the basis of SCA effects were found as potential hybrids for earliness and seed yield traits in both the environments.

Keywords: combining ability, GCA, SCA, yield traits, water stress, sunflower genotypes

Introduction

Breeding strategies for evolving drought tolerant genotypes for a specific environment have been presented as a basic solution to increase crop production (Rauf *et al*., 2016). Sunflower production last year was 57.32 million tons. This year's 50.70 estimated millions tons could represent a decrease of 6.62 million tons or 11.55% in sunflower production around the globe. Locally Pakistan produced 135,000 metric tons (USDA, 2023). The traditional sunflower oil contains oleic acid, linoleic acid from 90% fatty acids, while palmitic acid and stearic acid possess 8 to 10% fatty acids (Abdel-Rahem *et al*., 2021). It is also bitter fact, that development of drought tolerant crop varieties is intricate task due to lack of information on nearly all physiological variables which indicate the complete genetic mechanism and their relationship to yield and morphological characteristics (Zakhidov *et al*., 2016). It is a significant obstacle to boost up agricultural production on cumulative land basis. Water shortages in irrigated areas are also being investigated owing to canal closures and insufficient water supplies loss of cell turgor, closing of stomata, decrease in cell expansion and decreased leaf surface area are some of the physiological changes that occur in plants as a result of water stress. Photosynthesis and respiration both are reduced because of above mentioned anomalies (Razzaq *et al*., 2017). The information needed to develop water-stress tolerant sunflower varieties is though crucial yet significant differences existed in seed yield and 1000-

*Author for correspondence; E-mail: jatoiwajid@yahoo.com

seed weight which could contribute towards higher seed yield. Until now many variables of sunflower are studied and their mean squares for different characters under drought and regular irrigated conditions Pakistan's total agricultural area (4.9 million hectares) reported by (Khan *et al*., 2015). Such conditions cause un-predictability of water and nutrients uptake in crop plants which may cause retardation in plant growth and development, eventually reduces crop yield and quality (Yankov *et al*., 2015). Retaining 51 species and 19 subspecies, Helianthus is considered highly diversified genus among the crop species (Vukich *et al*., 2009), thus transferring drought resist genes through inter or intraspecific crosses seems a valuable choice. However, owing to a lack of rapid and concrete screening procedures as well as the impossibility to reduce drought stress in nature, growing drought tolerant cultivars is the only option left yet evolution of such varieties is very complicated task. Some tolerant genes, on the other hand, were discovered in wild kinds which have already been transferred into cultivated ones (Kaya *et al*., 2014). Droughts have been reported in Asia and elsewhere, as well as countries with dry and semiarid climates, in recent years (Farooq *et al*., 2014). Sunflower genetic resources can be screened efficiently under various environmental conditions, particularly under water stress conditions so as to develop drought tolerant inbreds for hybrid sunflower development (Geeta *et al*., 2012). This emphasizes the importance of cultivating drought tolerant crop varieties yet drought sensitivity in sunflowers is low to medium (Rauf *et al*., 2008).

Due to the preponderance of higher specific combining ability (SCA) variances/effects over general combining ability (GCA) variations, majority of the characteristics in the experimental trials demonstrated dominant type of genes controlling yield and oil traits (Aleem *et al*., 2015). Hence, such findings are important for improving both quantitative and qualitative characters in sunflower so as to meet the edible oil requirements of the country and also provide food security to world's growing population (Rizwan *et al*., 2020). Among many yield and oil traits, the extent of SCA was greater than GCA variances, suggesting that dominant genes predominated in the inheritance for majority of the traits (Bhoite *et al*., 2018). Similarly for most of the plant characteristics, the ratio of GCA variance to SCA was less than unity, signifying that non-additive gene action was playing predominating role (Borde *et al*., 2017). The ratio of GCA and SCA of genotypes help sunflower breeders to make better decisions regarding the development of hybrid crops. Lines and testers had good GCA effects for shoot length root length and root fresh weight but hybrids had negative SCA effects for all these traits (Iqbal *et al*., 2017). In a similar study the Ahmed *et al*. (2022) noted that the ratio of σ^2 GCA/σ^2 SCA was less than unity (1.0) for agronomic, seed yield and oil traits indicating that dominant genes performed crucial role in their inheritance. Lines crossed along with testers' analysis which is mostly used for integrating the combining ability tests, is the most capable approaches for evaluating huge number of parents (Throat *et al*., 2016). The leading role of SCA effects is thoroughly estimated which govern yield and associated traits (Aleem *et al*., 2015), while Machikowa *et al*. (2011) suggested the prevailing impact of GCA against SCA for yield contributing characters. Memon *et al*. (2014) observed greater role of SCA over GCA variances for seed yield and oil traits including oleic and linoleic acid (Rizwan *et al*., 2020; Shamshad *et al*., 2016). Related outcomes were also noted by Kholghi *et al*. (2014) for achene yield.

A heterotic performance of cross combinations is mostly determined by the combining abilities of the inbred parents involved in crosses (Tan, 2010). To achieve this objective, genetic divergence of existing germplasm and the combining ability of genotypes need to be documented. Heterotic hybrids were created by mating CMS inbred females with restorers having higher GCA and SCA effects (Meena *et al*., 2013; Tan *et al*., 2010). Higher GCA variation implies additive gene activity, which depicts the line's breeding value, while higher SCA variance suggests a stronger role for non-additive gene action which is pre-requisite for heterosis breeding (Shabbir *et al*., 2016). Line × tester analysis is most efficient approach to examine a large number of inbreds for their GCA and SCA estimates for yield and oil quality traits. It is important to develop inbred parents with strong combining ability before initiating heterosis breeding programed. In order to formulate an efficient breeding strategy, information on the GCA of inbred lines to be utilized as parents, as well as their unique combining ability would be extremely valuable (Vikas *et al*., 2015). Superiority of hybrid above lines and tester inbreds is an imperative contemplation to develop flourishing F_1s (Meena *et al*., 2013). Head diameter, 1000 seed weight, seed production and oil% all had upper edge SCA variations than GCA variances

(Andarkhor *et al*., 2012).Therefore, the objectives of this study were to determine GCA, SCA, additive, dominant and degree of dominance for yield and its related traits in sunflower. Also, identify the best combiner parents and their hybrids under well-watered and water- stressed conditions.

Materials and Methods

Water regimes were regarded as the most important component and in this they served as a main factor. Irrigation regimes with no water stress (well-watered) received frequent irrigations without any water stress, thus a total of 5 irrigations were applied whereas water stress treatment received mild to severe stress imposed on 50-day-old plants near to flower bud until seed formation i.e. 80 day old plants by withholding water for a period of 30 days. The space between plants and rows was fixed at 25 and 60 cm respectively. The seeds of eight parents (5 lines HO-1,Mehran, Thatta, PSF-025, SH-3915 and 03 testers UC-666,Peshawar-93 and B-2) their 15 F_1 hybrids were sown in split plot design with two treatments in four replications at oil seeds research institute, Tandojam during 2020. The data was examined for general and particular combining ability variations and their consequences for days to 75% flowering, days to 75% maturity, stem diameter (cm), head diameter (cm), No. of seeds/head, seed index (1000 achene weight, g) and seed yield/plant (g),biological yield/plant (g). The acquired data was subjected to analysis of variance using the statistical factorial plot model, as described by Gomez and Gomez (1984). Lines × tester analysis, a method created by Kempthorne (1957) and implemented by Singh and Chaudhry (1984) which was used to calculate estimates of combining ability. The words like well watered, optimum irrigation, normal irrigation and no water stress will be used interchangeably whereas for water stressed treatment, the words like drought stress, water stress and water stress environment may be used in this manuscript.

Results and Discussion

Line × tester mating scheme is a capable biometrical technique which supports evaluating massive number of inbred parents regarding general combining ability (GCA) and specific combining ability (SCA) impacts. However, its worth mainly depends upon the type of testers used. Line × tester mating scheme assesses greater number of lines against diallel and other mating designs. In abnormal conditions of inbred lines particularly self-incompatibility and male sterility where diallel analysis fail to apply then line × tester procedure can effectively be used to obtain information on inheritance of traits and the combining ability of parents. According to Nasreen *et al*. (2014), line × tester analysis continued to be foremost contributor in inheritance of plant characters. Dominant genes are not reliably fixable; therefore suitable for hybrid evolution, whereas additive or complementary types of epispastic gene interactions are exceedingly fixable thus such appropriate gene effects for crossing and selection of inbred parents for hybrid sunflower expansion.

