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PER SE PERFORMANCE AND HETEROSIS ESTIMATION IN SORGHUM FOR GRAIN YIELD AND SHOOT FLY RESISTANCE ATTRIBUTES

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SUMMARY

Fifteen hybrids derived from half-diallel mating design using six parents, including standard check GJ 43 were evaluated for *per se* performance and magnitude of heterosis to examine yield and attributing traits in sorghum. The *per se* performance of parents revealed that the parent GNJ 1 appeared numerically higher for grain yield per plant and 1000-grain weight. The parents SWARNA and DJ 6514 were found for days to flowering. Hybrids IS 18551 × SWARNA, SWARNA × GNJ 1 and GJ 43 × GNJ 1 recorded maximum total plant height and grain yield per plant. While the parents IS18551 and IS2205; the cross combination IS 18551 × IS 2205 were showed shoot fly resistance feature. The analysis of variance indicated that the genotypes used in the study were significant for all 12 characteristics, revealing the presence of genetic diversity in the genotypes. The mean sum of squares due to genotypes, parents, hybrids and parents *vs.* hybrids was highly significant found for all characteristics except the mean sum of squares due to parents *vs* hybrids for the seedling glossiness, days to flowering and total plant height, which indicated that sufficient amount of heterosis was appeared in crosses due to yield attributing characteristics and shoot fly resistance traits. The study of the most prominent heterotic hybrids for grain yield per plant *viz.,* GJ 43 × GNJ 1, SWARNA × GNJ 1 and IS 18551 × SWARNA evinced significant and positive heterosis over better parent and standard check GJ 43 for yield and shoot fly resistance attributes, respectively.

Key words: Sorghum, Shoot fly, heterosis, heterobeltiosis, parents *vs.* hybrids, *per se* performance

Sorghum [*Sorghum bicolor* (L.) Moench] is an often-cross-pollinated crop with diploid genome (2n = 2x = 20), that is approximately 25% smaller than maize. It is a C_4 plant with higher photosynthetic efficiency and greater resistance to abiotic stress (Reddy *et al*., 2009). Karnataka, Madhya Pradesh, Rajasthan, Andhra Pradesh, Gujarat and Maharashtra are India's major sorghum-growing states. India and Africa account for the largest share (> 70 %) of global sorghum area while Nigeria, USA, Mexico, India, Ethiopia and Sudan are the major sorghum producers (Kumar *et al.,* 2011). Besides being an important forage, food and feed crop, sorghum also provides raw material like fibre, alcohol, starch, dextrose syrup and biofuels used in producing various medicinal products. Sorghum is an essential agricultural crop that offers intensive animal feeding components and important staple foods for humans (Patel *et al.* 2020). Due to its resistance capacity to adapt in situations like drought, salt and high temperatures, sorghum considered as one of the best nutra-cereal crops in context of climate change (ICRISAT, 2015). Consequently, a result of improvements made with this crop will significantly change the socioeconomic status of those who live in semi-arid areas. In several tropical grass species, shoot fly of the genus *Atherigona* have been reported to cause "deadhearts" (Deeming, 1971). Shoot fly damage resulting in india losses up to 90.00 percent of the grain yield and 45.00 percent of the fodder yield (Sukhani and Jotwani, 1980). With little knowledge of agronomic and morphological traits, the majority of researchers studying shoot fly resistance have focused mostly on the inheritance of shoot-fly-resistant traits.

Understanding the nature of gene action a is crucial in crop breeding for resistance to the desired insect pest.

The heterosis investigation assists in realizing genetic diversity in many crops. Heterosis is measured as an increase or decrease in performance of the hybrid compared to the parental value in terms of percentages. In several crops, heterosis was used to enhance the yield and yield-related traits to select superior parents and hybrids for the further breeding programme. Selecting the most suitable parents is a crucial step for a breeder in a hybridization programme. The percentage of heterosis contributes to the choice of desirable parents for the development of superior hybrids (Patel *et al.,* 2020). Predominance of dominance type of gene action for resistance to shoot fly revealed that heterosis breeding is the best method for developing shoot fly resistance line in sorghum. Using standard heterosis, better parent and mid parental heterosis with diallel analysis can be used to identified superior hybrids and parental combinations for shoot fly resistance and grain yield attributes (Ariharasutharsan *et al.,* 2022).

