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Evaluation of staygreen sunflower lines and their hybrids for yield under drought conditions

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Abstract: The experimental material for the present study comprised of 28 inbred lines (including two checks) which were developed by mutation and hybridization among the lines from AICRP trials MARS, UAS, Dharwad and on the basis of SPAD readings and stay green nature, they were considered as drought tolerant lines. These lines were used for the present experiment and were evaluated under both normal and moisture stress condition in rain out shelter to study their root characteristics. Among 28 inbreds evaluated, eight inbred lines i.e. DSR-13, DSR-19, DSR-23, DSR-24, DSR-37, DSR-66, DSR-107 and DSR-132 were identified as drought tolerant nature which exhibited least reduction in their yield under moisture stress condition. Simultaneously hybridization programme was also initiated during summer 2018 using these 28 inbred lines as testers (males) and 5 CMS lines as female lines in Line × Tester fashion. Among 140 hybrids developed, only 40 F_1 hybrid combinations were further analyzed for heterosis and combining ability studies along with four checks RHA 6D-1, RHA 95C-1, KBSH-53 and Cauvery Champ. Most of the hybrid combinations showed significant negative heterosis for flowering indicating earliness, and also all the combinations showed a positive heterosis for plant height indicating tallness dominant over dwarf checks. The combinations CMS 7-1-1 A × DSR-37 (624 kg/ha), CMS-853A × DSR-19 (624 kg/ha), and CMS-853A × DSR-23 (619 kg/ha) exhibited significant maximum heterosis for seed yield (kg ha^{-1}) over the checks KBSH-53 (496.50 kg/ha) and Cauvery Champ (486.50 kg/ha) showing maximum seed yield per hectare.

Keywords: CMS; heterosis; inbreds; staygreen.

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Introduction

Sunflower (*Helianthus annuus* L.) is the most important oilseed crop after soybean in the world, belonging to Asteraceae/Compositae family originated from temperate North America and has high content of unsaturated fatty acids with a desirable quality. It is a diploid crop with an haploid genome size of about 3000 Mb with diploid chromosome number $2n = 34$. Sunflower has been successfully cultivated over a widely scattered geographical area across the world. It is a highly cross pollinated crop, which can be adapted to various environmental conditions having high yield potential. Due to its photo insensitiveness it can be grown in all seasons and can be taken in various inter and sequence cropping systems. Due to its moderate requirements and high oil quality, its average has been increased in both developing and developed countries.

However, the average productivity of crop is a major concern in India, which is less than half the world's average yield due to its cultivation under rainfed situation and the crop suffering from moisture stress and diseases-pests incidence. Along with the biotic stresses like pest and diseases, an abiotic stresses like drought, temperature and sunshine affect the productivity. Water stress is one of the major drawback to the crop yield throughout the world and the global climate change scenarios suggest a future increase in the risk of drought. Drought alone is responsible for 15–50% reduction of the yield (Geeta et al. 2012). Hence, it is necessary to save the yield loss due to drought in order to realize the full potential. Evidences indicate that sunflower is sensitive to water stress during vegetative phase and seed filling stage that causes considerable decrease in yield and oil content in sunflower. The identification of suitable genotypes exhibiting tolerance to moisture stress as well as those showing least percent reduction in their growth and yield attributes under soil moisture stress is necessary for the improvement of productivity under rainfed environment.

The root system of crop plays a very important role while considering drought tolerant breeding program. Root characteristics such as root biomass, maximum root length and the root volume helps to determine the efficiency of extraction of moisture from the soil. Sunflower genotypes having deep and extensive root system have the ability to extract water from depth of 270 cm. Root development and growth depends upon the several factors such as plant genotype, moisture or water availability, plant population and soil condition (Figure 1).

Thus breeding crop varieties along with stay green nature of crop with better performing root traits for effective utilization of water during stress condition is of great importance (Connor and Sadras 1992). From the agro eco analysis of growing seasons, it is evident that drought stress has a major impact on limiting productivity both in *kharif* and *rabi* seasons in the major sunflower growing areas, that causes significant recurring yield losses. Some of these have remained as major issues for many years demanding close attention. Sunflower production continues to face challenges especially in India, as the crop is often grown on marginal land which is inherently deficient in moisture and nutrients.

Heterosis is the most important contributions towards improvisation in agriculture with respect to yield. Since farmers mainly prefer hybrids to cultivate in larger areas, this heterosis exploitation is best suited for increase in the yield of the crop. The importance of hybrids especially in sunflower has been increasing now a days because of its higher seed yield capacity when compared with other cross-pollinated varieties in the world. Hybrids are more stable, highly self-fertile, with high yielding ability and more uniformity at maturity. Drought and disease tolerance breeding has gained its importance in obtaining hybrid varieties. The heterotic performance of a hybrid combination (showing superiority when compared to their parents) mainly depends upon the combining abilities of parents used.

Materials and methods

The present investigation was carried out during summer 2018 and *kharif* 2018 at H block and C_2 block, respectively at the college of Agriculture, Vijayapura to evaluate stay green sunflower lines and hybrids for yield under drought conditions.

Figure 1: Performance of inbreds with respect to root trait under stress condition along with checks.

Evaluation of inbred lines for drought tolerance

The experimental material for the present study comprised of 28 inbred lines (including two checks) which were developed by mutation and hybridization breeding (involving Texas 16 R, a wild relative of cultivated sunflower which was characterised by branching and small heads but was tolerant to drought) in AICRP on oilseeds, MARS, UAS, Dharwad. From earlier studies on the basis of SPAD reading and stay green nature, they were considered as drought tolerant lines.

These lines were used for the present experiment and were evaluated under both normal and moisture stress conditions in rain out shelter to study their yield and morpho-physiological traits for drought tolerance. Simultaneously hybridization programme was also initiated during summer 2018 using these 28 inbred lines as testers (males) and 5 CMS lines as female lines. Among the 140 hybrids developed, only the hybrids developed by using eight superior drought tolerant inbred (5 lines × 8 testers = 40 hybrids) were further analyzed for heterosis and combining ability studies along with four checks

In rainout shelter, the experiment was set up using PVC pipes of 1.2 m length which were split vertically in the middle and locking system was provided at two points along with the split end of the PVC pipes. The pipes were then put in the soil covering 2 ft height. The pipes were filled with soil: FYM: sand in the ratio 3:2:1. Two seeds were sown per pipe and totally 28 inbred lines and two checks were used for the evaluation. The details of which are given in Table 1. The experiment was laid out in randomized block design with two replications. In the first set of experiment, which comprised of evaluation of inbred lines under normal conditions for yield and root traits, irrigation at regular intervals was provided till maturity. In the second set, where in the inbreds were evaluated under stress condition, normal irrigation was given until flowering stage i.e. 45–50 DAS and later on the irrigation was withheld.

Table 1: List of 28 inbred lines evaluated under controlled conditions for drought tolerance in sunflower.