The variances from ANOVA showed significant differences between the genotypes, parents, hybrids, parent *vs* hybrids indicating existence of substantial variability in the mean squares of above mentioned breeding material (Table 1). This showed that the data is worth for combining ability determination, hybrid evaluation. However, the significance of lines and testers advocated that these parameters are enough justification to estimate GCA variances and estimates, particularly additive types. Whereas significant variances owing to parents vs. hybrids revealed that heterotic effects for all the characters exist and coinciding results were also reported by Mirarab and Ahmadikhah (2010). The ANOVA also revealed significant difference amongst the lines for all the traits excluding grain yield in well watered and head diameter in water stressed conditions (Table 1). Present results are in harmony with the outcomes of (Mustafa *et al*., 2023; Andarkhor *et al*., 2013; Ciric *et al*., 2013; Kang *et al*., 2013; Chandra *et al*., 2011) demonstrated that testers presented considerable variation for the all traits excluding head diameter in non-stress conditions only. However, highly significant differences were shown by testers for the all characters in water stress environment. Substantial differences were observed in all the traits by line × tester interaction in non-stress (Table 1). The variances among the lines were greater in stress than in normal conditions for days to 75% flowering, plant, head diameter, number of seeds/head, seed yield/head, seed index, seed/yield plant, biological yield/plant. For other traits eventually lines showed less variances. Such results revealed the existence of substantial genetic variability in newly evolved breeding material. Tyagi *et al*. (2018) from their analysis of variance revealed significant differences for the traits like plant height, head diameter, 1000 seed weight and seed yield/plant under non-stress and water stress environments. Considerable differences for lines *vs*

Table 1. ANOVA of F_1 sunflower hybrids for phenological and yield traits grown under well watered and water stressed environments

Characters	Mean squares					
	Replication (R)	Treatment (T)	Error (a)	Genotypes (G)	T x G	Error (b)
	D.F. 3	D.F. 1	D.F. 3	D.F .22	D.F. 22	D.F.132
Days to 75% flowering	1.83	2.60	0.33	195.75**	4.01	2.92
Days to 75% maturity	3.22	223.08**	4.71	199.84**	17.70**	4.64
Stem diameter	0.08	18.15*	0.60	15.96**	0.50*	0.29
Head diameter	0.3508	35.83*	1.74	59.88**	2.02**	0.95
Number of seeds/head	1782.00	763295.00	1628.00	237304.00**	6825.00*	4032.00
Seed index	0.89	2261.01**	3.42	181.08**	12.48**	2.09
Seed yield/plant	4.89	4643.10**	6.10	491.11**	16.95**	2.61
Biological yield/plant	177.00	156944.00**	154.00	6626.00**	1943.00**	46.00

**, *= 1 and 5% significant levels respectively

testers and lines and testers were observed for whole traits studied under well watered as well as water stressed conditions also. Analogous to our findings, Ghafari and Shariati (2018) indicated that the mean squares due to parents, crosses, parent's *vs* crosses were significant for seed yield/plant and the most of its attributes except for 50% flowering days, yet lines, testers and line × tester were significant for all studied traits. From the breeder's point of view, highly negative estimates or minimum positive for 50% flowering days and plant height along with high positive values for yield and its components would be useful for sunflower breeding programmes.

Concerning testers, the genetic variances under moisture stress conditions were higher than normal conditions for the characters like days to 75% maturity, stem diameter, head diameter, seed index, achene yield and biological yield. Variations among the testers denoted that additive genes and variances were important in tester inbreds under study. Regarding variances owing to lines × tester interactions. The higher variances under water stress were marked with respect to traits stem thickness, seeds/head, seed yield/plant and biological yield/plant. The large differences in mean squares due to lines by tester interactions showed the importance of exploiting SCA impacts of the hybrids and obtaining information on the importance of dominance variances and effects. Ahmad *et al*. (2022) described that the variance owing to lines and testers which is an indicator of GCA was momentous for whole characters evaluated. The variability due to the SCA of line × tester was substantial for all the traits except for days to maturity and seed yield. This significance advocated that testers were capable to distinguish on the basis of performance within the set of inbred lines. The values of variance due to GCA of lines and testers were higher than SCA for days to flowering and maturity, head diameter and seed weight indicates the prevalence of additive gene action in inheritance of these traits. Existence of additive as well as non-additive gene effects are adequate indication for using above approaches to increase agronomic, achene yield in *Helianthus annuus* L. Comparable outcomes of Khan *et al*. (2009) were likewise observed and stated that additive as well as non-additive genetic variations were important for morpho-yield traits in sunflower. Opposite to our results that dominant genes were prevailing for agronomic, seed yield (Rizwan *et al*., 2020; Golabadi *et al*., 2015; Andarkhor *et al*., 2012; Dudhe *et al*., 2009) reported predominance of additive genes.

Highly significant variances in genetic parameters for agronomic, achene yield in present study revealed that those sunflower breeders can achieve superfluous improvement in seed yield. Several previous investigators noted that SCA estimates are more crucial than GCA in determining seed yield of sunflower (Karasu *et al*., 2010; Mohanasundaram *et al*., 2010; Farrokhi *et al*., 2008; Skoric *et al*., 2007; Jan *et al*., 2005). Previous investigators like (Golabadi *et al*., 2015; Memon *et al*., 2015; Tabrizi *et al*., 2012; Khan *et al*., 2009) acknowledged that SCA and GCA are equally indispensable to scrutinize inbred parents in sunflower breeding. Manivaran and Ganesan (2001) sustained these conclusions and recognized parents for their combining ability as parents and crosses and showed noteworthy GCA and SCA correspondingly for 75%

blooming days (Thakare *et al*., 1999; Devaraj, 1996). The seed yield and plant height were under the control of completely dominant genes. Similarly Chandra *et al*. (2011) noted prevalence of dominant genes for agronomic and seed yield yet additive genes advocating. In consonance to our findings that dominant genes were prevailing for yield, capitulum size and oil content are in agreement with the findings of Machikowa *et al*. (2011). Significant negative GCA and SCA effects were found for plant height and life cycle duration (Ghaffari *et al*., 2011) are in complete agreement with the current findings.

General combining ability (GCA) and specific combining ability (SCA) effects. Selection of appropriate male and female inbred lines is imperative to accomplish the ambitions in sunflower breeding projects. The accurate information regarding essential genetic attributes like combining ability estimates, types of gene action and relative magnitude of genetic variance are important parameters in sunflower breeding programmes (Khan *et al*., 2009). The existence of non-additive genes is the principal endorsement for initiating the development of sunflower hybrids. The knowledge of combining ability of lines with testers is very crucial. Combining ability studies revealed the importance of both additive and non-additive genetic effects for seed yield traits in sunflower (Galabadi *et al*., 2015; Memon *et al*., 2015; Tabrizi *et al*., 2012; Khan *et al*., 2009; Skoric *et al*., 2007). CMS lines and tester with high GCA and SCA effects were crossed to obtain potential hybrids (Kaya and Atakisi, 2004). Therefore, prospect of adapting collective breeding methods like diallel, line × tester, pedigree or recurrent selections, etc. can be highly fruitful in using additive as well dominant variations and genes for evolving prospective hybrids. The GCA and SCA impacts for various traits are discussed hereunder.

Days to 75% flowering. The genetic variations in 75% flowering days are very advantageous since those cultivars will be earlier in maturity, thus harvest well in time to vacate the field for cultivation of next crop.The inbreds which exhibited high negative or minimum positive GCA impacts are regarded as desirable for evolving early maturing or short duration hybrids. The inferences recorded for GCA effects showed that four inbreds lines revealed negative, while one expressed adverse positive GCA effects for days to 75% flowering. The inbreds PSF-025, Mehran, SH-3915 and Thatta exhibited desired negative GCA which suggested that above inbreds performed are superior general combiners for earlier flowering in well watered irrigation conditions; However these parents gave lower mean performance (Table 2). These results further indicated that additive genes were advocating the plant height. From three, two testers such as UC-666 and B-2 expressed suitable negative GCA effects. Since, both these testers are desirable which may be crossed with promising females to generate early maturing hybrids. Adverse positive GCA effects was recorded by tester inbred Peshawar-93 for days to 75% flowering under non-stress, while under water stress conditions, the line PSF-025 revealed maximum negative effects followed by Mehran depicted

Table 2. GCA effects of lines and testers for phenological traits of sunflower grownunder well watered and water stressed environments

Lines	Days to 75% flowering		Days to 75% maturity	
	Well watered	Water stressed	Well watered	Water stressed
HO-1	4.49**	5.34**	9.22**	4.32**
Mehran	-1.36**	-1.47*	-15.43**	-0.81
Thatta	-0.46	0.75	1.48*	-0.03
PSF-025	-3.70**	-4.17**	-0.36	-3.75**
SH-3915	-0.46	0.04	5.08**	0.28
S.E. (gi.)	0.48	0.51	0.63	0.61
Testers				
UC-666	-1.67**	-1.92**	-8.58**	-1.16**
Peshawar-93	2.00**	1.81**	3.24**	1.20**
B-2	-1.32**	0.11	5.35**	-0.03
S.E. (gi.)	0.37	0.39	0.49	0.47

**, *= 1 and 5% significant levels respectively in (Table 2). Only one pollinator exhibited greater desirable negative GCA effects *i.e*. UC-666 in well waters conditions, while the two testers exhibited undesired positive GCA effects. For the phenological parameters, breeder focus on negative GCA affects rather those positive effects because the positive effects can lead to early flowering and maturity. The lines and testers which exhibited as good general combiners with negative GCA impacts for 75% flowering may be employed in crossing scheme for evolving early maturity hybrids. Kang *et al*. (2013) noted that lines G-093 and G-079 expressed considerable negative GCA effects while Kang *et al*. (2013) and Memon *et al*. (2015) reported that testers A-5 and A-85 manifested expressively deleterious GCA impacts for 75% flowering and 90% maturity. Positive GCA impacts for seed yield and oil content were also recorded. Chandra *et al*. (2011) stated that fewer female parents manifested progressive GCA effects for seed yield traits also showed required negative GCA for 50% flowering an maturity days showing their effectiveness in breeding for early maturing hybrids with higher yields. In a more recent study, Ahmed *et al*. (2022) observed that from restorer inbreds Rf8 (49 days) was the earliest for days to flowering among all, while latest was Rf14 (53.3 days). Among A-lines, A14 was the earliest (46.8 days) and A1 was the latest (54.6 days) inbred parents. It may be inferred from current findings that diminishing effects of dominant genes were employing significant role in decreasing 50% flowering and maturity days. Hence, combining ability of inbred parents is the definitive aspect showing usefulness of lines and testers in hybrids or synthetic varietal development. Very recently, Ahmed *et al*. (2022) identified lines A_4 and A_{31} with high negative GCA impacts were recognized as good general combiners for plant height.