MATERIALS AND METHODS

The experimental material used six parents (including check GJ 43) and their 15 half-diallel crosses. The half diallel crosses were made during the summer, 2021 at the Centre for Millets Research, Sardarkrushinagar Dantiwada Agricultural University, Deesa. In a Randomised Block Design (RBD) with three replications, a set of 21 genotypes comprised of six parents (including the check GJ 43) and their fifteen F_1 hybrids were sown in *Kharif*, 2022. Each genotype was sown in two rows of 2.0 m length with 45 cm inter-row spacing and 15 cm intra-row spacing. The plant protection measures and recommended agronomic practices were applied to raise a good-quality crop. The observations were recorded both as visual assessment (days to flowering) and measurement on randomly selected five competitive individual plants (seedling vigour, seedling glossiness, total plant height, shoot fly dead heart at 14 DAE, shoot fly dead heart at 21 DAE, shoot fly dead heart at 28 DAE, hydrocyanic acid content, 1000-grain weight, grain yield per plant, crude protein content and total phenol content). Panse and Sukhatme (1985) suggested Randomised Block Design (RBD) which is utilised to analyse the replication-wise mean values of each entry for the twelve traits. For each character, heterosis was calculated as an increase or decrease in the F_1 hybrid's mean value over the better parent or heterobeltiosis (Fonesca and Patterson, 1968) and over the standard check or standard heterosis Meredith and Bridge (1972).

RESULTS AND DISCUSSION

The analysis of variance indicated that the genotypes used in the study were found to be significant ($p \leq 0.01$) for all twelve characteristics (Table 1), revealing the presence of genetic diversity in the genotypes. Mean sum of square due to genotypes, parents, hybrids and parents *vs.* hybrids was highly significant found for all 12 characteristics except mean sum of square due to parents *vs.* hybrids for the seedling glossiness, days to flowering and total plant height, which indicated that sufficient amount of heterosis was appeared in crosses due to yield attributing characteristics and shoot fly resistance traits. Significant differences between parents revealed more diversity across parental lines.

The *per se* performance of parents was recognised as the most crucial criterion for selection. The analysis of parental mean values indicated that none of the parental genotypes was superior for all the characteristics under investigation. The mean performance of parents revealed that the parent GNJ 1 appeared numerically higher for grain yield per plant and 1000-grain weight than check variety GJ 43. The parents SWARNA and DJ 6514 were superior to the check GJ 43 for days to flowering. The mean performance of hybrids (Table 2) revealed that none of the hybrids were found to be superior for all the characteristics under examination. The parents IS18551 and IS2205; the cross combination IS 18551 × IS 2205 were showed shoot fly resistance feature. Based on mean performance crosses GJ 43 × GNJ 1 and SWARNA × GNJ 1 were recorded the maximum mean performance for grain yield per plant.

Considering its practical significance, heterosis was tested over better parent and standard check *i.e.,* GJ 43. These findings resulted that the extent of heterosis varied from cross to cross for all the characteristics. Certain cross combinations exhibited significant high heterosis for a particular trait. The superiority of hybrids over better parents generates a high-level transgressive segregation (Fonseca and Patterson, 1968). Importance of grain yield, out of 15 F_1 hybrids, five and four hybrids manifested significant and positive estimates of heterobeltiosis and standard heterosis over the check GJ 43 (Table 3 and Fig 1). A wide range of heterosis over better parent and standard

TABLE 1

Analysis of variance (mean sum of square) for experimental design of twelve traits in sorghum

Sources of variation	d.f.	Seedling vigour	Seedling glossiness	Days to flowering	Total plant height	Shoot fly dead heart at 14 DAE	Shoot fly dead heart at 21 DAE
Replications	2	0.11	0.01	7.73	181.43	38.42	242.96
Genotypes	20	3.14**	2.23**	78.81**	998.94**	374.05**	789.21**
Parents	5	7.07**	4.40**	140.80**	2573.83**	751.31**	1719.72**
Hybrids	14	1.91**	0.99**	62.08**	497.37**	220.42**	426.70**
Parents vs. Hybrids	1	0.70**	8.58	3.07	146.38	638.69**	1211.69**
Error	40	0.06	0.06	8.93	113.17	26.37	30.34

Sources of variation	d.f.	Shoot fly dead heart at 28 DAE	Hydrocyanic acid content	1000-grain weight	Grain yield/ plant	Crude protein content	Total phenol content
Replications	2	127.47	3.38	1.15	41.44	0.04	0.05
Genotypes	20	1033.32**	982.84**	52.52**	1780.18**	6.80**	3.82**
Parents	5	2320.80**	1198.65**	95.22**	3059.23**	12.50**	5.29**
Hybrids	14	529.14**	927.53**	37.82**	962.64**	5.08**	3.46**
Parents vs. Hybrids	1	1654.53**	678.20**	44.73**	6830.51**	2.31**	1.61**
Error	40	40.30	31.37	2.30	47.03	0.19	0.05

* P ≤ 0.05, ** P ≤ 0.01.