Sl. no	Inbreds	Sl. no	Inbreds
1	DSR-1	15	DSR-15
2	DSR-2	16	DSR-16
3	DSR-3	17	DSR-17
4	DSR-4	18	DSR-18
5	DSR-5	19	DSR-19
6	DSR-6	20	DSR-23
7	DSR-7	21	DSR-35
8	DSR-8	22	DSR-37
9	DSR-9	23	DSR-66
10	DSR-10	24	DSR-107
11	DSR-11	25	DSR-125
12	DSR-12	26	DSR-132
13	DSR-13	27	RHA 95 C-1 (Check)
14	DSR-14	28	RHA 6D-1 (Check)

Source of inbreds:- Inbreds were developed by mutation and hybridization breeding (involving Texas 16 R, a wild relative of cultivated sunflower which was characterised by branching and small heads but was tolerant to drought in AICRP on oilseeds, MARS, UAS, Dharwad.

Hybridization and generation of F_1 hybrids

The hybridization programme was initiated during summer 2018 using these 28 inbred lines as testers (males) and 5 CMS lines as female lines. Totally 140 hybrids were developed. Among 140 hybrids, fourty hybrids developed by using eight superior identified lines (5 lines × 8 testers = 40 hybrids) were further analyzed for heterosis and combining ability studies along with four checks. The parental lines used for hybridization are given in Table 2. The eight testers were sown twice with an interval of 15 days to synchronize flowering period with male sterile female lines. The spacing followed was 60 × 30 cm with a row length of 4 m. The recommended package of practices were followed to raise a good crop. To avoid pollination from other sources, each CMS lines was bagged before flowering period. Hybridization was effected in the morning from 6 to 8 am by collecting the pollen in petri plates and brushing on female lines. Till the seeds were set on the female lines, proper care was taken to avoid contamination from other pollens by bagging. The pollination process was repeated 2–3 times, so that all the florets were pollinated on the female parent.

The hybrid seeds set on the female parent were harvested separately, sun dried to proper seed moisture condition and threshed separately. Totally 140 hybrids were generated using 5 × 28 combination. But for hybrid evaluation only 40 hybrids were used (with identified superior inbred lines).

Evaluation of hybrids

The 40 hybrids along with four checks (RHA 95C-1, RHA 6D-1, KBSH-53 and cauvery champ) were evaluated in field condition during *kharif*, 2018 in randomized block

Table 2: List of male and female lines used for hybridization programme in sunflower.

Sl. No.	Male lines	Sl. No.	Female lines	Sl. No	Checks
1	DSR-13	1	CMS 21A	1	RHA 95 C-1
2	DSR19	2	CMS-1030A	2	RHA 6D-1
3	DSR 23	3	4546 × DSF 2A	3	KBSH-53
4	DSR 35	4	CMS 7-1-1 A	4	Cauvery champ
5	DSR 37	5	CMS-853A		
6	DSR 66				
7	DSR 107				
8	DSR 132				

design with two replications. Two rows of each hybrid were sown with a spacing of 60 × 30 cm and row length of 4 m. All the recommended package of practices were followed to raise a good crop. Protective irrigation was given for three times during the cropping period. Further the analysis was done using tnaustat software.

Results and discussion

In the present study, 28 sunflower inbred lines were evaluated for drought tolerance under controlled condition in rainout shelter in randomized complete block design with two replications at RARS, Vijayapura during summer 2017–18 to identify desired root traits under drought conditions. Among these eight inbreds (DSR-13, DSR-19, DSR-23, DSR-35, DSR-37, DSR-66, DSR-107, DSR-132) performed better under both normal and stress conditions. Those inbred lines which performed well with least percent reduction in stress conditions were selected and used for hybridization programme.

The analysis of variance exhibited significant differences among inbred lines for all the traits studied. The results of which are presented in Table 3. The 28 inbred lines were evaluated in rain out shelter under controlled conditions. Among these, eight superior performing lines both in normal conditions and stress condition with less percent reduction in stress condition were selected. These lines indicated stay green nature which are drought tolerant. Thus these lines can be used for development of OPV’s and drought tolerant hybrids.

Days to 50% flowering is an important trait which is used for breeding in order to know the synchronization of the flowering time and also to know the duration of the crop growth after flowering. DSR-37 exhibited earliness 52 days for 50% flowering in stress condition. DSR-37 and DSR-132 exhibited early maturity (80 and 81 days, respectively) under stress and also recorded earliness under normal condition. Similar result of earliness by an inbred line for 50% flowering and days to maturity were reported by Aliza and Fernandez-Martinez (1997) in sunflower.

SPAD readings were recorded at flowering stage (45 DAS) and at physiological maturity (60 DAS), to identify genotypes which retain higher leaf chlorophyll content even at maturity under drought stress condition. The inbred line DSR-107 showed maximum SPAD reading of 58.53 in stress and 60.18 in normal condition at 45 DAS, which retained leaf greenness even under moisture stress condition, indicating the trait is more influenced by genotype rather than environment (Tables 4 and 5).

Similarly at 60 DAS, DSR-66 (48.15 and 46.95 under normal and stress conditions) and DSR-132 (45.15 and 42.45) recorded higher SPAD values. When

Table 3: Analysis of variance for 13 different traits under normal and moisture stress condition in sunflower.

Source of variation	*df*	SPAD at 45 DAS		SPAD at 60 DAS		DFF		DM		PH (cm)		RWC (%)		HD (cm)	
		N	S	N	S	N	S	N	S	N	S	N	S	N	S
Replication	1	4.79	17.55	35.50	17.52	62.02	45.07	58.02	1.07	180.27	39.20	5.13	10.37	0.46	0.39
Treatment	29	58.13*	62.43*	33.34*	38.21*	98.47*	93.37*	40.74*	69.16*	198.75*	150.79*	70.75*	140.20*	6.43*	8.00*
Error	29	7.57	9.13	7.41	8.89	38.71	32.41	16.60	15.86	28.65	23.89	10.10	8.32	0.57	0.56

Source of variation	*df*	RL (cm)		FWR (g)		DWR (g)		Root/shoot ratio		Test weight (g)		Yield/plant (g)	
		N	S	N	S	N	S	N	S	N	S	N	S
Replication	1	10.58	8.82	1.53	1.22	1.22	0.12	0.0001	0.0010	0.16	0.36	0.01	0.20
Treatment	29	55.41*	49.96*	4.65*	5.37*	1.97*	4.54*	0.01*	0.01*	1.63*	2.34*	5.45*	7.34*
Error	29	2.98	4.76	0.33	0.46	0.26	0.26	0.0016	0.0022	0.73	0.92	0.71	0.70

DFF, days to 50% flowering; DM, days to maturity; PH, plant height; RWC, relative water content; HD, head diameter; RL, root length; FWR, fresh weight of roots; DWR, dry weight of root.

Table 4: The *per se* performance of inbred lines for 13 different traits under normal and stress conditions in sunflower.

