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Heterotic behaviour of sunflower hybrids in different environments

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Abstract
The heterotic behaviour of hybrids varied in magnitude and direction from hybrid to hybrid and environment to environment. Heterosis was expressed across all environments, but its higher magnitude was observed in *kharif* season at Parbhani (E_3 environment) for seed yield per plant. The five crosses *viz.*, SCH-11, SCH-16, SCH-25, SCH-12 and SCH-26 showed significant heterotic estimates over best check hybrid for seed yield per plant and significant or desirable heterosis for head diameter, seed filling, volume weight, 100 seed weight, oil content, days to flowering and days to maturity and therefore identified as best heterotic hybrids for seed yield per plant and its contributing characters. Heterotic expression for seed yield per plant in the hybrids SCH-11, SCH-16, SCH-25, SCH-12 and SCH-26 were associated with heterotic effect for head diameter, seed filling per cent, 100 seed weight and volume weight.

Keywords: sunflower, heterosis, hybrids, environment

Introduction
The cultivated sunflower (*Helianthus annuus* L.) is one of the most important oilseed crop in the world after soybean, rapeseed-mustard and groundnut. The importance of sunflower as an oilseed crop in India is of very recent origin. But its contribution towards attaining self-sufficiency in edible oil as well as to "yellow revolution" in the country is noteworthy (Mangala Rai, 2002) [9]. It is primarily grown for edible oil and is considered as good quality oil from the health point of view. Sunflower, a highly cross pollinated crop is ideal for heterosis exploitation. The discovery of cytoplasmic male sterility by Leclercq (1969) [8] in the progeny of a cross between *Helianthus petiolaris* Nutt. and cultivated sunflower (cv.Armavirskii 9345) and subsequent identification of genes for fertility restoration by many workers became a landmark in the development of several sunflower hybrids. The cytoplasmic male sterility based first commercial hybrids were made available in USA in 1972. Subsequently the cultivation of sunflower hybrids was spread to other parts of the world. In India, the development and release of first ever sunflower hybrid BSH-1 using male sterility systems from Bangalore (Seetharam *et al.* 1980) [14] provided the required fillip to expand sunflower cultivation in the country.

Hybrids are preferred over varietal populations because of their uniformity in growth, high productivity in terms of total seed yield and oil. Besides, hybrids are proven to be more self-fertile, resulting in increased seed set and seed filling. Hybrids are fertilizer responsive and are fairly tolerant to major foliar diseases (Seetharam 1981) [13]. Presently the hybrids synthesized and released in the country for commercial cultivation are single cross (SC) hybrids, where uniformity is a distinct advantage.

There is a need to develop new sunflower hybrids with improved seed yield and oil content to meet the challenges and tremendous demand of sunflower oil in the market. Exploitation of heterosis on commercial scale and the systematic varietal improvement through hybridization are the main tools to increase the sunflower production. In heterosis breeding programmes, a large number of experimental hybrids are produced and tested to identify hybrid vigour.

Materials and Methods
Three CMS lines *viz.*, 1) CMS 2A, 2) CMS 10 A and 3) CMS 234 A have been crossed with six restorer lines *viz.*, 1) EC-623008, 2) No.1147-2, 3) 99-RT, 4) RHA-1-1, 5) EC-601951 and 6) TSG-271 in line x tester fashion to produce eighteen hybrids during summer, 2018. The 18 hybrids and nine parental lines along with three checks, LSFH-35, LSFH-171 and Ajeet-531 were evaluated in randomized block design with two replications during two crop seasons i.e. *Rabi*, 2018 and *Kharif*, 2019 at two locations i.e. Parbhani and Latur comprising of four different environments *viz.*, E_1- Parbhani *Rabi*, 2018, E_2- Latur *Rabi*, 2018, E_3-Parbhani

Kharif, 2019 and E_4-Latur *Kharif*, 2019. The experiments at Parbhani location were conducted under normal irrigated condition while, experiments at Latur location were under rainfed condition. Each genotype was planted in a two row plot of 4.5 m length following spacing of 60 cm between rows and 30 cm between plants within a row. Two to three seeds of each entry were dibbled/hill in furrows at a depth of 2-3 cm. After 15 days, only one healthy seedling per hill was retained by removing remaining seedlings. Non-experimental material was planted at border rows to eliminate border effects. The agronomic and plant protection measures were followed as and when required during the period of crop growth to raise the healthy crop.