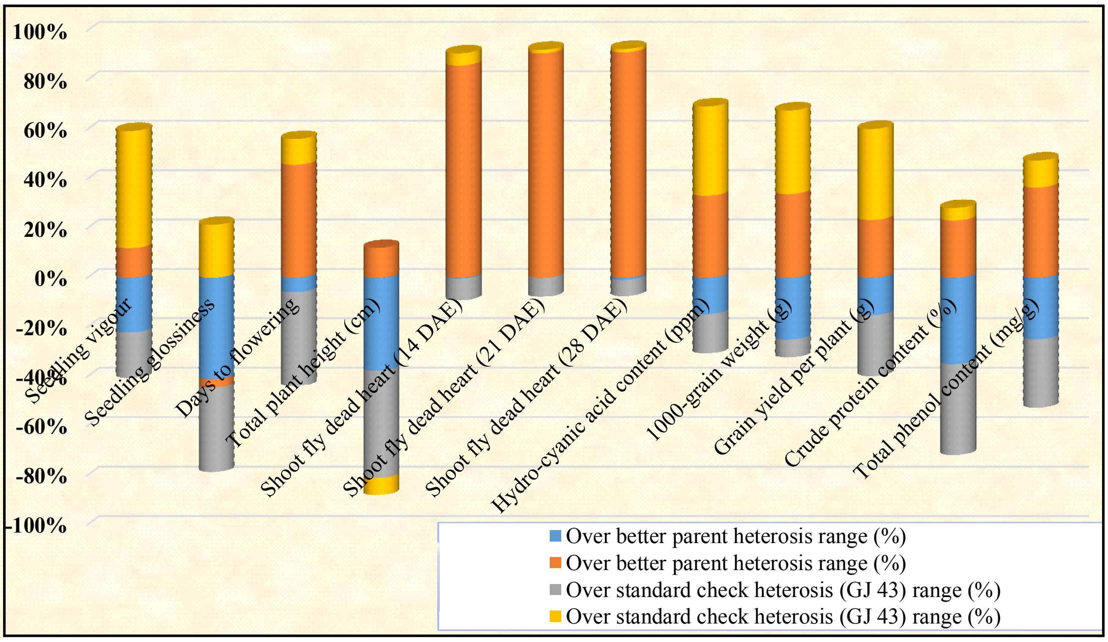

Fig. 1. Range of heterosis over better parent and standard check (GJ 43) in sorghum.

check was recorded for grain yield per plant (Fig 1.) *i.e.*, -10.93 (IS 2205 × GNJ 1) to 17.07 per cent (GJ 43 × GNJ 1) heterobeltiosis and -18.01 (IS 18551 × IS 2205) to 26.87 per cent (GJ 43 × GNJ 1) over GJ 43. The hybrids GJ 43 × GNJ 1 (17.07 and 26.87 %), SWARNA × GNJ 1 (13.15 and 23.44 %) and IS 18551 × SWARNA (8.44 and 18.29 %) evinced significant and positive heterosis over better parent and standard check GJ 43, respectively.

The aim of grain yield and shoot fly resistance in the present investigation, the top-ranking three hybrids GJ 43 × GNJ1, SWARNA × GNJ 1 and IS 18551 × SWARNA evinced significant and positive heterosis over better parent and standard check GJ 43 for yield and shoot fly resistance attributes under studied (Table 5). The low to high estimates of heterobeltiosis and standard heterosis for grain yield per plant also reported earlier by El-Dardeer *et al.*

TABLE 2
Mean performance of the parents and their F1 hybrids for twelve traits in sorghum