Sl.No.	Inbreds	SPAD @ 45DAS		SPAD @ 60 DAS		DFF		DM		PH (cm)		RWC (%)	
		N	S	N	S	N	S	N	S	N	S	N	S
1	DSR-13	44.18	40.88	38.53	40.24	77.00	74.00*	107.00*	92.00*	66.50*	62.75*	55.58*	51.08*
2	DSR-1	40.18	39.58	36.13	35.90	73.00	73.00*	95.00	89.00*	54.25	50.25	46.58	43.08
3	DSR-17	45.50	46.10	40.45	37.80	66.00	66.00*	99.00	92.00*	40.75	42.00	45.38	44.38
4	DSR-2	49.08	40.48	33.03	35.38	65.00*	65.00*	97.00	89.00*	40.00	42.25	45.30	40.80
5	DSR-19	49.08	47.78	42.93*	41.14	69.00*	66.00*	99.00	86.00*	55.00*	51.00	49.80	46.80
6	DSR-16	39.88	43.48	37.83	35.18	62.00	62.00	94.00	88.00*	42.25	42.00	46.10	35.60
7	DSR-3	41.23	39.13	34.18	34.53	69.00*	69.00	100.00	89.00*	59.25*	55.25*	46.28	39.28
8	DSR-23	43.45	40.65	37.80	40.01	73.00*	70.00*	99.00	91.00*	66.50*	64.25	52.28*	49.28*
9	DSR-15	46.80	40.90	37.25	36.60	57.00	57.00	93.00	84.00	46.00	42.00	46.98	35.48
10	DSR-4	40.20	38.10	33.15	35.50	71.00*	69.00*	103.0*	91.00*	55.75	51.75	51.08	35.08
11	DSR-14	38.88	34.98	31.33	27.18	58.00	56.00	100.0*	90.00*	42.25	40.50	37.95	35.45
12	DSR-35	42.20	46.40	36.55	35.26	75.00*	72.00*	94.00	83.00	65.25*	63.00*	55.08*	53.88*
13	DSR-5	46.18	45.08	36.63	29.98	61.00	58.00	100.0*	85.00*	45.50	42.50	43.75	30.25
14	DSR-6	52.60	50.00	33.55	36.90	57.00	56.00	104.0*	91.00	42.25	44.00	49.53	35.53
15	DSR-12	45.40	40.30	38.35	31.70	72.00*	73.00*	99.00	90.00	43.25	42.75	57.65*	38.65
16	DSR-37	51.43	50.53	44.43*	43.93*	55.00	52.00	90.00	80.00	66.25*	63.50*	58.75*	54.25*
17	DSR-18	44.18	40.88	38.53	40.24	77.00*	74.00*	107.0*	93.00*	65.50*	62.75*	55.58*	51.08*
18	DSR-7	44.93	42.83	33.88	35.23	57.00	55.00	99.00	90.00*	49.25	45.25	53.13	36.63
19	DSR-8	46.80	46.70	39.75	37.10	60.00	58.00	104.0*	89.00*	55.25*	51.25	41.70	35.20
20	DSR-66	55.10*	54.45*	46.95*	48.15*	57.00	54.00	95.00	86.00*	57.25*	53.25	55.53*	50.53*
21	DSR-125	55.80	52.15*	42.63*	41.88	64.00	61.00	101.0*	83.00	67.75*	63.75*	50.70	48.51*
22	DSR-107	60.18*	58.53*	43.03*	39.73	61.00	58.00	94.00	83.00	64.25*	60.25*	55.13*	51.13*
23	DSR-9	42.88	38.28	35.83	32.68	69.00*	67.00*	108.00	95.00*	51.25	47.25	45.65	35.65
24	DSR-10	39.38	33.78	35.38	33.23	58.00	57.00	100.00	91.00*	36.25	42.00	52.93*	39.93
25	DSR-11	41.78	41.18	33.73	36.58	64.00	64.00*	94.00	87.00*	43.75	40.50	48.35	34.35

Table 4: (continued)

Sl.No.	Inbreds	SPAD @ 45DAS		SPAD @ 60 DAS		DFF		DM		PH (cm)		RWC (%)	
		N	S	N	S	N	S	N	S	N	S	N	S
26	DSR-132	52.63	46.88	45.15*	42.45*	58.00	55.00	89.00	81.00	67.75*	65.75*	55.65*	51.90*
27	95 C-1	43.88	42.55	38.38	39.38	57.00	54.00	98.00	90.00*	51.00	46.50	58.75*	54.75*
28	6D-1	48.40	45.58	41.40*	35.90	57.00	57.00	100.0*	86.00*	60.00*	56.00*	51.80	50.80*
	Mean	46.15	43.86	38.10	37.14	63.82	62.43	98.64	88.00	53.54	51.22	50.46	43.33
	SEm (%)	1.95	2.14	1.92	2.11	4.4	4.03	2.88	2.82	3.78	3.46	2.25	2.04
	CD at 5%	5.63	6.18	5.57	6.10	12.72	11.64	8.33	8.14	10.95	10	6.50	5.90
	CV (%)	5.95	6.85	7.13	8.05	9.89	9.25	4.14	4.08	10.03	9.58	6.27	6.61

Sl.No.	Inbreds	HD (cm)		RL (cm)		FWR(g)		DWR (g)		R:S ratio		TW (g)		Seed Yl/pl (g)	
		N	S	N	S	N	S	N	S	N	S	N	S	N	S
1	DSR-13	8.60*	8.10*	16.38	19.88	8.68*	8.95*	6.98*	6.65*	0.25	0.32	4.10*	3.87*	8.70	8.20*
2	DSR-1	8.40*	5.30	12.70	15.35	8.00*	9.25*	5.50	6.95*	0.24	0.31	3.70*	3.22*	6.00	5.10
3	DSR-17	5.00	4.00	16.35	18.65	5.88	5.53	3.93	4.65	0.44*	0.40	3.50*	3.10*	6.20	3.50
4	DSR-2	5.95	3.90	13.10	11.43	4.70	5.90	3.95	3.20	0.30	0.31	3.56*	2.99*	5.90	4.50
5	DSR-19	8.50*	7.70*	14.43	18.43	6.04	7.24	4.78	5.10	0.27	0.37	4.02*	3.94*	8.80	8.50*
6	DSR-16	4.25	4.00	15.38	13.08	5.08	5.43	4.87	2.78	0.39	0.31	3.10	2.90*	4.20	4.00
7	DSR-3	6.65	5.00	16.35	18.50	3.33	4.33	3.05	2.23	0.28	0.34	3.56*	3.17*	5.90	4.20
8	DSR-23	8.25*	7.95*	16.55	20.55	5.36	6.56	4.56	4.53	0.23	0.32	4.11*	3.89*	8.40	8.00*
9	DSR-15	4.50	3.80	17.80	17.60	4.95	5.30	4.25	3.30	0.39	0.42	3.76*	3.10*	4.20	3.60
10	DSR-4	5.75	4.25	15.85	13.70	5.58	4.23	3.28	3.80	0.31	0.25	3.89*	3.45*	5.70	4.30
11	DSR-14	4.50	3.25	13.90	14.70	4.44	4.79	4.00	3.04	0.33	0.36	3.67*	3.10*	4.90	4.70
12	DSR-35	7.25	7.05*	16.03	20.03	6.57	7.34	4.97	5.00	0.25	0.32	4.33*	4.05*	8.40	8.10*
13	DSR-5	5.05	4.05	14.70	16.10	4.67	5.72	4.18	3.40	0.33	0.38	4.07*	3.44*	5.20	4.00
14	DSR-6	4.85	3.75	19.65	17.75	7.95*	6.90	5.65*	5.25	0.45*	0.42	3.23*	2.71*	4.80	3.90

