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HETEROTIC EFFECTS IN SUNFLOWER HYBRIDS FOR EARLINESS AND YIELD TRAITS UNDER WELL-WATERED AND STRESSED CONDITIONS

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SUMMARY

The climate is continuously changing, consequently increasing the drought-affected areas. As such, it challenges breeders to develop adaptive and drought-tolerant sunflower (*Helianthus annuus* L.) cultivars through evaluation and inducing genes tolerant to drought. Hence, the recent study aimed to assess the sunflower hybrids during 2019–2020 under well-watered and stressed conditions in a split-plot design with four replications at the Sindh Agriculture University, Tandojam, Pakistan. The observed data determined heterotic effects among 15 F_1 hybrids for days to 75% flowering, days to 75% maturity, stem diameter, head diameter, biological yield plant^{-1}, seeds head^{-1}, seed index, and seed yield plant^{-1}. The mean squares due to genotypes, treatments, and genotype by treatment were significant for all the traits, which exhibited that genotypes performed significantly across the environments for the above-cited traits. The F_1 hybrids, such as, Mehran × Pehawar-93, gave maximum negative heterotic effects for phonological traits which will benefit the development of short-duration sunflower hybrids. Further, F_1 hybrids like Thatta × UC-666 displayed higher heterotic effects for head diameter, stem diameter, number of seeds plant^{-1}, seed index, and biological plant^{-1} and PSF-025 × B2 and HO.1 × B2 gave higher heterotic effects for the number of seeds head^{-1} and seed yield plant^{-1} under stress environment.

Keywords: Sunflower (*Helianthus annuus* L.), split-plot design, well-watered and stressed-conditions, heterosis, heterobeltiosis, yield-related traits

Key findings: Four sunflower (*Helianthus annuus* L.) hybrids, Mehran × Peshawar-93, Thatta × UC-666, PSF 025 × B-2, and HO-1 × B-2 showed promising that could benefit future breeding programs for hybrid crop development.

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INTRODUCTION

Drought is one of the most severe environmental causes that reduce sunflower (*Helianthus annuus* L.) and other crops' yields. Drought stress requires understanding the nature of phenotypic traits that can recover their performance under water stress conditions and the complicated physiological and genetic mechanisms involved under stress conditions (Tyagi and Dhillon, 2016; Dudhe *et al*., 2017). In that context, one of the most focal objectives of plant breeders is to improve drought tolerance and water productivity in plants for such areas. Focusing on morphological, physiological, genetic, and molecular pathways that influence drought tolerance can help to evolve drought-tolerant cultivars for their cultivation in arid and semi-arid environments (Saremi-Rad and Mostafavi*,* 2020). Drought stress is also one of the harshest ecological factors that reduce crops' yields, particularly sunflower. Therefore, it is essential to recognize the subtle physiological and genetic mechanisms that increase the performance of sunflowers under water stress and contemplate the nature of phenotypic characteristics that escalate the performance under stress scenarios (Mohan and Seetharam, 2005; Geetha *et al*., 2012).

Soon, one of the central issues plant breeders foresee is to expand drought tolerance in crop plants and simultaneously increase water use efficiency in plants (Saremi-Rad and Mostafavi*,* 2020). By nature and from the genetic point of view, sunflower is a drought-prone field crop (Tyagi *et al*., 2018). Droughts are anticipated to become more severe in the coming years because of climate change. As an oilseed crop, sunflower is becoming widespread, accounting for around 87% of global vegetable oil production (Razzaq *et al.,* 2017). The lack of sufficient water supply becomes a critical issue that often affects plant progression and development. Given these facts, drought may cause a significant but adverse impact on food production. Water scarcity is a critical abiotic stress that leads to low yield in almost all crop plants, particularly in arid and semi-arid regions worldwide (Viscardi *et al.,* 2016). The yield fatalities owing to water shortage are very drastic in sunflowers (Kaya *et al.,* 2016; Prasad *et al*., 2008).

A prediction stated water stress at grain filling causes about 80% yield damages (Pekcan *et al.,* 2015). Heterosis is an increase or decrease in the F_1 hybrids' vigor compared with their mid- or better parental value. One of the objectives of such a study was to determine the extent of heterosis for various attributes and to identify prospective hybrids for hybrid seed production and oil content over typical check hybrids for commercial exploitation (Lakshman *et al.,* 2020). For this reason, sunflower breeding efforts primarily focused on enhancing heterosis, which has been shown as a viable tool for producing highly productive sunflower hybrids with superior agronomic features evolved from genetically diverse parents (Tyagi *et al.*, 2018). Until now, there have been little efforts to select diversified superior inbred to obtain a higher level of heterosis over check hybrids, but the discovery of cytoplasmic male sterility in sunflowers provided a breakthrough in heterosis breeding (Kanwal *et al.,* 2015) and hybrid superiority in F_1 hybrids and its commercial application to adopt it has brought sunflower as one of the world's most vital oil seed crop (Encheva *et al.,* 2015), which is a highly cross-pollinated and perfect field crop for exploring heterosis. One of the practical uses of CMS research is the generation of CMS equivalent to B lines utilized in the breeding of sunflower hybrid development (Tyagi *et al.,* 2018), and as a result, growers will get a higher quantity of seeds and oil yields and improved uniformity by manipulating heterosis for hybrid expansion (Bohra *et al.*, 2016).

