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RESEARCH ARTICLE

Effect of drought stress on combining ability and heterosis in grain sorghum (*Sorghum bicolor* L. Moench)

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Abstract

The current study was carried out at Shandaweel Agric. Res., Station, Sohag, Governorate, A.R.C., Egypt to assess the performance, combining ability and heterosis of 28 F_1 crosses, their 11 parents and the check hybrid Shandaweel-1 under two irrigations levels in 2022 and 2023 summer seasons for days to 50% blooming, plant height, 1000-grain weight and grain yield/plant. Years, irrigations, genotypes, their partitions (Parents, crosses and parent vs. crosses) and all interaction with the genotypes effects were significant ($p<0.01$) for all traits under study except between years and the second order effects for 1000-grain weight overall environments. Some crosses were significantly earlier, taller, heavier grain weight and higher grain yield compared to their parents and the check hybrid. The female parent BSH-32 appeared to be the best general combiners for earliness and grain yield at different environments. The cross ASH-32 × MR-812 recorded significant or non-significant SCA effects in desirable direction for earliness, plant height and grain yield under different environments. This cross was considered the best combination for these traits. Most of the crosses were significantly negative heterosis in days to blooming and positive in plant height and grain yield at different conditions. The crosses ASH-32 × MR-812 and ASH-32 × NM-36565 exhibited significant heterosis in desirable direction for earliness, taller plants and higher grain yield, coupled with significant specific combining ability and *per se* performance under different environments. Hence, these crosses could be utilized to develop the crosses with these traits.

Keywords: performance; combining ability; heterosis; grain sorghum; *Sorghum bicolor*; crosses.

1. Introduction

Grain sorghum (*Sorghum bicolor* L. Moench) is an important cereal crop in several regions of the globe, being the fifth most important cereal in the world after rice, wheat, maize and barley (Praveen *et al*., 2015). It is cultivated on about 44.00 million hectares around the world and produces a total 58.00 million tons of grain (FAO production yearbook, 2022). The grain is also used directly for poultry feeding. The stalks are used for animal feed, thatching and fuel (Muturi; 2013 and Muui *et al*., 2013).

In Egypt, grain sorghum is the fourth after wheat, rice and maize. The cultivated area about 208333.33 hectares and which produced about 672000 tons of grains (FAO STAT, 2022). Most of the cultivated areas concentrated in fayoum, Assiut and Sohag Governorates. It plays a very important role in providing nutrition to human race along with wheat, rice and maize.

Grain sorghum presents good adaptation for growing in environments with a water deficit, because of its dense and deep root system, ability to reduce transpiration through leaf rolling and stomatal closure, and reduced metabolic processes under drought stress (Blum; 2004; Reddy *et al.*, 2009). Consequently, sorghum has

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great potential for cultivation in regions subjected to water stress. Water deficit is one of the main causes of damage in metabolic and physiological processes of plants, leading to reductions in productivity (Taiz *et al*., 2017). Plant breeding mitigates the effects of drought by creating cultivars adapted to new climatic conditions, and resistant to evolving pests and diseases. The exploitation of drought tolerant crops, such as sorghum, reduces the impact of climate changes.

The traits like yield and its components are governed by polygenes with complex gene action and hence understanding the nature and magnitude of gene action help the breeder in selection of an appropriate breeding method (Jain and Patel, 2014).

The estimates of combining ability are useful in predicting relative performance of parental lines in hybrid combinations. Selection of parents for hybridization can be made with the help of combining ability analysis (Sprague and Tatum, 1942).

The heterosis plays an important role for increasing the productivity of crop without much increase in the cost of production. Grain yield is complex character rely on many traits. Yield potential accompanied with desirable combination of traits has always been the major objective of sorghum breeding program (Kumar, 2013). Thus, the phenomenon of heterosis has revolutions the production in many crops including sorghum in commercial basis.

Chikuta *et al.* (2017), Jadhav and Deshmukh (2017), Ingle *et al.* (2018), Sheunda *et al.* (2019), Gomes *et al.* (2020), Wagaw and Tadesse (2020), Ribeiro *et al.* (2021), El-Kady *et al.* (2022), El-Komoss *et al.* (2022) and Williams-Alanís *et al.* (2022) found that positive and significant general and specific combining ability effects, respectively, for some parental lines (Male and female lines) and crosses for grain yield and its components. A lot of sorghum researches reveal that some parents exhibited negative and highly significant general combining ability effects for days to blooming (El-Sherbeny *et al.,* 2019, El-Sagher; 2019, Wagaw and Tadesse, 2020; El-Kady *et al.,* 2022).

This study was undertaken to determine the performance, general and specific combining ability and heterosis of different grain sorghum genotypes in F_1 combinations for grain yield and some related traits as criteria for developing superior sorghum hybrids.

2. Materials and methods

This investigation was carried out to study the performance**,** combining ability and heterosis under drought stress at Shandaweel Agric. Res. Station, Sohag Governorate, A.R.C., Egypt.

2.1. Genetic materials

Twenty-eight grain sorghum crosses were produced by crossing the four CMS-lines (Cytoplasmic male sterile; A-lines) with the seven R-lines (Fertility restorer). The heads of both parents (A-lines and R-lines) were bagged individually before flowering and the pollen grains were collected from each of the seven restorers and pollination was done among the four female sterile lines and the seven restorer lines in the proper time as described by Kempthorne (1957). The A-lines included BTX-1, ICSB-73, ATX-635 and BSH-32 and the R-lines were ICSR93002, ZV-14, RSH-28, RSH-29, MR-812, NM36565 and RSH-60.

2.2. Evaluation of the genotypes

In 2022 and 2023 summer seasons, forty genotypes (28 crosses and their 11 parents (Four B-lines and seven R-lines) along with the hybrid Shandaweel-1 as the check) were sown in a split-plot arranged in a randomized complete block design (RCBD) with three replicates under the two levels of irrigation (Optimum, 100% and severe stress, 50% of the optimum). The main plot consisted of irrigation treatments, while the genotypes of grain sorghum were allocated to the sub-plots. Each plot consisted of one row per replicate 4 m long, with 60 cm apart between rows and plant spaced 20 cm between hills within each row. The sowing date was 22 and 24 June in 2022 and 2023 seasons, respectively. The agriculture practices were followed as recommended except irrigation treatments throughout the growing season. In each replication and in each genotype five plants were randomly selected for observation, except days to 50% blooming where observation was registered on plot basis. Three quantitative traits *viz.*, plant height, 1000-grain weight and green yield/plant.

