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Heterotic studies in three way cross hybrids of sunflower (*Helianthus annuus* L.) over environments

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Abstract
The useful heterotic behaviour of three way cross hybrids assorted in magnitude as well as direction among the hybrids and environments. Expression of standard heterosis was observed across entire environments but its magnitude for seed yield per plant was high in *Rabi* season at Latur (E_2 environment) and has been found to have high impact for expression of heterosis. The five hybrids *viz.*, TWCH-244, TWCH-343, TWCH-216, TWCH-234 and TWCH-133 exhibited significant heterotic estimates over best check hybrid for seed yield per plant and significant or desirable heterotic estimates 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 related Characters. Heterosis for seed yield per plant in the hybrids, TWCH-244, TWCH-343, TWCH-216, TWCH-234 and TWCH-133 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 and fourth 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) [11]. 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) [10] 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 several 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.

Hybrids are preferred over varietal populations because of their uniformity in growth, high productivity, more self-fertile, fertilizer responsive and are fairly tolerant to major foliar diseases (Seetharam, 1981) [17]. Presently the hybrids synthesized and released in the country for commercial cultivation are single cross (SC) hybrids, where uniformity is a distinct advantage. Recent foregoing breeding knowledge reveals that single cross hybrids became fairly stagnant for seed yield over the years and to break this yield plateau some new methods are being investigated. One such method has been widening genetic base of the single cross hybrids through production of three-way cross (TWC) hybrids, which have been adopted successfully in other countries (Anonymous, 1983) [1].

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. Therefore, it is essential to understand the genetic architecture of sunflower. 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, four inbred lines and six restorer lines were used for production of three way cross hybrids. Three CMS lines *viz*., 1) CMS 2A, 2) CMS 10 A and 3) CMS 234 A have been crossed with crossed with four inbred lines i.e. unrelated maintainers (B′) *viz*., 1) TSG-56, 2) PET-2-7-1 B, 3) 400 B and 4) EC-198089 in line x tester fashion to produce twelve sterile F_1's during summer, 2018. Since these inbreds were reported to be devoid of restorer genes, the crosses with them are supposed to be sterile. In order to confirm the extent of sterility, all the 12 F_1's were grown during *kharif*, 2018 and 100 per cent sterility was recorded. Meanwhile, all the six restorers lines *viz*., 1) EC-623008, 2) No.1147-2, 3) 99-RT, 4) RHA-1-1, 5) EC-601951 and 6) TSG-271 were sown in a separate block staggered to synchronize flowering with sterile single crosses. These 12 sterile F_1's were attempted as females to cross with six restorer lines to produce 72 three-way cross hybrids (TWCH).

One hundred entries comprising 72 three way cross hybrids, 25 parents (3 CMS lines, 4 Inbred lines, 12 TWCMS lines and 6 restorer 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) [15]. 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) [6] and Meredith and Bridge (1972) [12] for individual as well as over the environments.

Results and Discussion

The heterotic behavior of top ranking five three way cross hybrids over best standard check for different traits in individual and pooled environments is depicted in Table 1. The highest range of standard heterosis for days to 50 percent flowering in three way cross hybrids varied from -13.57 (TWCH-122) to 7.86 per cent (TWCH-146) in E_1 environment having 33 hybrids with significant negative heterosis. A total of 49 three way cross hybrids expressed significant negative heterosis on pooled basis. The hybrid TWCH-322 displayed highest significant negative heterosis on pooled basis also observed to have significant top ranking in E_1, E_2 and E_4 environments. The range of economic heterosis from -11.46 (TWCH-223) to 2.60 per cent (TWCH-146) was highest in E_2 environment with highest number of significant negative hybrids (36) for days to maturity. On pooled basis, 44 three way crosses recorded significant desirable heterosis. The crosses *viz*., TWCH-211, TWCH-223, TWCH-213 and TWCH-231 were observed to have earliest maturity in pooled environment also had top ranking earliest position in at least 2 environments. All this top ranking early maturing hybrids were derived from the crosses involving CMS-10 A and maintainer inbred TSG-56 and PET-2-7-1 B. The highest range of heterosis for plant height was observed from -16.35 (TWCH-222) to 30.57 per cent (TWCH-123) in E_2 environment with only one hybrid (TWCH-222) showing significant negative heterosis. Only TWCH-231 recorded significant negative heterosis on pooled basis for plant height.

