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Estimation of Heterosis and Combining Ability Effects on Grain Yield and Some Agronomic Traits of Sorghum under Three NPK Fertilizers Levels

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HETEROSIS and combining ability for grain yield and some agronomic traits were studied among thirty F1 grain sorghum crosses and their elven parents under three NPK levels during 2014 and 2015 seasons. Significant differences among genotypes were found for all studied traits, indicating wide genetic diversity. The interaction of genotypes with each of years and NPK levels were significant in most studied traits. The analysis of variance for combining ability revealed that the mean square due to entries, parents, parents vs. crosses, crosses, lines, testers, lines × testers turned up significant for all studied characters and suggesting that the experimental materials possessed considerable variability that both general and specific combining ability were involved in the genetic expression of these characters. The female line ICSB610 showed significant and negative general combining ability (GCA) effects for days to 50% heading and panicle length and positive for grain yield and plant height. It may be used to develop high yielding, early flowering, and tall hybrids with short panicles. For specific combining ability (SCA), effects, the crosses ICSA613 × ICSR89028 and ICSA20 × ICSR53 gave positive and highly significant SCA effects which indicated that these crosses can be considered desirable combiners. These crosses had also high grain yield *per se* and one of the parents with highest GCA effects. The observations on portioning of combining ability variance into additive and dominance variances indicated the role of both additive and dominance gene action. The magnitude of non-additive variance was higher than the additive variance by many folds for all studied traits.

Keywords: Heterosis, Combining ability, Sorghum, NPK nutrients

Grain sorghum (*Sorghum bicolor* L. Moench) is the fifth leading cereal crop in the world after maize, rice, wheat, and barley (FAOSTAT, 2014). However, sorghum grain is the staple food of poor and the most food-insecure people, living mainly in the semi-arid regions (Ali *et al.*, 2009 and Bibi *et al.*, 2010). Africa contributes more than 60% of the total land area under sorghum (FAOSTAT, 2012), but the yields have remained low (less than 1t ha^{-1}) due to continuous use of low yielding cultivars (Ringo *et al.*, 2015). Sorghum performs better under adverse soil and weather conditions as compared to other crops (Ejeta & Knoll, 2007). Worldwide, crop production is restricted by the

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concentrations and chemical forms of mineral elements, and adequate supplies of the essential mineral elements nitrogen (N), potassium (K), phosphorus (P) and the other essential mineral elements are required for maximal crop production (White & Brown, 2010). Phytoavailability of N, K, P, or S often limits low-input agriculture (Fageria *et al.*, 2011 and Mueller *et al.*, 2012). Moreover, sorghum is a C4 annual crop which can produce high forage biomass yields per unit of area (Rooney *et al.*, 2007) and uses nitrogen in a more efficient way compared to most C3 crops (Young & Long, 2000). Sorghum was investigated under low fertility conditions by several studies (Al-Naggar *et al.*, 2006; Hovny & El-Dsouky, 2007; Abd EL-Mottaleb, 2009; Omar *et al.*, 2014 and Amir & Mohamed, 2015). They stated that reducing N levels delayed flowering date, reduced grain yield plant^{-1} and reduced 1000 grain weight as well as significant positive GCA effects of female and male lines under low nitrogen level for grain yield plant^{-1} and 1000 grain weight. Utilization of grain sorghum hybrids can significantly increase yields in sorghum growing areas (House *et al.*, 1997) because they out-yield local cultivars and improved varieties by 20 - 60% (Bantilan *et al.*, 2004). This potential of hybrids is estimated from the percentage increase or decrease of their performance over the mid-parent (average heterosis) and better-parent (heterobeltiosis) (Hochholdinger & Hoecker, 2007). Furthermore, both types of heterosis were worked out in order to have broad picture of performance for materials across dry lands and sub-humid environments, and positive heterosis in a desired trend is preferred in selection for yield and its components (Lamkey & Edwards, 1999). Combining ability analysis is one of the powerful tools available to estimate the combining ability effects and aids in selecting the desirable parents and crosses for the exploitation of heterosis (Sarker *et al.*, 2002 and Rashid *et al.*, 2007). The general combining ability (GCA) of parental genotypes should be examined when the objective is the development of superior genotypes, while the specific combining ability (SCA) effects provide information about the performance of hybrids (Cruz & Regazzi, 1994). The differences in GCA are mainly due to the additive genetic effects and higher order additive interactions, while the differences in SCA are attributed to the non-additive dominance and other types of epitasis (Falconer, 1989). This information would be useful to investigate the performance and relationship of F1 hybrids and parents and to select suitable parents and population for designing an effective breeding program. Presence of heterosis, GCA and SCA effects for yield and its related traits are reported by Abo-Elwafa *et al.* (2005), Faiz *et al.* (2006), Hovny & El-Dsouky (2007), Saleem *et al.* (2008), Abd eL–Mottaleb (2009), Kanbar *et al.* (2011) and Omar *et al.* (2014).

This investigation aimed to: 1) Determine heterosis over mid- and better-parent for yield and agronomic traits by identifying suitable heterotic parents under NPK levels. 2) Assess the combining ability of current sorghum materials, aiming to a parental selection improvement for low NPK fertility tolerance in breeding programs to increase production.

Materials and Methods

Plant materials and hybrids development

Plant material of the experiment comprised of 30 F_1 grain sorghum crosses formed by crossing six inbred lines (cytoplasmic male sterility lines) to five testers in a line x tester mating design in the summer season of 2013 to generate the breeding material and two standard checks (Hybrid 305 and Dorado). The female lines (ICSA20, ICSA52, ICSA608, ICSA610, ICSA613 and ICSA93) and male lines (ICSR29, ICSR53, ICSR89028, ICSR91020 and ICSR93004) were obtained from India (International Crop Research Institute for Semi-Arid Tropics, ICRISAT).

Experimental site

The 43 grain sorghum entries were grown at Assiut Agricultural Research Farm, Assiut University, Assiut, Egypt. The preceding crop of the experimental site for the two seasons was wheat. The physical and chemical properties of experimental site are shown in Table 1.

TABLE 1. Some physical and chemical properties of representative soil samples of the experimental site before sowing (0-30 cm depth) for the two growth seasons.

Soil property	2010/2011 season*	2011/2012 season*
Particle - size distribution		
Silt (%)	27.4	27.3
Sand (%)	24.3	25.2
Clay (%)	48.3	47.5
Texture	Clay	Clay
Organic matter (%)	1.75	1.72
Field capacity (%)	42.8	43.2
EC (1:1 extract) (dS m^{-1})	0.74	0.77
pH (1:1 suspension)	8.2	8.1
Total nitrogen (%)	0.72	0.69
$CaCO_3$ (%)	3.4	3.5
KCl-extractable N (mg kg^{-1})	41.23	40.26
$NaHCO_3$-extractable P (mg kg^{-1})	4.36	4.65
NH_4OAC-extractable K (mg kg^{-1})	49.24	50.86

* Each value represents the mean of three replications.

Experimental design and field management

The field design was a randomize compete block design (RCBD) using strip plot arrangement with three replicates. NPK levels were allocated to the main plots and entries to subplots. Each entry (genotype) was placed in a three rows plot of 3 m long and 60 cm apart with 20 cm between plants. Trial was hand planted with 3-4 seeds per hill, which was later be thinned to secure two plants per hill. Planting was done in the two summer successive seasons at 17^{th} and 16^{th} of June in 2014 and 2015 seasons, respectively. Standard cultural practices for optimum sorghum production were carried out in both seasons. Three fertilizers levels, 100% (L1), 75% (L2) and 50% (L3) of the recommended doses, *i.e.* 240, 54 and 57.6 kg/ha of N, P and K fertilizers, respectively. Urea (46.5% N), Superphosphate (15% P_2O_5) and Potassium sulphate (48% K_2O) were used as a source of N, P and K, respectively. The super-phosphate and potassium sulfate were applied once before the first irrigation, while urea was divided into three doses and applied before the first, second and third irrigations.