The quantity of water given at each irrigation treatment (Optimum and the 50% of optimum) measured by a water counter is shown in Table 1. The quantity of water differed from irrigation to another according to the age of plant and temperature.

2.3. Statistical analysis

The obtained data were subjected to regular analysis of variance of split-plot design according to Gomez and Gomez (1984). The combined analysis was performed by MSTAT_C Computer program after carrying out homogeneity test (Bartlett, 1937). The analysis of variance using line × tester was performed according to Kempthorn (1957). Differences among means were assessed by the revised least significant differences (RLSD) at 5 and 1% levels of probability according to El-Rawi and Khalafalla (1980) as follow:

$$RLSD = t'_{\alpha} \times \sqrt{\frac{2MSerror}{yir}}$$

Where, t' from minimum-average-risk table, y = number of years, i = irrigation levels and r = number of replications.

2.4. Combining ability effects

General combining ability (GCA) effects for parental lines (Females and males) and specific combining ability (SCA) effects for crosses were estimated according to Singh and Chaudhary (1977).

2.5. Heterosis

Heterosis was calculated as the percentage of deviation of F_1's mean from the mean of better parent according to following formula computed by Bahatt (1971):

Heterosis =

$$\frac{F_1 - BP}{BP} \times 100$$

Where: Bp = Better parent.

To detect the significant of heterosis, the least significant difference (L.S.D) value from zero can be calculated as follows:

L.S.D of better parent heterosis = (S.E. × t_α /$\overline{BP}$) × 100

Where:

S.E. for better parent = $[2MSe/r]^{1/2}$

t_α = tabulated value at the degrees of freedom for the error.

MSe = mean squares for error, and r = number of replication

Table 1. The amount of irrigation water (m^3) used in each irrigation.

Irrigation	Genotypes			
	2022		2023	
	Optimum 100%	Stress 50%	Optimum 100%	Stress **50%**
Sowing irrigations	400	400	400	400
Mohayah irrigation	315	315	315	315
1	320	160	340	170
2	360	180	370	185
3	430	215	420	210
4	405	202.5	410	205
5	350	175	340	170
Total	2580	1647.5	2595	1865

3. Results

3.1. Analysis of variance

The results from the combined analysis of variance (Table 2) indicated that the mean squares due to seasonal effects were significant ($p<0.01$) for days to 50% blooming, plant height and grain yield, except for 1000-grain weight. This reveals the presence of climatic variations prevailing at the same location. Therefore, future evaluations of grain sorghum hybrids should be done in both seasons to give conclusive results. Similar observations were made by Sheunda *et al* (2019), El-Kady *et al* (2022) and El-Komoss *et al* (2022). Irrigation levels show significant ($p<0.01$) differences for all traits as it would be expected for optimum and stress irrigation levels. Mean squares presented that the effect of irrigation levels were more important than that of years for all traits. The differences among genotypes were significant ($p<0.01$), revealing thereby the presence of a wide range of variability. Mean squares due to all interactions *viz*., genotypes × year, genotypes × irrigations and genotypes × year × irrigations interaction effects were highly significant for all studied traits except the second order for 1000-grain weight. This indicates that it is essential to evaluate genotypes for such traits under different environments. Similar findings were also reported in grain sorghum by several workers (El-Sherbeny *et al;* 2019, Sheunda *et al;* 2019, Gomes *et al;* 2020 and El-Komoss *et al;* 2022).

Table 2. Combined analysis of variance for days to blooming, plant height, 1000-grain weight and grain yield/plant of 40 genotypes under overall environments.

S.O.V	d.f	Mean squres			
		Days to 50% blooming	Plant height (cm.)	1000- grain weight (g)	Grain yield / plant (g)
Years (Y)	1	32.55**	1178.13**	1.23	153.48**
Ea	4	0.70	54.88	0.27	4.11
Irrigation (I)	1	4410.47**	51958.41**	861.05**	16070.44**
Y × I	1	10.50*	2548.41*	6.03	12.23
Eb	4	1.38	205.05	1.19	9.75
Genotypes (G)	39	40.46**	4323.90**	16.05**	1122.58**
G × Y	39	9.74**	122.09**	0.83**	60.51**
G × I	39	13.57**	56.92*	2.95**	50.35**
G × Y × I	39	5.88**	68.87**	0.54	15.20**
Poled Error (Ec)	312	1.68	36.88	0.42	4.73

*, ** Significant at 0.05 and 0.01 of probability levels, respectively.

3.2. Mean performance

The data (Tables 3 and 4) exhibited that the normal irrigation level at 100 ET recorded earlier blooming, taller plant height, heavier 1000-grain weight and higher grain yield than the stress level at 50% ET over the two seasons. This suggests that both of temperature and edaphic factors could be playing a significant role in different plant growth stages.