Specific combining ability impacts of fifteen F1 hybrids were evaluated. The crosses HO-1 × B-2, Thatta × UC-666, PSF-025 × Peshawar-93 and Mehran × Peshawar-93 were among the top ranker which scored highly desirable negative SCA effects from fifteen hybrid evaluated in non-stress environments. Whereas in stress conditions, quite a few hybrids exhibited negative SCA effects, yet almost the same hybrids as under non-stress also exhibited maximum desirable SCA effects with respect days to 75% flowering (Table 3). The results indicated that these potential hybrids may be involved in breeding programme so as to obtain required level of earliness in sunflower hybrids under favorable and adverse environments. The crosses which involved good × good GCA parents hence used additive × additive gene interactions. As additive genes are fixable thus selection may be effective in early generations to exploit hybrids with early maturity in upcoming breeding programme. Kang *et al*. (2013) also observed that cross G-65×A-85 exhibited highest undesirable SCA impacts for 50% flowering and maturity days. Substantial amount of negative GCA and SCA impacts were recorded by Ghaffari *et al*. (2011) for plant height and life-cycle duration.

Days to 75% maturity. Since sunflower is shorter period crop, hence it condenses the menace of diseases and insects. Therefore, key emphasis in sunflower breeding is to evolve short duration hybrids (Kinman, 1975). To evolve early maturing cultivars, promising males and female parents with negative GCA may be crossed. Two inbred lines such as Mehran and PSF-025 were two highly short duration inbreds which expressed desired negative GCA effects are early maturing (Table 2). One tester *i.e*. UC-666 created highly negative GCA impacts for days to 75% maturity (Table 2) under well watered conditions. Yet in water stressed, line PSF-025 documented greater negative GCA effects followed by parents PSF-025 and Mehran for days to 75% maturity as same result got by Saif *et al*. (2023). Likewise, the tester UC-666 and B-2 also exhibited negative GCA effects among the three pollinators for days to 75% maturity. Among the testers, RGK26 and RGK56 showed suitable GCA impacts for days to maturity under both optimum and water stress conditions (Ghaffari and Shariati, 2018). For early maturity, potential females and testers with high negative GCA effects may be choice parents to be crossed for the expansion of early maturing hybrids. Comparable to present findings, Saleem *et al*. (2014) noted obvious negative GCA effect for first flowering days, whole flowering and maturity period in some tester parents. They observed that females G-93 and G-79 and males A-85 articulated negative GCA impacts for physiological maturity. For dropping 90% maturity days, non-additive genes were essential for the development of hybrids or synthetic varieties (Kang *et al*., 2013).

According to results, from fifteen crosses evaluated, hybrid HO-1 × B-2 exhibited maximum desirable negative SCA effects followed by SH-3915 × Peshawar-93 in non-stress (Table 3). However, in stress environment crosses HO-1 × B-2 expressed maximum desirable

Table 3. SCA effects of phenological traits for sunflower grown under well watered and water stressed environments

F_1 hybrids	Days to 75% flowering		Days to 75% maturity	
	Well watered	Water stressed	Well watered	Water stressed
HO-1 × UC-666	5.99**	3.43**	9.82**	5.11**
Mehran × UC-666	-1.13*	-0.50	21.97**	-0.96
Thatta × UC-666	-5.18**	-4.90**	1.81	-6.04**
PSF-025 × UC-666	1.50*	1.12*	10.45**	2.28**
SH-3915 × UC-666	0.47	0.86	5.46**	-0.27
HO-1 × Peshawar-93	4.72**	4.05**	0.55	6.02**
Mehran × Peshawar-93	-1.78*	-3.56**	11.9**	-3.92**
Thatta × Peshawar-93	1.67*	2.59**	0.59	1.82*
PSF-025 × Peshawar-93	-1.79*	-0.93	-4.94**	-1.83*
SH-3915 × Peshawar-93	-1.15	-2.12**	-8.08**	-2.08**
HO.1 × B-2	-10.68**	-7.47**	-10.86**	-11.02**
Mehran × B-2	2.89**	4.06**	16.14**	4.88**
Thatta × B-2	3.52**	2.32**	-2.39**	4.23**
PSF-025 × B-2	0.28	-0.16	-5.50**	-0.45
SH-3915 × B-2	0.67	1.28	2.63**	2.37**
S.E. (Si.)	0.83	0.88	1.10	1.05

**, *= 1 and 5% significant levels respectively

negative SCA effect followed by Thatta × UC-666 (Table 3). The potential females like Peshawar and SH-3915 and tester UC-666 with high negative GCA estimates may be crossed to develop early maturing hybrids. The hybrids with greater desirable SCA effects indicated the involvement of dominant genes with decreasing effect. The hybrid KBSH-44 exhibited higher desirable SCA effects for maturity said by Sakthivel (2003) whereas Ahmad *et al*., 2011) noted that lines A-01 and A-07 expressed considerably desirable GCA impacts for blooming and maturity.

***Stem diameter*.** Stem diameter with stiff stems is thought to provide resistance to lodging. Only one parent PSF-025 which showed positive GCA effects among the five lines for stem diameter, while two pollinators B-2 and UC-666, out of three recorded positive GCA effect in non-stress. However, the GCA impacts were very small. In stress conditions, four female lines such as SH-3915, Mehran, Thatta and HO-1 expressed desirable positive GCA effects and similar to non-stress situation, same testers UC-666 and B-2 also gave positive GCA effects for stem girth in water stress conditions (Table 4). Results indicated that female inbreds expressed very desirable GCA estimates and were identified as good general combiners for stem diameter. Therefore, expected that good combing females when crossed with potential tester, promising hybrids could be evolved with improved stem girth and providing lodging resistance. Imran *et al*. (2014) hybridized 10 lines with 03 testers and assessed higher affirmative GCA for stem diameter in fewer hybrids.

To examine SCA effects of hybrids for stem diameter, fifteen F_1 hybrids were evaluated but not many hybrids expressed positive SCA effects, yet crosses Thatta × UC-666, PSF-025 × B-2 and Mehran × Peshawar-93 revealed greater positive SCA effects in non-stress, whereas PSF-025 × B-2, Thatta × UC-666 and Mehran × Peshawar-93 manifested higher positive SCA effects respectively under drought stress (Table 5). The hybrids with higher positive SCA effects as mentioned above may have contributed advantageous non-additive genes with increasing effect for stem diameter. Hence prospective hybrids may be evolved which may accomplish preferred stem diameter. If greater magnitudes of SCA and GCA estimates are present then those hybrids are considered worthwhile either for hybrids evolution or single plant selection. Our results further suggested that parents which expressed greater GCA are those that produced potential hybrids with higher SCA estimates; therefore such parents are desirable for hybrid sunflower development with stiff stems (Chandra *et al*., 2011).

***Head diameter*.** Bigger heads size are needed to increase the number of achenes, consequently boost-up the seed yield (Hussain *et al*., 2018). Thus, head diameter is the most essential attribute increasing the seed yield directly (Memon *et al*., 2014) and indirectly (Adare, 2014). Head size in reasonable size is required because high increase in head size may cause imbalances in oil contents and achene yield as mentioned by Rameeh and Andarkhor (2017). It is important agronomic trait which is highly associated with yield and imposes firm influence on seeds/head, consequently produces remarkable impacts on seed yield (Skoric *et al*., 2012). Head diameter controlled by many minor genes exhibit low heritability which is limiting factor in to breed for larger capitulum (Hladni *et al*., 2011). In our study, four lines established positive GCA impacts in optimum and three in drought environments (Table 4). Among those, Mehran, SH-3915, Thatta and HO-1 manifested higher progressive GCA effects in normal irrigation conditions and three female lines like HO-1, Mehran and Thatta gave positive GCA effects in adverse environments. Thus two inbreds like Mehran and Thatta were consistent in their GCA effects under both the irrigation conditions. These inbreds revealed as best general combiners. From three testers, UC-666 displayed higher GCA effects in non-stress, while B-2 expressed positive GCA in stress conditions (Table 4) for head diameter. Results suggested that male and female parents with high performance and high GCA effects are good general combiners with additive genes; hence they are suitable parents to develop potential hybrids with bigger head diameter. The maximum GCA impacts were exhibited by L1 with the values of 3.46 followed by L2 as 3.06 for head diameter. These consequences were in harmony with (Rameeh and Andarkhor, 2017; Memon *et al*., 2015; Hladni *et al*., 2011).

Though so many crosses manifested negative SCA estimates, yet three crosses like Mehran × Peshawar-93, Thatta × UC -666 and PSF-025 × B-2 produced higher SCA effects for head diameter in non-stress environment. Likewise, in drought stress, from fifteen hybrids, three best performing crosses Thatta × UC-666, Mehran × Peshawar-93 and PSF-025 × B-2 exhibited higher SCA effects and higher per se mean performance (Table 5). According to present results, hybrids Thatta × UC-666, Mehran × Peshawar-93 and PSF-025 × B-2 revealed maximum desirable positive SCA effects indicated their aptitude to add advantageous non-additive genes with enhancing influences on capitulum size so as to accomplish desired capitulum size in sunflower. Kholghi *et al*. (2014) observed that inbred LR4 was possessed high GCA impacts for stem and head diameters. In another study, Tyagi and Dhillon (2016) noted that hybrid NC-41B × P100R was observed possessing high SCA for head size under optimal and drought circumstances, though 4 hybrids performed well under only normal irrigation regime and 23 under water stress environment out of 40 crosses tested. From testers, RHP-46 with greater GCA and high mid parent averages was found as good general combiner with predominantly additive genes for head sixe. The A-26 and HBRS-1 tester had high GCA for seed yield and

Table 4. GCA effects of lines and testers for various traits of sunflower grown under well watered and water stressed environment

Lines	Stem diameter		Head diameter	
	Well watered	Water stressed	Well watered	Water stressed
HO-1	-0.01	0.01	0.39	0.83*
Mehran	-0.02	0.43**	0.68*	0.54*
Thatta	-0.08	0.13	0.43	0.53*
PSF-025	0.66**	0.47**	0.50	-0.10
SH-3915	-0.74**	-0.04	-1.99**	-0.78*
S.E. (gi.)	0.17	0.14	0.32	0.24
Testers				
UC-666	0.05	0.28*	1.01**	-2.54**
Peshawar-93	-0.54**	-0.31*	-0.75**	-0.30
B-2	0.48**	0.03	-0.25	0.15
S.E. (gi.)	0.13	0.11	0.25	0.19