Heterosis is a phenomenon with an advantage of F_1 hybrids over their inbred cross-breeding and is linked closely to genetic differences across parental lines (Imran *et al.*, 2015). The main objective of evolving an ideal hybrid is to find out parents that possess desired genes to create better F_1 hybrids. To adopt F_1 sunflower hybrids as an oilseed crop, hybrid vigor maintain its dynamic strength with short duration, stability in performance, consistency in plant height, uniformity in the stand, larger capitulum, more seeds per capitulum, higher production, oil and protein contents, lodging, insect pest, and diseases resistance, with this altogether contribute to the development of an optimal sunflower hybrid plant structure (Imran *et al.*, 2015; Memon *et al.,* 2015). Previous observations revealed that sunflower hybrids have a high degree of heterosis and are more vigorous, self-fertile, high yielding, and resistant to foliar diseases than regular sunflower varieties (Khan *et al.,* 2015). Regarding this type of information, using morpho-agronomic traits quantified the genetic divergence of sunflower crops in several studies (Sujatha and Nadal, 2013). One of the most yield-limiting problems is the lack of quality seeds of locally adopted hybrids; however, acquiring this in sunflowers can primarily be via single-cross hybrids created by mating cytoplasmic male sterile inbred lines with fertility-restoring males (Hladni *et al.,* 2011). Although, numerous researchers have recorded high expression of heterotic effects toward yield and oil traits (Aslam *et al.,* 2010; Chahal *et al.*, 2019). High heterotic estimates obtained for yield compared with the parental average were 18.3% to 72.38%, with the heterobeltiosis 2.86% to 56.842% (Ahmed *et al.,* 2021). Several other researchers, like Depar *et al.* (2017), Khan *et al.* (2019), Lakshman *et al.* (2020), and Memon *et al.* (2015), reported positive high parent heterosis for yield (kg ha^{-1}). The line × tester analysis is a valuable tool for assessing a vast number of inbreds to determine their GCA and SCA effects; thus, such mating design helps determine the genetic architecture of vital traits (Naseem *et al.*, 2015). The presented study aimed to assess heterosis over mid- and better-parents in sunflower F_1 hybrids for earliness, morphological, and yield-related traits.

MATERIALS AND METHODS

The experiment on sunflower (*Helianthus annuus* L.) transpired during 2020–2021 at the Botanical Garden of Sindh Agriculture University, Tandojam, Pakistan. The water regime, regarded as the most vital component, was a main factor. Irrigation regimes with no water stress (well-watered) received frequent irrigations, with a total of five irrigations applied. Inversely, water-stress treatment received mild to severe stress imposed on 50-day-old plants near flower buds until seed formation, i.e., 80-day-old plants withheld with water for 30 days. The fixed space between plants and rows was 25 and 60 cm, respectively. Words like well-watered, optimum irrigation, normal irrigation, and no water stress were interchangeable, whereas for water-stressed treatment, drought stress, water stress, and water-stress environment were exchangeable in this article. During the autumn of the first year, five sunflower lines and three tester parents who performed better in the screening experiment gained selection for crossing and genetic analysis. The seeds of eight sunflower parents, including five lines, i.e., HO-1, Mehran, Thatta, PSF-025, and SH-3915 and three testers, i.e., UC-666, Peshawar-93, B-2, and their 15 F_1 hybrids, were well-stored for further studies. The third experiment comprised assessing the ability of CMS lines to combine with restorer testers and their F_1 hybrids in a split-plot design with two treatments in four replications. The traits recorded were for days to 75% flowering, days to 75% maturity, stem diameter (cm), head diameter (cm), biological yield $plant^{-1}$ (g), seeds $head^{-1}$, seed index (1000 achene weight, g), and seed yield $plant^{-1}$ (g).

Statistical analysis

The acquired data underwent analysis of variance (ANOVA) using the split-plot design by Gomez and Gomez (1984), with heterosis calculated by Fehr's method (1987).

RESULTS AND DISCUSSION

The variances from ANOVA showed significant differences between the genotypes, parents, hybrids, and parent *vs*. hybrids, indicating the existence of substantial variability in the mean squares of the earlier-mentioned breeding material (Table 1). The ANOVA also revealed significant differences among all traits' lines, excluding grain yield in well-watered and head

Table 1. Analysis of variance of sunflower F_1 hybrids for yield and quality parameters grown under well-watered and water-stressed environments.

Characters	Mean squares					
	Replication (R)	Treatment (T)	Error (a)	Genotypes (G)	T × G	Error (b)
Degree of freedom (d.f.)	3	1	3	22	22	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
Biological yield plant^{-1}	177.00	156944.00**	154.00	6626.00**	1943.00**	46.00
Seeds head^{-1}	1782.00		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^{-1}	4.89	4643.10**	6.10	491.11**	16.95**	2.61

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

diameter in water-stressed conditions (Table 1). Study results are in harmony with the outcomes of Chandra *et al.* (2011), Andarkhor *et al.* (2013), Ciric *et al.* (2013), and Kang *et al.* (2013). Likewise, testers presented considerable variation for all the traits, excluding head diameter in non-stress conditions and highly significant differences for all characters in water-stress environments. Substantial differences also emerged in all the attributes by line × tester interaction in non-stress environments (Table 1). The variances among the lines were better in stress than in normal conditions for days to 75% flowering, head diameter, number of seeds head^{-1}, seed index, and seed and biological yield plant^{-1}. For other traits, eventually, lines showed fewer variances.

The results revealed the existence of substantial genetic variability in newly evolved breeding material. Tyagi and Dhillon (2016), from their analysis of variance, reported significant differences in traits like plant height, head diameter, 1000-seed weight, seed yield plant^{-1}, and oil content under non-stress and water-stress environments. Considerable differences for lines vs. testers and lines and testers appeared for whole traits studied under well-watered and water-stressed conditions. Analogous to these findings, Ghafari and Shariati (2018) indicated that the mean squares due to parents, crosses, and parents vs. crosses were significant for seed yield plant^{-1} and most attributes except for 50% flowering days, yet, lines, testers, and line × tester were substantial 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 beneficial for sunflower breeding programs.

Days to 75% flowering

The desired negative parental average heterosis values extended from -0.44% to -13.54%, and recordings of the desired heterobeltiosis were from -0.52% to -16.95% and -0.81% to -16.97% in non-stress and stress environments (Table 2). Based on heterosis estimates, the F_1 hybrids, such as, HO-1 × B-2, PSF-025 × B-2, and Mehran × Peshawar-93, were the most desirable hybrids by expressing high mid-parent heterosis (MPH) in well-watered and moisture-stressed conditions (Table 2). Regarding heterobeltiosis, hybrids like Mehran × UC-666, HO-1 × B-2, and Mehran × Peshawar-93 exhibited maximum desirable negative values for days to 75% flowering under both environments. The above results indicated establishing at least two hybrids like HO-1 × B-2 and Mehran × Peshawar-93 that expressed the uppermost desirable parental average heterosis and better parent heterosis (BPH) in both the irrigation conditions among 15 attempted crosses, then evaluated. The presented research perceived

Table 2. Heterosis in sunflower F_1 hybrids for days to 75% flowering grown under well-watered and water-stressed environments.