Overall environments (Table 3), the blooming range of the F_1 crosses was 69.42 to 73.09 with the trail mean of 71.24 days. The earliest crosses were ASH-32 × RSH-60, ATX-1 × RSH-28 and ATX-1 × ICSR-93002. On the other side, the cross ATX-635 × ICSR-93002 took the longest number of days to bloom. The plant height of the F_1 crosses varied from 146.67 to 207.34 with the average of 175.66 cm. The tallest plant height was observed from the cross ATX-635 × RSH-28 (207.34 cm). On the other hand, the shortest cross was ASH-32 × RSH-60 (146.67 cm) which is statistically at par with ATX-1 × RSH-28 (150.09 cm) overall environments (Table 3). Regarding 1000-grain weight (Table 4), it is a very important influence for the determination of crop yield. The averages of 1000-grain weight differed widely among the tested F_1 crosses. It showed that the heaviest averages were 32.92, 27.14 and 30.03 g for the cross ICSA-70 × RSH-28, but the lightest grain weight was obtained from the crosses ASH-32 × RSH-60 (24.88 g), ASH-32 × ZSV-14 (24.91 g), ATX-635 × RSH-28 (25.08 g) and ASH-32 × ICSR-93002 (25.16 g) at normal and stress irrigation levels over the two seasons and the combined mean, respectively. The average 1000-grain weight for all the F_1 crosses was 27.85, 25.25 and 26.55 g under normal and stress irrigation levels over the two seasons as well as environments, respectively. Variance analysis exhibited that the presence of genetic variability on studied wheat genotypes for grain yield (Table 2). Grain yield is a function of combined effect of gene controlling yield components and influence of growing seasons and agricultural practices applied. Consequently, any variation or change in both them is responsible to bring a change in attained yield. The grain yield drop in environments with water stress involves various physiological processes in the plant. Water stress intensities are different from one year to another in the same place, exhibiting the importance of other edaphoclimatic factors linked to water stress and of in different seasons in the same location. Climatic variations that occur from one year to another and climatic factors, such as temperature, directly influence the intensity of water stress. Results in Table 4 exhibited that there was a large variation in grain yield/plant. Overall environments, the grain yield/plant for the F_1 crosses varied from 59.00 to 89.92 with an average of 71.70 g. The highest grain yield was exhibited from the cross ATX-635 × RSH-60 (89.92 g) is statistically at par with ATX-1 × RSH-95 (88.64 g). The lowest grain yield/plant was observed from the cross ATX-1 × MR-812 (59.00 g) followed by ASH-32 × ZSV-14 (59.73 g). Water stress reduced the grain yield by 18.23% in the average over the two seasons (Table 4). Reduction caused by water stress were also obtained by Menezes *et al* (2015), who found reductions of 39% in grain sorghum lines and by Batista *et al* (2017), who found reductions of 35 and 65% in two seasons of evaluation in grain sorghum hybrids. Batista *et al* (2019), who found reductions of 68.9 and 31.2% in two seasons of evaluation in grain sorghum hybrids. Sorghum is a cereal tolerant to drought, when compared to maize and wheat, but when it is exposed to intense water deficit, mainly during flowering, grain yield is significantly reduced. The superior cross for grain yield, blooming and plant height was ATX-635 × RSH-28 (Tables 3 and 4). It noted that the performances of the F_1 crosses were varied in yield hence selection of superior crosses based on *per se* performance is possible. The higher grain yield among the F_1 crosses were produced from high yielding female lines hence selection of female parents should be based on their *per se* performance. Similar observations were made by Mahmoud *et al* (2013) and Eatemad (2015)

Comparisons of all F_1 crosses with each of their parents and the check hybrid (Shandaweel-1) revealed that most of crosses were significantly earlier blooming, taller plants and higher grain yield/plant and some of crosses were significantly heavier 1000-grain weight than both their parents and checks for all studied traits overall environments (Tables 3 and 4). These data supports the results observed by Mindayea *et al* (2016) and El-Sagheer *et al* (2019).

3.3. Combining ability

Data in Table 5 exhibited that the mean squares due to parents, crosses and parents vs. crosses differed significantly ($p<0.01$) for all studied traits (Days to 50% blooming, plant height, 1000-grain weight and grain yield/plant) overall environments, pointing to the high degree of genetic variability existing among parents and crosses for this trait. In this regard, Ribeiro *et al* (2021), El-Komoss *et al* (2022) and El-Kady *et al* (2022) observed similar results in grain sorghum for these traits. The contrast of parents vs. crosses overall environments was sizable and highly significant, pointing to the potential of heterotic effects among hybrids.

Table 3. Average performance of forty genotypes for days to 50% blooming and plant height under normal and stress irrigation levels over the two seasons as well as overall environments.

No.	Pedigree	Days to 50% blooming Combined over years 100% E	Days to 50% blooming Combined over years 50% E	Combined overall environments	Plant height Combined over years 100% E	Plant height Combined over years 50% E	Combined overall environments
A-				Crosses			
1	ATX-1 × ICSR-93002	67.17	72.00	69.59	183.33	163.00	173.17
2	ATX-1 × ZSV-14	68.00	73.33	70.67	204.17	180.67	192.42
3	ATX-1 × RSH-28	66.17	72.83	69.50	159.67	140.50	150.09
4	ATX-1 × RSH - 95	69.50	74.67	72.09	193.33	169.67	181.50
5	ATX-1 × MR-812	69.00	74.67	71.84	174.00	153.33	163.67
6	ATX-1 × NM-36565	68.50	74.83	71.67	194.67	171.83	183.25
7	ATX-1 × RSH-60	68.50	74.67	71.59	204.67	180.83	192.75
8	ICSA-70 × ICSR-93002	68.00	72.67	70.34	169.83	151.83	160.83
9	ICSA-70 × ZSV-14	69.33	75.83	72.58	199.33	176.67	188.00
10	ICSA-70 × RSH-28	67.00	75.33	71.17	193.67	169.83	181.75
11	ICSA-70 × RSH-95	70.17	74.50	72.34	174.17	154.33	164.25
12	ICSA-70 × MR-812	69.33	75.67	72.50	202.67	175.33	189.00
13	ICSA-70 × NM-36565	69.00	73.33	71.17	189.17	171.50	180.34
14	ICSA-70 × RSH-60	70.50	74.00	72.25	181.33	157.50	169.42
15	ATX-635 × ICSR-93002	70.67	75.50	73.09	194.67	171.83	183.25
16	ATX-635 × ZSV-14	70.17	74.67	72.42	204.33	182.17	193.25
17	ATX-635 × RSH-28	65.67	74.50	70.09	222.00	192.67	207.34
18	ATX-635 × RSH-95	69.67	74.00	71.84	188.83	163.67	176.25
19	ATX-635 × MR-812	68.00	75.00	71.50	156.00	136.17	146.09
20	ATX-635 × NM-36565	70.00	73.33	71.67	196.00	174.67	185.34
21	ATX-635 × RSH-60	66.50	75.33	70.92	198.33	169.00	183.67
22	ASH-32 × ICSR-93002	65.50	75.00	70.25	168.33	149.17	158.75
23	ASH-32 × ZSV-14	68.83	72.83	70.83	184.00	160.33	172.17
24	ASH-32 × RSH-28	69.33	75.17	72.25	189.67	160.67	175.17
25	ASH-32 × RSH-95	67.17	73.67	70.42	210.83	188.33	199.58
26	ASH-32 × MR-812	68.00	73.17	70.59	176.67	160.00	168.34
27	ASH-32 × NM-36565	67.00	73.17	70.09	160.00	144.17	152.09
28	ASH-32 × RSH-60	69.17	69.67	69.42	154.17	139.17	146.67
	Range	65.50-70.67	69.67-75.83	69.42 -73.09	154.17-222.00	139.17-192.67	146.67-207.34
	Average	68.42	74.05	71.24	186.71	164.60	175.66
B-	Female parents						
29	BTX-1	66.50	77.17	71.84	167.83	147.67	157.75
30	ICSB-70	65.33	75.67	70.50	149.33	129.33	139.33
31	BTX- 635	69.50	76.33	72.92	148.33	129.17	138.75
32	BSH-32	70.00	76.67	73.34	155.50	135.50	145.5
	Range	65.33-70.00	75.67-77.17	70.50-73.34	148.33-167.83	129.17-147.67	138.75-157.75
	Average	67.83	76.46	72.15	155.25	135.42	145.33
C	Male parents						
33	ICSR 93002	71.83	74.17	73.00	181.67	165.00	173.34
34	ZSV-14	72.83	75.17	74.00	179.17	161.67	170.42
35	RSH-28	70.67	76.00	73.34	158.67	138.33	148.50
36	RSH-95	70.50	74.00	72.25	126.67	110.00	118.34
37	MR-812	72.33	77.00	74.67	177.83	153.17	165.50
38	NM-36565	70.67	76.17	73.42	152.50	133.50	143.00
39	RSH-60	71.50	75.17	73.34	163.33	143.33	153.33
	Range	70.50-72.83	74.00-77.00	72.25-74.67	126.67-181.67	110.00-165.00	118.34-173.34
	Average	71.48	75.38	73.43	162.83	143.57	153.20
D-	Check						
40	Shandaweel-1	70.33	75.67	73.00	180.00	164.00	172.00
$L.S.D_{05}$		1.40	1.53	1.04	8.33	4.91	4.86
$L.S.D_{01}$		1.84	2.01	1.36	10.92	6.44	6.30