Data collection

The data was recorded for days to 50% heading (HD; day) on whole plot basis, whereas plant height (PH; cm) and panicle length (PL; cm) on the average samples of five random competitive plants from each genotype were tagged in each replication (border plants were excluded). Seed index (SI; g) was recorded on the weight of 1000-grain in grams from each genotype per each replication, while, biological yield (BY; t ha^{-1}) and grain yield (GY; t ha^{-1}) were recorded on the total number of plants per plot, then the data of biological yield and grain yield per plot were transformed to t/ ha.

Statistical analysis and procedures

Analysis of Variance

30 F_1 hybrids, their parents and two check varieties were evaluated for grain yield and some agronomic traits over three NPK levels and two years. Years (Y) and NPK levels represent six different environmental conditions, according to this, the combined analysis was performed according to Steel *et al.* (1997) after carrying out the homogeneity using Bartlett test, to estimate the main effects of the different sources of variation and their interactions.

Correlation

Phenotypic correlations among studied traits were determined under overall NPK levels and years using Pearson's correlation test. The ANOVA and the correlation test were performed using SAS software (v 9.2, 2008).

Combining ability analysis

The general (GCA) and specific (SCA) combining ability of the parents and hybrids were worked out as per the method outlined by Kempthorne (1957) in order to determine the significance of differences among hybrids and parents.

Heritability

Broad (H^2_B) and narrow (H^2_N) sense heritability were measured as follows:

$$H^2_B = \sigma^2_G / \sigma^2_P \qquad\qquad H^2_N = \sigma^2_A / \sigma^2_P$$

where, σ_G^2 is the genetic variance, σ_P^2 is the phenotypic variance and σ_A^2 is the additive variance.

Heterosis

Mid-parent (MP) and best-parent (BP) heterosis percentages were computed by using the following fomulas:

$$MP_{ij} = \frac{F_{1ij} - Mp_{(F1ij)}}{Mp_{(F1ij)}} \qquad BP_{ij} = \frac{F_{1ij} - BP_{(F1ij)}}{BP_{(F1ij)}}$$

where MP_{ij} is the heterosis of the *ij*th cross; BP_{ij} is the heterobeltiosis (best-parent heterosis) of the *ij*th cross; F_{1ij} is the mean of the *ij*th F_1 cross; MP (F_{1ij}) is the mid-parent [(Parent1 + Parent2) / 2] for the $_{ij}$th cross; and BP(F_{1ij}) is the best parent values for the ijth cross. Significance was tested by the appropriate revised Least Significant Difference (LSD) at 5% level of significant according to Steel & Torrie (1981).

Results and Discussion

Data in Table 2 show that all the variance components, years, NPK levels, genotypes and interactions were affected significantly in all studied traits except plant height (PH) and biological yield which were not affected significantly by the NPK levels and years, respectively. Moreover, significant differences among genotypes were found for all studied traits, indicating wide genetic diversity. The interaction of genotypes with each of years and NPK levels were significant in most studied traits, reflecting that expression of these traits are controlled mostly by the non-additive effects of genes that are not stable under NPK levels over both years. Similarly, the analysis of variance for combining ability revealed that the mean square due to entries, parents, parents vs. crosses, crosses, lines, testers, lines × testers turned up significant for all studied characters suggesting that the experimental materials possessed considerable variability in both general and specific combining ability involved in the genetic expression of these characters (Table 3). The results obtained were concur with those obtained by Al-Nagar *et al.* (2007) and Abou-Amer & Kewan (2014) who found that N and NP levels and their interaction with genotypes had a highly significant effect on sorghum green fodder yield and grain yield (t/fad (fad=2400 m^2)). Variation among parents, crosses, parents vs crosses, lines, testers and line × testers also was observed in several sorghum studies such as Hovny & El-Dsouky (2007), Abdel-Mottaleb (2009), Essa (2009) and Mahdy *et al.* (2011).

TABLE 2. Mean squares of the combined analysis of variance for grain yield and agronomic traits.

S.V.	DF	50% HD	PH; cm	PL; cm	SI; g	BY; T/H	GY; T/H
Year (Y)	1	2449.8	35710.02	140.70	1308.14	5034.68	5.78
Y(Rep)	4	9.30	477.92	35.68	28.08	959.33	0.57
NPK levels (L)	2	274.21	1674.27	217.83	118.89	1244.41	134.12
YL	2	96.42	324.61	197.65	42.04	31.72	1.29
YL(Rep)	8	7.21	456.25	8.53	11.68	31.50	0.34
Genotypes (G)	42	195.59	7773.13	90.35	68.74	3284.03	17.57
GY	42	73.32	2035.31	36.95	35.50	220.58	16.70
GL	84	4.68	77.99	7.76	10.38	82.84	1.23
GYL	84	5.42	104.00	7.98	10.79	14.47	1.09
Error	504	1.72	104.55	5.99	7.95	71.94	0.38

*; ** Significant at the 0.05 and 0.01 probability levels, respectively

TABLE 3. Mean squares of the combined line × tester analysis for all studied traits overall environments (NPK levels and the two years).

Source	DF	50% HD	PH; cm	PL; cm	SI; g	BY; T/H	GY; T/H
Environments (Envi)	5	626.8**	7766.8**	187.5**	318.2**	1455.9*	54.5**
Rep(Envi)	12	8.2**	423.2**	17.1**	14.7*	392.2**	0.5
Entries (E)	40	191.9**	6951.8**	89.4**	69.5**	3301.3**	17.7**
Parents (P)	10	348.2**	2217.6**	92.6**	129.2**	2903.3**	5.3**
P vs C	1	41.8**	200523**	1383.2**	239.6**	76785.4**	482.4**
Crosses (C)	29	143.2**	1909.4**	43.7**	43.0**	904.6**	5.9**
Lines (L)	5	80.8**	1885.3**	43.8**	112.4**	1587.3**	25.7**
Testers (T)	4	573.5**	5435.8**	94.5**	90.6**	3414.3**	39.8**
L*T	20	72.7**	1210.2**	33.5**	16.1**	231.9**	15.2**
Envi*E	200	19.1**	499.7**	13.8**	15.3**	86.5	4.4**
Envi*P	50	15.7**	605.5**	13.4**	21.1**	35.9	5.6**
P vs C *Envi	5	7.1**	213.5	24.2**	8.5	92.3*	86.7**
Envi*C	145	20.7**	473.0**	13.7**	13.5**	103.7**	1.2**
Envi*L	25	15.4	584.2	19.9**	20.6*	77.0	9.7**
Envi*T	20	49.0**	590.4	21.2**	16.2	393.5**	3.8**
Envi*L*T	100	16.4**	421.8**	10.6**	11.3**	52.4	2.7**
Error	480	1.8	107.5	6.1	7.5	71.8	0.37

*; ** Significant at the 0.05 and 0.01 probability levels, respectively.

Days to 50% heading

As an average of the genotypes (Table 4), heading date was delayed by decline the amount of NPK fertilizers added. Since, significant difference between L1 (69.7 day) and L3 (71.7 day) was observed. Similar result was observed by Omar *et al.* (2014) who found that mean days to 50% flowering of hybrids and their parents were increased by increasing nitrogen stress. Under the three NPK levels, female lines and crosses were earlier than male lines and check varieties. About half of the crosses were earlier than the earliest check variety (Hybrid 305), and the last was earlier than Dorado cultivar. The results furthermore, reveal that elven crosses exhibited significant and negative mid-parent heterosis (Table 5). Also, elven crosses show highly significant and negative specific combining ability (SCA) indicating that these crosses can be considered as good combiners for earliness. Among the parental lines, five lines show negative and highly significant general combining ability (Table 6). The cross (ICSA610 × ICSR29) shows significant and negative mid-parent heterosis and had highest negative SCA values among crosses (Table 7). The female line ICSB610 had the highest negative GCA among females and involved in the best cross in days to 50% heading. The previous results indicated that this line may be harboring the genes that underlay the earliness, whereas in testers, ICSR91020 gave maximum GCA effect (-3.76**), these parents contributed to improving short duration to heading in the crosses. These results are in harmony with those obtained by Hovny & El-Dsouky (2007), Abdel-Mottaleb (2009), Essa (2009), Mahdy *et al.* (2011), Abou-Amer & Kewan (2014), Omar *et al.* (2014) and Amir & Mohamed (2015).