F_1 hybrids	Days to 75% flowering			
	Well watered		Water stressed	
	M.P. (%)	B.P. (%)	M.P. (%)	B.P. (%)
HO.1 × UC-666	23.89	14.84	20.93	13.76
Mehran × UC-666	-5.54	-16.95	-5.93	-16.97
Thatta × UC-666	-0.44	-4.02	1.68	-0.81
PSF-025 × UC-666	-0.54	-9.06	-2.24	-9.60
SH-3915 × UC-666	7.63	1.68	5.47	-1.13
HO.1 × Peshawar-93	17.90	17.02	18.97	16.91
Mehran × Peshawar-93	-8.00	-12.53	-11.53	-15.98
Thatta × Peshawar-93	9.16	4.06	12.98	7.04
PSF-025 × Peshawar-93	-7.78	-8.46	-6.79	-6.87
SH-3915 × Peshawar-93	2.26	-0.52	-1.26	-2.60
HO.1 × B-2	-13.54	-16.50	-5.87	-10.10
Mehran × B-2	-6.93	-9.09	-5.12	-7.29
Thatta × B-2	5.18	-2.33	6.18	-2.11
PSF-025 × B-2	-10.73	-12.52	-11.00	-13.48
SH-3915 × B-2	-1.49	-6.70	-1.48	-5.57

M.P. = Mid parent heterosis, B.P. = Better parent heterosis.

positive and deleterious heterosis for 75% number of flowering days, which is similar to Habib *et al.* (2007), recognizing the highest desirable heterosis and heterobeltiosis in crossed ORI-6 × RL-69 and ORI-6 × RL-77 flower initiation days. They also noted that the combination ORI-20 × RL-77 showed the highest increases over mid and better parent for the flowering period. Equivalent to present outcomes, Memon *et al.* (2015) observed that hybrid HO-1 × PAC-64-A manifested desired negative parental average heterosis and heterobeltiotic effects for preliminary blooming and maturity.

Negative heterosis for the blooming period is the validation of early maturity, even as positive estimates accentuate that hybrids will cause a delay in harvest. Gowtham (2006) established that a great figure of hybrids created negative heterosis in blooming and maturity. Opposite to latest outcomes, Jarwar *et al.* (2004) reported positive average parental heterosis for flowering and 100% maturity days. There was positive and negative heterosis for this trait in various crosses; nevertheless, the majority of parental average and BPH for flowering and maturity period was negative, which showed the earlier maturity of the hybrids against respective parentages (Haddadan *et al.*, 2020).

Days to 75% maturity

Negative heterosis is deemed valuable for 75% of maturity days. When some other crops (rice and cotton) follow sunflower, growers become concern about growing early maturing hybrids to vacate the field for the said crops (Saleem-Uddin *et al.*, 2014). The 75% flowering and 75% maturity revealed overall negative parental average and high parent heterosis, which indicated F_1 hybrids are achievable for higher yield production with early maturity. The results concerning the heterosis in 75% maturity revealed that seven F_1 hybrids gave negative parental average heterosis under well watered, and 10 hybrids exhibited negative relative heterosis in water-stress conditions (Table 3). Among the F_1s, Mehran × Peshawar-93 gave maximum undesirable relative heterotic effects, followed by the PSF-025 × B-2 and PFS-025 × Peshawar-93 in non-stress conditions. Meanwhile, in stress conditions, the F_1 hybrids HO.1 × B-2, Mehran × Peshawar-93, and PSF-025 × B-2 gave negative MPH.

Table 3. Heterosis in sunflower F_1 hybrids for days to 75% maturity grown under well-watered and water-stressed environments.

F_1 hybrids	Days to 75% Maturity			
	Well watered		Water stressed	
	M.P. (%)	B.P. (%)	M.P. (%)	B.P. (%)
HO.1 × UC-666	11.33	8.18	9.55	5.84
Mehran × UC-666	-4.36	-10.44	-4.25	-10.34
Thatta × UC-666	-1.88	-3.17	-2.75	-4.01
PSF-025 × UC-666	1.80	-2.07	-1.05	-4.82
SH-3915 × UC-666	3.17	0.09	1.45	-1.38
HO.1 × Peshawar-93	10.10	9.68	8.01	7.10
Mehran × Peshawar-93	-5.77	-8.96	-8.66	-10.85
Thatta × Peshawar-93	4.72	2.71	2.48	-0.53
PSF-025 × Peshawar-93	-4.65	-5.26	-6.76	-7.13
SH-3915 × Peshawar-93	-1.67	-1.87	-2.33	-3.75
HO.1 × B-2	0.00	-1.94	-10.30	-12.78
Mehran × B-2	-1.78	-3.60	-3.96	-4.40
Thatta × B-2	2.20	-1.31	1.44	-3.41
PSF-025 × B-2	-4.77	-5.65	-8.50	-10.63
SH-3915 × B-2	8.18	6.24	-1.44	-4.74

M.P. = Mid parent heterosis, B.P. = Better parent heterosis.

The negative MPH varied in normal and water stress from -1.67% to -5.77% and -1.05% to -10.30%, respectively. A similar range for BPH in non-stress and drought stress was recorded.

The crosses, such as, Mehran × UC-666, followed by Mehran × Peshawar-93, produced the highest negative heterobeltiosis in non-stress, and HO-1 × B-2 and Mehran × Peshawar-93 exhibited BPH in stress conditions (Table 3). The positive heterosis in days to maturity is undesirable in the sense that such hybrids will take more days to harvest and may delay the cultivation of other crops. In contrast, negative heterosis means those hybrids will take fewer days to maturity. Two hybrids, like Mehran × UC-666, followed Mehran × Peshawar-93, which manifested higher yet desirable negative relative heterosis and heterobeltiosis in both environments. In agreement with these outcomes, Kant and Srivastava (2012) also documented significantly desirable negative inbreeding depression for 50% blooming and maturity days.

Stem diameter

Stem thickness is a very appropriate agronomic trait that provides toughness to plants to tolerate overwhelming adverse atmospheres and offers resistance to lodging. The heterotic effects regarding stem diameter in Table 4 indicated that 13 F_1 hybrids expressed essential relative heterosis in stress and non-stress conditions. The range of relative heterosis was 13.30% to 97.26% and 5.51% to 116.71 in both environments, respectively. The same range for BPH was 0.43% to 91.08% in no stress and 4.76% to 112.12% in drought stress. The F_1 hybrids, such as, Thatta × UC-666, PSF-025 × B-2, and HO-1 × B-2 were the most desired hybrids, which expressed high relative heterosis of 97.26% and 116.71%, 96.56% and 97.33%, and 81.26% and 51.87%, respectively, in non-stress and water stress.