Table 4: (continued)

Sl.No.	Inbreds	HD (cm)		RL (cm)		FWR(g)		DWR (g)		R:S ratio		TW (g)		Seed Yl/pl (g)	
		N	S	N	S	N	S	N	S	N	S	N	S	N	S
15	DSR-12	4.45	3.85	15.55	16.15	3.54	3.89	3.06	2.38	0.36	0.38	3.56*	3.06*	4.50	2.70
16	DSR-37	8.65*	8.25*	34.90*	35.15*	8.03*	9.28*	6.28*	6.83*	0.53*	0.55*	4.80*	4.34*	10.10*	9.50*
17	DSR-18	4.50	3.90	12.53	14.83	3.81	4.35	3.55	3.25	0.29	0.34	2.95	2.81*	5.00	3.90
18	DSR-7	5.00	3.75	18.70	18.08	4.80	4.00	2.59	3.70	0.41*	0.37	3.60*	3.12*	5.30	4.80
19	DSR-8	4.95	4.10	15.35	17.30	4.03	4.88	3.53	2.58	0.28	0.34	4.00*	3.34*	4.70	3.60
20	DSR-66	8.75*	8.80*	19.40	20.90	8.01*	9.21*	6.31*	6.63*	0.34	0.40	4.78*	4.48*	8.10	7.10
21	DSR-125	7.00	6.40	18.48	22.48	6.18	7.03	4.18	4.73	0.27	0.35	3.78*	3.34*	7.80	7.20
22	DSR-107	6.75	6.15	18.18	22.18	4.85	6.05	3.61	4.75	0.28	0.37	3.90*	3.12*	7.30	6.60
23	DSR-9	4.50	4.45	19.85	22.50	5.78	6.05	5.18	3.75	0.39	0.48	4.00*	3.11*	4.80	3.70
24	DSR-10	4.00	3.90	14.78	12.88	5.60	5.10	3.30	4.75	0.35	0.38	3.43*	3.09*	5.90	3.80
25	DSR-11	3.75	3.65	10.93	12.83	4.22	4.42	4.00	2.18	0.25	0.32	3.77*	3.23*	5.20	4.00
26	DSR-132	9.25*	8.70*	33.50*	33.85*	8.50*	9.35*	5.70*	6.73*	0.49*	0.51*	4.34*	4.08*	9.10*	8.10*
27	95 C-1	7.00	6.75	15.28	17.18	5.21	6.11	4.61	4.56	0.30	0.38	3.23	2.88*	6.10	5.10
28	6D-1	7.10	6.50	14.90	16.30	6.34	6.70	5.64*	5.15	0.25	0.29	3.80*	3.23*	6.20	5.70
	Mean	6.18	5.47	17.20	18.51	5.72	6.21	4.48	4.35	0.33	0.37	3.81	3.36	6.34	5.37
	SEm (%)	0.53	0.53	1.22	1.54	0.41	0.48	1.05	0.36	0.03	0.03	0.45	0.43	0.59	0.59
	CD at 5%	1.54	1.53	3.53	4.46	1.18	1.39	1.42	1.05	0.08	0.10	1.91	1.82	1.72	1.71
	CV (%)	11.91	13.17	10.32	11.58	10.2	10.6	11.01	11.95	12.69	12.72	13.84	14.22	13.21	15.27

DFF- Days to 50 % flowering, DM- Days to maturity, PH- Plant height, RWC- Relative water content, HD- Head diameter, RL- Root length, FWR- Fresh weight of roots, DWR- Dry weight of roots, R:S- root to shoot ratio

Table 5: Top eight inbreds selected based on er se performance and percent reduction under stress condition for seven different traits in sunflower.

Inbreds	SPAD AT 60 DAS			Plant height (cm)			RWC (%)			Root length (cm)			Root : shoot ratio			Test weight (g)			Seed yl/pl (g)		
	N	S	%R	N	S	%R	N	S	%R	N	S	%R	N	S	%R	N	S	%R	N	S	%R
DSR-13	38.53	40.24	−4.44	65.50	62.75	4.2	55.58	51.08	8.10	16.38	19.88	−21.3	0.25	0.32	−28.0	4.10	3.87	5.61	8.70	8.20	5.71
DSR-19	42.93	41.14	4.17	55.00	51.00	7.27	49.80	46.78	6.02	14.43	18.43	−27.7	0.27	0.37	−37.0	4.02	3.94	1.9	8.80	8.50	3.4
DSR-23	37.80	40.01	−5.85	65.50	64.25	3.38	52.28	49.28	5.74	16.55	20.55	−24.1	0.23	0.32	−39.1	4.11	3.89	5.2	8.40	8.10	3.5
DSR-35	35.55	35.76	3.53	65.25	63.00	3.45	55.08	54.88	2.18	16.03	20.03	−24.9	0.25	0.32	−28.0	4.33	4.05	6.4	8.40	8.10	3.5
DSR-37	44.43	43.93	1.1	66.25	63.50	4.4	58.75	54.25	7.6	34.90	35.15	−0.2	0.53	0.55	−3.8	4.80	4.34	9.5	10.10	9.50	5.9
DSR-66	46.95	48.15	1.18	57.25	53.25	6.99	55.53	50.53	9.00	19.40	20.90	−7.7	0.34	0.40	−17.6	4.78	4.48	6.2	8.10	7.10	12.3
DSR-107	43.03	39.73	7.67	64.25	60.25	6.23	55.13	51.13	8.89	18.18	22.18	−22	0.28	0.37	−32.1	3.90	3.12	20.0	7.30	7.50	6.1
DSR-132	42.63	41.88	5.98	67.75	65.75	2.95	55.65	49.20	6.74	33.50	33.85	−1.04	0.49	0.51	−4.0	4.34	4.08	5.9	9.11	8.10	10.9
RHA 95 C-1	38.25	39.38	−2.61	50.50	46.50	8.82	58.75	54.75	6.81	15.28	17.18	−12.4	0.30	0.38	−26.6	3.23	2.88	10.8	6.10	5.10	16.3
RHA 6D-1	41.40	35.90	13.29	60.00	56.00	6.67	51.30	54.80	1.93	14.90	16.30	−9.4	0.25	0.29	−16.0	3.80	3.23	15.0	6.20	5.70	8.0
Mean	**41.19**	**40.51**		**61.75**	**58.80**		**55.66**	**52.39**		**19.22**	**21.71**		**0.31**	**0.37**		**3.81**	**3.36**		**7.94**	**7.36**	

DFF, days to 50% flowering; DM, days to maturity; PH, plant height; RWC, relative water content; HD, head diameter; RL, root length; FWR, fresh weight of roots; DWR, dry weight of roots; TW, test weight; Yl/Pl, yield per plant; **%R**, percent reduction; −, indicates increase in its percent.

compared with SCMR values at 45 DAS, no much reduction in chlorophyll content was observed among these two lines. In tall fescue, higher SPAD values at two stages of crop growth were reported by Kantety et al. (1996); Bullock and Anderson (1998).