Plant height (PH)

The plant height of sorghum genotypes decreased as a result of reducing the amount of NPK fertilizers comparing with 100% of recommended NPK. The average reduction in plant height was not significant. However, the majority of the crosses were taller than their parents and the check verities indicating the existence of heterosis under all studied NPK levels. As an average, the maximum plant height (204.5 cm) was set by the cross ICSA608 × ICSR29 followed by ICSA613 × ICSR53 (200.8 cm) as *per se* hybrid performance (Table 4). Among female lines, ICSB93 set the tallest plant height (156.0 cm) whereas in testers, ICSR53 gave the highest value of plant height (162.9 cm). Line ICSB613 gave maximum (6.03**) positive GCA effects and involved in the second taller cross (Table 6), this line tends to increase plant height. Whereas among the testers, ICSR29 manifested maximum (10.00**) positive GCA effects and involved in the second taller cross indicating that both the parents retain more additive genes, thus may be utilized in hybridization programs for improving plant height in segregating population. The crosses (ICSA608 × ICSR29) and (ICSA52 × ICSR89028) gave maximum SCA effects of 12.06 and 11.74, respectively, which may be considered suitable for hybrid crop development (Table 7). These findings are in agreement with those obtained by Hovny & El-Dsouky (2007), Abdel-Mottaleb (2009), Essa (2009), Mahdy *et al.* (2011) and Amir & Mohamed (2015).

TABLE 4. Mean performance of the 30 F1 hybrids. their respective parents and check varieties under three NPK levels (100, 75 and 50%) over both years for days to 50% heading, plant height and panicle length.

Traits / Genotypes	50% HD				PH; cm				PL; cm			
Irrigation / Hybrids	100%	75%	50%	Mean	100%	75%	50%	Mean	100%	75%	50%	Mean
ICSA20 × ICSR29	70.5	70.8	72.0	**71.1**	198.1	203.6	196.1	**199.3**	30.4	28.9	29.4	**29.6**
ICSA20 × ICSR53	71.3	72.2	74.7	**72.7**	173.8	178.3	174.2	**175.4**	30.4	27.5	28.6	**28.8**
ICSA20 × ICSR89028	71.0	71.8	73.2	**72.0**	173.3	165.1	165.3	**167.9**	31.9	30.6	30.6	**31.0**
ICSA20 × ICSR91020	66.8	67.7	69.3	**67.9**	175.9	177.1	177.2	**176.7**	32.2	30.7	29.9	**30.9**
ICSA20 × ICSR93004	74.2	74.5	75.2	**74.6**	184.7	183.3	169.7	**179.2**	33.1	29.2	26.8	**29.7**
ICSA52 × ICSR29	73.3	72.2	75.3	**73.6**	183.2	185.8	181.4	**183.5**	31.8	29.8	27.7	**29.8**
ICSA52 × ICSR53	68.7	69.8	71.7	**70.1**	186.4	185.2	183.1	**184.9**	27.5	25.1	26.0	**26.2**
ICSA52 × ICSR89028	69.2	68.5	70.0	**69.2**	198.6	191.7	189.3	**193.2**	31.9	29.7	30.9	**30.8**
ICSA52 × ICSR91020	65.3	66.5	67.3	**66.4**	180.8	179.8	181.6	**180.7**	28.7	26.5	25.6	**26.9**
ICSA52 × ICSR93004	67.5	69.3	70.3	**69.0**	171.9	173.8	165.9	**170.5**	30.8	30.9	30.7	**30.8**
ICSA608 × ICSR29	70.2	69.7	72.3	**70.7**	210.9	206.6	196.1	**204.5**	30.3	29.5	31.7	**30.5**
ICSA608 × ICSR53	69.3	70.2	72.3	**70.6**	184.2	183.0	179.4	**182.2**	31.8	26.9	29.3	**29.3**
ICSA608 × ICSR89028	71.5	71.3	74.7	**72.5**	182.5	181.0	175.6	**179.7**	32.6	31.4	31.0	**31.7**
ICSA608 × ICSR91020	64.0	65.8	67.0	**65.6**	177.1	172.6	166.1	**171.9**	32.3	29.9	31.3	**31.2**
ICSA608 × ICSR93004	75.5	76.8	75.3	**75.9**	182.0	173.4	166.8	**174.1**	30.2	28.4	29.4	**29.3**
ICSA610 × ICSR29	65.3	66.3	68.2	**66.6**	195.8	190.2	192.6	**192.9**	30.6	27.8	30.2	**29.5**
ICSA610 × ICSR53	68.5	70.2	72.3	**70.3**	187.5	186.4	180.9	**184.9**	27.8	26.8	28.3	**27.6**
ICSA610 × ICSR89028	70.7	72.2	74.7	**72.5**	180.7	176.3	172.0	**176.3**	28.7	27.8	28.7	**28.4**
ICSA610 × ICSR91020	66.8	67.2	67.8	**67.3**	181.9	182.3	181.2	**181.8**	30.9	30.4	29.8	**30.4**
ICSA610 × ICSR93004	68.7	69.0	70.3	**69.3**	189.6	187.1	171.9	**182.9**	28.8	27.5	25.5	**27.3**
ICSA613 × ICSR29	71.3	70.2	72.5	**71.3**	190.4	189.6	183.6	**187.9**	29.3	27.3	27.1	**27.9**
ICSA613 × ICSR53	66.5	67.3	67.2	**67.0**	202.2	202.9	197.4	**200.8**	32.7	30.7	28.2	**30.5**
ICSA613 × ICSR89028	69.3	69.8	72.8	**70.6**	194.9	189.0	183.1	**189.0**	32.3	29.3	29.3	**30.3**
ICSA613 × ICSR91020	64.8	66.7	68.8	**66.8**	191.9	193.6	191.4	**192.3**	32.9	30.6	29.4	**31.0**
ICSA613 × ICSR93004	71.0	74.3	73.0	**72.8**	159.8	178.2	168.1	**168.7**	27.9	30.2	30.2	**29.4**
ICSA93 × ICSR29	72.5	72.3	75.5	**73.4**	185.1	184.7	177.1	**182.3**	32.5	31.6	31.9	**32.0**
ICSA93 × ICSR53	67.8	68.7	69.2	**68.6**	182.6	184.2	181.1	**182.6**	28.7	26.1	26.3	**27.0**
ICSA93 × ICSR89028	70.8	71.2	74.2	**72.1**	182.6	177.0	172.7	**177.4**	32.8	28.8	32.4	**31.3**
ICSA93 × ICSR91020	64.5	65.5	66.0	**65.3**	167.4	162.4	165.1	**165.0**	32.2	31.9	29.6	**31.2**
ICSA93 × ICSR93004	72.3	73.8	74.2	**73.4**	166.3	164.5	157.8	**162.9**	29.7	27.3	28.6	**28.5**
Hybrid's mean	**69.3**	**70.1**	**71.6**	**70.3**	**184.1**	**183.0**	**178.1**	**181.7**	**30.8**	**29.0**	**29.1**	**29.6**
Female lines												
ICSB20	68.0	68.3	67.2	**67.8**	132.5	135.0	132.4	**133.3**	27.1	25.9	27.1	**26.7**
ICSB52	65.5	65.0	67.8	**66.1**	148.1	143.0	145.1	**145.4**	25.1	26.0	25.8	**25.6**
ICSB608	67.3	67.7	68.2	**67.7**	133.0	133.9	129.6	**132.2**	26.7	22.5	27.5	**25.6**
ICSB610	67.5	68.0	69.3	**68.3**	129.8	129.8	132.7	**130.8**	26.9	27.4	26.3	**26.9**
ICSB613	68.5	67.7	70.5	**68.9**	133.8	132.1	131.8	**132.6**	25.1	23.6	23.2	**24.0**
ICSB93	65.3	66.2	68.8	**66.8**	153.9	152.2	161.9	**156.0**	27.2	24.9	27.1	**26.4**
Female's Mean	**67.0**	**67.2**	**68.6**	**67.6**	**138.5**	**137.7**	**138.9**	**138.4**	**26.4**	**25.1**	**26.2**	**25.9**
Males lines												
ICSR29	76.8	75.0	77.5	**76.4**	154.1	155.8	155.1	**155.0**	29.3	27.1	28.1	**28.2**
ICSR53	70.5	71.8	73.3	**71.9**	162.5	165.9	160.4	**162.9**	23.9	22.8	24.4	**23.7**
ICSR89028	78.2	75.5	77.2	**77.0**	154.4	151.2	141.8	**149.1**	28.7	28.3	28.1	**28.4**
ICSR91020	68.3	70.5	71.8	**70.2**	146.2	155.7	144.8	**148.9**	33.1	29.2	32.7	**31.7**
ICSR93004	78.0	78.3	78.5	**78.3**	143.9	145.4	141.1	**143.5**	24.3	23.7	26.9	**25.0**
Male's Mean	**74.4**	**74.2**	**75.7**	**74.7**	**152.2**	**154.8**	**148.6**	**151.9**	**27.9**	**26.2**	**28.0**	**27.4**
Check varieties												
Hybrid 305	70.0	69.8	71.7	**70.5**	204.2	203.4	202.2	**203.3**	31.3	29.2	30.2	**30.2**
Dorado	75.0	77.7	75.3	**76.0**	131.9	132.9	126.7	**130.5**	26.0	25.7	25.2	**25.6**
Check's Mean	**72.5**	**73.8**	**73.5**	**73.3**	**168.1**	**168.2**	**164.5**	**166.9**	**28.7**	**27.5**	**27.7**	**27.9**
Overall Mean	**69.7^{A}**	**70.3^{B}**	**71.7^{C}**	**70.6**	**173.3^{A}**	**172.7^{A}**	**168.6^{B}**	**171.5**	**29.7^{A}**	**28.0^{B}**	**28.5^{C}**	**28.7**
Rev. LSD 5% Genotypes		**0.27**				**5.86**				**1.46**		
Rev. LSD 5% for NPK level		**0.50**				**N.S.**				**0.55**		
Rev.LSD 5% for NPK x G		**1.60**				**N.S.**				**3.78**		