Obervations were recorded on days to 50 per cent flowering, days to maturity, plant height (cm), head diameter (cm), seed filling (%), 100 seed weight (gm), volume weight (g/100ml), hull content (%), oil content (%), seed yield per plant (g). The observations for all the traits were recorded on five randomly selected competitive plants in each entry from each replication in each environment except days to 50 per cent flowering and days to maturity which were recorded on plot basis. The mean data for different characters obtained from the experiments was statistically analyzed for individual as well as pooled over the environments by the usual statistical procedure (Panse and Sukhatme 1985) [11]. The treatment mean values for each trait were used for the estimation of heterosis. It was calculated as deviation of F_1 over mid parent, better parent and standard checks. Heterosis for various traits was estimated as as per cent increase or decrease of the hybrid over best standard check as per the procedure suggested by Fonesca and Patterson (1968) [5] and Meredith and Bridge (1972) [10] for individual as well as over the environments.

Results and Discussion

The heterotic behavior of top ranking five hybrids over best standard checks for different traits in individual and pooled environments is depicted in Table 3. The highest range of standard heterosis in hybrids from -14.29 (SCH-13) to 1.43 per cent (SCH-14) for days to 50 per cent flowering was noticed in E_1 environment with nine hybrids showing significant negative heterotic values. Fifteen single cross hybrids showed significant negative standard heterosis in pooled analysis. The SCH-22 and SCH-21 found to have significant on pooled basis also recorded significant higher heterotic effect across the environments. The range of useful heterosis among crosses varied from -7.02 (SCH-22) to 3.51 per cent (SCH-31) and it was maximum in E_4 with five crosses displaying significant negative heterosis for days to maturity. As many as 15 single crosses had significant negative heterosis on pooled basis. The SCH-23 was found earliest in pooled environment also had earliest maturity in E_1, E_2 and E_3 environments. Highest range of standard heterosis from -2.70 (SCH-16) to 21.75 per cent (SCH-24) was observed in E_4 environment for plant height. Only two hybrids showed significant negative standard heterosis in E_1 environment considering pooled and all other environments.

For head diameter the range of useful heterosis over best check among single crosses varied from -31.65 (SCH-14) 16.65 per cent (SCH-26). It was highest in E_2 environment with two hybrids showing significant positive heterosis. Four crosses recorded significant positive heterosis for head diameter in pooled environment. The crosses *viz.*, SCH-11, SCH-12 and SCH-26 displayed highest useful heterosis on pooled basis for head diameter. The range of heterosis was highest for seed filling in E_2 environment and it was varied from -15.01 (SCH-35) to 17.00 per cent (SCH-32) with four hybrids showing significant desirable heterosis on pooled basis. Ten hybrids showed significant positive heterosis in pooled studies. The SCH-26 recorded top ranking on pooled basis also showed its role in top ranking five hybrids across the environments. The highest range of heterosis in crosses in the range of -25.97 (SCH-15) to 45.44 per cent (SCH-25) was observed in E_4 environment with three significant positive hybrids for 100 seed weight. Five crosses noticed to have significant positive heterosis on pooled basis. The crosses *viz.*, SCH-25, SCH-32 and SCH-22 recorded highest heterosis over best check in pooled environment also had higher values of economic heterosis at least in three environments. For volume weight, the highest range of heterosis over best check was varied from -15.83 (SCH-15) to 38.62 per cent (SCH-32) in E_3 environment with highest significant positive hybrids (7). In pooled environment nine hybrids found to have significant desirable economic heterosis. The highest heterotic hybrid SCH-32 on pooled basis also recorded highest heterotic values in E_1, E_2 and E_3 environments.