The F_1 hybrids HO-1 × B-2 gave maximum BPH, followed by Thatta × UC-666 and PSF-025 × B-2 in non-stress conditions. Under a stress environment, the F_1 hybrids, such as, Thatta × UC-666, recorded the highest heterobeltiosis, followed by PSF-025 × B-2 and HO-1 × UC-666 for stem diameter. The two high-performing hybrids, like PSF-025 × B-2 and Thatta × UC-666, came from crosses that involved the inbred with high × high and low × high GCA parents, indicating that additive and complementary genes

Table 4. Heterosis in sunflower F_1 hybrids for stem diameter grown under well-watered and water-stressed environments.

F_1 hybrids	Stem diameter			
	Well watered		Water stressed	
	M.P. (%)	B.P. (%)	M.P. (%)	B.P. (%)
HO.1 × UC-666	46.82	34.39	56.12	53.16
Mehran × UC-666	17.81	6.89	28.19	10.55
Thatta × UC-666	97.26	90.47	116.71	112.12
PSF-025 × UC-666	23.22	11.58	12.32	-0.96
SH-3915 × UC-666	15.24	12.62	22.28	16.66
HO.1 × Peshawar-93	27.97	7.86	23.36	5.09
Mehran × Peshawar-93	38.82	37.93	42.85	42.20
Thatta × Peshawar-93	13.58	0.43	5.51	-6.94
PSF-025 × Peshawar-93	-4.76	-5.57	-9.21	-11.11
SH-3915 × Peshawar-93	-2.10	-8.73	-1.02	-10.64
HO.1 × B-2	81.26	91.08	51.87	44.64
Mehran × B-2	13.30	-0.86	9.32	-3.21
Thatta × B-2	26.28	25.56	5.70	4.76
PSF-025 × B-2	96.56	71.67	97.33	78.74
SH-3915 × B-2	50.53	41.41	11.11	9.19

M.P. = Mid parent heterosis, B.P. = Better parent heterosis.

influenced the maximum expression of heterosis in stem diameter, respectively. Aligning to these outcomes, Habib *et al.* (2006) found that hybrids ORI-3 × RL- 77 and ORI-3 × RL-84 displayed higher affirmative relative heterosis and heterobeltiosis for stem diameter. Haddadan *et al.* (2020), while evaluating 18 F_1 hybrids for heterosis, observed expression of positive MPH ranging up to 33.0% and BPH up to 47.8%. The close association of stem thickness of F_1 hybrids with BPH and MPH indicated the heterotic manifestation above character (Tabrizi *et al.*, 2012). The hybrids with a thick stem may be worthwhile for lodging resistance.

Head diameter

The capitulum size directly involved higher yield production in sunflowers, as larger heads consequently increase achene's seed yield and oil quantity (Table 5). Regarding the heterotic effects concerning head diameter, the results revealed that except for only one hybrid, 14 F_1s exhibited desirable positive relative heterosis in both non-stress and drought-stressed conditions. Similarly, 13 hybrids in non-stress and 12 under stress conditions showed positive better parent heterobeltiosis. The array of relative positive heterosis under stress varied from 3.43% to 52.34%, and a similar range for BPH was 0.14% to 50.57% (Table 5). Hybrids like Thatta × UC-666 and HO-1 × B-2 were among the top two for parental average and high parent heterosis, respectively, in regular irrigation. Likewise, in a stressful environment, the crosses, HO-1 × B-2, Thatta × UC-666, and PSF-025 × B-2, gave maximum MPH for this character.

Relating to high parent heterosis, hybrids like Thatta × UC-666 and HO-1 × B-2 recorded maximum positive heterosis in a stress environment. The two best hybrids that manifested high mid- and better parent heterosis in normal and adverse environments resulted from crossing good × good and good × poor GCA parents, respectively. It suggests that additive and complementary genes were accountable for high heterosis manifestation in both the hybrids. The helpful heterosis extended from 28% to 60% for head size (Karasu *et al.,* 2010). Analogous to study findings, substantial hybrids expressed negative heterosis, yet positive heterosis was also prominent. Haddadan *et al.* (2020) reported the 18 crossbreeds assessed all

Table 5. Heterosis in sunflower F_1 hybrids for head diameter grown under well-watered and water-stressed environments.

F_1 hybrids	Head diameter			
	Well watered		Water stressed	
	M.P. (%)	B.P. (%)	M.P. (%)	B.P. (%)
HO.1 × UC-666	34.99	34.99	28.49	26.15
Mehran × UC-666	13.62	3.10	12.77	2.72
Thatta × UC-666	63.39	61.03	51.44	50.57
PSF-025 × UC-666	29.03	17.80	5.90	-1.28
SH-3915 × UC-666	27.31	23.82	11.75	8.77
HO.1 × Peshawar-93	17.61	9.24	18.26	9.15
Mehran × Peshawar-93	37.21	33.78	29.30	25.17
Thatta × Peshawar-93	12.23	5.68	9.00	2.90
PSF-025 × Peshawar-93	-5.79	-7.53	-4.68	-5.43
SH-3915 × Peshawar-93	4.10	-0.71	3.92	0.14
HO.1 × B-2	49.91	45.93	52.34	47.76
Mehran × B-2	13.34	0.40	3.43	-9.79
Thatta × B-2	21.47	16.58	22.45	16.03
PSF-025 × B-2	44.50	28.76	46.06	30.18
SH-3915 × B-2	13.81	7.83	14.26	6.11

M.P. = Mid parent heterosis, B.P. = Better parent heterosis.

showed positive MPH up to 33.7%, with some negative BPH observed, yet the positive BPH was up to 40.7%.

Biological yield per plant

Sizable F_1 hybrids manifested negative relative or high parent heterosis in water-stressed or drought-stressed environments. Nevertheless, the highest heterosis resulted with PSF-025 × B-2 for both MPH and BPH, with HO.1 × B-2 giving the next high score for relative and heterobeltiosis, yet, Mehran × Peshawar-93 came as third for only relative heterosis in normal conditions (Table 6). Very interestingly, quite a few numbers of hybrids produced positive heterotic effects in water-stress environment; nonetheless, the maximum relative heterosis and heterobeltiosis appeared with Thatta × B-2, followed by PSF-025 × B-2 for biological yield plant^{-1} (Table 9).