TABLE 4 (Cont.) Mean performance of the 30 F1 hybrids. their respective parents and check varieties under three NPK levels (100, 75 and 50%) over both years for biological yield, grain yield and seed index.

Traits / Genotypes	SI; g				BY; T/H				GY; T/H			
Irrigation / Hybrids	**100%**	**75%**	**50%**	**Mean**	**100%**	**75%**	**50%**	**Mean**	**100%**	**75%**	**50%**	**Mean**
ICSA20 × ICSR29	25.6	25.9	27.6	**26.4**	58.4	62.8	57.8	**59.7**	4.1	3.8	3.8	**3.9**
ICSA20 × ICSR53	25.8	23.6	24.5	**24.6**	53.6	55.8	54.9	**54.8**	5.9	6.9	6.0	**6.3**
ICSA20 × ICSR89028	26.4	26.7	26.0	**26.4**	55.7	54.3	55.8	**55.3**	6.0	5.6	4.7	**5.4**
ICSA20 × ICSR91020	27.3	26.0	25.1	**26.1**	39.6	50.4	39.4	**43.1**	5.8	5.2	4.1	**5.0**
ICSA20 × ICSR93004	25.4	25.3	24.9	**25.2**	58.1	62.4	58.1	**59.5**	5.7	5.1	4.7	**5.2**
ICSA52 × ICSR29	29.7	29.6	26.8	**28.7**	46.7	42.2	40.5	**43.1**	6.0	3.8	4.3	**4.7**
ICSA52 × ICSR53	27.8	26.0	27.4	**27.1**	49.4	44.6	44.8	**46.3**	7.6	6.5	5.7	**6.6**
ICSA52 × ICSR89028	31.7	28.0	24.9	**28.2**	54.7	38.0	43.6	**45.4**	5.8	5.2	5.0	**5.3**
ICSA52 × ICSR91020	27.9	26.7	27.0	**27.2**	32.2	34.5	25.4	**30.7**	6.5	5.1	4.0	**5.2**
ICSA52 × ICSR93004	29.5	26.8	26.3	**27.5**	48.9	53.7	47.8	**50.1**	7.2	7.4	6.6	**7.1**
ICSA608 × ICSR29	28.8	28.8	27.1	**28.2**	53.7	52.4	46.5	**50.9**	5.8	5.0	5.2	**5.3**
ICSA608 × ICSR53	26.2	26.3	24.9	**25.8**	52.6	50.5	53.0	**52.0**	5.1	4.8	4.0	**4.6**
ICSA608 × ICSR89028	27.7	26.4	25.7	**26.6**	43.9	42.7	41.2	**42.6**	8.6	6.5	6.3	**7.1**
ICSA608 × ICSR91020	26.1	23.0	25.3	**24.8**	35.2	37.0	29.0	**33.7**	7.4	6.9	5.6	**6.6**
ICSA608 × ICSR93004	23.7	24.4	23.0	**23.7**	53.0	51.2	46.1	**50.1**	8.1	7.2	6.5	**7.3**
ICSA610 × ICSR29	25.8	25.6	26.1	**25.8**	56.7	48.3	44.7	**49.9**	5.8	4.6	4.3	**4.9**
ICSA610 × ICSR53	25.9	23.8	24.9	**24.9**	50.2	47.5	40.0	**45.9**	6.5	5.8	4.6	**5.6**
ICSA610 × ICSR89028	26.5	24.0	24.0	**24.8**	49.9	45.6	40.6	**45.4**	7.5	7.2	5.9	**6.9**
ICSA610 × ICSR91020	24.9	26.5	25.4	**25.6**	35.5	40.3	33.7	**36.5**	7.2	6.2	6.0	**6.5**
ICSA610 × ICSR93004	24.9	25.6	24.1	**24.9**	55.5	47.0	43.8	**48.8**	7.9	6.5	6.2	**6.9**
ICSA613 × ICSR29	30.6	26.4	28.2	**28.4**	49.2	59.5	51.0	**53.2**	6.4	4.5	3.6	**4.8**
ICSA613 × ICSR53	30.5	29.7	25.9	**28.7**	55.3	63.7	56.9	**58.6**	3.8	3.5	3.1	**3.5**
ICSA613 × ICSR89028	30.9	28.7	26.7	**28.8**	58.5	52.4	52.3	**54.4**	7.5	6.6	6.6	**6.9**
ICSA613 × ICSR91020	30.8	28.9	26.3	**28.7**	46.2	45.7	33.9	**41.9**	6.7	3.7	3.2	**4.5**
ICSA613 × ICSR93004	26.0	25.2	23.5	**24.9**	46.4	45.7	42.2	**44.8**	5.9	5.1	4.4	**5.1**
ICSA93 × ICSR29	28.3	30.0	28.1	**28.8**	56.0	56.6	50.7	**54.4**	4.6	4.4	3.0	**4.0**
ICSA93 × ICSR53	27.2	25.4	25.6	**26.1**	56.5	43.0	44.2	**47.9**	7.4	6.0	4.8	**6.1**
ICSA93 × ICSR89028	25.1	28.1	24.0	**25.7**	45.5	55.2	49.1	**49.9**	4.9	4.4	3.6	**4.3**
ICSA93 × ICSR91020	27.9	27.5	28.0	**27.8**	42.4	43.3	47.4	**44.4**	6.8	6.3	5.4	**6.2**
ICSA93 × ICSR93004	26.2	24.2	25.0	**25.1**	55.7	55.6	50.1	**53.8**	6.1	5.2	5.2	**5.5**
Hybrid's mean	27.4	26.4	25.7	**26.5**	49.8	49.4	45.5	**48.2**	6.4	5.5	4.9	**5.6**
Female lines												
ICSB20	24.4	22.3	24.9	**23.9**	12.6	14.5	20.2	**15.8**	6.4	5.3	4.1	**5.3**
ICSB52	29.6	29.4	27.0	**28.7**	16.0	8.0	15.4	**13.1**	5.1	4.6	3.8	**4.5**
ICSB608	24.2	23.8	22.6	**23.5**	16.7	14.6	13.2	**14.8**	5.8	4.9	3.3	**4.7**
ICSB610	23.0	20.7	20.3	**21.3**	13.5	11.8	12.1	**12.5**	5.3	4.7	4.6	**4.9**
ICSB613	25.5	23.1	24.7	**24.4**	19.4	15.0	14.5	**16.3**	5.1	4.6	3.5	**4.4**
ICSB93	24.8	26.3	25.4	**25.5**	21.4	22.6	23.4	**22.5**	6.3	5.3	4.5	**5.4**
Female's Mean	**25.6**	**24.6**	**24.4**	**24.8**	**21.3**	**19.4**	**20.6**	**20.5**	**5.8**	**5.0**	**4.1**	**4.9**
Males lines												
ICSR29	31.6	31.9	26.5	**30.0**	58.2	44.5	44.9	**49.2**	5.2	5.4	4.5	**5.0**
ICSR53	26.4	27.7	24.7	**26.3**	35.2	37.8	31.6	**34.9**	5.3	4.1	3.4	**4.3**
ICSR89028	26.1	27.7	28.3	**27.4**	39.8	39.6	31.2	**36.9**	6.0	5.2	4.4	**5.2**
ICSR91020	22.0	20.1	23.9	**22.0**	26.4	22.5	16.7	**21.9**	4.9	4.1	4.1	**4.4**
ICSR93004	24.1	24.9	24.7	**24.6**	43.4	41.0	34.3	**39.6**	6.4	6.2	5.7	**6.1**
Male's Mean	**26.0**	**26.5**	**25.6**	**26.0**	**40.6**	**37.1**	**31.7**	**36.5**	**5.6**	**5.0**	**4.4**	**5.0**
Check varieties												
Hybrid 305	28.5	26.8	30.6	**28.6**	56.3	49.7	51.4	**52.5**	6.7	6.2	5.1	**6.0**
Dorado	27.1	26.7	24.4	**26.1**	28.1	28.1	25.7	**27.3**	6.9	6.6	6.3	**6.6**
Check's Mean	**27.8**	**26.8**	**27.5**	**27.4**	**42.2**	**38.9**	**38.6**	**39.9**	**6.8**	**6.4**	**5.7**	**6.3**
Overall Mean	**26.9^{A}**	**26.1^{B}**	**25.6^{C}**	**26.2**	**43.8^{A}**	**42.6^{A}**	**39.5^{B}**	**42.0**	**6.2^{A}**	**5.4^{B}**	**4.7^{C}**	**5.4**
Rev. LSD 5% Genotypes		**1.73**				**4.86**				**0.35**		
Rev. LSD 5% for NPK level		**0.69**				**1.05**				**0.11**		
Rev.LSD 5% for NPK x G		**4.34**				**N.S.**				**0.73**		