**, *= 1 and 5% significant levels respectively

Table 5. SCA effects for various traits of sunflower grown under well watered and water stressed environments

F_1 hybrids	Stem diameter		Head diameter	
	Well watered	Water stressed	Well watered	Water stressed
HO-1 × UC-666	-0.36	-0.16	-1.17**	1.82**
Mehran × UC-666	-0.50	-0.60*	-2.73**	1.93**
Thatta × UC-666	2.19**	2.42**	3.44**	6.07**
PSF-025 × UC-666	-0.88*	-1.54**	-0.13	0.95*
SH-3915 × UC-666	-0.41	-0.08	0.61	2.73**
HO-1 × Peshawar-93	0.05	0.05	-0.56	-0.69
Mehran × Peshawar-93	1.89**	1.71**	4.70**	3.82**
Thatta × Peshawar-93	-0.46	-0.71*	-1.22**	-1.47**
PSF-025 × Peshawar-93	-1.29**	-1.28**	-2.99**	-2.01**
SH-3915 × Peshawar-93	-0.26	0.25	0.07	0.36
HO-1 × B-2	0.35	0.11	1.74*8	1.58**
Mehran × B-2	-1.38**	-1.10**	-1.97**	-3.05**
Thatta × B-2	-1.71**	-1.68**	-2.20**	-1.89**
PSF-025 × B-2	2.18**	2.83**	3.13**	3.76**
SH-3915 × B-2	0.58	-0.16	-0.68	-0.38
S.E. (Si.)	0.30	0.24	0.55	0.42

**, *= 1 and 5% significant levels respectively

associated characters, noted by Ahmad *et al*. (2011). They concluded that above testers may be hybridized with prospective lines to evolve hybrids with bigger heads.

Number of seeds/head. Combing ability helps plant breeders in evolving potential hybrids, synthetics or composites in sunflower. Considerable amount of GCA effects were articulated by the inbred lines and testers, nonetheless, three female lines such as Thatta, HO-1 and Mehran expressed better positive GCA effects in non-stress environment. The GCA estimates determine additive gene effects and such inbreds are considered as good general combiners. The other two female lines SH-3915 and PSF-025 demonstrated undesirable negative GCA effects (Table 6). Out of three tester, two of them such as UC-666 and Peshawar-93 manifested supreme GCA effects in normal irrigation; hence these parents can add favorable additive genes for increasing seeds/head. The tester Peshawar-93 displayed higher GCA effects in adverse conditions (Table 6). The same female lines with exactly same ranking as in non-stress, gave higher positive GCA effects in drought environments. Analogous to our results reported by Ahmad *et al*. (2011) perceived some pollinators with high GCA impacts for seed index and yield/plant and suggested such inbreds may be involved for hybrid evolution. They suggested that lines Thatta, HO.1, Mehran and PSF-025 may be hybridized with Peshawar-93tester to generate rewarding hybrids and other varieties. Ahmad *et al*. (2012) conducted another study and stated like capitulum size and number of seeds/plant are also an important yield associated character which inflicts undeviating effect on overall production. Zia *et al*. (2013) also proposed that higher number of seeds may be obtained from bigger heads, subsequently more grain production.

Quite greater number of hybrids expressed negative SCA impacts; nevertheless, top scoring three crosses were also identified as Mehran × UC-666, HO-1 B-2 and PSF-025 with higher SCA effects for number of seeds/head in non-stress conditions. Similarly in stress environment, from fifteen crosses, the same three hybrids with little change in SCA values ranking, showed higher SCA effects and those crosses are Mehran × peshwar-93, PSF-025 × B-2 and HO-1 × B-2 (Table 7). These hybrids with high mean performance and higher SCA effects possess dominant genes with increasing effect for numbers of seeds/head are desirable for hybrid sunflower expansion. Outcomes by and large revealed that outstanding general combiner inbreds and specific combiner hybrids may be valuable for expansion of sunflower hybrids or composites. Current consequences are in covenant with the findings of Hladni *et al*. (2011) who also observed preponderance of SCA estimates and dominant genes for the achenes per capitulum whilst

Table 6. GCA effects of lines and testers for various traits of sunflower grown under well watered and water stressed environments

Lines	Number of seeds/head		Seed index	
	Well watered	Water stressed	Well watered	Water stressed
HO-1	70.62**	106.18**	-1.39**	-0.31
Mehran	46.53*	7.91	1.98**	1.46**
Thatta	84.51**	109.39**	3.46**	2.29**
PSF-025	-7.05	-35.02	-0.30	0.44
SH-3915	-194.62**	-188.45**	-3.78**	-3.06**
S.E. (gi.)	19.23	17.38	0.49	0.33
Testers				
UC-666	6.62**	-14.10**	0.58**	-0.93**
Peshawar-93	5.57**	16.91**	-1.06**	-0.93**
B-2	-12.19**	-2.80**	0.47	1.86**
S.E. (gi.)	0.13	0.11	0.25	0.19

**, *= 1 and 5% significant levels respectively

Table 7. SCA effects of various traits for sunflower grown under well watered and water stressed environments

F_1 hybrids	Number of seeds/head		Seed index	
	Well watered	Water stressed	Well watered	Water stressed
HO-1 × UC-666	-80.87*	-60.91*	-4.63**	-2.90*8
Mehran × UC-666	-111.28**	-52.64	1.37	-2.42*
Thatta × UC-666	120.74**	140.51**	8.27**	11.3**
PSF-025 × UC-666	-10.20	-105.88**	-2.72**	-4.15**
SH-3915 × UC-666	81.12*	78.94*	-2.24*	-2.65*
HO-1 × Peshawar-93	-60.57	-111.92**	1.01	-1.40
Mehran × Peshawar-93	258.52**	274.07**	3.39**	6.88**
Thatta × Peshawar-93	-30.47	-5.65	-1.16	-3.50**
PSF-025 × Peshawar-93	-114.15**	-113.09**	-4.08**	-3.65**
SH-3915 × Peshawar-93	-53.28	-43.41	0.90	0.85
HO-1 × B-2	140.94**	172.84**	3.65**	4.31**
Mehran × B-2	-147.22**	-221.44**	-4.74*	-4.46**
Thatta × B-2	-90.25**	-134.84**	-7.07**	-10.29**
PSF-025 × B-2	124.36**	218.99**	6.81**	7.81**
SH-3915 × B-2	-27.82	63.47	1.37	1.81*
S.E. (Si.)	33.31	30.10	0.84	0.58

**, *= 1 and 5% significant levels respectively

Andarkhor *et al*. (2012) established two females as high combiners for number of seeds/plant, capitulum size, seed yield and thousand-seed weight.

Seed index. Among five female lines, two of them like Thatta and Mehran explicated maximum positive GCA effects in well watered. However, the tester UC-666 is categorized as uppermost tester with supreme GCA impacts followed by B-2 in non-stress environments (Table 6). In drought stress, three lines (including two same lines of normal irrigation *i.e*. Mehran and Thatta) such as Thatta and Mehran and PSF-025 exhibited higher positive GCA effects. Out of three, only one pollinator B-2 manifested maximum GCA effects under both the environments; hence this parent can contribute desirable genes in hybridization scheme (Table 6). These results indicated that Thatta and Mehran from females and B-2 from males which showed high mean performance and good general combining ability may be crossed to develop potential hybrids with increased seed index. These male and female inbreds with additive genes may also be crossed to develop new inbred lineswith higher seed weight. Similar, to our findings, testers RF81-25 and RF81-30 observed by Andarkhor *et al*. (2012) and similarly Ahmad *et al*. (2011) distinguished that pollinators A-26 and HBRS-1 exhibited considerably positive GCA impacts for head size, grain yield and 1000-achene weight are important for breeding determinations. Tyagi and Dhillon (2016) reported that line ARG-6A was high combiner for 100-achne weight under normal and drought stress circumstances. Although ARG-3A was detected as high combiner under water stressed situations however, pollinator P69R was potential combiner with progressive GCA under both the circumstances.

Among the fifteen hybrids evaluated, the cross Thatta × UC-666 was found as best specific combiner with high SCA effects in normal and stress environments, yet followed by PSF × B-2 and Mehran × Peshawar-93 in both normal and water stress environments (Table 7). It is very important to note that all the three top scoring hybrids recorded higher mean performance and also maximum SCA effects in drought against normal conditions; hence it is worth to further exploit these hybrids under adverse environments which is the need of the time. It was recommended that if greater GCA in two or in one parent exists, such hybrids are assets to be explored, and indicated that such effects are fixable and single plant selection is important for improving seed index in sunflower. The above cited hybrids are rewarding and justify due deliberation in forthcoming breeding schemes. Existing possessions are in conformity with that. Ahmad *et al*. (2012) who noted that hybrids A-165 × A-26, A-41 × A-35, A-1 × G-12 and A-41 × HBPS-1 demonstrated progressive SCA impacts for 100-achene weight and seed yield thus endorsed as potential hybrids for cultivation. Andarkhor *et al*. (2013) also observed expressively progressive SCA impacts for higher seed width and greater 100-seed weight. Analogous to our findings, Tyagi and Dhillon (2016) observed that from 6 hybrids, only NC-41B × P69R was famous having high SCA for 100-achene mass under regular and moisture deficit conditions. Parallel to our results, Ahmed *et al*. (2022) identified crosses like CMS-23×Rf-20, CMS-31×Rf-8 and CMS6×Rf-11 with high SCA estimates for 100-seed weight.