Both good hybrids Thatta × B-2, followed by PSF-025 × B-2, by expressing high heterosis, involved both the inbreds with good × good GCA parents, revealing that additive × additive interaction of genes was responsible for the manifestation of high heterosis. Thus, developing potential hybrids or selecting single plants with desirable biological yield could come from early filial generations. Tyagi *et al.* (2018) noted CMS-234A and CMS-PRUN-29A (48.11 and 31.44) as significantly good general combiners with additive genes for biological yield plant^{-1} under regular irrigation and water-stress conditions. Ahmed *et al.* (2021) stated supremacy of A5 and A7 inbreds in seed yield and other related traits is attributable to improved biomass production.

Seeds per head

The quantity of seeds plant^{-1} is a leading parameter that unswervingly affects seed yield plant^{-1}. The results from the recent research, presented in Table 7, indicated that the number of seeds head^{-1} showed a rational extent of heterosis in specific crosses under well-watered and moisture shortage environments. From 15 crosses evaluated, 13 hybrids expressed positive relative heterosis, with 12 manifesting BPH under a normal irrigation regime. Concerning stress conditions, 10 crosses showed positive relative heterosis, while nine exhibited BPH. The positive parental average heterosis varied from 5.19% to 54.82% and positive BPH fluctuated from 5.35% to 49.11% in optimal irrigation. Likewise, the relative positive heterosis

Table 6. Heterosis in sunflower F_1 hybrids for biological yield per plant grown under well-watered and water-stressed environments.

F_1 hybrids	Biological yield plant^{-1}			
	Well watered		Water stressed	
	M.P. (%)	B.P. (%)	M.P. (%)	B.P. (%)
HO.1 × UC-666	-14.63	-18.04	16.88	14.70
Mehran × UC-666	-22.57	-22.83	-2.30	-12.57
Thatta × UC-666	-0.87	-2.65	37.06	32.41
PSF-025 × UC-666	-18.57	-19.74	-7.82	-18.33
SH-3915 × UC-666	-14.45	-18.80	19.07	17.56
HO.1 × Peshawar-93	-17.78	-23.41	8.77	0.18
Mehran × Peshawar-93	0.77	-2.04	22.62	16.66
Thatta × Peshawar-93	-24.50	-28.13	-1.94	-4.97
PSF-025 × Peshawar-93	-23.24	-24.57	-15.33	-20.31
SH-3915 × Peshawar-93	-13.96	-0.20	-6.70	-11.48
HO.1 × B-2	6.38	0.09	35.95	23.11
Mehran × B-2	-13.20	-14.74	-13.54	-16.25
Thatta × B-2	-7.94	-11.46	54.76	47.33
PSF-025 × B-2	11.77	11.01	46.89	40.72
SH-3915 × B-2	-9.04	-15.37	-11.97	-17.93

M.P. = Mid parent heterosis, B.P. = Better parent heterosis.

Table 7. Heterosis in sunflower F_1 hybrids for seeds per head grown under well-watered and water-stressed environments.

F_1 hybrids	Seeds head^{-1}			
	Well watered		Water stressed	
	M.P. (%)	B.P. (%)	M.P. (%)	B.P. (%)
HO.1 × UC-666	23.95	18.68	25.99	21.43
Mehran × UC-666	5.19	-2.23	1.10	-8.29
Thatta × UC-666	38.29	37.44	43.23	41.38
PSF-025 × UC-666	11.31	5.35	-2.70	-8.03
SH-3915 × UC-666	10.90	9.58	3.96	1.69
HO.1 × Peshawar-93	17.14	5.57	15.39	4.49
Mehran × Peshawar-93	26.81	25.44	24.41	20.10
Thatta × Peshawar-93	16.71	8.94	22.92	13.83
PSF-025 × Peshawar-93	-3.67	-4.49	-6.81	-7.64
SH-3915 × Peshawar-93	-7.59	-14.21	-10.98	-14.79
HO.1 × B-2	54.82	49.11	58.24	56.69
Mehran × B-2	8.44	-6.34	-8.97	-20.80
Thatta × B-2	27.93	18.82	22.78	18.68
PSF-025 × B-2	30.26	14.38	33.90	21.16
SH-3915 × B-2	7.95	0.80	-1.51	-7.93

M.P. = Mid parent heterosis, B.P. = Better parent heterosis.

extended from 1.10% to 58.24%, but positive BPH varied from 1.69% to 56.69% under moisture stress. The two best hybrids, HO-1 × B-2 and Thatta × UC-666, demonstrated the highest relative heterotic effects in water stress conditions. The same F_1 hybrids HO-1 × B-2 and Thatta × UC-666 also showed the maximum values of mid and better parent heterosis in drought environments. Thus, these two hybrids proved very stable in performing maximum heterosis in normal and adverse conditions. The hybrids PSF-025 × Peshawar-93 showed undesirable parental average and high parent heterosis under well-watered and water-shortage conditions. Two high heterotic F_1 hybrids, like HO-1 × B-2 and Thatta × UC-666, were noted as involving parents holding good × poor and high × low GCA impacts.

The results indicated that the heterosis manifesting from the said hybrids was due to additive × non-additive complementary gene interactions. Parallel to these outcomes, Goksoy and Turan (2004) observed rational magnitudes of relative and high parent heterosis fluctuated from -15% to 53% and -17% to 47%, respectively, for the number of achenes head^{-1}. Conferring to Amin *et al.* (2014a), achenes head^{-1} and head width demonstrated substantially progressive heterosis. Haddadan *et al.* (2020) evaluated 18 F_1 hybrids, revealing that all the crosses established positive parental average heterosis varying from 27.7% to 127.0%, with some giving negative BPH, yet the positive BPH fluctuated from 17.2% to 200.3%. The association between the achenes of F_1s and the BPH is the existence of heterosis (Jan *et al.,* 2005).

Seed index

Higher seed weight of either 100 or 1000 seeds may directly contribute to seed yield per plant or kg ha^{-1}. Most F_1 hybrids showed beneficial positive mid-parent heterotic effects except one, which created a negative heterotic impact in non-stress conditions (Table 8). Similarly, 10 crosses showed positive BPH in normal irrigation. The positive parental average heterosis in a well-watered condition ranged from 0.00% to 37.06%, while in drought stress, the range was 0.00% to 35.62%. Likewise, the same variation for positive BPH was 0.00% to 33.16% in non-stress and 0.00% to 33.95% in drought-stress conditions. The high relative heterosis materialized from the hybrids Thatta × UC-666, followed by PSF-025 × B-2 and HO-1 × B-2, yet, maximum heterobeltiosis were with the same hybrids, with just a change in ranking for the last two, i.e., Thatta × UC-666, HO-1 × B-2, and PSF-025 × B-2, in normal conditions. Under stress, the maximum relative and high parent heterosis also came from the same three cross combinations, PSF-025 × B-2, Thatta × UC-666, and HO-1 × B-2.