The crosses has been ranged from -20.87 (SCH-36) to 9.65 per cent (SCH-24) was maximum for hull content in E_1 environment with highest number of significant desirable hybrids (5). Significant negative heterosis was observed in six crosses on pooled basis. The cross SCH-36 recorded highest desirable heterotic value in E_1 and pooled environment for hull content. The hybrids for oil content were assessed with highest oil content check LSFH-35. The range of heterosis among hybrids on pooled basis varied from -5.06 (SCH-15) to 14.34 per cent (SCH-35) with superiority of E_2 environment having one hybrid with significant positive heterosis. Only two hybrids SCH-35 and SCH-36 displayed significant positive heterosis on pooled basis for oil content. A wide range of heterosis from -64.40 (SCH-14) to 32.59 per cent (SCH-11) was observed in environment E_2 but the maximum number of hybrids (8) showing significant positive heterosis were observed in E_3 environment for seed yield per plant. Five crosses displayed significant desirable heterosis over best check in pooled environment. The cross SCH-11 recorded highest economic heterosis on pooled basis also showed superior performance across the environments.

The heterotic behavior of hybrids over best standard check (Table 1) indicated that the magnitude and direction of standard heterosis varied from hybrid to hybrid and environment to environment. Heterosis was expressed across all environments but its higher magnitude was observed in *kharif* season at Parbhani (E_3 environment) for seed yield per plant. The impact of *Kharif* season at Parbhani was high for expression of heterosis. This is more attributed to proper distribution of rainy days and management of irrigation facilities during *Kharif* season at Parbhani favoured expression of hybrids. The low estimates of mean heterosis during *Rabi* season at Latur could be due to mutual cancellation of desirable environmental effect in the expression of heterosis (Ghodke 1999) [6].

Seed yield per plant is such an important character that decides the direction of the breeding strategy in all breeding programmes. Though yield is complex character directly or indirectly influenced by other yield component traits. The heterotic behavior of hybrids over best standard check pooled over environemnts (Table 2) indicated that five crosses *viz.*, SCH-11, SCH-16, SCH-25, SCH-12 and SCH-26 reported highly significant heterotic estimates over best check hybrid for seed yield per plant along with better *per se* performance. High levels of standard heterosis have also been reported by

Chizega *et al*. (2008) [2], Sujatha and Reddy (2009) [17], Chandra *et al*.(2013) [1], Kulkarni and Supriya (2017) [7] and Tyagi *et al*.(2020) [18] in their respective studies for seed yield. All the above heterotic hybrids were involved either line or tester with higher *per se* performance and either of the parent possessed high GCA effect. This indicated that either of the parents showed have better GCA effect and *per se* performance for getting high heterotic hybrids. Similar results have been reported by Rukminidevi *et al.* (2005) [12], Chandra *et al*. (2013) [1] and Depar *et al.* (2017) [3].

On the basis heterosis study, considering best performing hybrids over best standard check, *per se* performance and SCA effect (Table 3) crosses *viz*., SCH-11, SCH-16, SCH-25, SCH-12 and SCH-26 found to have significant heterosis in desirable direction over best check hybrid as well as high mean performance and therefore identified as best heterotic hybrids for seed yield per plant. These hybrids also manifested significant or desirable heterotic estimates for head diameter, seed filling, volume weight, 100 seed weight, oil content, days to flowering and days to maturity. Moreover, these crosses also found to have significant or desirable SCA effects. These hybrids involved parents with high x high, high x low and low x low GCA effects. This finding supported the conclusion of Sujatha and Reddy (2009) [17] and Sreedhar *et al*. (2010) [16]. It has also been observed that most of the parents involved in above crosses were noticed with high GCA effect indicating that favourable genes got accumulated in the aforesaid crosses.

Seed yield directly or indirectly influenced by its related component traits, the trait itself holds great importance and studied along with other characters (Chandra *et al*. 2013) [1]. Heterotic expression across various characters indicated that heterosis for seed yield per plant in the hybrids, SCH-11, SCH-16, SCH-25, SCH-12 and SCH-26 were associated with heterotic effect for head diameter, seed filling per cent, 100 seed weight and volume weight. This increase in seed yield per plant was appeared due to increase in head diameter, seed filling percentage, 100 seed weight and volume weight. Spoorthy and Nadaf (2016) [15] in their study reported that hybrids performed better with respect to yield, head diameter and other yield component traits. Dhutmal (2017) [4] also found contribution of head diameter, seed filling per cent, 100 seed weight and volume weight towards expression of heterosis for seed yield per plant in hybrids.