Seed yield/plant. The utmost breeding aim in sunflower is to breed high yielding, resolute and dynamic F_1 hybrids. Inbreds with high diversity, hence are rewording to be suitable parents for hybrid evolution (Inamullah *et al*., 2006). Present results indicated that in moisture deficiency, HO-1 is classified 1st by manifesting higher positive GCA whereas Thatta and Mehran were rated as second and third with greater desirable GCA effects individually for seed yield/plant (Table 8). Only one pollinator Peshawar-93 showed desired GCA which indicated additive genes were advocating for grain yield. Nonetheless, in water stressed situation, 04 females added positive GCA, hitherto greater GCA was rated by HO.1 followed by Mehran Thatta and PSF-025 for grain yield/plant. Among the 03 testers, two B-2 and Peshawar-93 exhibited positive GCA effects in stress conditions (Table 8). The higher performance and GCA estimates of female lines HO.1, Thatta and Mehran while testers B-2 and Peshawar-93 their being good general combiners with additive genes are important parents for hybridization and selection programmes. Two tester inbreds RGK56 and RGK26 were appropriate combiner for oil content under optimum and water stressed conditions respectively the later had desired GCA impacts for seed and oil yields under water stressed condition too as said by Ghaffari *et al*. (2018). Current outcomes are in agreement with those of Binodh *et al*. (2008) who noted that some CMS lines as high general combines for seed yield/plant, while Tabrizi *et al*. (2012) estimated GCA and SCA by crossing 05 CMS lines with 04 pollinators and observed some lines as best combiners for seed and oil yields. Among the testers Rf1 was a good general combiner for head diameter, number of seeds/plant, oil seed content and seed yield/plant (Ahmed *et al*., 2022).

From fifteen crosses, seven F_1 hybrids showed positive SCA effects for seed yield/plant/plant, nonetheless crosses PSF-025 × B-2, Thatta × UC-666 and Mehran × Peshawar-93 recorded upper edge SCA impacts, whilst remaining eight SCA were detrimental as indicated in Table 9 under drought stress situation. From fifteen crosses, the hybrids SH-3915 × UC-666 demonstrated the maximum positive SCA value followed by SH-3915 × Peshawar-93 and SH-3915 × B-2 in stress condition (Table 9). It is worth to note that so many hybrids with negative SCA revealed to be poor specific combiners for seed yield/plant (Table 9). The hybrids which expressed higher positive SCA effects in non-stress were much greater than SCA estimates in water stress conditions. These results indicated that per se hybrid performance in stress were poor. Since the supreme hybrids is supposed to express high SCA and GCA in both or minimum in one parent, hence contemporary hybrids seem valuable and demonstrating that such impacts are fixable mechanisms and single plant selection will be desirable for boosting achene yield/plant in sunflower. Similar to our results, Kanwal *et al*. (2015); Karasu *et al*. (2010) recognized some hybrids CMS-10 × RHA- 03, CMS-01 × RHA-10, CMS-10 × RHA-10, A18 × G79 and CMS-23 × RHA-10 with high per se performance and SCA effects, thus they were promising hybrids for achieving more seed yield/plant. Comparable results were recently noted by Ahmed *et al*. (2022) who investigated 35 crosses, from which seven crosses had shown significant positive SCA effects for seed yield/plant. The hybrids A4×R14 followed by A6 × Rf-14, A31 × Rf-8, A28 × Rf-20, A23 × Rf-20, A1× Rf-1 and A14 × Rf11 showed high positive SCA impacts in the range of for seed yield/plant.

Biological yield/plant. Higher dry biomass yield/plant may provide more assimilates; hence higher seed yield could be achieved. Out of five, three females articulated greater constructive GCA estimations and two other lines revealed deleterious GCA effects, nonetheless, females PSF-025, Mehran and HO-1 recorded positive GCA effects for biological yield/plant. Among the pollinators, only B-2 gave large GCA estimates in optimal environments (Table 8). The uppermost GCA estimation was perceived in the lines Thatta followed by PSF-025 in stress. Comparable to higher GCA impacts under non-stress, the same tester B-2 exhibited maximum effects under drought stress conditions. These results suggested that female parents PSF-025, Mehran and HO-1 and tester B-2 are good general combiners possessing higher GCA estimates with additive genes. Hence these are suitable male and female inbreds to be crossed for hybrid sunflower developments or to select single plants from filial segregating generations. Tyagi *et al*. (2018) reported that CMS-DV-10A and CMS-XA were high combiner lines for biomass production from wild source in optimal irrigation whereas, in water shortage, the lines CMS-XA, CMS-ARG-6A and CMS-PRUN-29A were recognized as potential parents. The CMS-234A and CMS-PRUN-29A were prospective parents for biomass production under both optimal and water shortage conditions. The tester, P69R showed the high biomass regarding this traits in stress and non-stress conditions.

Among the fifteen cross combinations formed from five lines and three testers under this study, nine recorded undesirable SCA effects (ranged from -6.14 to-112.21), yet suitable progressive SCA impacts extended as 4.20 to 46.80 for biomass yield (Table 9). The hybrids like Mehran × Peshawar-93 recorded higher positive SCA values for biomass production followed by PSF-025 × B-2 and Thatta × UC-666 under normal irrigation. From 15 F_1 hybrids, Mehran × peshawar-93, PSF-025 × B-2 and Thatta × B-2 displayed higher positive SCA estimations, while eight hybrids demonstrated deleterious SCA effects for biological yield in water stressed situation (Table 9). These hybrids with higher SCA effects and hybrid performance under normal or stress conditions indicated that dominant genes were present in the parents, hence such crosses are worth to be exploited for hybrid sunflower so as to increase biological yield of seed and oil. Tyagi *et al*. (2018) successfully identified three hybrids CMS-38A × RCR-8297, CMS-XA × P124R and CMS-ARG-6A × P124R which exhibited higher SCA for biological yield/plant.

Proportional contribution of lines, testers and their interactions. Variable proportionate contributions were articulated by the lines, testers and line × tester interface for the manifestation of the traits studied. For comparative involvement of lines, testers and their interaction, sunflower breeders have observed variable results for the same traits. In the current research, the analysis of five lines and three testers were determined so as to approximate the comparative contributions of females, males and males by female's interaction against the total genetic variance. The genetic contributions under non-stress and drought stress conditions for the characteristics like agronomic and seed oil parameters are accessible in Table 10. Concerning to proportionate contributions of inbreds and their interactions, the lines contributed greater portion as compared to the tester parents in the expression of all the traits under well watered and moisture deficient environments excluding days to 75% flowering in non-stress and seed yield/plant in both optimum and drought circumstances. This is attributed to maternal effects of female parents for almost all the characters studied. It was quite difficult to compare genetic variances between non-stress and water stress, yet the genetic variances in water stress were lower than non-stress for plant height and chlorophyll content while for linoleic acid the genetic variances were *vice versa* being greater in non-stress than in drought stress. Results further revealed that interaction of lines x tester manifested much higher contribution for most the characters in non-stress and water stress respectively were; days to 75% flowering (51.50, 46.65%), days to 75 % maturity (70.70, 56.38%), days to seed formation (60.98, 74.46%), plant height

Table 8. GCA effects of lines and testers for various traits of sunflower grown under well watered and water stressed environment

Lines	Seed yield/plant		Biological yield/plant	
	Well watered	Water stressed	Well watered	Water stressed
HO-1	3.99**	3.85**	0.34	0.06
Mehran	1.65**	2.52**	3.00	-5.48**
Thatta	2.26**	1.82**	-1.16	25.86**
PSF-025	-8.81**	1.27**	9.84**	8.31**
SH-3915	-8.11**	-9.48**	-12.00**	-28.72**
S.E. (gi.)	0.50	0.40	2.03	1.89
Testers				
UC-666	-1.12**	-1.48**	-13.36**	-9.66**
Peshawar-93	1.25**	0.67*	-9.71**	-15.38**
B-2	-0.11	0.94**	23.09**	25.08**
S.E. (gi.)	0.41	0.31	1.57	1.47

**, *= 1 and 5% significant levels respectively

Table 9. SCA effects for various traits of sunflower grown under well watered and water stressed environment

F_1 hybrids	Seed yield/plant		Biological yield/plant	
	Well watered	Water stressed	Well watered	Water stressed
HO-1 × UC-666	-7.38**	-7.30**	-6.14*	-6.32*
Mehran × UC-666	-4.04**	-5.97**	-112.21**	-6.95*
Thatta × UC-666	12.85**	-5.27**	35.86**	9.98**
PSF-025 × UC-666	4.89**	-4.72**	-13.89**	-28.29**
SH-3915 × UC-666	1.99**	6.03**	4.20	31.56**
HO-1 × Peshawar-93	-0.22	-9.58**	-10.54**	-0.87
Mehran × Peshawar-93	9.84**	-8.25**	46.80**	55.79**
Thatta × Peshawar-93	-2.94**	-7.55**	-22.29**	-35.75**
PSF-025 × Peshawar-93	2.90**	-7.00**	-23.29**	-26.53**
SH-3915 × Peshawar-93	-1.22**	3.75**	9.30**	7.35**
HO-1 × B-2	7.61**	-9.85**	16.66**	7.29**
Mehran × B-2	-5.80**	-8.52**	-26.00**	-48.87**
Thatta × B-2	-9.91**	-7.82**	-13.59**	25.74**
PSF-025 × B-2	17.21**	-7.27**	37.16**	54.79**
SH-3915 × B-2	-0.79**	3.48**	-13.50**	-38.95**
S.E. (Si.)	0.19	0.69	3.52	3.28