Table 1: Heterotic behaviour of three way cross hybrids (TWCH) over best standard check in individual and pooled environments

Characters			E_1	E_2	E_3	E_4	Pooled
Days to 50% flowering	Range of heterosis		-13.57 to 7.86	-12.32 to 7.25	-10.81 to 6.31	-13.89 to 5.56	-11.47 to 5.03
	Mean heterosis		-3.51	-4.65	-4.91	-3.95	-4.23
	No. of signifi. hybrids	+ve	4	5	1	1	4
		-ve	33	47	43	33	49
	Top ranking hybrids		TWCH-122, TWCH-142, TWCH-322, TWCH-222, TWCH-322	TWCH-121, TWCH-122, TWCH-322, TWCH-221, TWCH-111	TWCH-321, TWCH-326, TWCH-211, TWCH-212, TWCH-313	TWCH-321, TWCH-341, TWCH-322, TWCH-342, TWCH-222	TWCH-322, TWCH-222, TWCH-122, TWCH-342, TWCH-332
Days to maturity	Range of heterosis		-8.00 to 2.50	-11.46 to 2.60	-5.23 to 2.91	-8.19 to 4.09	-6.26 to 2.04
	Mean heterosis		-2.22	-3.97	-1.56	-1.94	-2.46
	No. of signifi. hybrids	+ve	1	--	--	2	1
		-ve	27	36	6	17	44
	Top ranking hybrids		TWCH-213, TWCH-211, TWCH-223, TWCH-231,	TWCH-223, TWCH-231, TWCH-113, TWCH-222,	TWCH-323, TWCH-324, TWCH-213, TWCH-214,	TWCH-211, TWCH-226, TWCH-325, TWCH-212,	TWCH-211, TWCH-223, TWCH-213, TWCH-231,

			TWCH-233	TWCH-121	TWCH-221	TWCH-221	TWCH-212
Plant height (cm)	Range of heterosis		-20.99 to 15.73	-16.35 to 30.57	-3.77 to 26.71	-15.25 to 20.93	-7.09 to 16.65
	Mean heterosis		2.28	9.49	13.58	0.99	5.58
	No. of Signifi. hybrids	+ve	16	36	49	11	41
		-ve	4	1	--	6	1
	Top ranking hybrids		TWCH-111, TWCH-122, TWCH-231, TWCH-332, TWCH-211	TWCH-222, TWCH-221, TWCH-231, TWCH-223, TWCH-331	TWCH-326, TWCH-346, TWCH-345, TWCH-331, TWCH-341	TWCH-245, TWCH-331, TWCH-232, TWCH-341, TWCH-243	TWCH-231, TWCH-331, TWCH-232, TWCH-222, TWCH-221
Head diameter (cm)	Range of heterosis		-19.04 to 24.91	-31.65 to 21.69	-8.66 to 33.74	-14.67 to 22.01	-3.11 to 20.78
	Mean heterosis		6.92	-0.15	13.30	6.27	6.82
	No. of Signifi. hybrids	+ve	18	10	38	13	32
		-ve	1	12	--	1	--
	Top ranking hybrids		TWCH-242, TWCH-231, TWCH-244, TWCH-133, TWCH-324	TWCH-116, TWCH-216, TWCH-312, TWCH-234, TWCH-343	TWCH-313, TWCH-111, TWCH-234, TWCH-132, TWCH-222	TWCH-222, TWCH-234, TWCH-124, TWCH-346, TWCH-135	TWCH-234, TWCH-244, TWCH-124, TWCH-343, TWCH-216
Seed filling (%)	Range of heterosis		-30.85 to 9.09	-19.11 to 20.89	-11.13 to 7.16	-18.47 to 8.91	-11.24 to 9.41
	Mean heterosis		-1.74	-0.10	0.29	1.90	1.18
	No. of Signifi. hybrids	+ve	9	8	--	1	17
		-ve	18	8	5	2	8
	Top ranking hybrids		TWCH-246, TWCH-316, TWCH-243, TWCH-244, TWCH-114	TWCH-344, TWCH-111, TWCH-222, TWCH-116, TWCH-216	TWCH-145, TWCH-321, TWCH-343, TWCH-143, TWCH-234	TWCH-234, TWCH-244, TWCH-342, TWCH-222, TWCH-314	TWCH-343, TWCH-244, TWCH-246, TWCH-234, TWCH-216