Table 1: Heterotic behavior of hybrids over best standard check in individual and pooled environments

Characters	Parameters		E_1	E_2	E_3	E_4	Pooled
Days to 50% flowering	Range of heterosis		-14.29 to 1.43	-13.04 to 1.45	-10.81 to -3.60	-12.96 to 1.85	-12.47 to -0.60
	Mean heterosis		-5.00	-6.16	-6.21	-3.14	-5.19
	No. of Signifi. hybrids	+ve	--	--	--	--	--
		-ve	9	14	13	5	15
	Top ranking hybrids		SCH-13, SCH-22, SCH-21, SCH-12, SCH-11	SCH-22, SCH-23, SCH-21, SCH-13, SCH-12	SCH-21, SCH-22, SCH-34, SCH-25, SCH-24	SCH-22, SCH-21, SCH-32, SCH-34, SCH-25	SCH-22, SCH-21, SCH-13, SCH-12, SCH-23
Days to maturity	Range of heterosis		-5.00 to -1.50	-8.85 to -1.56	-5.23 to 1.16	-7.02 to 3.51	-5.85 to -0.27
	Mean heterosis		-1.94	-5.30	-1.68	-2.24	-2.24
	No. of Signifi. hybrids	+ve	--	--	--	--	--
		-ve	6	14	2	2	11
	Top ranking hybrids		SCH-23, SCH-31, SCH-22, SCH-13, SCH-32	SCH-23, SCH-13, SCH-22, SCH-21, SCH-24	SCH-23, SCH-22, SCH-35, SCH-34, SCH-33	SCH-22, SCH-21, SCH-26, SCH-23, SCH-33	SCH-23, SCH-22, SCH-21, SCH-24, SCH-13
Plant height (cm)	Range of heterosis		-13.47 to 6.10	-2.91 to 18.65	1.35 to 21.71	-2.70 to 21.75	-3.50 to 13.58
	Mean heterosis		-3.77	10.31	13.13	10.75	5.51
	No. of Signifi. hybrids	+ve	--	8	12	8	7
		-ve	2	--	--	--	--
	Top ranking hybrids		SCH-12, SCH-13, SCH-21, SCH-22, SCH-11	SCH-32, SCH-21, SCH-34, SCH-13, SCH-31	SCH-21, SCH-26, SCH-22, SCH-24, SCH-34	SCH-16, SCH-36, SCH-21, SCH-35, SCH-14	SCH-21, SCH-22, SCH-13, SCH-32, SCH-11
Head diameter (cm)	Range of heterosis		-11.80 to 12.80	-31.65 to 16.65	-17.90 to 22.24	-7.34 to 26.41	-5.02 to 16.04
	Mean heterosis		2.76	-3.55	4.40	8.37	3.08
	No. of Signifi.hybrids	+ve	1	2	4	2	4
		-ve	--	5	1	--	--
	Top ranking hybrids		SCH-16, SCH-26, SCH-21, SCH-25, SCH-12	SCH-26, SCH-11, SCH-31, SCH-12, SCH-36	SCH-12, SCH-11, SCH-33, SCH-15, SCH-36	SCH-11, SCH-12, SCH-24, SCH-26, SCH-32	SCH-11, SCH-12, SCH-26, SCH-16, SCH-25
Seed filling (%)	Range of heterosis		-16.23 to 5.90	-15.01 to 17.00	-9.10 to 10.01	-5.42 to 6.58	-1.90 to 8.40
	Mean heterosis		0.32	2.09	3.93	3.58	3.23
	No. of Signifi. hybrids	+ve	--	4	6	--	10
		-ve	2	3	2	--	--
	Top ranking hybrids		SCH-26, SCH-15, SCH-21,	SCH-32, SCH-31, SCH-26,	SCH-11, SCH-24, SCH-26,	SCH-31, SCH-21, SCH-16,	SCH-26, SCH-31, SCH-11,