S. No.	Parents/Hybrids	Seedling vigour	Seedling glossiness	Days to flowering	Total plant height (cm)	Shoot fly dead heart (14 DAE)	Shoot fly dead heart (21 DAE)	Shoot fly dead heart (28 DAE)	Hydro-cyanic acid content (ppm)	1000-grain weight (g)	Grain yield/ plant (g)	Crude protein content (%)	Total phenol content (mg/g)
Parent													
1.	IS 18551	4.47	4.45	74.33	275.00	4.05 (00.00)	4.05 (00.00)	4.05 (00.00)	19.51	20.05	66.07	7.05	7.50
2.	IS 2205	4.27	4.31	75.67	259.90	4.05 (00.00)	4.05 (00.00)	4.05 (00.00)	13.37	21.54	102.39	7.87	6.54
3.	SWARNA	1.15	1.52	57.33	210.50	44.51 (49.46)	59.01 (73.05)	71.97 (90.27)	39.11	34.73	148.34	11.35	3.86
4.	DJ 6514	1.26	2.18	65.67	241.50	25.95 (19.34)	41.23 (43.49)	48.53 (56.04)	69.03	22.24	110.64	8.25	4.71
5.	GJ 43 (C)	2.12	2.32	72.67	296.50	26.98 (20.60)	50.98 (59.65)	51.38 (60.74)	23.61	24.56	135.98	11.66	5.89
6.	GNJ 1	1.35	2.46	70.33	256.50	29.92 (25.05)	44.30 (41.70)	48.93 (56.63)	30.03	29.57	147.36	11.09	6.47
Parental mean:		2.44	2.87	69.33	256.65	22.57	33.93	38.15	32.44	25.44	118.46	9.54	5.82
F_1 Hybrid													
7.	IS 18551 × IS 2205	4.48	3.01	76.33	287.50	4.05 (00.00)	4.05 (00.00)	4.05 (00.00)	18.28	23.26	111.48	9.46	6.20
8.	IS 18551 × SWARNA	2.67	2.97	61.67	256.80	26.62 (20.14)	39.37 (40.29)	48.98 (56.92)	17.69	27.51	160.85	8.89	5.47
9.	IS 18551 × DJ 6514	2.83	1.93	68.33	249.10	33.53 (30.53)	48.50 (56.05)	52.63 (63.00)	38.70	24.08	124.52	8.86	6.55
10.	IS 18551 × GJ 43	2.37	2.48	70.67	257.30	28.91 (23.95)	42.10 (45.05)	49.80 (58.54)	30.81	25.14	124.27	8.62	6.23
11.	IS 18551 × GNJ 1	2.27	2.01	70.67	251.70	20.15 (26.72)	44.43 (49.01)	56.04 (67.62)	18.11	28.63	142.50	9.09	3.98
12.	IS 2205 × SWARNA	2.07	1.97	62.33	269.50	29.46 (24.32)	43.81 (47.94)	50.91 (60.11)	23.05	24.83	158.65	9.74	3.79
13.	IS 2205 × DJ 6514	2.70	2.18	71.00	250.40	37.47 (37.19)	46.50 (52.45)	52.56 (62.45)	4.45	22.49	119.33	8.81	3.35
14.	IS 2205 × GJ 43	2.10	2.53	72.67	275.60	31.92 (28.28)	45.81 (51.41)	48.42 (55.94)	36.00	29.12	145.75	10.67	5.58
15.	IS 2205 × GNJ 1	2.23	2.37	71.33	273.60	30.48 (26.29)	46.06 (51.85)	51.77 (61.66)	4.89	25.09	131.25	10.73	6.89
16.	SWARNA × DJ 6514	1.36	1.25	59.33	240.40	33.30 (30.37)	46.10 (51.90)	55.87 (68.28)	9.96	26.72	142.09	7.93	4.64
17.	SWARNA × GJ 43	1.20	1.35	67.00	266.50	26.34 (20.05)	51.52 (45.81)	61.48 (51.62)	53.32	28.05	144.50	11.26	5.52
18.	SWARNA × GNJ 1	1.67	1.22	70.00	247.70	33.13 (30.68)	46.55 (52.60)	54.02 (65.34)	12.54	30.86	167.85	10.62	6.06
19.	DJ 6514 × GJ 43	1.47	2.21	69.00	248.10	35.79 (34.92)	48.47 (55.67)	55.25 (66.62)	24.50	34.12	143.00	12.18	6.01
20.	DJ 6514 × GNJ 1	1.73	1.37	70.33	260.50	33.43 (30.45)	41.72 (44.31)	43.45 (54.31)	67.19	25.88	134.12	10.62	5.39
21.	GJ 43 × GNJ 1	1.91	2.00	72.00	265.50	39.79 (40.98)	59.66 (50.63)	57.18 (70.18)	18.19	33.93	172.51	12.07	6.43
	Hybrid mean:	2.20	2.06	68.84	260.01	29.62	43.64	49.49	25.17	27.31	141.51	9.97	5.47
	General mean:	2.27	2.29	68.98	259.05	27.61	40.87	46.25	27.25	26.78	134.92	9.84	5.57
	Range	1.15 to 4.48	1.22 to 4.45	57.33 to 76.33	210.5 to 296.5	4.05 to 44.51	4.05 to 59.66	4.05 to 71.97	4.45 to 69.03	20.05 to 34.73	66.07 to 172.51	7.05 to 12.18	3.35 to 7.5
	S.Em.(±)	0.14	0.15	1.73	6.14	2.97	3.18	3.67	3.23	0.88	3.96	0.25	0.13
	C.D. at 5 %	0.39	0.42	4.93	17.56	8.48	9.09	10.48	9.24	2.50	11.32	0.72	0.38
	C.V. %	10.51	11.13	4.33	4.11	18.68	13.48	13.73	20.55	5.67	5.08	4.44	4.12