Table 1: Contd…

Characters			E_1	E_2	E_3	E_4	Pooled
100 seed weight (g)	Range of heterosis		-24.80 to 40.40	-21.50 to 58.84	-31.84 to 45.57	-26.08 to 34.17	-21.11 to 30.82
	Mean heterosis		9.72	8.98	2.23	-4.30	4.46
	No. of signifi. hybrids	+ve	28	29	21	14	30
		-ve	3	9	16	34	16
	Top ranking hybrids		TWCH-242, TWCH-344, TWCH-124, TWCH-314, TWCH-322	TWCH-142, TWCH-342, TWCH-122, TWCH-312, TWCH-322	TWCH-314, TWCH-114, TWCH-312, TWCH-313, TWCH-343	TWCH-322, TWCH-313, TWCH-321, TWCH-312, TWCH-342	TWCH-322, TWCH-342, TWCH-312, TWCH-314, TWCH-142
Volume weight (g/100ml)	Range of heterosis		-26.11 to 22.53	-22.79 to 30.29	-20.79 to 30.92	-40.91 to 22.47	-23.62 to 16.65
	Mean heterosis		-2.70	4.57	7.36	-8.57	0.99
	No. of signifi. hybrids	+ve	9	18	32	8	23
		-ve	19	6	3	37	16
	Top ranking hybrids		TWCH-342, TWCH-144, TWCH-112, TWCH-324, TWCH-341	TWCH-134, TWCH-124, TWCH-242, TWCH-224, TWCH-231	TWCH-112, TWCH-332, TWCH-242, TWCH-122, TWCH-233	TWCH-222, TWCH-122, TWCH-322, TWCH-312, TWCH-331	TWCH-312, TWCH-242, TWCH-332, TWCH-232, TWCH-112
Hull content (%)	Range of heterosis		-21.27 to 15.92	-17.45 to 7.95	-21.55 to 6.25	-19.96 to 4.06	-17.93 to 5.26
	Mean heterosis		-2.33	-3.93	-5.39	-5.07	-4.51
	No. of signifi. hybrids	+ve	2	--	--	--	--
		-ve	10	12	13	8	31
	Top ranking hybrids		TWCH-332, TWCH-336, TWCH-335, TWCH-221, TWCH-241	TWCH-335, TWCH-312, TWCH-332, TWCH-222, TWCH-134	TWCH-136, TWCH-324, TWCH-134, TWCH-335, TWCH-233	TWCH-335, TWCH-134, TWCH-232, TWCH-221, TWCH-312	TWCH-335, TWCH-134, TWCH-221, TWCH-232, TWCH-332
Oil content (%)	Range of heterosis		-23.81 to 15.84	-16.17 to 33.23	-21.55 to 13.43	-10.41 to 28.80	-12.74 to 21.58
	Mean heterosis		-1.05	4.52	-2.30	3.90	1.08
	No. of signifi. hybrids	+ve	--	11	1	10	7
		-ve	6	1	9	--	6
			TWCH-221, TWCH-336, TWCH-335, TWCH-115, TWCH-321	TWCH-222, TWCH-221, TWCH-231, TWCH-233, TWCH-335	TWCH-221, TWCH-243, TWCH-131, TWCH-316, TWCH-246	TWCH-221, TWCH-222, TWCH-233, TWCH-335, TWCH-231	TWCH-221, TWCH-335, TWCH-222, TWCH-236, TWCH-233
Seed yield/ plant (g)	Range of heterosis		-52.76 to 42.31	-64.40 to 69.21	-43.69 to 55.81	-62.67 to 28.81	-32.52 to 35.30
	Mean heterosis		-2.91	1.47	11.74	-12.40	-0.73
	No. of signifi.	+ve	16	20	25	5	11

	hybrids	-ve	18	20	5	26	20
	Top ranking hybrids		TWCH-231, TWCH-133, TWCH-324, TWCH-343, TWCH-244	TWCH-216, TWCH-236, TWCH-343, TWCH-132, TWCH-234	TWCH-313, TWCH-114, TWCH-343, TWCH-314, TWCH-124	TWCH-244, TWCH-222, TWCH-234, TWCH-313, TWCH-224	TWCH-244, TWCH-343, TWCH-216, TWCH-234, TWCH-133

Note: TWCH-Three way cross hybrids are of three digits. 1st digit relates to CMS lines, 2nd digit relates to maintainer inbred lines and 3rd digit relates to restorer lines