The high heterotic hybrids, such as PSF-025 × B-2 and Thatta × UC-666, both used the inbred having high × high GCA effects, suggesting that all the parents contributed additive genes for the expression of heterosis for seed index. Therefore, these hybrids are also valuable for discovering potential hybrids or plants selected from initial filial generations. Similar to presented consequences, Khan *et al.* (2004) established

Table 8. Heterosis in sunflower F_1 hybrids for seed index grown under well-watered and water-stressed environments.

F_1 hybrids	Seed index			
	Well watered		Water stressed	
	M.P. (%)	B.P. (%)	M.P. (%)	B.P. (%)
HO.1 × UC-666	1.08	0.00	-4.47	-9.60
Mehran × UC-666	16.4	10.64	2.42	-1.74
Thatta × UC-666	37.06	33.16	33.64	24.83
PSF-025 × UC-666	3.12	-1.98	0.00	0.00
SH-3915 × UC-666	0.81	-0.53	-7.12	-9.09
HO.1 × Peshawar-93	5.48	2.53	-7.52	-8.79
Mehran × Peshawar-93	12.78	11.38	16.49	13.29
Thatta × Peshawar-93	9.07	7.96	-7.69	-7.69
PSF-025 × Peshawar-93	-6.76	-7.92	-5.88	-12.08
SH-3915 × Peshawar-93	0.00	-2.53	-5.47	-9.89
HO.1 × B-2	18.21	17.58	17.99	12.99
Mehran × B-2	2.90	-1.68	2.99	0.00
Thatta × B-2	3.55	1.13	-11.62	-16.48
PSF-025 × B-2	22.12	16.68	35.62	33.95
SH-3915 × B-2	7.81	6.95	9.48	8.48

M.P. = Mid parent heterosis, B.P. = Better parent heterosis.

that hybrid TS-4 × TR-11 showed supreme (105.0%) heterotic impacts for 1000-grain mass. Goksoy and Turan (2004) disclosed that the amount of heterosis and heterobeltiosis were up to 42.7% and 21.0%, respectively, for 1000-grain mass. Amin *et al.* (2014) identified exceedingly progressive heterosis for 100-grain weight. Likewise, Bajaj *et al.* (2003) detected gainful heterosis for 1000-grain weight, extending from 26.5% to 48.8% as average parental heterosis (Hladni *et al.,* 2007). Karasu *et al.* (2010) recorded a considerable extent of heterobeltiosis up to 173.1% for the seed index. More recently, Haddadan *et al.* (2020) working with 18 hybrids, observed substantial heterosis for achene weight, yet, in particular crossbreeds, the heterosis was with R29 × A212 (98.7%) and R19 × A212 (71.5%). They noted that both types of heterosis, i.e., negative and positive, existed, but average parental positive heterosis was up to 54.0%, with positive BPH noted up to 98.7%. Manzoor *et al.* (2016) stated significantly positive heterosis over mid, better, and commercial checks for 1000-achene weight in hybrids, such as, A18.6×A2.5 and A18.6×A13.1. The 1000 achene weight ranged from -2.07% to 12.16% for a midparent, -25.36% to 9.32% for a better parent, and -30.44% to 7.89% for standard heterosis.

Seed yield plant^{-1}

The heterosis illustrating yield plant^{-1} is available in Table 9. The hybrids Mehran × Peshawar-93, PSF-25 × B-2, and HO-1 × B-2 recorded higher positive relative heterosis in normal and water-stress conditions, showing their stability in both environments. A high better parent heterosis resulted from Mehran × Peshawar-93, PSF-025 × B-2, and HO-1 × B-2 in a non-stress condition. Notably, the same three hybrids were among the top three scorers in heterobeltiosis for seed yield plant^{-1}. All the three best-performing hybrids comprised inbreds with good × good, good × poor, and good × poor GCA parents, respectively.

The results revealed that additive and complementary interaction of genes were accountable for expressing higher heterosis; thus, exploiting hybrid vigor will be the right approach to developing sunflower hybrids. Comparable with current findings, EL-Satar *et al.* (2015) identified fewer capable hybrids for seed yield presenting high heterosis and over-dominance gene for heterobeltiosis. Encheva and Penchev (2015) confirmed hybrid Rada, obtained from a single cross between Bulgarian CMS-2607 and mutant 12002-RF, noted progressive parental average heterosis in seed

Table 9. Heterosis in sunflower F_1 hybrids for seed yield per plant grown under well-watered and water-stressed environments.

F_1 hybrids	Seed yield plant^{-1}			
	Well watered		Water stressed	
	M.P. (%)	B.P. (%)	M.P. (%)	B.P. (%)
HO.1 × UC-666	-12.12	-14.45	-19.82	-22.95
Mehran × UC-666	-9.70	-13.04	-13.98	-21.01
Thatta × UC-666	14.30	11.70	16.70	10.11
PSF-025 × UC-666	-8.05	-14.20	-17.62	-24.51
SH-3915 × UC-666	-16.25	-18.31	-26.42	-29.57
HO.1 × Peshawar-93	9.43	4.55	-2.50	-10.51
Mehran × Peshawar-93	22.92	18.70	37.53	32.09
Thatta × Peshawar-93	2.06	-2.85	1.69	-5.00
PSF-025 × Peshawar-93	-0.12	-0.32	-1.45	-5.14
SH-3915 × Peshawar-93	-11.22	-15.35	-12.70	-19.57
HO.1 × B-2	20.99	14.22	33.82	22.83
Mehran × B-2	-2.78	-7.25	-4.11	-7.90
Thatta × B-2	-9.82	-15.18	-16.90	-22.36
PSF-025 × B-2	22.59	20.81	32.52	27.57
SH-3915 × B-2	-11.61	-16.72	-21.01	-27.23

M.P. = Mid parent heterosis, B.P. = Better parent heterosis.

yield. In a similar study, Ghaffari and Shariati (2018) recognized two crossbreeds, i.e., AGK148 × RGK56 and AGK222 × RGK19, were desirable combiners for seed and oil yield, while AGK52 × RGK26 was preferable for oil yield under moisture-stressed conditions. Under optimal conditions, AGK344 × RGK56 recorded maximum affirmative SCA impacts for seed yield. Goksoy *et al.* (2000) and Goksoy and Turan (2004) showed positive SCA effects for seed yield in some hybrids. Usually, the high manifestation of heterosis was linked with genetic diversity between inbreds (Hladni *et al.,* 2007). Ahmed *et al.* (2021) obtained high heterosis for seed yield, compared with the parental mean (17.68% to 72.38%) and 2.86% to 56.84% over the better parent.