**, *= 1 and 5% significant levels respectively

(52.53, 42.14%), stem diameter (85.94, 89.83%), head diameter (83.74, 79.97%), number of seed/head (67.58, 81.12%), seed index (93.75, 91.60%), seed yield/plant (89.20, 88.80%), biological yield/plant (92.15, 89.57%) seed yield Kg/ha (93.77, 95.77%), chlorophyll content (61.28, 40.22%), linoleic acid (47.10,71.26%) oleic acid (98.93, 82.23%), oil content (96.15, 96.45%) and protein content (90.20, 85.22%) in both the conditions. Such variances indicated that the characters under consideration were supported by both dominant and additive genes with maternal and paternal influences. Higher relative influence of lines × testers to whole genetic variances revealed greater SCA effects for all the traits under current investigation and non-additive and over-dominant genes were controlling the characters under investigation. Analogous to our results, Tyagi

Table 10. Proportion contribution of lines, testers and line × tester interaction of sunflower genotypes for seed yield related traits grown under well watered and water stressed environments

Traits	Well watered			Water stressed		
	Lines (L)	Testers (T)	L x T	Lines (L)	Testers (T)	L x T
Days to 75% flowering	23.56	24.93	51.50	27.54	25.81	46.65
Days to 75% maturity	19.25	13.74	70.70	19.42	24.20	56.38
Stem diameter	10.37	3.69	85.94	6.33	3.84	89.83
Head diameter	10.29	5.97	83.74	12.26	7.77	79.97
Number of seed/head	16.47	15.95	67.58	12.72	6.17	81.12
seed index	4.04	2.21	93.75	4.39	4.00	91.60
seed yield/plant	2.88	7.92	89.20	1.88	9.32	88.80
Biological yield/plant	6.63	1.23	92.15	8.57	1.86	89.57

and Dhillon (2016) reported greater variance of female parents over testers in the manifestation for all the characters under both the irrigation regimes. Similar to our results, they also found higher contributions of interaction component i.e. lines × testers for head size, 100 seed weight, seed yield and oil content under both customary and drought environments. Dominant genetic variance played a leading part in the hereditary of above traits (Tyagi and Dhillon, 2016). Greater involvement of line × tester interfaces in the manifestation of different characters was also stated by Marinkovic *et al*. (2017) and Shinde *et al*. (2016). Also reported higher involvement of female × male interaction revealed predominance of paternal and maternal effects prompting the characters. In the comparative influence of parents and their interactions, the involvement of females was greater over male's regardless moisture conditions. Nonetheless, their over-all interaction for the evaluated traits comprising of grain yield, harvest index and oil quantity were higher than the testers and female lines (Tyagi *et al*., 2018).

Assessment of genetic variances due to GCA **(σ^2A)** ***and SCA*** **(σ^2D).** The characteristics like all agronomical, yield and oil quality are presented in Tables 11 and 36 which demonstrated that additive as well as dominant genes were operating in the expression of traits in present investigation. By and large, majority of the attributes with few exceptions exhibited substantial variances due to lines, testers and line × tester in well watered conditions (Table 11). The mean squares owing to line × testers were much greater than lines or testers itself, yet these mean squares are not exact eloquent of real genetic variances *i.e*. additive variance (σ^2A) and dominant variance (σ^2D). Therefore, to address these important variances, four genetic components likeσ^2GCA (σ^2A), σ^2SCA (σ^2D), σ^2SCA /σ^2GCA and (σ^2SCA /σ^2GCA)$^{1/2}$ which are named as additive variance, dominance variance, proportion of dominance to additive variance and degree of dominance respectively were determined. These components easily explain the importance of gene action prevailing for particular trait. The components like σ^2GCA and σ^2A variances showed the importance of additive gene action and theoretically assumed that it is fixable effect, whereas σ^2SCA and σ^2D variances revealed the importance of dominant gene action and their effects are not perpetual, yet σ^2SCA/σ^2GCA and (σ^2SCA /σ^2GCA)$^{1/2}$ indicated the proportion and extent of dominance respectively. The later types of components and gene action are employed in the hybrid evolution. The variances due σ^2A and σ^2D and amount of dominance (σ^2D/σ^2A)$^{1/2}$ for various characters are accessible in Table 11 in non-stress and Table 12 under water stress conditions which indicated that σ^2SCA variances were far greater than σ^2GCA indicating that all the traits under study were predominantly controlled by dominant genes in both the environments. Similar to our findings, Tyagi and Dhillon (2016) observed that gene action articulated upper fraction of SCA over GCA for stem height, head size, 100 grain mass, seed yield and oil quantity indicating greater importance of non-additive genes action (Table 11). A dominant gene effect for oil quantity was observed by (Shinde *et al*., 2016; Imran *et al*., 2015; Parameswari *et al*., 2004). The predominance of dominant genes (σ^2D) over σ^2A was best perceived in F_1s under normal irrigation. The proportion of dominant variances and genes (σ^2SCA/

σ^2 GCA) and degree of dominance $(\sigma^2 D/ \sigma^2 A)^{1/2}$ are best descriptors for types of genes operating for particular trait. In present study, the ratio of dominant variances and degree of dominance (Table 11) in normal irrigation indicated that both proportion and degree of dominance respectively were much higher than unity or 1.0 for day to 75% flowering, days to 75% maturity, days to seed formation, plant height, stem diameter, head diameter, number of seeds/head, seed index, seed yield/plant, biological yield/plant, seed yield Kg/ha, chlorophyll content, linoleic acid, oleic acid, oil content and protein content. Such results clearly demonstrated the predominance of dominant genes controlling all the studied traits in normal irrigation conditions. These results are much different for traits evaluated under drought stress where only six traits like days to maturity expressed proportion of dominant genes and degree of dominance above 1.0. Those traits are 75% flowering, 75% maturity and seed formation period, plant height and linoleic acid. It was also noted that degree of dominance under drought stress for many traits did not reach to a unity (Table 12) but some were very close to unity in several other traits signifying the importance of both types, additive and dominant genes operating for such traits. It means quite a number of character were predominantly controlled by dominant genes in normal conditions whereas in drought stress, about half of the traits were predominantly advocated by additive genes. Yet it does not mean that additive genes were not functioning which can be judged by substantial additive genetic variances (σ^2A) in both normal and in stress environments. Very similar to our results, Ahmed *et al*. (2022) observed that the ratio of σ^2 GCA/σ^2SCA was less than unity for all the traits studied indicating that non-additive gene effects played an important role in the inheritance of agronomic, seed yield and phenological traits. The mean squares due to treatments (non-stress and water stress were substantial for entire parameters investigated except for proline. Similarly, the lines, tester and lines × tester interactions were also considerable for all the studied attributes over irrigation conditions. Parents and their hybrids also exhibited high GCA and SCA estimates. The ratio of σ^2GCA/σ^2SCA effect were P>0.5 for biological yield and oil content under normal water environment, while under water stress environment predominance of additive over non-additive genetic effects were recorded.

The dominance variances (σ^2 D) were much larger than the additive (σ^2A) for all the investigated characters (Tables 11 and 12). Likewise Shinde *et al*. (2016) perceived that dominant variance was prominent in the inheritance of phenological, yield and oil quantity in sunflower also quantified that when σ^2SCA variances are bigger over σ^2GCA, then dominant genes are supporting those traits. Current outcomes and results from previous investigators sustenance the scope of heterosis breeding (Ciric *et al*., 2013). Nonetheless some former scientists are not agreeing with current findings like Golabadi *et al*. (2015) witnessed that maturity, seed index and oil quantity were mainly controlled by additive genes. They nonetheless supposed that capitulum size, seed yield, and oil yield were promoted by additive and non-additive genes. Kanwal *et al*. (2015) disclosed that the plant height, head size, 100-seed weight and seed yield were operated by additive genes nonetheless 50% flowering maturity days were operated by non-additive genes. Our results designated that genetic variances for SCA were higher than GCA owing to dominant variances (σ^2 D). Karasu *et al*. (2010)

Table 11. Estimation of genetic variance due to GCA, SCA, additive, dominant, ratio of SCA to GCA and degree of dominance under well watered environment

Characters	σ^2GCA	σ^2A	σ^2SCA	σ^2D	σ^2 SCA/σ^2 GCA	$(\sigma^2 D/\sigma^2 A)^{1/2}$
Days to 75% flowering	0.29	1.16	30.81	123.25	106.24	10.31
Days to 75% maturity	0.65	2.59	28.42	113.69	43.72	6.61
Stem diameter	0.10	0.42	1.36	5.45	13.60	3.69
Head diameter	0.35	1.40	5.23	20.94	14.94	3.87
Number of seeds/head	485.65	1942.59	23254.09	93016.35	47.88	6.92
Seed index	1.82	7.27	17.78	71.12	9.77	3.13
Seed yield/plant	4.00	15.99	51.48	205.91	12.87	3.59
Biological yield/plant	59.81	239.22	619.82	2479.27	10.36	3.22

Table 12. Estimation of genetic variance due to GCA, SCA and additive, dominant, ratio of SCA to GCA and degree of dominance under water stressed environments

Characters	σ^2GCA	σ^2A	σ^2SCA	σ^2D	σ^2 SCA/σ^2 GCA	(σ^2 D/σ^2 A)$^{1/2}$
Days to 75% flowering	5.84	23.36	24.39	97.55	4.18	2.04
Days to 75% maturity	9.23	36.92	25.82	103.27	2.80	1.67
Stem diameter	1.25	5.01	0.64	2.57	0.51	0.71
Head diameter	2.82	11.27	2.51	10.06	0.89	0.94
Number of seeds/head	16831.45	67325.80	13838.12	55352.46	0.82	0.91
Seed index	21.16	84.62	10.59	42.35	0.50	0.71
Seed yield/plant	61.49	245.95	42.72	170.87	0.69	0.83
Biological yield/plant	971.39	3885.56	498.83	1995.31	0.51	0.71

described upper edge of SCA variance for yield and head width. Somewhat controversial to our findings, Golabadi *et al*. (2015) observed that traits like maturity, plant height, head size, stem thickness, 1000-seed weight, seed yield and oil quantity, stated that σ^2 A was greater for maturity, plant height, head size, seed weight and oil%, degree of dominance was high for stem thickness, seed yield indication that for first group of traits additive genes were important while for later two traits non-additive genes were advocating both the traits. Similar study was carried out by Rizwan (2020) who noted greater σ^2 SCA over the σ^2 GCA in spring and autumn crops for head thickness, seed index, yield/plant, oleic acid% and linoleic acid%. These results indicated preponderance of dominant genes controlling the traits studied.