TABLE 3

The number of hybrids with a significant heterotic effect in sorghum

Characters	Over better parent				Over standard check (GJ 43)			
	+ve	-ve	Total	Range (%)	+ve	-ve	Total	Range (%)
Seedling vigour	2	10	12	-51.52 to 28.15	4	4	8	-43.40 to 111.32
Seedling glossiness	0	13	13	-56.63 to -4.74	2	4	6	-47.41 to 29.74
Days to flowering	4	-	4	-2.75 to 22.09	-	4	4	-18.35 to 5.05
Total plant height (cm)	2	8	10	-16.33 to 5.28	-	14	14	-18.91 to -3.03
Shoot fly dead heart (14 DAE)	10	-	10	-2.36 to 825.10	3	2	5	-84.99 to 47.51
Shoot fly dead heart (21 DAE)	9	0	9	0.00 to 1097.61	1	4	5	-92.06 to 17.02
Shoot fly dead heart (28 DAE)	8	0	8	-10.45 to 1283.62	1	2	3	-92.12 to 19.66
Hydro-cyanic acid content (ppm)	6	5	11	-74.54 to 169.35	4	4	8	-81.14 to 184.57
1000-grain weight (g)	3	7	10	-28.51 to 38.91	7	0	7	-8.41 to 38.91
Grain yield per plant (g)	5	3	8	-10.93 to 17.07	4	4	8	-18.01 to 26.87
Crude protein content (%)	3	6	9	-30.13 to 20.11	0	12	12	-32.01 to 4.43
Total phenol content (mg/g)	9	2	11	-38.59 to 57.06	3	6	9	-43.20 to 16.98

TABLE 4

Comparative study of heterotic crosses for grain yield per plant with other attributes

S. No.	Hybrids (F1's)	Heterosis over		Useful and significant heterobeltiosis/ standard heterosis for components
		Better parent	Standard parent GJ 43	
1.	IS 18551 × SWARNA	8.44* (160.85)	18.29**	SV, SG, DF, TWT
2.	SWARNA × GNJ 1	13.15** (167.85)	23.44**	SV, HCN, TWT, TPC
3.	GJ 43 × GNJ 1	17.07** (172.51)	26.87**	HCN, TWT, TPC

*P ≤ 0.05, **P ≤ 0.01.

Figures in the parentheses indicated the mean performance.

Where,

SV	:	Seedling vigour	HCN	:	Hydrocyanic acid content
SG	:	Seedling glossiness	TWT	:	1000-grain weight
DF	:	Days to flowering	TPC	:	Total phenol content

(2011), Kumar *et al.* (2011), Jain and Patel (2014), Boratkar and Ninghot (2015), Al-Aaref *et al.* (2016), Jain and Patel (2016), Jadhav and Deshmukh (2017), Wagaw and Tadessee (2020) and Joshi *et al.* (2021). These hybrids also demonstrated significant and positive heterosis over better parent or standard check for various characteristics *viz.,* seedling vigour, seedling glossiness, days to flowering, hydrocyanic acid content, 1000-grain weight, crude protein content and total phenol content (Table 4).