Table 4. Average performance of forty sorghum genotypes for 1000-grain weight and grain yield/plant under normal and stress irrigation levels over the two seasons as well as overall environments.

No.	Pedigree	1000-grain weight Combined over years		Combined overall environments	Grain yield/plant Combined over years		Combined overall environments
		100% E	50% E		100% E	50% E	
A-				Crosses			
1	ATX-1 × ICSR-93002	30.27	26.73	28.50	70.65	55.02	62.84
2	ATX-1 × ZSV-14	27.60	24.55	26.08	82.88	67.38	75.13
3	ATX-1 × RSH-28	25.71	24.04	24.88	74.63	53.07	63.85
4	ATX-1 × RSH - 95	28.48	26.40	27.44	96.77	80.50	88.64
5	ATX-1 × MR-812	27.56	24.47	26.02	64.50	53.50	59.00
6	ATX-1 × NM-36565	28.27	25.58	26.93	84.93	49.22	67.08
7	ATX-1 × RSH-60	28.04	26.01	27.03	77.67	67.17	72.42
8	ICSA-70 × ICSR-93002	30.86	27.05	28.96	89.09	79.50	84.30
9	ICSA-70 × ZSV-14	28.47	25.28	26.88	70.99	51.42	61.21
10	ICSA-70 × RSH-28	32.92	27.14	30.03	72.90	58.85	65.88
11	ICSA-70 × RSH-95	25.93	23.95	24.94	74.74	62.24	68.49
12	ICSA-70 × MR-812	28.74	26.46	27.60	73.30	63.99	68.65
13	ICSA-70 × NM-36565	27.77	25.38	26.58	71.57	54.34	62.96
14	ICSA-70 × RSH-60	28.13	25.24	26.69	92.00	80.67	86.34
15	ATX-635 × ICSR-93002	26.53	24.65	25.59	83.93	66.13	75.03
16	ATX-635 × ZSV-14	27.93	24.77	26.35	74.53	58.17	66.35
17	ATX-635 × RSH-28	26.48	23.67	25.08	70.33	63.17	66.75
18	ATX-635 × RSH-95	28.56	26.24	27.40	79.14	59.66	69.40
19	ATX-635 × MR-812	28.77	26.36	27.57	68.83	53.50	61.17
20	ATX-635 × NM-36565	28.55	26.40	27.48	74.50	61.64	68.07
21	ATX-635 × RSH-60	26.49	24.66	25.58	95.33	84.50	89.92
22	ASH-32 × ICSR-93002	26.45	23.86	25.16	91.17	77.37	84.27
23	ASH-32 × ZSV-14	25.97	23.85	24.91	66.93	52.53	59.73
24	ASH-32 × RSH-28	27.45	25.12	26.29	89.40	72.84	81.12
25	ASH-32 × RSH-95	26.68	24.19	25.44	79.57	67.67	73.62
26	ASH-32 × MR-812	26.40	24.58	25.49	78.50	70.50	74.50
27	ASH-32 × NM-36565	27.17	25.33	26.25	75.83	68.67	72.25
28	ASH-32 × RSH -60	27.50	25.67	26.59	84.33	73.00	78.67
	Range	25.71 - 32.92	23.67- 27.14	24.88 - 30.03	64.50-96.77	49.22-84.50	59.00-89.92
	Average	27.85	25.25	26.55	78.89	64.51	71.70
B-	Female parents						
29	BTX-1	29.67	26.77	28.22	68.88	56.67	62.78
30	ICSB-70	28.39	26.29	27.34	72.90	55.05	63.98
31	BTX- 635	27.48	25.99	26.74	70.50	54.98	62.74
32	BSH-32	28.00	26.03	27.02	72.83	63.42	68.13
	Range	27.48- 29.67	25.99- 26.77	26.74 - 28.22	68.88-72.90	54.98-63.42	62.74-68.13
	Average	28.39	26.27	27.33	71.28	57.53	64.40
C	Male parents						
33	ICSR 93002	28.78	25.65	27.22	74.17	63.17	68.67
34	ZSV-14	29.12	25.75	27.44	63.32	47.16	55.24
35	RSH-28	25.80	23.12	24.46	63.83	48.41	56.12
36	RSH-95	25.95	22.80	24.38	50.97	42.50	46.74
37	MR-812	25.17	23.95	24.56	57.00	42.88	49.94
38	NM-36565	28.38	26.08	27.23	62.67	47.44	55.06
39	RSH-60	29.00	26.22	27.61	67.90	48.23	58.07
	Range	25.17 - 29.12	22.80 -26.22	24.38 - 27.61	50.97-74.17	42.50-63.17	46.74-68.67
	Average	27.46	24.80	26.13	62.84	48.54	55.69
D-	Check						
40	Shandaweel-1	29.34	25.05	27.20	84.00	72.95	78.48
$L.S.D_{05}$		0.68	0.78	0.52	2.85	1.99	1.74
$L.S.D_{01}$		0.89	1.03	0.68	3.74	2.61	2.28

The differences among female parents were significant (p<0.01) and (p<0.05) for days to 50% blooming and 1000-grain weight, respectively, overall environments. Mean squares due to the male parents were significant (p<0.01 or 0.05) for all traits under study except for plant height. The interaction of females with males was significant (p<0.01) for all the studied traits, revealing the presence of specific effects for these traits. Similar variability among the parents and hybrids was also reported for these traits by Chikuta *et al.* (2017), Ingle *et al.* (2018), El-Sherbeny *et al.* (2019), Gomes *et al.* (2020), Ribeiro *et al.* (2021) and El-Komoss *et al.* (2022).