Conclusion

In continuance, predominance of dominant genes was revealed the amount of dominance that was above 1.0 exhibited that over dominant genes were operating for investigated traits. Similarly, the fraction of σ^2 D/ σ^2A is obviously higher than 1.0, signifying super dominant gene effects for all investigated characters. Former researchers like Kaya and Atakisi (2004) and Mohanasundaram *et al*. (2010) established great fraction of dominant gene variances. Abdel-Satar *et al*. (2017) and Memon *et al*. (2015) also established degree of revealed very essential variations among sunflower inbred lines. The situation is getting worse when reservoirs of water storage have dropped as a result of silt deposition and also water quantity drops to a dead level. Since rainfall occurrence and quantity are often extremely variable throughout the sunflower growing season, therefore water shortage is expected to affect 14% of dominance being greater than 1.0, signifying the important role of over-dominant genes in the inheritance characters they studied.

Conflict of Interest. The authors declare that they have no conflict of interest.

References

Abdel-Rahem, M., Tamer, H.A.A., Hamdy, A.Z. 2021. Heterosis for seed, oil yield and quality of some different hybrids sunflower. *Crops and Lipids*, **28:** 1-9.

Abdel-Satar, M.A., Ahmed, A.A.E.H., Hassan, T.H.A. 2017. Response of seed yield and fatty acid compositions for some sunflower genotypes to spacing and nitrogen fertilization. *Information Process Agriculture*, **12:** 241-252.

Adare, Z.M. 2014. Characterization and association among yield and yield related traits in Sunflower (*Helianthus annuus* L.) genotypes. *Current Research Agriculture Science*, **1:** 77-82.

Ahmad, M.W., Ahmed, M.S., Tahir, H.N. 2012. Combining ability analysis for achene yield and related traits in sunflower (*Hellianthus annuus* L.). *Chilean Journal of Agriculture Research*, **72:** 21-26.

Ahmad, S., Saleem T.M. Khan Khan, A.M. 2011. Genetic studies of some important quantitative characters in *Gossypium hirsutum* L. *International Journal Agriculture Biology*, **2:** 121-124.

Ahmed, M.A., Noaman, H.M., Zahran, H.A. 2022. Combining ability estimation for yield and its components of sunflower inbred lines. *Egyptian Journal Chemistry*, **65:** 19-28.

Aleem, M.U., Sadaqat, H.A., Saif, U.M., Asif, M., Qasrani, S.A., Shabir, M.Z., Hussain, M.A. 2015. Estimation of gene action for achene yield in sunflower (*Helianthus annuus* L.). *American-Eurasian Journal Agriculture and Environment Science*, **15:** 727-732.

Andarkhor, S.A., Rameeh, V., Alitabar, A.R. 2013. Estimation of genetic parameters for yield components and seed yield in sunflower using line x tester analysis. *African Journal Biotechnology*, **12:** 3978-3983.

Andrakhor, S.A., Mastibege, N., Rameeh, V. 2012. Combining ability agronomic traits in sunflower using line x tester analysis. *International Journal of Biology*, **4:** 89-95.

Bhoite, K.D., Dubey, R.B., Vyas, M., Mundra, S. L., Ameta, K.D. 2018. Evaluation of combining ability and heterosis for seed yield in breeding lines of sunflower (Helianthus annuus L.) using line x tester analysis. *Journal of Pharmacognosy and Phytochemistry*, **7:** 1457-1464.

Binodh, A.K., Manivannan, N., Varman, P.V. 2008. Combining ability analysis for yield and its contributing characters in Sunflower (*Helianthus annuus* L.). *Madras Agriculture Journal*, **9:** 295-300.

Borde, S.R., Toprope, V.N., Sonawane, V.G., Thakur, N.R. 2017. Combining ability studies in maintainers lines in sunflower (*Hellianthus annuus* L.). *Journal of Research Angrau*, **45:** 1-6.

Chandra, B.S., Kumar, S.S., Rangantha, A.R.G., Dudhe, M.Y. 2011. Identification of restorers for diverse CMS sources in sunflower (*Helianthus annuus* L.). *Journal of Oilseeds Research*, **28:** 71-73.

Ciric, M., Jocic, S., Cvejic, S., Jockovic, M., Canak, P., Marinkovic R., M. Ivanovic, M. 2013. Combining abilities of new inbred lines of sunflower (*Helianthus annuus* L.). *Genetica*, **43:** 289-296.

Devaraj, N. 1996. Combining ability analysis in sesame (*Sesame indicum* L.). *M.Sc. Thesis*, University Agriculture Science, Bangalore, India.

Dudhe, M.Y., Moon, M.K., Lande, S.S. 2009. Evaluation of restorer lines for heterosis studies on sunflower (*Helliathus annuus* L.). *Journal of Oilseeds Research*, **46:** 140-144.

Farooq, M., Hussain, M., Siddique, K.H.M. 2014. Drought stress in wheat during flowering and grain-filling periods. *Critical Review of Plant Sciences*, **3:** 331-349.

Farrokhi, E., Khodabandeh, A., Ghaffari, M. 2008. Studies on general and specific combining abilities in sunflower. Breeding and Genetics: In: *Proceeding of 17th International Sunflower Conference Córdoba*, pp. 561-565, Spain.

Geeta, A., Suresh, J., Saidaiah, P. 2012. Study on response of sunflower (*Hellianthus annuus* L.) genotypes for root and yield character under water stress. *Current Biotica*, **6:** 32-41.

Ghaffari, M., Shariati, F. 2018. Combining ability of sunflower inbreed lines under drought stress. *Helia*, **41:** 201-212.

Ghaffari, M., Farrokhi, E. Mirzapour, M. 2011. Combining ability and gene action for agronomic traits and oil content in sunflower (*Helianthus annuus* L.) using F_1 hybrids. *Crop Breeding Journal*, **1:** 73-84.

Golabadi, M., Golkar, P., Shahsavari, M.R. 2015. Genetic analysis of agro-morphological traits in promising hybrids of sunflower (*Helianthus annuus* L.) *Actaagriculturae Slovenica*, **105:** 249-260.

Gomez, K.A., Gomez, A.A. 1984. *Statistical Procedures from Agricultural Research*, pp. 680, 2nd (ed.), John Wiley and Sons, Inc., New York., U.S.A.

Hladani, N., Skoric, D., Balalic, M.K., Jocic, S., Dusanic, N. 2011. Line x tester analysis for yield component in sunflower (*Helianthus annuus* L.). *Genetica*, **42:** 297-306.

Hussain, M.A., Bibi, A., Ali, I., Mahmood, T. 2017. Combining ability analysis through line x tester method for agronomic and yield related component in sunflower (*Hellianthus annuus* L.). *Journal of Agriculture Basic Sciences*, **2:** 63-69.

Imran, M., Malook, S.U., Qureshi, S.A., Nawaz, M.A., Shabaz, M.K., Asif, M., Ali, Q. 2015. Combining ability analysis for yield related traits in sunflower. *American-Eurasian Journal of Agriculture and Environmental Sciences*, **15:** 424-436.

Imran, M., Saif-ul-Malook, H.M., Ahamed, M.M., Abrar, A.S., Nazick, M.W., Anjum, M., Sarfaraz, M.K., Shahbaz, M., Ubaid-Ullah, M., Bibi, A. 2014. Combining ability analysis for yield and yield components in sunflower (*Helianthus annuus* L.). *International Archeology Applied Science Technology*, **3:** 13-21.

Inamullah, H.A., Mohammad, F., Sirajuddin, F., Hassan, G., Gul, R. 2006. Evaluation of the heterotic and heterobeltiotic potential of wheat genotypes for improved yield. *Pakistan Journal Botany*, **17:** 1159-1168.

Iqbal, A., Saif, R., Zafar, R., Khan, R.M., Mahmood, N., Hina, S. 2017. Exploiting the heterosis and heterobeltiosis of sunflower at plant maturity stage. *Global Journal Plant Breeding and Genetics*, **4:** 383-388.

Jan, M., Farhatullah, R., Hassan, G. 2005. Combining ability analysis in sunflower (*Helianthus annuus* L.). *Pakistan Journal Biology Science*, **11:** 710-713.

Kang, S.A., Khan, F.A., Ahsan, M.Z., Chatha, W.S., Saeed. F. 2013. Estimation of combining ability for the development of hybrid genotypes in (*Helianthus annuus* L.). *Journal of Biological Agriculture*, **3:** 68-74.

Kanwal, N., Sadaqata, H.A., Ali, Q., Ali, F., Bibic, I., Niazi, N.K. 2015. Breeding progress for morphology and genetic pattern in (*Helianthus annuus* L.). *Life Science Journal*, **21:** 49-56.

Karasu, A.M., Oz, M., Sicik, M., Goksoy, A.T., Turan, Z.M. 2010. Combining ability and heterosis for yield and yield component in sunflower. *Notule Botaniceae Hortiagrobotane Cluj*, **38:** 259-264.

Kaya, Y. Atakisi, I.K. 2004. Combining ability analysis of some yield characters of sunflower (*Helianthus annuus* L.). *Helia*, **27:** 75-84.

Kaya, Y. 2014. Alien Gene Transfer in Crop Plants, In: *Rapid Achievements and Impacts*, A. Pratap. (ed), Vol. **2**, pp. 281-315, Springer Press, USA.

Kempthorne, O. 1957. *An Introduction to Genetic Statistics*, pp. 468-473, John Wiley and Sons, Inc. New York, USA.