CONCLUSIONS

Heterosis is the supreme aspect for the breeder to increase the progression of a quantitative genetic framework of the plant. Based on all the hybrids, the study concludes that significant interactions occur between line and tester and their heterotic effect on the performance of a botanical character, such as days to 75% flowering, days to 75% maturity, stem diameter, head diameter, number of seeds head^{-1}, seed index, seed yield head^{-1}, seed yield plant^{-1}, and biological yield plant^{-1} of sunflower under water-stressed and non-water stressed conditions. The F_1 hybrids, Mehran × Peshawar-93, Thatta × UC-666, PSF 025 × B-2, and HO-1 × B-2, expressed the maximum heterotic effects for yield traits; therefore, a higher preference for their use for hybrid crop development under adverse environments.

REFERENCES

Ahmed MA, Tamer HA, Hassan, Hamdy AZ (2021). Heterosis for seed, oil yield, and quality of some different hybrids sunflower. *OCL - Oilseeds and Fats, Crops and Lipids* 28: 1-9.

Amin W, Malook S, Mumtaz A, Ashraf S, Ahmad HM, Hafeez K, Sajjad M, Bibi A (2014). Combining ability analysis and effect of seed priming on seedling traits in Sunflower (*Helianthus annuus* L.). *Report and Opinion*. 6(7): 19-30.

Aslam S, Khan SM, Saleem M, Qureshi AS, Khan A, Aslam M, Khan SM (2010). Heterosis for the movement of oil quality in sunflower (*Helianthus annuus* L.). *Pak. J. Bot.* 42(2): 1003-1008.

Bajaj RK, Kamaljit AK, Narinder K, Sharma SR (2003). Estimation of heterosis and inbreeding depression in sunflower (*Helianthus annuus* L.). *J. Agric. Res.* 40: 146-150.

Bohra AU, Jha C, Adhimoolam P, Bisht D, Singh NP (2016). Cytoplasmic male sterility (CMS) in hybrid breeding in field crops. *Pl. Cell Report.* 35(5): 967-993.

Chahal RK, Dhillon SK, Kandhola SS, Kaur G, Kaila V, Tyagi V (2019). Magnitude and nature of gene effects controlling oil content and quality components in sunflower (*Helianthus annuus* L.). *Hellia* 42(70): 73-84.

Chandra BS, Kumar SS, Rangantha ARG, Dudhe MY (2011). Identification of restorers for diverse CMS sources in sunflower (*Helianthus annuus* L.). *J. Oilseeds. Res.* 28(1): 71-73.

Ciric M, Jocic S, Cvejic S, Jockovic M, Canak P, Marinkovic RM, Ivanovic M (2013). Combining abilities of new inbred lines of sunflower (*Helianthus annuus* L.). *Genetica,* 43(3): 289-296.

Depar S, Baloch MJ, Kumbhar MB, Chachar QD (2017). Heterotic performance of F_1 hybrids for phonological, yield, oil, and protein traits of sunflower. *Pak. J. Agric. Agric. Eng. Vet. Sci.* 33(1): 12-22.

Dudhe MY, Rajguru AB, Bhoite KD, Madhuri P (2017). Genetic evaluation and identification of stable sunflower genotypes under semi-arid dryland conditions of Telangana and Maharashtra state. *SABRAO J. Breed. Genet.* 49(1): 83-93.

EL-Satar MAA, Fahmy RM, Hassan THA (2015). Genetic control of sunflower seed yield and its components under different edaphic and climate conditions: The 9th Plant Breeding International Conference. *Egyptian J. Plant Breed.* 19: 103-123.

Encheva J, Georgiev G, Penchev E (2015). Heterosis effects for agronomically important traits in sunflower (*Helianthus annuus* L.). *Bulgarian. J. Agric. Sci.* 21(2): 336-341.

Fehr WR (1987). Principles of Cultivar Development. Theory and Technique. *Macmillan Pub. Comp. Inc.,* New York, pp. 115-119.

Geetha A, Sivasankar A, Prayaga L, Suresh J, Saidaiah P (2012). Screening of sunflower genotypes for drought tolerance under laboratory conditions using PEG. *SABRAO J. Breed. Genet.* 44(1): 28-41.

Ghaffari M, Shariati F (2018). Combining ability of sunflower inbred lines under drought stress. *Helia* 41(69): 201-212.

Goksoy AT, Turan ZM (2004). Combining abilities of certain characters and estimation of hybrid vigor in sunflower (*Helianthus annuus* L.). *Acta Agron. Hung.* 52: 361-368.

Goksoy AT, Turkec A, Turan ZM (2000). Heterosis and combining ability in sunflower (*Helianthus annuus* L.). *Ind. J. Agric. Sci.* 70: 525-529.

Gomez KA, Gomez AA (1984). Statistical Procedures for Agriculture Research. *John Wiley & Sons Inc. 2nd Ed.* New York, USA.

Gowtham P (2006). Genetic analysis of yield and oil quality traits in sunflower (*Helianthus annuus* L.) M. Sc. Thesis submitted to the University of Agricultural Sciences, Karnataka, India.

Habib H, Mehdi SS, Rashid A, lqbaf S, Anjurm MA (2006). Heterosis studies in sunflower (*Helianthus annuus* L.). Crosses for agronomic traits and oil yield stress. *Pak. J. Agric. Sci.* 4(3):131-135.

Habib H, Mehdi SS, Rashid A, Zafar M, Anjum SM (2007). Heterosis and heterobeltiosis studies for flowering traits, plant height, and seed yield in sunflower. *Int. J. Agric. Biol.* 9: 355-358.

Haddadan AK, Ghuffari M, Hervan EM, Alizadeh B (2020). Impact of parent inbred lines on heterosis expression for agronomic characteristics in sunflower. *Czech. J. Genet. Plant Breed.* 56 (3): 123-132.