For head diameter the highest range of hetrosis in E_2 environment varied from -31.65 (TWCH-222) to 21.69 per cent (TWCH-116) having 10 significant desirable hybrids. Thirty two crosses recorded significant positive heterosis in pooled environment. Three way crosses *viz.*, TWCH-234, TWCH-244 and TWCH-124 displayed highest useful heterosis on pooled basis for head diameter. The highest heterotic range for seed filling per cent has been from -19.11 (TWCH-145) to 20.89 per cent (TWCH-344) in E_2 environment with seven hybrids showing significant desirable heterosis. A total of 17 three way cross hybrids expressed significant positive heterosis over best check in pooled environment. Hybrid TWCH-343 recorded highest significant desirable heterosis followed by TWCH-244 and TWCH-246 showing the involvement of maintainer inbred EC-198089 in the hybrids. Economic heterosis among three way crosses was highly varied from -21.50 (TWCH-131) to 58.84 per cent (TWCH-142) in E_2 environment with highest number of hybrid (29) observed to have significant desirable useful heterosis for 100 seed weight. Significant superiority over best check was recorded in 30 three way crosses in pooled environment. The crosses *viz.*, TWCH-322, TWCH-342, TWCH-312 and TWCH-314 found to have top ranking crosses on pooled basis were derived from the crosses involving CMS-234 A and inbred maintainer TSG-56, PET-2-7-1 B and EC-198089. The hybrids recorded highest range of useful heterosis in E_4 environment for volume weight which was in the range of -40.91 (TWCH-215) to 22.47 per cent (TWCH-222) with eight significant desirable hybrids. A total of 22 three way cross hybrids displayed significant positive heterosis on pooled basis. Hybrid TWCH-312 recorded highest significant positive useful heterosis followed by TWCH-242 and TWCH-332 in pooled environment.

The highest range of standard heterosis for hull content was in the range of -21.27 (TWCH-332) to 15.92 per cent (TWCH-341) which was maximum in E_1 environment having 10 crosses with significant desirable economic heterosis. Total 31 three way crosses found to have significant negative heterosis over best check on pooled basis. Most of the top ranking three way crosses *viz*., TWCH-335, TWCH-134, TWCH-232 and TWCH-332 involved maintainer inbred 400 B. For oil content three way cross hybrids has been varied from -12.74 (TWCH-345) to 21.58 per cent (TWCH-221) for standard heterosis in pooled environment with superiority of environment E_2 showing 11 hybrids with significant desirable heterosis. On pooled basis, 7 hybrids showed significant positive heterosis over best check LSFH-35. Hybrid TWCH-221 recorded highest standard heterosis followed by TWCH-335 and TWCH-122. All the top ranking hybrids were synthesized from the hybrids involving either CMS-10 A or CMS-234 A and inbred maintainers PET-2-7-1 B and 400 B. The highest range of heterosis for seed yield per plant found to varied from -64.40 (TWCH-223) to 69.21 per cent (TWCH-216) in E_2 environment having 20 crosses with significant positive economic heterosis. A total of 11 crosses recorded significant desirable heterosis on pooled basis. The cross TWCH-244 followed by TWCH-343 and TWCH-216 recorded higher significant standard heterosis for seed yield per plant.

The heterotic behavior of three way cross hybrids over best standard check (Table 1) revealed that the magnitude as well as direction of usful heterosis assorted among hybrids and environments. Expression of standard heterosis was observed across entire environments but its magnitude for seed yield per plant was high in *Rabi* season at Latur (E_2 environment). The *Rabi* season at Latur has been found to have high impact for expression of heterosis. Three way cross hybrids expressed better compared to their parents in rainfed situation during *Rabi* season at Latur. This better expression of three way cross hybrids compared to single cross hybrids might be due to buffering capacity against rainfed situation and heterotic effect in female of three way cross hybrids due to involvement of additional inbred line incorporated in these hybrids for getting maximum seed yield. The estimates of mean heterosis were appeared low during *Kharif* season at Latur could be due to mutual cancellation of desirable environmental effect in the heterosis expression. High mean heterosis was reported during *Kharif* season at Parbhani is due to appropriate distribution of rainy days and management of irrigation facility during dry spells. These results are in aggreemnt with earlier reports of Ghodke (1999) [7].