Khan, S., Choudhary, S., Pandey, A., Khan, M.K., Thomas, G. 2015. Efficient oil source for human consumption. *Emergent Life Sciences Research*, **1:** 1-3.

Khan, S.A., Ahmed, H., Khan, A., Saeed, M., Khan, S.M., Ahmed, B. 2009. Using line x tester analysis for earliness and plant height traits in sunflowers (*Hellianthus annuus* L.). *Recent Research in Science and Technology*, **1:** 202-206.

Kholghi, M., Maleki, H.H., R. Darvishzadeh. R. 2014. Diallel analysis of yield and its related traits in sunflower (*Helianthus annuus* L.) under well-watered and water- stressed conditions. *Agriculturae Conspectus Scientificus*, **79:** 175-181.

Kinman, M.L. 1975. Studies on some features of oil sunflower and their significance in breeding in Poland. Hodowla Rosl. *Aklim Nasienn*, **19:** 89-131.

Machikowa, T., Saetang, C., Funpeng, K. 2011. General and specific combining ability for quantitative characters in sunflower. *Journal Agriculture of Science*, **4:** 91-95.

Manivaran, N., Ganesan, J. 2001. Line x tester analysis in sesame (*Sesamum indicum* L.). *Indian Journal Agriculture Research*, **35:** 90-94.

Marinkovic, R., Skoric, D., Dozet, B., Jovanovic, D. 2017. Line x tester analysis of the combining ability in sunflower. *Helia*, **34:** 79-88.

Meena, H.P., Sujatha, M., Varaprasad, K.S. 2013. Achievements and bottlenecks of heterosis breeding of sunflower (*Helianthus annuus* L.) in India. *Indian Journal of Genetic*, **73:** 123-130.

Memon, S., Baloch, M.J., Baloch, G.M., Jatoi, W.A. 2015. Combining ability through line x tester analysis for phenological, seed yield and oil traits in sunflower (*Helianthus annuus* L.). *Euphytica*, **204:** 199-209.

Memon, S., Baloch, M.J., Baloch, G.M., Kerrio, M. I. 2015. Heterotic effect in F_1s and inbreeding 1 depression in F_2 hybrids of sunflower. *Pakistan Journal Scientific and Industries Research (Biological Science)*, **58:** 1-10.

Memon, S., Baloch, M.J., Baloch, G.M., Kerrio, M.I. 2014. Heritability and correlation studies for phenological seed yield and oil traits in sunflower. *Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences*, **30:** 159-171.

Mirarab, M., Ahmadikhah, M. 2010. Study on genetics of some important phonological traits in rice using line x tester. Scholars of research library. *Annals of Biology Research*, **1:** 119-125.

Mohanasundaram, K., Manivannan, N., Varman, P.V. 2010. Combining ability analysis for seed yield and its components in Sunflower (*Helianthus annuus* L.). *Electronic Journal Plant Breeding*, **1:** 864-868.

Mustafa, W., Tarique, K., Zafar, H., Affan, Q.H., Rafique, M., Khan, M.I., Ashraf, W., Asghar, M. 2023. Combining ability analysis for various morphological traits sunflower (*Helianthus annuus* L.). *Biological and Clinical Sciences Research Journal*, **183:** 1-6.

Nasreen, S., Ishaque, M., Khan, M.A., Din, S.U., Gillani, S.M. 2014. Combining ability analysis for seed protein, oil content and fatty acids composition in sunflower (*Hellianthus annuus* L.). *Pakistan Journal Agriculture Research*, **27:** 174-187.

Parameswari, C., Muralidharan, V., Subbalakshmi, B. 2004. Genetic analysis of yield and important traits in sunflower hybrids. *Journal Oil Seeds Research*,

21: 168-170.

Rameeh, V., Andarkhor, S.A. 2017. Line × tester analysis for duration of flowering, yield components and seed yield in sunflower (*Helianthus annuus* L.). *Helia*, **40:** 61-70.

Rauf, S. 2008. Breeding sunflower *(Hellianthus annuus* L.) for drought tolerance. *Communication in Biometry and Crop. Science*, **3:** 29-44.

Rauf, S., Jamil, N., Tariq, S.A., Khan, M., Kausar, M. 2016. Progress in modification of 12 sunflower oil to expand its industrial value. *Journal of the Science Food and Agriculture*, **97:** 17-25.

Razzaq, H., Tahir, N.H.M., Sadaqat, H.A. Sadia, B. 2017. Screening of sunflower accessions under drought stress condition, an experimental assay. *Journal Soil Science and Plant Nutrition*, **17:** 262-271.

Rizwan, M.H., Sadaqat, A., Iqbal, M.A., Awan, F.S. 2020. Genetic assessment and combining ability analysis of achene yield and oil quality traits in (*Hellianthus annuus* L.) hybrids. *Pakistan Journal Agriculture Science*, **57:** 101-108.

Saleem, U, Khan, M.A., Gull, S., Usman, K., Saleem, F. Y., Sayal, O.U. 2014. Line × tester analysis of yield and yield related attributes in different sunflower genotypes. *Pakistan Journal Botany*, **46:** 659-665.

Saif, R., Iqbal, A., Bibi, A., Ahmed, N. 2023. Genetic analysis of earliness, yield, oil quality-related traits and DNA-based hybrid authentication in sunflower. *SABRAO Journal of Breeding and Genetics*, **55:** 329-343.

Sakthivel, K. 2003. Line x tester analysis for combining ability in kharif sunflower (*Helianthus annuus* L.). *Journal Eco Biology*, **15:** 299-303.

Shabbir, R.N., Waraich, E.A., Ali, H., Nawaz, F., Ashraf, M.Y., Ahmad, R., Awan, M.I.S., Ahmad, S., Iran, M., Hussain, S., Ahmad, Z. 2016. Supplemental exogenous NPK application alters biochemical processes to improve yield and drought tolerance in wheat (*Triti cumaestivum* L.). *Environment Science Pollution Research*, **23:** 2651-2662.

Shamshad, M., Dhillon, S.K., Kaur, G. 2016. Heterosis for oil content and oil quality in sunflower (*Helianthus annuus* L.). *Current Advisory Agriculture Science*, **8:** 44-48.

Shinde, S.R., Sapkale, R.B., Pawar, R.M. 2016. Combining ability analysis for yield and its components in sunflower (*Helianthus annuus* L.). *International Journal of Agriculture Science*, **12:** 51-55.

Singh, R.K., Choudhry, B.D. 1984. *Biometrical in quantitive genetics Analysis*, 318 pp., Kalyani Publisher, New Delhi, India.

Skoric, D., Jocic, S., Hladni, N., Vannozzi, G.P. 2007. An analysis of heterotic potential for agronomic important traits in sunflower (*Helianthus annuus* L.). *Helia*, **30:** 55-74.

Skoric, D., Seiler, G.J., Zhao, L., Chao-Chien, J., Miller, J.F., Charlet, L.D. 2012. Sunflower genetics and breeding. International Monography Serbian Acad. *Science Arts, Branch in Novi Sad*, **3:** 1-20.

Tabrizi, M., Hassanzadeh, F., Moghaddam, M., Alavikia, S., Aharizad, S., Ghaffari, M. 2012. Combining ability and gene action in sunflower using line x tester method. *Journal Plant Physiology Breeding*, **2:** 35-44.

Tan, A.S. 2010. Study on the determination of combining abilities of inbred lines for hybrid breeding using line × tester analysis in sunflower (*Helianthus annuus* L.). *Helia*, **33:** 131-148.

Thakare, V.V., Parde, S.B., Pande, M.K., P.S. Lahaneand, P.S., Peshattiwar, P.D. 1999. Combining ability studies in sesamum. *Journal Maharashtra Agriculture University*, **3:** 256-259.

Thorat, A.W., Vaidya, E.R., Gupta, V.R., Bharsakal, S.P., Mohod, V. 2016 Combining ability and gene action studies for yield and its component in sunflower (*Helianthus annuus* L.). *International Journal Current Microbiology Applied Science*, **6:** 598-605.

Tyagi, V., Dhillon, S.K., Kaushik, P., Kaur, G. 2018. Characterization for drought tolerance and physiological efficiency in novel cytoplasmic male sterile sources of sunflower (*Hellianthus annuus* L.). *Journal of Agronomy*, **8:** 02-20.

Tyagi, V., Dhillon, S.K. 2016. Cytoplasmic effects on combining ability for agronomic traits in sunflower under different irrigation regimes. *SABRAO Journal of Breeding and Genetics*, **48:** 295-308.

USDA. 2023. U.S. Department of Agriculture, Economic Research Service. Food Price Outlook Data, Retried January 29, 2025 from http://www.ers.usda.gov.

Vikas, K., Shankegoud, I. Govindappa, M.R. 2015 Evaluation and characterization of sunflower germplasm accessions for quantitative characters. *Electronic Journal of Plant Breeding*, **6:** 257-263.

Vukich, M., Schulman, A.H., Giordani, T., Natali, L., Kalendar, R., Cavallini, A. 2009. Genetic variability in sunflower (*Helianthus annuus* L.) and in the *Helianthus* genus as assessed by retro-transposon-based molecular markers. *Theoretical and Applied Genetics*, **119:** 1027-1038.

Yankov, B., Tahsin. N.T. 2015. Genetic variability and correlation studies in some drought-resistant sunflower (*Helianthus annuus* L.) genotypes. *Journal of Central European Agriculture*, **16:** 212-220.

Zakhidov, E., Nematov, S., Kuvondikov, V. 2016 Monitoring of the drought tolerance of various cotton genotypes using chlorophyll fluorescence. *Applied Photosynthesis*, 91-110.

Zia, Z., Sadaqat, H.A., Tahir, M.H.N., Sadia, B. 2013. Correlation and path coefficient analysis of various traits in sunflower (*Helianthus annuus* L.). *Journal Global Innovation Agriculture Society Science*, **3:** 5-8.