TABLE 5. Heterosis of F1 hybrids over their respective mid parents (MP) and better parents (BP) over NPK levels and years.

Hybrids	50% HD		PH; cm		PL; cm		SI; g		BY; T/H		GY; T/H	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
ICSA20 × ICSR29	-1.4	4.8**	38.3**	28.6**	7.9	5.1	-2.1	-12.1	83.7**	21.3	-24.8**	-26.4**
ICSA20 × ICSR53	4.1**	7.2**	18.4**	7.7	14.3*	7.9	-1.8	-6.3	116.4**	57.1**	31.3**	19.3*
ICSA20 × ICSR89028	-0.5	6.1**	18.9**	12.6*	12.6*	9.3	2.9	-3.6	109.9**	49.8**	3.4	3.0
ICSA20 × ICSR91020	-1.6	0.2	25.2**	18.7**	5.9	-2.4	14.0	9.5	129.0**	97.0**	5.1	-3.8
ICSA20 × ICSR93004	2.1	10.0**	29.5**	24.9**	15.0*	11.2	3.9	2.4	115.3**	50.6**	-9.0	-15.2**
ICSA52 × ICSR29	3.3*	11.3**	22.2**	18.4**	10.8	5.9	-2.1	-4.2	38.4*	-12.3	-1.1	-6.3
ICSA52 × ICSR53	1.5	6.0**	19.9**	13.5**	6.2	2.2	-1.6	-5.8	92.7**	32.7	49.9**	46.3**
ICSA52 × ICSR89028	-3.2**	4.7**	31.2**	29.5**	14.2*	8.6	0.6	-1.8	81.7**	23.2	9.9	2.4
ICSA52 × ICSR91020	-2.6	0.4	22.8**	21.4**	-5.9	-14.9*	7.3	-5.2	75.1*	40.1	16.9	15.1
ICSA52 × ICSR93004	-4.3**	4.5**	18.1**	17.3**	21.7**	20.2**	3.4	-4.0	90.3**	26.8	33.3**	15.9*
ICSA608 × ICSR29	-1.9	4.4**	42.5**	32.0**	13.5	8.4	5.6	-5.9	58.8**	3.4	10.1	6.1
ICSA608 × ICSR53	1.2	4.3**	23.5**	11.8*	19.1**	14.8	3.6	-1.9	109.3**	49.2*	2.5	-1.6
ICSA608 × ICSR89028	0.2	7.1**	27.7**	20.5**	17.4**	11.5	4.6	-2.7	64.7**	15.5	44.3**	36.7**
ICSA608 × ICSR91020	-4.9**	-3.1*	22.3**	15.5**	8.8	-1.6	9.0	5.5	83.7**	54.2	47.4**	42.6**
ICSA608 × ICSR93004	4.0**	12.1**	26.3**	21.3**	16.0*	14.6	-1.4	-3.6	84.3**	26.7	34.5**	18.8*
ICSA610 × ICSR29	-7.9**	-2.4	35.0**	24.4**	7.4	4.9	0.5	-13.9	62.0**	1.5	-0.5	-2.2
ICSA610 × ICSR53	0.4	3.0	25.9**	13.5**	9.2	2.8	4.4	-5.4	94.0**	31.7	22.9*	15.8
ICSA610 × ICSR89028	-0.2	6.2**	26.0**	18.2**	2.7	0.0	1.9	-9.3	84.0**	23.1	36.4**	31.6**
ICSA610 × ICSR91020	-2.8**	-1.5	30.0**	22.1**	3.8	-4.1	18.2*	16.5	112.5**	66.7*	40.2**	33.2**
ICSA610 × ICSR93004	-5.4**	1.5	33.4**	27.5**	5.3	1.5	8.2	1.1	87.4**	23.2	25.4**	12.7
ICSA613 × ICSR29	-1.8	3.5	30.7**	21.2**	7.1	-0.9	4.4	-5.3	62.5**	8.2	2.6	-3.6
ICSA613 × ICSR53	-4.8**	-2.7	35.9**	23.3**	28.1**	27.5**	13.2	9.2	129.1**	68.2**	-20.9*	-22.1*
ICSA613 × ICSR89028	-3.1**	2.6	34.2**	26.7**	15.9*	6.8	11.2	5.3	104.4**	47.4*	43.2**	32.3
ICSA613 × ICSR91020	-4.0**	-3.1*	36.7**	29.2**	11.4	-2.2	23.5**	17.4	119.5**	91.5**	3.5	2.8
ICSA613 × ICSR93004	-1.1	5.6**	22.2**	17.6**	20.4**	18.0*	1.6	1.3	60.3**	13.2	-2.3	-15.7*
ICSA93 × ICSR29	2.6*	10.0**	17.2**	16.9**	17.3**	13.8	3.8	-4.0	51.9**	10.7	-23.2**	-25.5**
ICSA93 × ICSR53	-1.1	2.7	14.5**	12.1*	7.9	2.3	0.7	-0.9	67.0**	37.3	26.0**	13.5
ICSA93 × ICSR89028	0.3	7.9**	16.3**	13.7*	14.5*	10.5	-2.5	-5.9	68.2**	35.4	-18.8*	-19.8*
ICSA93 × ICSR91020	-4.6**	-2.2	8.2	5.8	7.5	-1.4	17.1*	9.1	99.9**	97.3**	26.6**	14.9
ICSA93 × ICSR93004	1.3	10.0**	8.8	4.4	11.0	7.9	0.5	-1.2	73.5**	36.1*	-4.1	-10.0

*; ** Significant at the 0.05 and 0.01 probability levels, respectively. MP and BP are the mid-parent and better-parent heterosis, respectively .