		SCH-35, SCH-14	SCH-36, SCH-11	SCH-31, SCH-16	SCH-26, SCH-12	SCH-25, SCH-21

Characters	Parameters		E1	E2	E3	E4	Pooled
100 seed weight (g)	Range of heterosis		-17.60 to 20.20	-12.27 to 29.29	-35.25 to 13.92	-25.97 to 45.44	-17.63 to 21.06
	Mean heterosis		1.86	9.58	-1.88	-4.13	1.03
	No. of Signifi. hybrids	+ve	3	9	4	3	5
		-ve	1	1	3	8	6
	Top ranking hybrids		SCH-32, SCH-22, SCH-25, SCH-34, SCH-21	SCH-32, SCH-26, SCH-25, SCH-22, SCH-12	SCH-32, SCH-12, SCH-26, SCH-34, SCH-21	SCH-25, SCH-32, SCH-22, SCH-12, SCH-14	SCH-25, SCH-32, SCH-22, SCH-34, SCH-12
Volume weight (g/100ml)	Range of heterosis		-17.78 to 20.00	-12.49 to 27.21	-15.83 to 38.62	-14.09 to 19.42	-5.41 to 24.18
	Mean heterosis		4.60	4.57	10.73	-0.45	6.03
	No. of Signifi. hybrids	+ve	5	2	7	2	9
		-ve	1	--	1	4	1
	Top ranking hybrids		SCH-32, SCH-16, SCH-34, SCH-22, SCH-11	SCH-15, SCH-16, SCH-32, SCH-11, SCH-14	SCH-32, SCH-31, SCH-12, SCH-22, SCH-33	SCH-32, SCH-22, SCH-25, SCH-21, SCH-34	SCH-32, SCH-16, SCH-22, SCH-34, SCH-31
Hull content (%)	Range of heterosis		-20.87 to 9.56	-13.27 to 9.28	-24.06 to 2.12	-15.82 to 2.55	-14.89 to 3.51
	Mean heterosis		-5.10	-3.16	-6.29	-3.59	-4.85
	No. of Signifi. hybrids	+ve	--	--	--	--	--
		-ve	5	3	3	2	6
	Top ranking hybrids		SCH-36, SCH-21, SCH-12, SCH-33, SCH-16	SCH-35, SCH-22, SCH-25, SCH-26, SCH-32	SCH-11, SCH-36, SCH-21, SCH-22, SCH-16	SCH-35, SCH-36, SCH-26, SCH-34, SCH-11	SCH-36, SCH-11, SCH-21, SCH-35, SCH-16
Oil content (%)	Range of heterosis		-12.25 to 6.99	-4.97 to 33.66	-12.05 to 6.15	-9.26 to 29.44	-5.06 to 14.34
	Mean heterosis		-0.26	1.89	-1.64	2.62	0.56
	No. of Signifi. hybrids	+ve	--	1	--	1	2
		-ve	1	--	4	8	2
			SCH-33, SCH-35, SCH-13, SCH-21, SCH-31	SCH-35, SCH-21, SCH-36, SCH-12, SCH-31	SCH-36, SCH-13, SCH-33, SCH-21, SCH-16	SCH-35, SCH-36, SCH-14, SCH-21, SCH-26	SCH-35, SCH-36, SCH-21, SCH-13, SCH-33
Seed yield/ plant (g)	Range of heterosis		-28.27 to 16.52	-64.40 to 32.59	-53.91 to 42.78	-19.68 to 42.53	-2.69 to 23.68
	Mean heterosis		-2.96	-11.21	10.91	3.80	0.24
	No. of Signifi. hybrids	+ve	2	2	8	4	5
		-ve	3	5	1	--	4
	Top ranking hybrids		SCH-14, SCH-24, SCH-11, SCH-12, SCH-21	SCH-11, SCH-31, SCH-16, SCH-36, SCH-26	SCH-31, SCH-25, SCH-11, SCH-16, SCH-26	SCH-25, SCH-16, SCH-11, SCH-14, SCH-32	SCH-11, SCH-16, SCH-25, SCH-12, SCH-26

Table 2: Per cent heterosis of hybrids over best standard checks pooled over environments for different characters