Plant height was recorded at physiological maturity stage. Maximum plant height was recorded by DSR-132 (67.75 cm) in normal and 65.75 cm in stress condition compared to checks RHA 95 C-1 and RHA 6D-1 with a height of 51 and 60.00 cm in normal condition and 46.50 and 56 cm in stress condition. Similar results were reported in sunflower by Hiremath and Nadaf (2017).

Relative water content (%) indicates moisture content in leaf. The stressed plants exhibit reduction in the leaf water content compared to non stressed plants. Check 6D-1 exhibited least percent reduction (1.97%) followed by DSR-35 (2.18%). It indicates that inbreds with least percent reduction in RWC under stress conditions are drought tolerant in nature due to retention of leaf water content for prolonged period of time. Similar kind of result was reported by Ehab 2006 in cotton.

Under stress conditions, uptake of water by the plants is directly related to root development (Hurd 1974; Richards 1993 in wheat). However, root characteristics vary depending upon the climatic conditions. Stress tolerance related with varying root traits is found in some of the crop species. The root system plays a very important role in drought tolerance breeding. Certain root characters like root length, root biomass, and root to shoot ratio determine the efficiency of water extraction from deeper layer of soil profile. A deeper root system would allow water extraction from lower soil profiles and, thus, it is predicted that the plant will perform better under moisture stress when its growth is dependent on water stored deeper layer of soil. Sunflower has a deep and extensive root system which can extract water up to 270 cm (Gimenez and Fereres 1986; Connor and Sadras 1992; Rachidi et al. 1993).

The plants have more root length under stress conditions when compared to normal irrigated one. The maximum root length of 33.5 and 34.9 cm were recorded by DSR-37 and DSR-132 in normal condition where as in stress conditions, the same inbred exhibited more root length (35.15 and 33.85 cm) when compared to others, indicating its ability to extract water from deeper layer of the soil. Pace et al. (1999) reported that, drought-stressed seedlings exhibited increase in root length but with a reduced diameter. On the other hand, Prior et al. (1995) showed that, inadequate soil moisture reduces root elongation in cotton. Some of the inbreds which were better performing with respect to root length in the present study were DSR-37, DSR-132, DSR-66, DSR-19, DSR-23 etc.

Similarly the plants that exhibit high root to shoot ratio are considered as drought tolerant plants. In the present study root to shoot ratio was higher under stress conditions. Highest root to shoot ratio was recorded by DSR-37 (0.55). Where as under normal conditions DSR-37 exhibited maximum root to shoot ratio of 0.53. Similarly Hiremath and Nadaf (2017) reported highest root to shoot ratio in DSR-14 and DSR-47 sunflower inbreds under stress condition.

Fresh weight and dry weight of roots were recorded at harvesting stage. Fresh weight was taken immediately after the harvest of the crop. Maximum fresh weight of root was recorded by DSR-132 (9.35 g) compared to other inbreds and checks [95 C-1 (6.11 g) and 6D-1 (6.7 g)] in stress condition. Similarly dry weight of roots were recorded after sun drying. The maximum dry weight of roots was recorded by DSR-37 (6.83 g) in stress condition. Similar results were reported by Lorens et al. (1987) in maize genotypes, which showed different root lengths and root densities in water limited conditions.

Seed yield is strongly influenced by water availability (Gimenez and Fereres 1986). Hence moisture stress is reflected in the depressed yields (Nisar-Ahmed 2007). The plants under control recorded highest seed yield, whereas the stressed plants exhibited lower yield. But the inbred DSR-37 exhibited better performance in both normal (10.10 g) and stress (9.50 g) with percent reduction of 5.94% in stress condition. Alza and Fernandez (1997) reported similar results in sunflower.

Analysis of variance revealed that there was significant difference observed among the lines for all the traits except for days to maturity, and for testers there was significant difference for most of the traits except for head diameter and test weight. Similarly for line × tester combination shown significant difference except for head diameter (Table 6). This indicating the varying performance of cross combinations and existence of variability in the materials used and also considerable amount of average heterosis was reflected in the hybrids.

Heterosis in the negative direction is desired with respect to days to flowering, since it is closely related with days to maturity even though there is a genetic difference from flowering to maturity. Thus negative value indicates the earliness over the standard check used. The crosses CMS 7-1-1 A × DSR-37 and CMS-1030-A × DSR-13 exhibited highest negative values of –25% over KBSH-53 and -28% over cauvery champ. The earliness in sunflower hybrids was also reported by Saleem (2011) and Reddy et al. (2002).

The hybrids evaluated, exhibited significant positive heterosis over the checks KBSH-53 and cauvery champ for the plant height. This indicates the predominance of tallness over dwarfness which found to be the dominant character as reported by

Table 6: Analysis of variance (mean sum of square) for seed yield and its components in checks and experimental hybrids of sunflower.

Source	*df*	SPAD at 45 DAS	SPAD at 60 DAS	Days to 50% flowering	Days to maturity	Plant height (cm)	Head diameter (cm)	Test weight (g)	Seed yield (kg/ha)	Oil content (%)	Oil yield (kg ha^{-1})
Replications	1	5.96	0.12	0.16	36.92	2.83	1.39	0.20	1238.22	0.02	0.01
Treatments	43	16.88*	43.45*	49.63*	62.64*	855.74*	3.83*	0.43*	17259.87*	22.53*	9.66*
Cross	39	17.48*	44.85*	23.42*	33.71*	650.00*	3.31*	0.31*	16352.30*	23.82*	9.04*
Lines (C)	4	10.92*	18.71*	46.60*	25.51	2800.02*	18.48*	0.55*	66172.51*	38.98*	14.46*
Testers (C)	7	27.26*	48.76*	26.27*	47.05*	424.41*	1.60	0.17	9909.42*	33.66*	11.24*
Line x tester (C)	28	15.97*	47.61*	19.39*	31.55*	399.25*	1.57	0.32*	10845.80*	19.19*	7.71*
Checks	3	5.32	5.32	23.50	111.16	76.62	0.43	0.63	20232.16	1.43	20.68
Checks vs. cross	1	28.49	102.98	1150.04	1045.09	11216.93	34.22	4.15	43738.20	35.79	0.89
Error	43	6.96	7.44	6.07	19.24	36.44	0.28	0.12	2799.71	4.41	1.95

*Significant at 5%.

Table 7: Standard heterosis (%) over the check (KBSH-53 and Cauvery champ) for SPAD at 45 DAS and SPAD at 60 DAS in sunflower.