TABLE 6. Estimates of general combining ability (GCA) of lines and testers for all studied traits overall environments.

Parents	50% HD	PH; cm	PL; cm	SI; g	BY; T/H	GY; T/H
Lines						
ICSB20	1.36**	-2.01	0.37	-0.78**	6.24**	-0.42**
ICSB52	-0.65**	0.85	-0.72**	1.22**	-5.11**	0.20**
ICSB608	0.75**	0.76	0.76**	-0.69*	-2.37**	0.62**
ICSB610	-1.11**	2.04	-1.00**	-1.32**	-2.95**	0.57**
ICSB613	-0.61**	6.03**	0.19	1.37**	2.35**	-0.60**
ICSB93	0.25	-7.67**	0.40	0.19	1.84*	-0.38**
S.E. (gi) lines	0.140	1.093	0.260	0.833	0.893	0.065
S. E. (gi-gj)	0.198	1.546	0.368	1.178	1.263	0.092
Testers						
ICSR29	0.82**	10.00**	0.25	1.22**	3.65**	-0.96**
ICSR53	-0.44**	3.43**	-1.38**	-0.34	2.67**	-0.14**
ICSR89028	1.17**	-1.13	0.96**	0.23	0.60	0.42**
ICSR91020	-3.76**	-3.63**	0.63**	0.18	-9.85**	0.10
ICSR93004	2.20**	-8.66**	-0.46	-1.29**	2.94**	0.58**
S.E. (gi) testers	0.128	0.998	0.237	0.760	0.815	0.059
S.E. (gi-gj)	0.180	1.411	0.336	1.075	1.153	0.084

*; ** Significant at the 0.05 and 0.01 probability levels, respectively.

Panicle length (PL)

Data exhibited in Table 4 show that panicle length was affected significantly by the reduction in NPK levels. The large panicle in the hybrid is initiated earlier and develops faster than in its parents (Blum, 1990). However, the majority of the crosses had longer panicle than their parents indicating the existence of mid-parent (MP) and better-parent heterosis (BP) (Table 5). About half of the crosses had longer panicle than the best check variety (Hybrid 305). The cross ICSA93 × ICSR29 had longer panicle (32.0 cm) followed by ICSA608 × ICSR89028 which recorded 31.7 cm. The testers had longer panicle than lines. For combining ability effects, the highest positive GCA of 0.76 and 0.96 were manifested by the line ICSB608 and tester ICSR89028, respectively (Table 6). Implying that both the parents were good general combiners. For SCA effects, half crosses showed positive SCA effects, hence, the cross (ICSA52 × ICSR93004) had positive and highly significant SCA effects (2.34**) followed by the cross (ICSA613 × ICSR53) (2.07**). The previous results indicated that these crosses can be considered as good combiners for panicle length. This is in agreement with the findings of Hovny & El-Dsouky (2007), Abdel-Mottaleb (2009), Essa (2009), Mahdy *et al.* (2011) and Amir & Mohamed (2015).

TABLE 7. Estimates of specific combining ability (SCA) of 30 F_1 hybrids for all studied traits overall environments.

Hybrids	50% HD	PH; cm	PL; cm	SI; g	BY; T/H	GY; T/H
ICSA20 × ICSR29	-1.39**	9.56**	-0.67	-0.57	1.56	-0.33*
ICSA20 × ICSR53	1.48**	-7.72**	0.19	-0.78	-2.38	1.26**
ICSA20 × ICSR89028	-0.85**	-10.68**	0.05	0.39	0.20	-0.16
ICSA20 × ICSR91020	0.03	0.64	0.28	0.21	-1.50	-0.20
ICSA20 × ICSR93004	0.73*	8.20**	0.16	0.74	2.12	-0.57**
ICSA52 × ICSR29	3.12**	-9.08**	0.63	-0.22	-3.64	-0.10
ICSA52 × ICSR53	0.83**	-1.12	-1.33	-0.36	0.46	0.95**
ICSA52 × ICSR89028	-1.62**	11.74**	0.96	0.21	1.72	-0.85**
ICSA52 × ICSR91020	0.48	1.81	-2.60**	-0.73	-2.60	-0.70**
ICSA52 × ICSR93004	-2.81**	-3.35	2.34**	1.10	4.05	0.70**
ICSA608 × ICSR29	-1.17**	12.06**	-0.15	1.20	1.34	0.11
.ICSA608 × ICSR53	-0.02	-3.72	0.34	0.30	3.48	-1.46**
ICSA608 × ICSR89028	0.26	-1.65	0.31	0.54	-3.86	0.53**
ICSA608 × ICSR91020	-1.69**	-6.93**	0.13	-1.21	-2.27	0.36**
ICSA608 × ICSR93004	2.62**	0.24	-0.62	-0.84	1.30	0.46**
ICSA610 × ICSR29	-3.42**	-0.92	0.65	-0.59	1.00	-0.27
ICSA610 × ICSR53	1.56**	-2.25	0.35	0.01	-2.06	-0.39**
ICSA610 × ICSR89028	2.11**	-6.28**	-1.21*	-0.62	-0.50	0.31*
ICSA610 × ICSR91020	1.83**	1.68	1.11	0.24	1.06	0.21
ICSA610 × ICSR93004	-2.08**	7.77	-0.90	0.95	0.50	0.13
ICSA613 × ICSR29	0.80**	-9.88**	-2.18**	-0.70	-0.99	0.84**
ICSA613 × ICSR53	-2.27**	9.66**	2.07**	1.14	5.37**	-1.39**
ICSA613 × ICSR89028	-0.22	2.37	-0.48	0.66	3.20	1.51**
ICSA613 × ICSR91020	0.83**	8.22**	0.52	0.59	1.19	-0.53**
ICSA613 × ICSR93004	0.86**	-10.38**	0.07	-1.70**	-8.76**	-0.43**
ICSA93 × ICSR29	2.06**	-1.75	1.73**	0.88	0.72	-0.25
ICSA93 × ICSR53	-1.57**	5.16*	-1.62	-0.32	-4.88*	1.02**
ICSA93 × ICSR89028	0.31	4.50	0.38	-1.19	-0.75	-1.33**
ICSA93 × ICSR91020	-1.47**	-5.42*	0.56	0.89	4.13*	0.85**
ICSA93 × ICSR93004	0.68*	-2.49	-1.05	-0.26	0.78	-0.30*
S.E. SCA	0.312	2.444	0.581	0.647	1.997	0.145
SE (Sij-Skl)	0.442	3.457	0.822	0.915	2.824	0.205

*; ** Significant at the 0.05 and 0.01 probability levels, respectively.