CONCLUSION

For all of the twelve studied traits, the analysis of variance revealed that significant differences are present due to genotypes, which is supported by parents and their hybrid under examination possessing sufficient genetic diversity. The mean performance of parents revealed that the parent GNJ 1 appeared numerically higher for grain yield per plant and 1000-grain weight than check variety GJ 43, while the parents IS 18551 and IS 2205 was found promising for shoot fly resistance attributes. Based on the comparative study of the best heterotic hybrid, the crosses IS 18551 × SWARNA, SWARNA × GNJ 1 and GJ 43 × GNJ 1 were promising found for grain yield per plant manifested significant positive heterosis over both better parent and standard check GJ 43. These three crosses having potential to generate desirable segregants for selection of superior plants

TABLE 5

The top-ranking parents concerning mean performance; F_1 hybrids concerning mean performance and heterosis over better parent and standard check GJ 43

Characters	Best performing parents	Best performing hybrids	Heterosis over	
			Better parent	Standard check
Seedling vigour	IS 18551 (4.47)	IS 18551 × IS 2205 (4.48)	0.22	111.32**
Seedling glossiness	IS 18551 (4.45)	IS 18551 × SWARNA (2.97)	-33.26**	28.02**
	IS 2205 (4.31)	IS 18551 × IS 2205 (3.01)	-32.36**	29.74**
Days to flowering	SWARNA (57.33)	SWARNA × DJ 6514 (59.33)	8.72*	-14.23**
	DJ 6514 (65.67)	IS 2205 × SWARNA (62.33)	7.56	-5.14**
Total plant height (cm)	GJ 43 (296.50)	IS 18551 × IS 2205 (287.50)	4.54*	-3.03
	IS 18551 (275.00)	IS 2205 × GJ 43 (275.60)	-	-
Shoot fly dead heart at 14 DAE	IS 18551 (4.05)	IS 18551 × IS 2205 (4.05)	0.00	-84.99**
	IS 2205 (4.05)	IS 18551 × GNJ 1 (20.15)	397.45**	-25.32**
Shoot fly dead heart at 21 DAE	IS 18551 (4.05)	IS 18551 × IS 2205 (4.05)	0.00	-92.06**
	IS 2205 (4.05)	IS 18551 × SWARNA (39.37)	1.19	-18.17*
Shoot fly dead heart at 28 DAE	IS 18551 (4.05)	IS 18551 × IS 2205 (4.05)	0.00	-92.12**
	IS 2205 (4.05)	DJ 6514 × GNJ 1 (43.45)	-10.45	-15.42*
Hydrocyanic acid content (ppm)	IS 2205 (13.37)	IS 2205 × DJ 6514 (4.45)	-74.54**	-57.83**
	IS 18551 (19.51)	IS 2205 × GNJ 1 (4.89)	-66.68**	-81.14**
	-	SWARNA × DJ 6514 (9.96)	-58.24**	-46.89*
1000-grain weight (g)	SWARNA (34.73)	DJ 6514 × GJ 43 (34.12)	38.91**	38.91**
	GNJ 1 (29.57)	GJ 43 × GNJ 1 (33.93)	14.72**	38.14**
	GJ 43 (24.56)	SWARNA × GNJ 1 (30.86)	18.58**	18.58**
Grain yield per plant (g)	SWARNA (148.34)	GJ 43 × GNJ 1 (172.51)	8.44*	18.29**
	GNJ 1 (147.36)	SWARNA × GNJ 1 (167.85)	17.07**	26.87**
	GJ 43 (135.98)	IS 18551 × SWARNA (160.85)	6.95	16.67**
Crude protein content (%)	GJ 43 (11.66)	DJ 6514 × GJ 43 (12.18)	20.11**	-18.92**
	SWARNA (11.35)	GJ 43 × GNJ 1 (12.07)	7.39*	-24.04**
Total phenol content (mg/g)	IS 18551 (7.50)	IS 2205 × GNJ 1 (6.89)	39.09**	11.21**
	IS 2205 (6.54)	IS 18551 × DJ 6514 (6.55)	57.06**	2.91
	GNJ 1 (6.47)	GJ 43 × GNJ 1 (6.43)	27.65**	2.06

for grain yield and shoot fly resistance attributes in sorghum.

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