Sl No	Crosses	SPAD at 45 DAS			SPAD at 60 DAS		
		F_1 mean	% Heterosis over		F_1 mean	% Heterosis over	
			KBSH 53	C Champ		KBSH 53	C Champ
1	CMS 21A × DSR-13	37.73	0.72	1.70	32.73	0.83	1.96
2	CMS 21A × DSR19	36.56	−2.40	−1.46	31.56	−2.77	−1.68
3	CMS 21A × DSR 23	38.03	1.52	2.51	33.03	1.76	2.90
4	CMS 21A × DSR 35	38.82	3.63	4.64	33.82	4.19	5.36
5	CMS 21A × DSR 37	43.94	17.30*	18.44*	39.94	23.04*	24.42**
6	CMS 21A × DSR 66	36.04	−3.79	−2.86	31.04	−4.37	−3.30
7	CMS 21A × DSR-107	38.92	3.90	4.91	33.92	4.50	5.67
8	CMS 21A × DSR-132	41.33	10.33	11.40	40.33	24.25**	25.64**
9	CMS-1030A × DSR-13	38.15	1.83	2.82	33.14	2.11	3.26
10	CMS-1030A × DSR-19	36.87	−1.58	−0.62	31.87	−1.82	−0.72
11	CMS-1030A × DSR-23	30.92	−17.4*	−16.66*	25.92	−20.15*	−19.25*
12	CMS-1030A × DSR-35	32.49	−13.27	−12.43	33.49	3.17	4.33
13	CMS-1030A × DSR-37	41.77	11.51	12.59	38.27	17.90*	19.22*
14	CMS-1030A × DSR-66	42.61	13.75	14.85*	37.61	15.87	17.17*
15	CMS-1030A × DSR-107	41.79	11.56	12.64	36.79	13.34	14.61
16	CMS-1030A × DSR-132	41.53	10.86	11.94	36.53	12.54	13.80
17	4546 × DSF 2A × DSR13	34.83	−7.02	−6.12	29.83	−8.10	−7.07
18	4546 × DSF 2A × DSR19	36.33	−3.02	−2.08	31.33	−3.48	−2.40
19	4546 × DSF 2A × DSR23	32.07	−14.3*	−13.56	29.07	−10.44	−9.44
20	4546 × DSF 2A × DSR35	39.63	5.79	6.82	34.63	6.69	7.88
21	4546 × DSF 2A × DSR37	40.11	7.07	8.11	38.11	17.41	18.72*
22	4546 × DSF 2A × DSR66	40.26	7.47	8.52	35.26	8.63	9.84
23	4546 × DSF 2A × DSR107	38.53	2.86	3.85	33.53	3.30	4.45

Table 7: (continued)

Sl No	Crosses	SPAD at 45 DAS			SPAD at 60 DAS		
		F_1 mean	% Heterosis over		F_1 mean	% Heterosis over	
			KBSH 53	C Champ		KBSH 53	C Champ
24	4546 × DSF 2A × DSR132	40.40	7.84	8.88	44.75	37.86**	39.41**
25	CMS 7-1-1 A × DSR-13	35.98	−3.95	−3.02	30.98	−4.56	−3.49
26	CMS 7-1-1 A × DSR-19	39.44	5.29	6.31	34.44	6.10	7.29
27	CMS 7-1-1 A × DSR-23	37.43	−0.08	0.89	32.43	−0.09	7.29
28	CMS 7-1-1 A × DSR-35	37.80	0.91	1.89	45.2	39.25**	40.81**
29	CMS 7-1-1 A × DSR-37	36.63	−2.22	−1.27	45.85	41.25**	42.83**
30	CMS 7-1-1 A × DSR-66	39.03	4.19	5.20	34.03	4.84	6.01
31	CMS 7-1-1 A × DSR-107	38.22	2.03	3.02	33.22	2.34	3.49
32	CMS 7-1-1 A × DSR-132	36.46	−2.67	−1.73	34.96	7.70	8.91
33	CMS-853A × DSR-13	39.53	5.53	6.55	34.53	6.38	7.57
34	CMS-853A × DSR-19	41.78	11.53	12.61	45.18	39.19**	40.75**
35	CMS-853A × DSR-23	39.02	4.16	5.18	45	38.63**	40.19**
36	CMS-853A × DSR-35	38.78	3.52	4.53	33.78	4.07	5.23
37	CMS-853A × DSR-37	37.58	0.32	1.29	32.58	0.37	1.50
38	CMS-853A × DSR-66	40.18	7.26	8.30	35.18	8.38	9.60
39	CMS-853A × DSR-107	44.53	18.87*	20.03**	34.53	6.38	7.57
40	CMS-853A × DSR-132	35.43	−5.42	−4.50	30.43	−6.25	−5.20
C1	KBSH-53	37.46			32.46		
C2	Cauvery champ	37.10			32.10		

*Significance at 1%. **Significance at 5% .

Table 8: Standard heterosis (%) over the check (KBSH-53 and Cauvery champ) for days to 50 % flowering and days to maturity in sunflower.

Sl No	Crosses	Days to 50% flowering			Days to maturity		
		F_1 mean	% Heterosis over		F_1 mean	% Heterosis over	
			KBSH-53	C. Champ		KBSH-53	C. Champ
1	CMS 21A × DSR-13	65	−9.72**	−13.33**	97	−9.35*	−19.83**
2	CMS 21A × DSR19	57	−20.83**	−24.00**	96	−10.28*	−20.66**
3	CMS 21A × DSR 23	58	−19.44**	−22.67**	96	−10.28*	−20.66**
4	CMS 21A × DSR 35	56	−22.22**	−25.33**	99	−7.48	−18.18**
5	CMS 21A × DSR 37	55	−23.61**	−26.67**	93	−13.08**	−23.14**
6	CMS 21A × DSR 66	59	−18.75**	−22.00**	95	−11.21**	−21.49**
7	CMS 21A × DSR-107	60	−16.67**	−20.00**	104	−2.80	−14.05**
8	CMS 21A × DSR-132	55	−23.61**	−26.67**	97	−9.35*	−19.83**
9	CMS-1030A × DSR-13	54	−25.00**	−28.00**	97	−9.35*	−19.83**
10	CMS-1030A × DSR-19	60	−16.67**	−20.00**	99	−7.48	−18.18**
11	CMS-1030A × DSR-23	66	−9.03*	−12.67**	100	−6.54	−17.36**
12	CMS-1030A × DSR-35	56	−22.22**	−25.33**	104	−2.80	−14.05**
13	CMS-1030A × DSR-37	57	−20.83**	−24.00**	105	−1.87	−13.22**
14	CMS-1030A × DSR-66	61	−15.28**	−18.67**	107	0.00	−11.57**
15	CMS-1030A × DSR-107	58	−20.14**	−23.33**	93	−13.08**	−23.14**
16	CMS-1030A × DSR-132	57	−20.83**	−24.00**	97	−9.35*	−19.83**
17	4546 × DSF 2A × DSR13	63	−13.19**	−16.67**	102	−4.67	−15.70**
18	4546 × DSF 2A × DSR19	65	−10.42**	−14.00**	90	−15.89**	−25.62**
19	4546 × DSF 2A × DSR23	61	−15.97**	−19.33**	98	−8.41*	−19.01**
20	4546 × DSF 2A × DSR35	60	−16.67**	−20.00**	107	0.00	−11.57**
21	4546 × DSF 2A × DSR37	60	−16.67**	−20.00**	105	−1.87	−13.22**
22	4546 × DSF 2A × DSR66	67	−6.94*	−10.67**	95	−11.21**	−21.49**

Table 8: (continued)