Seed Index (g)

Presented data in Table 4 investigate that seed index was decreased upon decreasing NPK fertilizer so that, L2 and L3 caused 2.97 and 4.83% reduction in seed index, respectively. This reduction was not significant. Similar results were obtained by Omar *et al.* (2014), who stated that plant height, 1000-grain weight and grain yield/plant of hybrids and parents were decreased with increasing nitrogen stress. Five crosses out of thirty gave higher seed index than the best check variety (Hybrid 305). However, the mean performance of F1 hybrids *per se* showed that hybrid ICSA613 × ICSR91020 manifested highest (28.7 g) seed index and recorded the highest positive and significant mid-parent heterosis (23.5%) while next maximum value (28.7 g) was given by ICSA93 × ICSR29 (Table 5). Among the lines, ICSB52 (28.68 g) and testers, ICSR29 (29.99 g) recorded maximum seed index (Table 4). Among the parental lines, ICSB613 (1.37**), ICSB52 (1.22**) and tester, ICSR29 (1.22**) exhibited positive and highly significant GCA effects (Table 6). The SCA effects revealed that sixteen out of thirty F1 hybrids exhibited positive non-significant effects, yet the maximum SCA effect (1.20) was given by ICSA608 × ICSR29 and next ranker was ICSA613 × ICSR53. These results are in accordance with the findings of Hovny & El-Dsouky (2007), Abdel-Mottaleb (2009), Essa (2009), Makanda *et al.* (2010), Mahdy *et al.* (2011) and Aminu & Izge (2013).

Biological yield (t ha^{-1})

Biological yield was decreased significantly as NPK fertilizer decreased so that NPK level 2 and NPK level 3 caused 2.7 and 9.7% reduction in biological yield (t ha^{-1}), respectively as compared with level 1. This is to be logic since the same trend was true with regard to plant height, panicle length and seed index. Abou-Amer & Kewan (2014) stated that fodder yield was increased significantly by increasing N and P fertilizer levels. Also, Hussein & Alva (2014) reported that the increased rates of N, P, K increased the plant growth and biomass. Sorghum hybrids produce more biomass as compared with their parents (Sahoo, 2010). On average, most crosses exhibited remarkable increase in biological yield than their parents and the check varieties indicating the existence of heterosis under all NPK levels. Nine crosses out of thirty produced higher biological yield than the best check variety (Hybrid 305). However, the highest cross in biological yield was ICSA20 × ICSR29 and recorded (59.7 t ha^{-1}) followed by the cross ICSA20 × ICSR93004 and recorded (59.5 t ha^{-1}). However, all crosses showed positive and high significant mid-parent heterosis, whereas few crosses showed significant high-parent heterosis (Table 5). The cross (ICSA613 × ICSR53) showed significant and positive mid-parent (129.1 %) and high-parent (68.2%) heterosis followed by the cross ICSA20 × ICSR91020 and recorded 129 and 97% mid- and high parent heterosis, respectively. For combining ability effects, the highest positive GCA of 6.24** and 3.65** were manifested by the line ICSB20 and tester ICSR29, respectively (Table 6). implying that both the parents were good general combiners. Concerning SCA effects, few crosses showed positive SCA effects, hence, the cross ICSA613 × ICSR53 positive and highly significant SCA effects (5.37**) followed by the cross ICSA93 × ICSR91020 (4.13*) (Table 7). The previous results indicated that these crosses can be considered as good combiners for biological yield. Haussmann *et al.* (1999) studied the quantitative genetic parameters of grain sorghum under variable stress conditions. They found that the relative hybrid mean superiority over the mid parent values was highest for grain yield followed by plant height and above ground dry matter. Our findings are in accordance with the findings of Hovny & El-Dsouky (2007), Abdel-Mottaleb (2009), Essa (2009), Mahdy *et al.* (2011), Omar *et al.* (2014) and Amir & Mohamed (2015).

Grain yield (t ha^{-1})

Grain yield occupies a unique place among plant characters. As an average, grain yield (t ha^{-1}) of sorghum genotypes, decreased as a result of reducing the amount of NPK fertilizers as compared with recommended NPK fertilizers. Average reduction in grain yield was 12.9 and 24.2% in 75% and 50% NPK, respectively. This is to be expected since the same obtained was observed with regard to seed index and biological yield and consequently produced the highest mean values of grain yield. Shrotriya (1998) reported that balanced application of NPK caused up to 122% increase in sorghum yield in India. El–Aref *et al.* (2005) reported that nitrogen levels significantly affected the grain yield and stated that applying 125 kg N/fad was more effective compared with other studied nitrogen levels. Al-Nagar *et al.* (2006) reported that Low-N stress caused a significant reduction in grain yield / plant of 17.9 and 15.2% for parental lines and their F1s, respectively. Also, significant increase in grain yield by increasing NP levels were observed by Abou-Amer & Kewan (2014). Dorado recorded higher grain yield than Hybrid 305 cultivar, this result is in contrast with those obtained by Abdo *et al.* (2014) under water stress conditions. Among the F1 hybrids *per se*, the crosses ICSA608 × ICSR93004 and ICSA52 × ICSR93004 produced top (7.2 ton ha^{-1}) and next maximum (7.1 ton ha^{-1}) grain yield (Table 4). Seven crosses out of thirty produced higher grain yield than the best check variety (Drorado). Among the parents, tester ICSR93004 produced highest grain yield (6.1 ton ha^{-1}) whereas among the females, maximum grain yield (5.4 t ha^{-1}) was yielded by the line ICSB93 (Table 4). This result indicated that these high yielding hybrids and parental lines are tolerant to low NPK fertility. It was observed that the tester ICSR93004 has participated the highest yielding crosses. In plant breeding, it is normally assumed that when good performing parents are crossed with each other, they are anticipated to produce better hybrids but this assumption was not always true (Baloch & Bhutto, 2003). The majority of the crosses showed positive heterosis in relation to their parents, thirteen crosses had positive and high significant mid- and high parent heterosis (Table 5). The cross (ICSA52 × ICSR53) showed significant and positive mid-parent (49.9 %) and high-parent (46.3%) heterosis followed by the cross ICSA608 × ICSR91020 and recorded 47.4 and 42.6% mid- and high parent heterosis, respectively. By pooling the review of literature on heterosis studies, Abo-Elwafa (2005), Hovny & El-Dsouky (2007) and Abdel-Mottaleb (2009) observed high relative heterosis and heterobeltiosis for grain yield. For GCA effects, the female line ICSB608 showed the highest positive GCA effects (0.62**) whereas the male line ICSR93004 gave maximum (0.58**) GCA effects. For SCA, effects, the crosses

ICSA613 × ICSR89028 and ICSA20 × ICSR53 gave positive and highly significant SCA effects indicating that these crosses can be considered desirable combiners. This is in agreement with the findings of Hovny & El-Dsouky (2007), Abdel-Mottaleb (2009), Essa (2009), Mahdy *et al.* (2011), Omar *et al.* (2014) and Amir & Mohamed (2015).

Correlation among studied traits

Data in Table 8 show the mutual correlation among traits studied overall NPK levels and over two seasons. Looking at the correlation data under NPK levels, it can be concluded that, heading dates was correlated positively and significantly with each of BY (r=0.252**) and SI (r=0.090*), whereas, it was negative but non-significant with GY and that may be due to the decline of the amount of NPK fertilizers added as stress conditions. This decline led to decrease GY and delayed heading time. Plant height was associated positively and significantly with all studied traits with exception of days to 50% heading. Biological yield was correlated positively and significantly with GY and SI. Also, data showed that there was a positive correlation but weak between GY and SI and this may be due to the weakness of NPK accumulation as a result of fertilizers deficiency. Tag El-Din *et al.* (2012) found a positive and non-significant correlation between grain yield and 1000-kernel weight. Also, Almeida Filho *et al.* (2014) reported a positive association between plant height and grain yield and negative correlation with days to flowering. Omar *et al.* (2014) found that plant height had positive and highly significant correlation with grain yield/plant under two N levels. While, 1000 grain weight had negative and highly significant correlation with grain yield / plant under two N levels.

TABLE 8. Phenotypic correlations among six traits computed overall environments.

Traits	PH; cm	PL; cm	SI; g	BY; T/H	GY; T/H
50% HD	0.065	-0.012	0.090*	0.252**	-0.034
PH; cm		0.349**	0.313**	0.594**	0.183**
PL; cm			0.133**	0.301**	0.024
SI; g				0.267**	0.061
BY; T/H					0.088*

*; ** Significant at the 0.05 and 0.01 probability levels, respectively.