3.4. Combining ability effects

General combining ability effects (GCA): The primary criteria for selection of favourable parents are usually based on mean values and additive gene action for traits under consideration. Genetically, general combining ability is associated with additive gene action. For days to 50% blooming, where negative GCA effects are desirable, BSH-32 from female lines and RSH-28 from the male lines showed the highest significant (p<0.01) negative GCA effects under normal and stress irrigation levels over the two seasons as well as overall environments (Table 5).

Table 5. Combined analysis of variance for days to 50% blooming, plant height, 1000-grain weight and grain yield/plant of 40 genotypes under the two irrigation levels in the two seasons.

S.O.V	d.f	Mean squres			
		Days to 50% blooming	Plant height (cm.)	1000- grain weight (g)	Grain yield /plant (g)
Parents (P)	10	15.50**	3103.26**	20.55**	240.23**
Crosses (C)	27	27.39**	2871.98**	14.26**	884.24**
Females (F)	3	85.86**	2990.18	22.61*	640.29
Males (M)	6	29.70**	2016.68	32.08**	2013.58*
F × M	18	16.87**	3137.37**	6.93**	548.45**
P vs. C	1	642.69**	59661.03**	13.33**	16601.00**
Poled Error (Ec)	304	1.71	37.59	0.42	4.78

*, ** *Significant at 0.05 and 0.01 of probability levels, respectively.*

This indicates that these lines contributed to improving short duration to blooming in the crosses. Both BSH-32 and RSH-28 were superior in terms of *per se* performance for grain yield/plant. Favourable highly significant positive GCA value for plant height was obtained for the female line BTX-635 and the male line ZSV-14 under normal and stress irrigation levels over the two seasons as well as overall environments (Table 6). This contributed to increase plant height in the crosses. For 1000-grain weight under normal and stress irrigation levels over the two seasons and overall environments (Table 6), the female parent ICSB-70 and the male parents ICSR 93002 and RSH-95 displayed that positive and highly significant GCA effects, in which means that these parents had desirable genes to increase the size of grain and attributed for increasing the total grain yield. Results in Table 6 for grain yield/plant exhibited that the female lines BTX-1 and BSH-32 and the male lines ICSR 93002, RSH-95 and RSH-60 appeared positive and significant (p<0.01) GCA effects. These lines can be considered the best combiners for increasing grain yield/plant, which means that these lines had desirable genes for grain yield/plant. The parents selected for a particular trait were not always acceptable for other trait. For example, RSH-95 had high mean grain yield and highly significant positive GCA effect but longer duration to blooming was unfavourable in this study under different conditions. While, RSH-28 showed the highest significant (p<0.01) negative GCA effect favourable for blooming but low mean grain weight and yield under different conditions. From this study detected that the female line BSH-32 appeared to be the best general combiner for earliness and grain yield at different conditions (Table 6). The male parent ICSR 93002 recorded significant ($p<0.01$) and favourable GCA effects for 1000-grain weight and grain yield/plant. Similarly, the male parent RSH-28 depicted significant and desirable GCA effects for earliness and plant height. Further, the male parent RSH-95 illustrated significant ($p<0.01$) GCA effects in favourable direction for plant height, 1000-grain weight and grain yield/plant. The above promising male parents having high GCA effects for yield can be suitably incorporated in hybrid breeding programmes. These results are in agreement with those obtained by Chikuta *et al.* (2017), Ingle *et al.* (2018), El-Sagheer *et al.* (2019), Wagaw and Tadesse (2020), Veldandi *et al.* (2021) and El-Komoss *et al.* (2022).

3.5. Specific combining ability effects (SCA)

Superior cross combinations were selected based on both hybrid performance and SCA effects. Earliness has been considered advantageous to stabilize sorghum yield as it well combat mid-season and terminal drought conditions. For days to 50% blooming where negative SCA effects are desirable, ATX-1 × ICSR-93002 and ATX-635 × RSH-28 showed the highest significant ($p < 0.05$ or 0.01) negative SCA effects under normal and stress irrigation levels over the two seasons as well as overall environments (Table 7). Both or either of the parents indicated high GCA effects for earliness and hence they could be exploited for development of early maturing crosses. For plant height, seven crosses detected positive and significant or highly significant SCA effects under the two irrigation levels over the two seasons as well as overall environments (Table 7). Among twenty eight crosses, six crosses recorded significant ($p<0.01$) positive SCA effects in desirable direction for 1000-grain weight under normal and stress irrigation levels over the two seasons as well as overall environments (Table 7). For grain yield/plant under normal and stress irrigation levels as well as overall environments, six crosses exhibited higher magnitude of positive significant ($p<0.01$) SCA effects in desirable direction for this trait (Table 7). These crosses were considered the best combinations for grain yield/plant. Similar findings were obtained by Chikuta *et al* (2017), Jadhav and Deshmukh (2017), Ingle *et al* (2018), El-Sherbeny *et al* (2019), Wagaw and Tadesse (2020), Veldandi *et al.* (2021), El-Kady *et al.* (2022), El-Komoss *et al.* (2022) and Williams-Alanís *et al.* (2022).

3.6. Heterosis

Estimates of percentage heterosis of the better parent of 28 F_1 crosses for all the studied traits under normal and stress irrigation levels over the two seasons as well as overall environments are presented in Table 8.

3.6.1. Days to 50% blooming

A negative heterosis estimate for days to 50% blooming is favourable because it implies that the crosses bloomed earlier than their parents. Favourable (Negative and significant or non-significant) better parent heterosis was observed for days to 50% blooming in 11, 15 and 20 crosses under normal and stress irrigation levels over the two seasons as well as overall environments, respectively. Three of them *viz.*, ATX-635 × RSH-28, ASH-32 × MR-812 and ASH-32 × RSH-60 registered negative and significant standard heterosis for days to 50% blooming combined with significant specific combining ability and *per se* performance at both irrigation levels over the two seasons as well as overall environments. Hence, these hybrids could be utilized to develop the crosses with good blooming.

Table 6. Estimates of general combining ability effects for days to 50% blooming, plant height, 1000-grain weight and grain yield/plant under normal and stress irrigation over the two seasons as well as overall environments.