Seed yield per plant is an important character and directly or indirectly influenced by its component traits. The heterotic behavior of three way cross hybrids over best standard check pooled over environments (Table 2) revealed that five hybrids *viz.*, TWCH-244, TWCH-343, TWCH-216, TWCH-234 and TWCH-133 exhibited highly significant heterotic estimates over best check hybrid along with better *per se* performance for seed yield per plant. These results obtained are coinciding with those mentioned by Naresh *et al.* (1996) [13], Channakrishnnaiah *et al.* (1996) [3], Halaswamy (1998) [8], Halaswamy *et al*. (2003) [9], Neelima (2007) [14] and Singh (2013) [18]. 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) [16] and Depar *et al.* (2017) [4].

Table 2: Percent heterosis of three way cross 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)
TWCH-111	-8.45**	-3.27**	-2.71	3.01	6.25**	-2.04	5.64*	-3.34	3.37	-2.28
TWCH-112	-5.84**	-3.67**	-0.70	8.90*	-8.30**	8.69**	13.38**	-4.65	4.49	-22.75**

TWCH-113	-7.24**	-4.76**	3.32	-1.64	-0.35	-7.77**	5.96*	-2.10	-12.55**	-12.87**
TWCH-114	-1.81	-1.50	4.04	11.26**	3.83	17.17**	-5.42*	-2.86	-8.86**	19.84**
TWCH-115	-1.41	-1.09	5.49*	4.26	-0.66	0.74	-14.04**	-6.19*	1.95	10.26*
TWCH-116	-0.80	-1.22	4.13	7.44*	2.40	-14.75**	-2.52	-4.13	-0.55	-17.23**
TWCH-121	-8.25**	-3.67**	3.90	12.50**	2.13	-1.30	-3.11	-4.46	2.61	-8.09
TWCH-122	-9.86**	-3.95**	-0.14	10.82**	-3.08	22.23**	9.00**	-7.82**	0.55	-19.33**
TWCH-123	-6.84**	-4.08**	12.96**	5.41	3.74	-3.53	-4.5	-3.47	-0.87	-0.63
TWCH-124	-2.41*	-2.18*	16.65**	18.30**	5.97*	20.16**	10.67**	-2.34	2.37	27.18**
TWCH-125	-1.81	-0.14	8.84**	7.58*	-2.87	3.09	-4.77	-5.90*	3.32	-18.98**
TWCH-126	3.42**	2.04*	10.72**	8.34*	-0.78	-15.26**	-2.59	-5.55*	-0.51	-16.34**
TWCH-131	0.20	0.41	6.26*	-0.96	-0.62	-21.11**	0.5	-4.90	4.56	-18.21**
TWCH-132	-3.22**	-2.45**	4.53	14.00**	-7.11**	15.79**	7.84**	-1.22	-2.96	-5.92
TWCH-133	-1.41	-0.68	16.38**	13.89**	5.42*	3.65	-6.76**	0.10	-1.63	30.10**
TWCH-134	5.03**	1.36	9.09**	1.32	5.18*	4.55	10.36**	-12.92**	5.23	0.76
TWCH-135	0.80	-0.27	8.89**	8.47*	-0.75	-8.64**	-8.44**	-3.05	-5.99	-23.60**
TWCH-136	3.42**	-1.09	9.60**	11.83**	4.96*	-5.83*	0.25	-8.90**	-1.27	7.88
TWCH-141	-4.23**	-2.59**	5.65*	6.69	3.85	6.03*	3.15	-8.07**	2.49	-2.44
TWCH-142	-8.05**	-3.54**	3.65	12.09**	-8.32**	23.82**	0.71	-6.88**	-3.75	-10.51*
TWCH-143	-4.63**	-2.86**	8.32**	6.34	-2.27	-9.40**	-1.59	-5.40*	-2.09	0.26
TWCH-144	-0.20	0.00	12.86**	10.39**	1.76	-1.12	2.13	0.08	-9.60**	-6.23
TWCH-145	1.01	1.22	8.88**	9.23**	0.30	-0.36	-7.76**	-1.83	-2.24	2.4
TWCH-146	3.02**	0.14	7.66**	8.42*	-0.16	-6.36*	-1.47	0.10	-4.4	9.01
TWCH-211	-9.05**	-6.26**	0.69	8.43*	1.62	2.07	-1.43	-2.23	-0.57	3.28
TWCH-212	-9.05**	-5.58**	4.34	14.61**	-1.15	13.26**	7.16**	-6.00*	0.6	8.52
TWCH-213	-6.04**	-6.12**	9.74**	9.22**	6.68**	-4.52	-9.94**	-2.33	-3.32	4.17
TWCH-214	-1.61	-2.45**	6.17*	7.06*	1.91	11.93**	-4.06	-2.64	1.83	7.3
TWCH-215	-2.41*	-2.18*	6.90**	3.94	-2.90	-10.99**	-23.62**	-4.25	-0.11	-13.06**
TWCH-216	-3.62**	-2.72**	8.30**	16.90**	7.35**	10.81**	2.69	-2.85	-0.07	33.23**
TWCH-221	-8.05**	-4.90**	-2.72	-0.38	5.84*	3.68	0.86	-12.73**	21.58**	-6.03
TWCH-222	-10.26**	-5.03**	-2.74	7.80*	1.92	6.16*	8.99**	-9.96**	14.26**	-8.11
TWCH-223	-6.84**	-6.26**	5.37*	-2.30	-0.10	6.29*	0.13	-2.89	7.22*	-19.21**
TWCH-224	-3.22**	-3.67**	3.65	5.58	-2.79	0.10	3.38	-2.47	-0.59	4.53
TWCH-225	-3.22**	-2.59**	1.47	1.82	-3.91	3.40	-19.07**	-1.98	4.84	-12.64*
TWCH-226	-1.81	-2.72**	4.40	-0.97	1.44	0.54	-6.94**	-6.06*	8.71**	-11.64*
TWCH-231	-7.65**	-6.12**	-7.09**	14.75**	4.45	-7.31**	5.48*	-8.51**	8.62**	14.67**
TWCH-232	-9.05**	-4.76**	-3.97	-0.83	1.08	7.82**	13.48**	-12.07**	2.85	-21.22**
TWCH-233	-4.63**	-4.90**	9.65**	3.84	1.06	-10.09**	5.64*	-6.77**	11.56**	-5.15
TWCH-234	-0.60	-1.77	7.96**	20.78**	7.38**	-2.89	-0.41	1.13	5.00	32.32**