Genetic components

Data in Table 9 show the genetic components and contribution of the lines, testers and their interaction of all studied traits overall NPK levels and years. The line × tester analysis revealed that the contribution of the testers to the total sum of squares was higher than of lines in all studied traits except in SI. Since the maximum contribution (55.26%) of the testers was noted for days to 50% heading while the lowest values was recorded for grain yield (26.89%). Lines were contributed as maximum value (45.07%) in seed index and the lowest one was observed for days to 50% heading (9.73%). For the line × tester interaction, the maximum contribution to the total some of squares was 52.91% in panicle length whereas the minimum contribution was 17.68% in case of biological yield. It was observed that the variance due testers was higher than those of lines and that confirmed by the contribution of lines and testers in previous discussion. The results revealed that, dominance variance (σ_D^2) was high and additive genetic variance (σ_A^2) was low in magnitude for all the traits. The ratio of (σ_A^2/σ_D^2) ranged from 0.05 (panicle length and grain yield) to 0.55 (biological yield). The observations on portioning of combining ability variance into additive variance (σ_A^2) and dominance variance (σ_D^2) indicated role of both additive and dominance gene action. The magnitude of non-additive variance was higher than the additive variance by many folds for all studied traits. Broad-sense heritability was moderate to high (43.21-85.74%) for panicle length and days to 50% heading but low for seed index (31.46%). Whereas narrow-sense heritability was very low and ranged between 0.69% (panicle length) and 4.18% (days to 50% heading). Mohammed (2009) reported that additive is important in the expression of days to flower, forage yield and stem diameter and non-additive gene actions is important in the expression of plant height. Mahdy *et al.* (2011) found that both additive and non-additive are important for the inheritance of plant height and grain yield, while they found that the additive effect is controlling days to 50% flowering. Several researchers have indicated that additive and non-additive are important in the inheritance of grain yield and some agronomic traits (Kenga *et al.*, 2004; Abdel-Mottaleb, 2009, Mohammed, 2009 and Mahdy *et al*., 2011).

In conclusion, significant differences were observed among entries, parents, parents vs. crosses, crosses, lines, testers, lines × testers, turned for all the characters studied suggesting that the experimental materials possessed considerable variability. The majority of the crosses were earlier, taller, longer panicle, higher in biological yield, higher in grain yield and heavier in seed index than their parents under combined NPK levels and two seasons. In addition, decreasing NPK fertilizers decline in plant height, panicle length, biological yield, seed index and grain yield/plant. While, decreasing NPK fertilizers led to increasing days to 50% flowering. These results are in harmony with those obtained by Abo-Elwafa (2005), Hovny & El-Dsouky (2007), Abdel-Mottaleb (2009) and Omar *et al.* (2014). They concluded that most of the F1 crosses were earlier, taller, heavier grain weight and higher grain yield compared with their parents. A comparison of GCA effects of individual lines for grain yield showed that much of the positive GCA obtained was contributed by ICSA608. ICSA610, ICSR89028 and ICSR93004 under NPK levels and over two years. This suggests a wide adaptation and high potential of these lines for use as a parent in developing well-adapted hybrids with high yield potential and can be considered as best general combiners. On the other hand, the female line ICSB610 showed significant and negative GCA effects for days to 50% heading and panicle length and positive GCA effects for grain yield and plant height. It may be used to develop high yielding, early flowering, and tall hybrids with short panicle length. For SCA, effects, the crosses ICSA613 × ICSR89028 and ICSA20 × ICSR53 gave positive and highly significant SCA effects indicating that these crosses can be considered desirable combiners. The crosses which recorded high SCA effects, had high yield *per se* and one of the parents involved with highest GCA effects. Thus, hybrid combination with high mean, with favorable SCA estimate and involving at least one of the parents with high GCA, would tend to increase the concentration of favorable alleles; an appreciable situation to any breeder.

TABLE 9. Genetic components estimates and proportional contribution to the total variation of the lines × tester analysis for the studied traits over environments.

	50% HD	PH; cm	PL; cm	SI; g	BY; T/H	GY; T/H
Genetic components estimates						
Cov H.S. Lines	0.09	7.50	0.11	1.07	15.06	0.12
Cov H.S.Tester	4.64	39.13	0.56	0.69	29.47	0.23
Cov.H.S. (average)	0.26	2.55	0.04	0.10	2.46	0.02
Cov F.S. (Hybrids)	13.29	151.30	2.83	3.61	92.25	1.47
Additive var. (σ^2 A)	0.51	5.11	0.07	0.20	4.91	0.04
Dominance var. (σ^2 D)	3.94	61.26	1.53	0.48	8.90	0.82
σ^2 A / σ^2 D	0.13	0.08	0.05	0.41	0.55	0.05
$(\sigma^2 D / \sigma^2 A)^{0.5}$	2.77	3.46	4.53	1.56	1.35	4.65
H^2_B	85.74	77.95	43.21	31.46	71.43	70.62
H^2_N	4.18	1.05	0.69	1.79	1.96	2.79
Proportional contribution to total variation (%)						
Lines	9.73	17.02	17.26	45.07	30.25	21.71
Testers	55.26	39.27	29.82	29.06	52.06	26.89
L×T	35.01	43.71	52.91	25.86	17.68	51.40

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تقدير قوة الهجين والقدرة علي الائتلاف لمحصول الحبوب وبعض الصفات المحصولية للذرة الرفيعة تحت ثلاث مستويات من الأسمدة النيتروجينة والفوسفاتية والبوتاسية

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تم دراسة قوة الهجين والقدرة علي الائتلاف لمحصول الحبوب وبعض الصفات المحصولية لعدد ثلاثين هجيناً من الذرة الرفيعة وأبائها الأحد عشر تحت ثلاثة مستويات مختلفة من الأسمدة النيتروجينة والفوسفاتية والبوتاسية خلال موسمي ٢٠١٤ و ٢٠١٥. وجدت فروق معنوية بين التراكيب الوراثية لجميع الصفات المدروسة، مما يدل علي وجود تنوع وراثي واسع بينها. كان التفاعل بين التراكيب الوراثية مع كل من السنوات، ومستويات الأسمده الثلاثة معنوياً لعظم الصفات المدروسة. كشف تحليل التباين للقدرة الائتلافية أن متوسط التباين لكل من التراكيب الوراثية, الأباء, الأباء ضد الهجن, السلالات, والكشاف , والسلالة × الكشاف كان معنوياً لجميع الصفات المدروسة مبيناً أن المواد التجريبية تمتلك تبايناً كبيراً حيث القدرة العامة والخاصة علي الائتلاف تدخل بالاشتراك في التعبير الجيني للصفات المدروسة. أظهرت السلالة ICSB610 تأثيراً معنوياً وسلبياً للقدرة العامة على الائتلاف لصفة عدة الأيام حتى ٥٠٪ طرد نورات وطول النورة وأظهرت تأثيراً ايجابياً لصفتي محصول الحبوب وارتفاع النبات. ويمكن استخدام هذه السلالة فى تكوين هجن عالية المحصول , مبكرة في التزهير, طويلة السيقان وقصيرة النورات. بالنسبة للقدرة الخاصة علي الائتلاف, فان الهجينين ICSA613 × ICSR89028 وICSA20 × ICSR53 أعطيا تأثيراً SCA إيجابياً ومعنوياً لصفة المحصول والتي يمكن اعتبارها هجناً مرغوبة لصفة المحصول كما أن أحد الآباء ذو التأثير العالي للقدرة العامة على الائتلاف أشترك في تكوين هذه الهجن. الملاحظات على تجزئة تباين القدرة الائتلافية الى تباين مضيف وسيادي أشارت الي الدور الحيوي الذي يلعبه الفعل الاضافي والسيادي في وراثة الصفات المدروسة. كما كان اتجاه التباين الغير اضافي أعلى من التباين الاضافى عدة مرات لكل الصفات المدروسة.