No.	Parents	Days to 50% blooming			Plant height (cm.)			1000-grain weight (g)			Grain yield/plant (g)		
		Over seasons		Overall	Over seasons		Overall	Over seasons		Overall	Over seasons		Overall
		100% ET	50% ET	env.	100% ET	50% ET	env.	100% ET	50% ET	env.	100% ET	50% ET	env.
A-	Female parents												
1	BTX-1	-0.36	0.23**	-0.06	-0.95	1.09	0.07	-0.08	-0.13	-0.11	2.71**	3.44**	3.08**
2	ICSB-70	0.88*	0.59**	0.74**	1.26	0.68	0.97	0.72**	0.74**	0.73**	-1.86**	-1.89**	-1.88**
3	BTX- 635	0.88*	0.59**	0.74**	8.05**	5.42**	6.74**	-0.03	-0.21	-0.12	-2.14**	-3.34**	-2.74**
4	BSH-32	-1.40**	-1.41**	-1.41**	-8.36**	-7.20**	-7.78**	-0.60**	-0.40**	-0.50**	1.29**	1.80**	1.54**
S.E.		0.39	0.07	0.14	1.16	0.67	0.67	0.09	0.11	0.07	0.39	0.07	0.24
B-	Male parents												
1	ICSR 93002	-0.55	0.01	-0.27	-6.68**	-5.64**	-6.16**	2.10**	0.68**	1.39**	11.27**	10.87**	11.07**
2	ZSV-14	0.20	0.14	0.17	10.03**	10.36**	10.19**	-0.75**	-0.84**	-0.80**	-4.20**	-5.65**	-4.92**
3	RSH-28	-1.93**	-1.20**	-1.56**	7.45**	1.32	4.38**	-1.12**	-0.46**	-0.79**	-3.91**	-4.65**	-4.28**
4	RSH-95	1.32*	0.43**	0.88**	2.70	4.40**	3.55**	1.14**	0.46**	0.80**	4.32**	3.62**	3.97**
5	MR-812	0.40	0.85**	0.63**	-8.47**	-8.39**	-8.43**	-0.37**	0.01	-0.18*	-8.95**	-5.76**	-7.36**
6	NM-36565	0.28	-0.11	0.08	-2.97	0.94	-1.01	-0.30*	0.22	-0.04	-2.14**	-1.93**	-2.04**
7	RSH-60	0.28	-0.11	0.08	-2.05	-2.98**	-2.51**	-0.70**	-0.06	-0.38**	3.61**	3.49**	3.55**
S.E.		0.62	0.13	0.19	1.53	0.89	0.88	0.12	0.14	0.09	0.62	0.13	0.32

*, ** *Significant at 0.05 and 0.01 of probability levels, respectively.*

Table 7. Estimates of specific combining ability effects for days to 50% blooming, plant height, 1000-grain weight and grain yield/plant under normal and stress irrigation levels over the two seasons as well as overall environments.

No.	Crosses	Days to 50% blooming (days)			plant height (cm)			1000-grain weight (g)			grain yield/plant (g)		
		Over seasons		Overall	Over seasons		Overall	Over seasons		Overall	Over seasons		Overall
		100% ET	50% ET	envi.	100% ET	50% ET	envi.	100% ET	50% ET	envi.	100% ET	50% ET	envi.
1	ATX-1 × ICSR-93002	-2.52*	-1.77**	-2.15**	2.70	2.95*	2.83	0.34	0.21	0.28	-1.01	1.98**	0.49
2	ATX-1 × ZSV-14	0.23	-0.57*	-0.17	2.16	4.62**	3.39	0.19	0.07	0.13	10.06**	18.33**	14.20**
3	ATX-1 × RSH-28	0.52	-0.40	0.06	-23.26**	-26.51**	-24.88**	-1.33**	-0.82**	-1.08**	-4.19**	-13.11**	-8.65**
4	ATX-1 × RSH-95	0.44	0.48	0.46	-6.01*	-0.42	-3.21	0.04	0.62**	0.33	0.94	4.07**	2.50**
5	ATX-1 × MR-812	0.19	0.06	0.13	-1.01	-3.96**	-2.49	-0.23	-0.87**	-0.55**	-7.15**	-11.56**	-9.35**
6	ATX-1 × NM-36565	0.48	1.18**	0.83*	5.66	5.20**	5.43**	0.41	0.04	0.23	8.34**	7.44**	7.89**
7	ATX-1 × RSH-60	0.65	1.02**	0.83*	19.74**	18.12**	18.93**	0.58*	0.75**	0.67**	-7.01**	-7.15**	-7.08**
8	ICSA-70 × ICSR-93002	0.41	-1.46**	-0.53	-8.51**	-7.81**	-8.16**	-0.20	0.17	-0.01	0.40	3.14**	1.77**
9	ICSA-70 × ZSV-14	-3.51**	1.58**	-0.96*	1.78	1.02	1.40	0.26	-0.07	0.09	-2.97**	-7.76**	-5.37**
10	ICSA-70 × RSH-28	-1.05	-0.09	-0.57	-1.30	3.23*	0.96	1.01**	1.41**	1.21**	-1.34	1.02**	-0.16
11	ICSA-70 × RSH-95	0.70	-0.05	0.33	-16.05**	-15.35**	-15.70**	-0.23	0.18	-0.03	-1.98	0.23	-0.88
12	ICSA-70 × MR-812	0.79	0.70**	0.74*	23.61**	18.44**	21.03**	0.16	0.25	0.20	4.10**	4.25**	4.17**
13	ICSA-70 × NM-36565	0.58	-0.67**	-0.05	4.61	5.27**	4.94**	-0.89**	-1.03**	-0.96**	-4.45**	-8.39**	-6.42**
14	ICSA-70 × RSH-60	2.08*	-0.01	1.04**	-4.14	-4.81**	-4.47*	-0.12	-0.90**	-0.51**	6.24**	7.51**	6.88**
15	ATX-635 × ICSR-93002	3.08**	1.37**	2.22**	7.04*	7.45**	7.24**	0.08	-1.28**	-0.60**	1.68	-2.44**	-0.38
16	ATX-635 × ZSV-14	1.83	-0.59*	0.62	-0.01	1.79	0.89	0.47*	0.36	0.42*	0.85	0.44	0.65
17	ATX-635 × RSH-28	-2.05*	-0.92**	-1.48**	20.24**	21.33**	20.79**	-0.61*	-1.12**	-0.86**	-3.64**	3.77**	0.07
18	ATX-635 × RSH-95	0.20	-0.55*	-0.17	-8.17**	-10.76**	-9.46**	-0.50*	0.53**	0.01	1.43	-0.84**	0.30
19	ATX-635 × MR-812	-0.55	0.04	-0.26	-29.84**	-25.46**	-27.65**	0.94**	1.10**	1.02**	-0.10	0.22	0.06
20	ATX-635 × NM-36565	-0.59	-0.67**	-0.63	4.66	3.70**	4.18*	0.64**	0.93**	0.79**	-1.24	-0.47	-0.85
21	ATX-635 × RSH-60	-1.92	1.33**	-0.30	6.08*	1.95	4.01*	-1.02**	-0.53**	-0.77**	1.01	-0.70**	0.16
22	ASH-32 × ICSR-93002	-0.97	1.87**	0.45	-1.23	-2.60*	-1.91	-0.22	0.90**	0.34	-1.08	-2.68**	-1.88**
23	ASH-32 × ZSV-14	1.45	-0.42	0.51	-3.93	-7.43**	-5.68**	-0.92**	-0.36	-0.64**	-7.94**	-11.01**	-9.47**
24	ASH-32 × RSH-28	2.57*	1.41**	1.99**	4.32	1.95	3.13	0.93**	0.53**	0.73**	9.17**	8.31**	8.74**
25	ASH-32 × RSH-95	-1.35	0.12	-0.61	30.23**	26.53**	28.38**	0.69**	-1.32**	-0.32	-0.39	-3.46**	-1.93**
26	ASH-32 × MR-812	-0.43	-0.80**	-0.61	7.23*	10.99**	9.11**	-0.87**	-0.48*	-0.67**	3.15**	7.08**	5.12**
27	ASH-32 × NM-36565	-0.47	0.16	-0.15	-14.93**	-14.18**	-14.56**	-0.17	0.06	-0.05	-2.66**	1.42**	-0.62
28	ASH-32 × RSH-60	-0.80	-2.34**	-1.57**	-21.68**	-15.26**	-18.47**	0.56*	0.68**	0.62**	-0.24	0.33	0.04
S.E.		1.03	0.26	0.38	3.06	1.26	1.77	0.24	0.20	0.19	1.03	0.26	0.63