Table 2: Contd…

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)
TWCH-235	-0.20	-0.95	5.04	2.16	-2.14	-7.44**	-6.66**	-2.37	5.29	-13.80**
TWCH-236	-3.62**	-1.77	6.73**	9.24**	1.89	-6.77*	0.6	-2.68	12.20**	7.46
TWCH-241	-6.44**	-2.99**	-0.02	2.11	5.09*	-1.81	1.71	-7.75**	3.71	-1.24
TWCH-242	-8.65**	-3.81**	5.75*	13.92**	-4.66*	19.47**	15.68**	-5.78*	-0.57	1.88
TWCH-243	-6.04**	-4.76**	5.59*	5.92	1.69	-1.69	-0.62	-7.03**	3.66	3.9
TWCH-244	-5.43**	-3.27**	10.93**	19.97**	9.33**	23.64**	10.57**	-6.63*	5.89	35.30**
TWCH-245	-3.02**	-0.82	0.87	3.87	-0.60	-3.68	-7.92**	-4.14	0.08	-3.92
TWCH-246	-0.60	-0.82	6.55*	5.40	8.19**	-5.75*	-0.56	-5.90*	4.56	6.94
TWCH-311	-6.24**	-2.99**	11.62**	5.74	4.58	9.99**	5.43*	-8.10**	2.03	4.24
TWCH-312	-7.44**	-3.54**	8.15**	5.16	-11.24**	28.16**	16.65**	-9.17**	2.82	-13.39**
TWCH-313	-7.04**	-4.08**	10.15**	3.58	4.92*	21.34**	6.06*	3.84	-1.56	9.89*
TWCH-314	-1.81	-0.27	12.04**	3.15	3.46	27.29**	2.03	0.99	-3.22	8.34
TWCH-315	-3.02**	-0.95	5.62*	3.66	-1.72	-3.09	-8.81**	0.71	-1.41	-5.31
TWCH-316	-3.02**	0.14	7.97**	2.26	5.44*	-8.36**	-5.38*	-4.73	5.07	-11.21*
TWCH-321	-7.04**	-2.72**	6.79**	-0.85	3.19	12.93**	1.61	-5.04	0.17	-6.52
TWCH-322	-11.47**	-3.95**	2.38	7.78*	-7.66**	30.82**	8.94**	-0.10	-11.51**	-14.77**
TWCH-323	-6.04**	-4.76**	10.00**	-2.49	4.68*	-13.98**	-5.46*	1.25	-6.54*	-8.43
TWCH-324	-5.43**	-1.50	6.79**	13.15**	2.46	3.12	2.17	-9.77**	3.17	21.36**
TWCH-325	-4.02**	-2.72**	5.83*	5.35	-4.83*	6.77*	-9.67**	-8.76**	2.38	-8.69
TWCH-326	-5.84**	-1.77	3.96	2.97	7.02**	4.37	4.9	-7.62**	0.79	6.09
TWCH-331	-5.23**	-2.59**	-6.18*	1.67	4.10	5.60*	8.79**	-6.34*	-1.91	-4.91
TWCH-332	-9.46**	-2.45**	-0.70	8.93*	-8.21**	14.08**	15.38**	-11.84**	-1.52	-32.52**
TWCH-333	-5.63**	-3.13**	9.46**	12.70**	4.19	5.32	-3.16	-5.20*	-3.39	9.09
TWCH-334	-0.80	-2.18*	3.88	6.67	-1.32	5.21	0	-2.93	1.33	-2.11
TWCH-335	-0.80	0.54	8.01**	7.55*	-1.40	4.04	-5.25*	-17.93**	15.15**	-1.21