Hybrids	Days to 50% flowering	Days to maturity	Plant height (cm)	Head diameter (cm)	Seed filling (%)	100 seed weight (g)	Volume weight (g/100ml)	Hull content (%)	Oil content (%)	Seed yield/ plant (g)
SCH-11	-5.84**	-3.40**	4.09	16.04**	7.08**	2.68	7.64**	-10.00**	1.65	23.68**
SCH-12	-7.24**	-3.40**	4.56	14.18**	-0.46	10.22**	3.47	-5.76*	0.14	10.14*
SCH-13	-8.45**	-3.95**	1.97	-3.12	4.45*	-9.79**	1.01	-4.14	3.78	-18.43**
SCH-14	-0.60	-0.41	6.60*	-4.02	1.17	0.87	8.05**	-2.03	-4.89*	3.06
SCH-15	-1.81	-0.27	10.79**	4.22	0.27	-8.41*	-2.21	-1.55	-5.06*	-9.45
SCH-16	-3.82**	-1.50	4.95	8.59*	4.47*	2.63	15.98**	-5.92*	1.49	18.80**
SCH-21	-10.87**	-4.49**	-3.50	-0.37	5.37**	0.10	1.51	-9.86**	4.38	-3.68
SCH-22	-12.47**	-5.85**	0.94	-2.38	-1.90	13.37**	15.97**	-4.72	-4.39	-20.69**
SCH-23	-6.84**	-5.85**	8.91**	-5.02	2.24	-13.16**	-5.41*	3.51	-4.43	-13.71**
SCH-24	-3.42**	-3.95**	6.50*	2.03	4.74*	2.84	6.08*	2.36	-0.66	5.64
SCH-25	-6.44**	-2.45*	5.30	5.84	5.71**	21.06**	8.51**	-4.50	-0.05	17.90**
SCH-26	-0.60	-1.77	5.71	10.08**	8.40**	6.44	2.93	-4.63	1.15	9.80*
SCH-31	-5.03**	-1.50	6.10*	2.37	7.63**	-6.29	9.03**	-4.21	-0.25	3.40
SCH-32	-5.84**	-2.99**	2.65	3.49	-1.22	18.40**	24.18**	-2.73	-3.37	-7.96
SCH-33	-3.82**	-3.54**	13.58**	2.82	2.83	-17.63**	4.66	-5.26	2.91	-0.97

SCH-34	-4.43**	-2.72**	4.39	-3.16	3.84*	10.22**	11.18**	-3.07	-2.25	-13.02**
SCH-35	-3.42**	-1.22	7.21*	0.50	-0.65	-7.74*	-5.00	-9.82**	14.34**	-2.57
SCH-36	-2.41*	-1.63	8.38**	3.41	4.15*	-7.31*	0.96	-14.89**	5.54*	2.33
SE	0.59	0.90	4.34	0.48	1.46	0.17	1.13	0.88	0.78	1.93
CD 5%	1.18	1.79	8.66	0.96	2.90	0.33	2.25	1.76	1.56	3.86
CD 1%	1.56	2.38	11.50	1.28	3.86	0.44	2.99	2.33	2.07	5.12

* Significant at 5% level and ** significant at 1% level.

Note: SCH-Single cross hybrid are of two dgits.1st digit relates to CMS lines and 2nd digit relates to restorer lines.

Table 3: Best heterotic hybrids for seed yield per plant and related traits in sunflower

Hybrids	Seed yield/ plant (g)	SCA effects	Heterosis over best check (%)	Heterosis over best check for related traits	
				Significant heterosis	Desirable heterosis
SCH-11	50.08	4.65**	23.68**	Head diameter, seed filling, volume weight, hull content, days to 50% flowering and days to maturity	100 seed weight and oil content
SCH-16	48.10	1.66	18.80**	Head diameter, seed filling, volume weight, hull content, days to 50% flowering and days to maturity	100 seed weight, oil content and days to maturity
SCH-25	47.74	6.87**	17.90*	Seed filling, 100 seed weight, volume weight, days to 50% flowering and days to maturity	Head diameter and hull content
SCH-12	44.60	4.82**	10.14	Head diameter, 100 seed weight, hull content, days to 50% flowering and days to maturity	Volume weight and oil content
SCH-26	44.46	0.21	9.80*	Head diameter, seed filling and 100 seed weight	Volume weight, hull content, oil content, days to 50% flowering and days to maturity

* Significant at 5% level and ** significant at 1% level

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