*, ** *Significant at 0.05 and 0.01 of probability levels, respectively.*

Table 8. Percentage heterosis of the better parent of 28 F_1 crosses for days to 50% blooming, plant height, 1000-grain weight and grain yield/plant under normal and stress irrigation levels over the two seasons as well as overall environments.

No.	Crosses	Days to 50% blooming (days)			plant height (cm)			1000-grain weight (g)			grain yield/plant (g)		
		Over seasons		Overall	Over seasons		Overall	Over seasons		Overall	Over seasons		Overall
		100% ET	50% ET	envi.	100% ET	50% ET	envi.	100% ET	50% ET	envi.	100% ET	50% ET	envi.
1	ATX-1 × ICSR-93002	1.00	-2.93*	-3.13*	0.91	-1.21	-0.10	2.02	0.22	0.01	-4.75*	-12.90**	-8.49**
2	ATX-1 × ZSV-14	2.25*	-2.45*	-1.63	13.93**	11.75**	12.91**	-6.98**	-7.95**	-7.58**	20.33**	18.93**	19.67**
3	ATX-1 × RSH-28	-0.50	-4.17**	-3.26*	-5.06*	-4.86*	-4.86*	-13.35**	-9.86**	-11.84**	8.35**	-6.35**	1.70
4	ATX-1 × RSH-95	4.51**	0.91	0.35	15.19**	14.90**	15.06**	-4.01*	-1.01	-2.76	40.49**	42.05**	41.19**
5	ATX-1 × MR-812	3.76**	-3.03**	0.00	-2.15	0.10	-1.11	-7.11**	-8.25**	-7.80**	-6.36*	-5.59*	-6.02**
6	ATX-1 × NM-36565	3.01*	-1.76	-0.24	15.99**	16.36**	16.16**	-4.72*	-4.09*	-4.57*	23.30**	-13.15	6.85**
7	ATX-1 × RSH-60	3.01*	-0.67	-3.67*	21.95**	22.46**	22.19**	-5.49*	-2.47	-4.22*	12.76**	18.53**	15.36**
8	ICSA-70 × ICSR-93002	4.09**	-2.02	-0.23	-6.51**	-7.98**	-7.22**	7.23**	2.89	5.93*	20.12**	25.85**	22.76**
9	ICSA-70 × ZSV-14	6.12**	0.88	2.95*	11.26**	9.28**	10.32**	-2.23	-3.84*	-2.04	-2.62	-6.59**	-4.33*
10	ICSA-70 × RSH-28	2.56*	-0.45	0.95	22.06**	15.01**	22.39**	15.96**	3.23*	9.84**	0.00	6.90**	2.97
11	ICSA-70 × RSH-95	7.41**	0.68	2.61*	16.63**	4.51*	17.89**	-8.67**	-8.90**	-8.78**	2.52	13.39**	7.05**
12	ICSA-70 × MR-812	6.12**	0.00	2.84*	13.97**	14.47**	14.20**	1.23	0.42	0.95	0.55	16.24**	7.30**
13	ICSA-70 × NM-36565	5.62**	-3.09*	0.95	24.05**	16.14**	26.21**	-2.18	-3.46	-2.78	-1.91	-1.29	-1.59
14	ICSA-70 × RSH-60	7.91**	-1.56	2.48*	11.02**	6.66**	10.49**	-3.00*	-3.99*	-2.38	26.20**	46.54**	34.95**
15	ATX-635 × ICSR-93002	1.68	1.78	-0.92	7.16**	4.14*	5.92**	-7.82**	-5.16*	-5.99*	13.16**	4.69*	9.26**
16	ATX-635 × ZSV-14	0.96	-0.67	-0.69	14.04**	12.68**	13.40*	-4.09*	-4.69*	-3.62*	5.43*	5.80*	5.75*
17	ATX-635 × RSH-28	-5.51**	-1.97	-3.88*	39.91**	39.28**	39.60**	-3.71*	-8.93**	-6.21**	-0.24	14.90**	6.39*
18	ATX-635 × RSH-95	0.24	0.00	-0.57	27.30**	26.71**	27.03**	3.93*	0.96	2.47	12.26**	8.51**	10.62**
19	ATX-635 × MR-812	-2.16*	-1.74	-1.95	-12.27**	-11.10**	-11.73**	4.69*	1.42	3.10	-2.39	-2.69	-2.50
20	ATX-635 × NM-36565	0.72	-3.73*	-1.71	28.52**	30.84**	29.61**	0.60	1.23	0.92	5.67*	12.11**	8.50**
21	ATX-635 × RSH-60	-4.32**	0.00	-2.74*	21.43**	17.91**	19.79**	-8.66**	-5.95*	-7.35**	35.22**	53.69**	43.32**
22	ASH-32 × ICSR-93002	-6.43**	1.12	-3.77*	-7.34**	-9.59**	-8.23**	-8.10**	-8.34**	-7.72**	22.92**	22.35**	22.72**
23	ASH-32 × ZSV-14	-1.67	-3.11*	-3.42*	2.70	-0.82	1.02	-10.82**	-8.37**	-8.89**	-8.10**	-17.17**	-12.33**
24	ASH-32 × RSH-28	-0.96	-1.09	-1.49	19.54**	16.15**	17.96**	-1.96	-3.50*	-2.70	22.75**	14.85**	19.07**
25	ASH-32 × RSH-95	-4.04**	-0.45	-2.53*	35.58**	38.99**	37.17**	-4.71*	-7.07**	-5.84*	9.25**	6.70**	8.06**
26	ASH-32 × MR-812	-2.86*	-4.66**	-3.75*	-0.65	4.46*	1.72	-5.72**	-5.57*	-5.66*	7.79**	11.16**	9.35**
27	ASH-32 × NM-36565	-4.29**	-3.94*	-3.75*	2.89	6.40**	4.53*	-4.26*	-2.88	-3.60*	4.12*	8.28**	6.05*
28	ASH-32 × RSH-60	-1.19	-7.32**	-5.34**	-5.42**	-2.91	-4.34*	-5.17*	-2.10	-3.69*	15.90**	15.11**	0.79