TWCH-336	-5.43**	-3.54**	2.88	-2.54	4.37	11.93**	3.6	-11.03**	5.65	3.6
TWCH-341	-7.04**	-2.99**	-2.02	4.73	-0.10	6.16*	11.51**	5.26*	-2.72	-7.57
TWCH-342	-9.66**	-3.54**	4.26	-3.11	0.02	29.57**	11.27**	0.06	-0.69	-9.21
TWCH-343	-6.44**	-1.77	10.09**	17.78**	9.41**	23.18**	11.06**	0.66	-4.07	35.28**
TWCH-344	-1.21	0.68	8.15**	4.66	3.11	17.40**	-4.06	2.19	-2.11	5.42
TWCH-345	-2.41*	-0.68	5.62*	-1.81	-2.33	7.49**	-2.81	1.19	-12.74**	-11.07*
TWCH-346	-1.61	-1.22	5.00	13.37**	3.84	-2.73	4.79	-1.72	2.04	11.07*
SE	0.61	0.85	3.80	0.50	1.82	0.13	1.08	0.84	1.03	2.00
CD 5%	1.20	1.67	7.48	0.99	3.57	0.26	2.13	1.66	2.02	3.94
CD 1%	1.57	2.21	9.85	1.30	4.71	0.35	2.81	2.19	2.66	5.19

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

On the basis heterosis study, considering best performing hybrids over best standard check, *per se* performance and SCA effect (Table 3) three way way crosses *viz*., TWCH-244, TWCH-343, TWCH-216, TWCH-234 and TWCH-133 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. This finding supported the conclusion of Sujatha and Reddy (2009) [21]. Seed yield is a complex character and directly or indirectly influenced by its component traits, the trait itself holds great importance and studied along with other characters (Chandra *et al*. 2013) [2]. Heterotic expression across various characters indicated that heterosis for seed yield per plant in the hybrids, TWCH-244, TWCH-343, TWCH-216, TWCH-234 and TWCH-133 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) [19] in their study reported that hybrids performed better with respect to yield, head diameter and other yield component traits. Dhutmal (2017) [5] 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 single cross hybrids. While high heterotic hybrids for seed yield had simultaneous desirable heterotic effects for component characters like head diameter, seed filling and test weight was observed in three way cross hybrids (Sreedhar *et al*., 2010) [20].

Table 3: Best heterotic three way cross 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**
TWCH-244	54.79	5.91**	35.30**	Head diameter, seed filling, 100 seed weight, volume weight, hull content, days to 50% flowering and days to maturity	Oil content
TWCH-343	54.77	10.81**	35.28**	Head diameter, seed filling, 100 seed weight, volume weight and days to 50% flowering	Days to maturity
TWCH-216	53.95	9.25**	33.23**	Head diameter, seed filling, 100 seed weight, days to 50% flowering and days to maturity	Volume weight and hull content,
TWCH-234	53.58	6.63**	32.32**	Head diameter and seed filling	Oil content, days to 50% flowering and days to maturity
TWCH-133	52.68	10.93**	30.10**	Head diameter and seed filling	Volume weight, days to 50% flowering and days to maturity

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

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