Hladni N, Skoric D, Balalic K, Sakac M, Miklic V (2007). Heterosis for ergonomically important traits in (*Helianthus annuus* L.). *Helia* 30(47): 191-198.

Hladni N, Skoric D, Balalic MK (2011). Line x tester analysis for yield component in sunflower (*Helianthus annuus* L.). *Genetica* 42(2): 297-306.

Imran M, Malook SU, Qureshi SA, Nawaz MI, Shabaz MK, Asif M, Ali Q (2015). Combining ability analysis for yield-related traits in sunflower. *Am-Eur. J. Agric. Environ. Sci.* 15 (3): 424-436.

Jan M, Farhatullah R, Hassan G (2005). Combining ability analysis in sunflower (*Helianthus annuus* L.). *Pak. J. Biol. Sci.* 11 (8): 710-713.

Jarwar AD, Islamuddin M, Kalhoro RB, Lashari MI (2004). Heterosis and heterobeltiosis studies in sunflower. *Indus J. Plant Sci.* 3(6): 229-234.

Kang SA, Khan FA, Ahsan MZ, Chatha WS, Saeed F (2013). Estimation of combining ability for the development of hybrid genotypes in (*Helianthus annuus* L.). *J. Biol. Agric.* 3(1): 68-74.

Kant R, Srivastava RK (2012). Heterosis and inbreeding depression studies in urdbean (*Vigna mungo* L.) (Hepper). *J. Food Legumes* 25: 102-108.

Kanwal NH, Sadaqata A, Ali Q, Ali F, Bibic I, Niazi NK (2015). Breeding progress for morphology and genetic pattern in *Helianthus annuus* L. *Life Sci. J.* 21(5): 49-56.

Karasu AM, Oz M, Sicik AT, Goksoy ZM, Turan T (2010). Combining ability and heterosis for yield and yield component in sunflower. *Not. Bot. Hort. Agron. Cluj*, 38(3):259-264.

Kaya Y, Pekcan V, Cicek N (2016). Effects of drought on morphological traits of some sunflower lines*. Ekin J.* 2: 54-68.

Khan IU, Arshad M, Khan MA, Ashraf M, Saleem A, Awan S, Azam S, Shah SS (2019). Heterosis expression analysis and its impact on different agro-morphological character in sunflower (*Helianthus annuus* L.) hybrids. *Pak. J. Agric. Res.* 32 (2): 325-333.

Khan MS, Khalil IH, Swati MS (2004). Heterosis for yield component in sunflower (*Helianthus annuus* L.). *Asian J. Plant Sci.* 3(2): 207-210.

Khan S, Choudhary S, Pandey A, Khan MK, Thomas G (2015). Efficient oil source for human consumption. *Emergent Life Sci. Res.* 1: 1-3.

Lakshman SS, Chakrabarty NR, Godki MK, Kole PC (2020). Heterosis study in sunflower (*Helianthus annuus* L) hybrid for yield attributing traits in high salinity conditions for identification of superior sunflower hybrid for coastal saline belts. *Euro. J. Exp. Biol.* 1(2): 1-10.

Manzoor M, Sadaqat HA, Tahir MHN, Sadia B (2016). Genetic analysis of achene yield in sunflower (*Helianthus annuus* L.) Through pyramiding of associated genetic factors. *Pak. J. Agric. Sci.* 53(1): 113-119.

Memon S, Baloch MJ, Baloch GM, Kerrio MI (2015). Heterotic effect in F_1s and inbreeding depression in F_2 hybrids of sunflower. *Pak. J. Sci. Ind. Res. Biol. Sci.* 58(1): 1-10.

Mohan GS, Seetharam A (2005). Genetic divergence in lines of sunflower derived from inter specific hybridization. *SABRAO J. Breed. Genet.* 37: 77–84.

Naseem Z, Ahtsham SA, Annum N, Arshad S, Khalid MAR, Anam R, Ali Q (2015). Genetic variability among sunflower accession for relative growth and seedling traits. *Academia Arena* 7(8): 1-8.

Pekcan V, Evci G, Yilmaz MI, Balkan AS, Rrdal SC, Cikek N, Ekmekci Y, Kaya Y (2015). Drought effect and yield traits of some sunflower inbred lines. *Agric. For.* 61(4): 101-107.

Prasad PVV, Staggenborg S, Ristic Z, Ahuja L, Reddy V, Anapalli S, Yu Q (2008). Impacts of drought and or heat stress on physiological, developmental, growth, and yield processes of crop plants. *American Society of Agronomy, Crop Science Society of America,* Soil Science Society of America: Madison, WI, USA.

Razzaq H, Tahir HH, Sadaqat HA, Sadia H (2017). Screening of sunflower accessions under drought stress condition, an experimental assay. *J. Soil Sci. Plant Nutri.* 17(3): 262-271.

Saleem U, Khan MA, Gull S, Usman K, Saleem FY, Sayal OU (2014). Line × tester analysis of yield and yield-related attributes in different sunflower genotypes. *Pak. J. Bot.* 46: 659-665.

Saremi-Rad A, Mostafavi K (2020). Study of genetic and phenotypic diversity of sunflower (*Helianthus annuus* L.) genotypes for agro-morphological traits under normal and drought stress conditions. *Plant Prod.* 43(2): 227-240.

Sujatha K, Nadaf HL (2013). Correlation for yield and yield traits in mutant and segregating genotypes in sunflower (*Helianthus annuus* L.). *Mol. Pl. Breed.* 3 (2): 265-266.

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. *J. Plant Physiol. Breed.* 2: 35-44.

Tyagi V, Dhillon DK, Kaushik P, Kaur G (2018). Characterization for drought tolerance and physiological efficiency in novel cytoplasmic male sterile sources of sunflower (*Helianthus annuus* L.). *J. Agron.* 8(10): 02-20.

Tyagi V, Dhillon SK (2016). Cytoplasmic effects on combining ability for agronomic traits in sunflower under different irrigation regimes. *SABRAO J. Breed. Genet.* 48(3): 295-308.

Viscardi S, Ventorino V, Duran P, Maggio A, Pascale DD, Mora ML, Pepe O (2016). Assessment of plant growth promoting activities and abiotic stress tolerance of strains for potential use in sustainable agriculture. *J. Soil Sci. Plant Nutr.* 16(11): 848-863.