**, ** Significant at 0.05 and 0.01 of probability levels, respectively.*

3.6.2. Plant height

Among twenty eight crosses, the cross ATX-635 × RSH-28 recorded positive and significant ($p<0.01$) tallest useful heterosis under normal (39.91%) and stress (39.28%) irrigation levels over the two seasons as well as overall environments (39.60).

Whereas, the cross ATX-635 × MR-812 registered negative and significant ($p<0.01$) shortest useful heterosis under normal (- 12.27%) and stress (- 11.10%) irrigation levels over the two seasons as well as overall environments (-11.73%). A positive and significant ($p<0.01$) standard heterosis in desirable direction was illustrated by most of the crosses for plant height at both irrigation levels over the two seasons as well as overall environments. Four of them (No. 7, 12, 15, and 17) showed negative and significant standard heterosis for plant height, coupled with significant specific combining ability and *per se* performance at both irrigation levels over the two seasons as well as overall environments. Hence, these crosses could be utilized to develop the crosses with good plant height.

3.6.3. 1000-grain weight

Among 28 F_1 crosses, the cross ICSA-70 × RSH-28 exhibited positive and significant ($p<0.01$) heaviest useful heterosis under normal (15.96%) and stress (3.23%) irrigation levels over the two seasons as well as overall environments (9.84%). This cross showed significant ($p<0.01$) standard heterosis combined with good specific combining ability and mean performance at both irrigation levels over the two seasons and overall environments. Hence, these crosses could be utilized to develop the crosses with good 1000-grain weight. Whereas, the lightest useful heterosis negative and significant ($p<0.01$) was observed by the cross ATX-1 × RSH-28 under normal (- 13.35%) and stress (- 9.86%) irrigation levels over the two seasons as well as overall environments (- 11.84%). A positive and significant ($p<0.01$) standard heterosis in desirable direction was illustrated by some of the crosses for 1000-grain weight at both irrigation levels over the two seasons and overall environments.

3.6.4. Grain yield/plant

The heterosis plays an important role for increasing the productivity of crop without much increase in the cost of production. Grain yield is complex trait rely on many characters. A positive heterosis value for grain yield is desirable because it implies that the crosses outperformed the parents. Among 28 F_1 crosses, the cross ATX-635 × RSH-60 registered positive and significant ($p<0.01$) highest useful heterosis under normal (35.22%) and stress (53.69%) irrigation levels over the two seasons as well as overall environments (43.32%). On the other hand, the lowest useful heterosis negative and significant ($p<0.01$) was obtained by the cross ASH-32 × ZSV-14 under normal (- 8.10%) and stress (-17.17%) irrigation levels over the two seasons as well as overall environments (– 12.33%). Sixteen crosses exhibited positive and significant ($p<0.01$) heterosis over the better parents at the two levels of irrigation over the two seasons and overall environments. Four of them (ATX-1 × ZSV-14, ICSA-70 × RSH-60, ASH-32 × RSH-28 and ASH-32 × MR-812) recorded significant ($p<0.01$) standard heterosis for grain yield, coupled with significant specific combining ability and *per se* performance at both irrigation levels over the two seasons and overall environments. Hence, these crosses could be utilized to develop the crosses with grain yield. The findings of the present investigation are consistent with the earlier reports of Mahmoud *et al.* (2013), Eatemad (2015), Mindaya *et al.* (2016), Chikuta *et al.* (2017), El-Sagheer (2019), El-Kady (2022) and El-Komoss *et al.* (2022).

4. Conclusion

The current study estimated performance, combining ability and heterosis for some agronomic traits under water stress to identify promising sorghum hybrids for further selection and breeding**.** The genotypes exhibited a wide genetic diversity for all traits under study. Some crosses were significantly earlier, taller, heavier grain weight and higher grain yield compared to their parents and the check hybrid under different environments. However, drought applications caused decreases in performance of plant height. 1000-grain weight and grain yield/plant but it increased days to blooming. The female parent BSH-32 appeared to be the best general combiners for earliness and grain yield with high per se performance for grain yield at different environments. The cross ASH-32 × MR-812 recorded significant or non-significant SCA effects in desirable direction for earliness, plant height and grain yield under different environments. The crosses ASH-32 × MR-812 and ASH-32 × NM-36565 exhibited significant heterosis in desirable direction for earliness, taller plants and higher grain yield, coupled with significant specific combining ability and *per se* performance under different environments.

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All authors are contributed in this research

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Data presented in this study are available on fair request from the respective author.

Ethics Approval and Consent to Participate

Not applicable

Consent for Publication

Not applicable.

Conflicts of Interest

The authors disclosed no conflict of interest.

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