SI No	Crosses	Days to 50% flowering			Days to maturity		
		F_1 mean	% Heterosis over		F_1 mean	% Heterosis over	
			KBSH-53	C. Champ		KBSH-53	C. Champ
23	4546 × DSF 2A × DSR107	57	−21.53**	−24.67**	96	−10.28*	−20.66**
24	4546 × DSF 2A × DSR132	56	−22.22**	−25.33**	97	−9.35*	−19.83**
25	CMS 7-1-1 A × DSR-13	65	−10.42**	−14.00**	98	−8.41*	−19.01**
26	CMS 7-1-1 A × DSR-19	56	−22.92**	−26.00**	101	−5.61	−16.53**
27	CMS 7-1-1 A × DSR-23	55	−24.31**	−27.33**	99	−7.94	−18.60**
28	CMS 7-1-1 A × DSR-35	59	−18.06**	−21.33**	99	−7.48	−18.18**
29	CMS 7-1-1 A × DSR-37	54	−25.00**	−28.00**	103	−3.74	−14.88**
30	CMS 7-1-1 A × DSR-66	55	−24.31**	−27.33**	92	−14.02**	−23.97**
31	CMS 7-1-1 A × DSR-107	57	−21.53**	−24.67**	96	−10.28*	−20.66**
32	CMS 7-1-1 A × DSR-132	55	−23.61**	−26.67**	93	−13.08**	−23.14**
33	CMS-853A × DSR-13	56	−22.92**	−26.00**	97	−9.35*	−19.83**
34	CMS-853A × DSR-19	58	−19.44**	−22.67**	96	−10.28*	−20.66**
35	CMS-853A × DSR-23	58	−19.44**	−22.67**	99	−7.48	−18.18**
36	CMS-853A × DSR-35	57	−21.53**	−24.67**	101	−5.61	−16.53**
37	CMS-853A × DSR-37	56	−22.22**	−25.33**	97	−9.35*	−19.83**
38	CMS-853A × DSR-66	58	−19.44**	−22.67**	99	−7.48	−18.18**
39	CMS-853A × DSR-107	55	−24.31**	−27.33**	100	−6.54	−17.36**
40	CMS-853A × DSR-132	58	−20.14**	−23.33**	92	−14.02**	−23.97**
C1	KBSH-53	72			107		
C2	Cauvery champ	75			121		

*Significance at 1%. **Significance at 5%.

Table 9: Standard heterosis (%) over the check (KBSH-53 and Cauvery champ) for plant height and head diameter in sunflower.

Sl. No	Crosses	Plant height (cm)			Head diameter (cm)		
		F_1 mean	% Heterosis over		F_1 mean	% Heterosis over	
			KBSH-53	C. Champ		KBSH-53	C. Champ
1	CMS 21A × DSR-13	112.20	47.83**	40.78**	6.49	13.07	10.19
2	CMS 21A × DSR19	103.40	36.23**	29.74**	6.25	8.89	6.11
3	CMS 21A × DSR 23	88.20	16.21*	10.66	6.58	14.63	11.71
4	CMS 21A × DSR 35	104.00	37.02**	30.49**	6.30	9.76	6.96
5	CMS 21A × DSR 37	112.60	48.35**	41.28**	7.70	34.15**	30.73**
6	CMS 21A × DSR 66	128.60	69.43**	61.36**	7.57	31.88**	28.52**
7	CMS 21A × DSR-107	126.50	66.67**	58.72**	6.80	18.47*	15.45
8	CMS 21A × DSR-132	114.80	51.25**	44.04**	5.76	0.35	−2.21
9	CMS-1030A × DSR-13	120.90	59.29**	51.69**	6.25	8.89	6.11
10	CMS-1030A × DSR-19	124.40	63.90**	56.09**	7.06	23.00*	19.86*
11	CMS-1030A × DSR-23	127.80	68.38**	60.35**	6.23	8.54	5.77
12	CMS-1030A × DSR-35	132.40	74.44**	66.12**	7.51	30.84**	27.50**
13	CMS-1030A × DSR-37	169.10	122.79**	112.17**	9.10	58.54**	54.50**
14	CMS-1030A × DSR-66	104.60	37.81**	31.24**	7.27	26.66**	23.43*
15	CMS-1030A × DSR-107	110.40	45.45**	38.52**	7.76	35.19**	31.75**
16	CMS-1030A × DSR-132	125.00	64.69**	56.84**	7.90	37.63**	34.13**
17	4546 × DSF 2A × DSR-13	108.60	43.08**	36.26**	6.80	18.47*	15.45
18	4546 × DSF 2A × DSR-19	102.50	35.05**	28.61**	7.02	22.30*	19.19*
19	4546 × DSF 2A × DSR-23	96.60	27.27**	21.20**	6.82	18.82*	15.79
20	4546 × DSF 2A × DSR-35	97.00	27.80**	21.71**	7.46	29.97**	26.66**
21	4546 × DSF 2A × DSR-37	77.20	1.71	−3.14	6.95	21.08*	18.00
22	4546 × DSF 2A × DSR-66	84.60	11.46	6.15	5.72	−0.35	−2.89
23	4546 × DSF 2A × DSR-107	90.60	19.37*	13.68	6.07	5.75	3.06

Table 9: (continued)

Sl. No	Crosses	Plant height (cm)			Head diameter (cm)		
		F_1 mean	% Heterosis over		F_1 mean	% Heterosis over	
			KBSH-53	C. Champ		KBSH-53	C. Champ
24	4546 × DSF 2A × DSR-132	107.20	41.24**	34.50**	9.01	56.97**	52.97**
25	CMS 7-1-1 A × DSR-13	92.80	22.27**	16.44*	6.67	16.20	13.24
26	CMS 7-1-1 A × DSR-19	98.00	29.12**	22.96**	8.06	40.42**	36.84**
27	CMS 7-1-1 A × DSR-23	91.10	20.03*	14.30	7.94	38.33**	34.80**
28	CMS 7-1-1 A × DSR-35	91.10	20.03*	14.30	9.20	60.37**	56.28**
29	CMS 7-1-1 A × DSR-37	114.10	50.33**	43.16**	9.42	64.11**	59.93**
30	CMS 7-1-1 A × DSR-66	89.10	17.39*	11.79	6.44	12.20	9.34
31	CMS 7-1-1 A × DSR-107	105.60	39.13**	32.50**	8.21	43.03**	39.39**
32	CMS 7-1-1 A × DSR-132	140.70	85.38**	76.54**	7.36	28.22**	24.96**
33	CMS-853A × DSR-13	129.10	70.09**	61.98**	9.46	64.81**	60.61**
34	CMS-853A × DSR-19	125.90	65.88**	57.97**	9.47	65.07**	60.87**
35	CMS-853A × DSR-23	123.40	62.58**	54.83**	9.70	68.99**	64.69**
36	CMS-853A × DSR-35	121.40	59.95**	52.32**	8.05	40.24**	36.67**
37	CMS-853A × DSR-37	124.90	64.56**	56.71**	8.72	51.92**	48.05**
38	CMS-853A × DSR-66	120.00	58.10**	50.56**	9.56	66.55**	62.31**
39	CMS-853A × DSR-107	110.70	45.85**	38.90**	10.19	77.53**	73.01**
40	CMS-853A × DSR-132	129.80	71.01**	62.86**	10.13	76.48**	71.99**
C1	KBSH-53	75.90			5.74		
C2	Cauvery champ	79.70			5.89		

*Significance at 1%. **Significance at 5%.

Table 10: Standard heterosis (%) over the check (KBSH-53 and Cauvery champ) for test weight and yield ha^{-1} in sunflower.

Sl. No	Crosses	Test weight (g)			Yield ha^{-1}(kg)		
		F_1 mean	% Heterosis over		F_1 mean	% Heterosis over	
			KBSH-53	C. Champ		KBSH-53	C. Champ
1	CMS 21A × DSR-13	3.34	−4.30	−3.75	446.15	−10.17	−8.30
2	CMS 21A × DSR19	3.38	−3.15	−2.59	388.46	−21.75	−20.16
3	CMS 21A × DSR 23	3.65	4.58	5.19	513.46	3.42	5.53
4	CMS 21A × DSR 35	3.57	2.29	2.88	512.31	3.42	5.30
5	CMS 21A × DSR 37	3.77	8.02	8.65	479.23	−3.52	−1.50
6	CMS 21A × DSR 66	3.83	9.74	10.37	479.23	−3.52	−1.50
7	CMS 21A × DSR-107	3.89	11.46	12.10	502.31	1.11	3.24
8	CMS 21A × DSR-132	3.39	−2.87	−2.31	477.35	−3.83	−1.89
9	CMS-1030A × DSR-13	4.03	15.47	16.14	471.54	−5.04	−3.08
10	CMS-1030A × DSR-19	3.73	6.88	7.49	511.54	3.02	5.14
11	CMS-1030A × DSR-23	4.24	21.49*	22.19*	494.23	−0.50	1.58
12	CMS-1030A × DSR-35	3.91	12.03	12.68	559.62	12.69	15.02
13	CMS-1030A × DSR-37	4.06	16.33	17.00	561.54	13.09	15.42
14	CMS-1030A × DSR-66	3.57	2.29	2.88	417.31	−15.91	−14.23
15	CMS-1030A × DSR-107	3.51	0.57	1.15	511.54	3.02	5.14
16	CMS-1030A × DSR-132	3.81	9.17	9.80	390.38	−21.35	−19.76
17	4546 × DSF 2A × DSR-13	3.71	6.30	6.92	351.92	−29.10*	−27.67*
18	4546 × DSF 2A × DSR-19	3.10	−11.17	−10.66	378.85	−23.67	−22.13*
19	4546 × DSF 2A × DSR-23	3.21	−8.02	−7.49	398.08	−19.84	−18.18
20	4546 × DSF 2A × DSR-35	3.19	−8.60	−8.07	353.85	−28.70*	−27.27*
21	4546 × DSF 2A × DSR-37	3.37	−3.44	−2.88	319.23	−35.75**	−34.39**
22	4546 × DSF 2A × DSR-66	3.54	1.43	2.02	384.62	−22.56	−20.95
23	4546 × DSF 2A × DSR-107	3.50	0.29	0.86	305.77	−38.47**	−37.15**

Table 10: (continued)

Sl. No	Crosses	Test weight (g)			Yield ha^{-1}(kg)		
		F_1 mean	% Heterosis over		F_1 mean	% Heterosis over	
			KBSH-53	C. Champ		KBSH-53	C. Champ
24	4546 × DSF 2A × DSR-132	4.62	32.38**	33.14**	607.50	22.36**	24.86*
25	CMS 7-1-1 A × DSR-13	4.01	14.90	15.56	503.85	1.51	3.56
26	CMS 7-1-1 A × DSR-19	3.45	−1.15	−0.58	574.92	15.81	18.17
27	CMS 7-1-1 A × DSR-23	3.92	12.32	12.97	542.31	9.26	11.46
28	CMS 7-1-1 A × DSR-35	4.51	29.23**	29.97**	618.50	24.57**	27.12*
29	CMS 7-1-1 A × DSR-37	4.77	36.82**	37.46**	624.00	25.68**	28.25*
30	CMS 7-1-1 A × DSR-66	3.24	−7.16	−6.63	528.85	6.55	8.70
31	CMS 7-1-1 A × DSR-107	3.55	1.72	2.31	563.46	13.49	15.81
32	CMS 7-1-1 A × DSR-132	3.69	5.73	6.34	571.15	15.01	17.39
33	CMS-853A × DSR-13	3.80	8.88	9.51	398.08	−19.84	−18.18
34	CMS-853A × DSR-19	4.40	26.07**	26.80**	624.00	25.68*	28.25*
35	CMS-853A × DSR-23	4.46	27.94**	28.53**	619.00	24.67*	27.23*
36	CMS-853A × DSR-35	4.04	15.76	16.43	415.77	−16.31	−14.55
37	CMS-853A × DSR-37	3.62	3.72	4.32	557.69	12.39	14.62
38	CMS-853A × DSR-66	3.74	7.16	7.78	519.23	4.53	6.72
39	CMS-853A × DSR-107	3.77	8.02	8.65	353.85	−28.70*	−27.27*
40	CMS-853A × DSR-132	3.72	6.59	7.20	542.31	9.16	11.46
C1	KBSH-53	3.29			496.50		
C2	Cauvery champ	3.47			486.50		

Table 11: Standard heterosis (%) over the check (KBSH-53 and Cauvery champ) for Oil content and oil yield in sunflower.

Sl No	Crosses	Oil content (%)			Oil yield (kg ha $^{-1}$)		
		F_1 mean	% Heterosis over		F_1 mean	% Heterosis over	
			KBSH-53	C Champ		KBSH -53	C. Champ
1	CMS 21A × DSR-13	35.50	−4.52	−2.07	158.82	−13.84	−9.41
2	CMS 21A × DSR19	36.11	−2.88	−0.39	140.23	−23.93	−20.02
3	CMS 21A × DSR 23	40.61	9.23	12.03*	209.44	13.63	19.47
4	CMS 21A × DSR 35	39.73	6.87	9.62	203.46	10.38	16.06
5	CMS 21A × DSR 37	41.35	11.22	14.07*	198.56	7.73	13.26
6	CMS 21A × DSR 66	36.46	−1.92	0.59	175.14	−4.99	−0.10
7	CMS 21A × DSR-107	35.91	−3.42	−0.94	180.34	−2.15	2.89
8	CMS 21A × DSR-132	40.44	8.77	11.56	192.85	4.62	10.00
9	CMS-1030A × DSR-13	41.60	11.90*	14.77*	196.82	6.78	12.27
10	CMS-1030A × DSR-19	41.12	10.60	13.44*	210.50	14.20	20.07
11	CMS-1030A × DSR-23	40.14	7.95	10.73	198.09	7.47	12.99
12	CMS-1030A × DSR-35	43.40	16.73**	19.73**	242.68	31.66**	38.43**
13	CMS-1030A × DSR-37	37.75	1.53	4.14	211.28	14.62	20.51
14	CMS-1030A × DSR-66	38.47	3.48	6.14	159.04	−13.72	−9.28
15	CMS-1030A × DSR-107	40.00	7.59	10.35	205.04	11.24	16.96
16	CMS-1030A × DSR-132	37.16	−0.04	2.52	144.82	−21.44	−17.40
17	4546 × DSF 2A × DSR-13	36.12	−2.85	−0.36	128.17	−30.47*	−26.89*
18	4546 × DSF 2A × DSR-19	34.43	−7.38	−5.01	130.67	−29.11*	−25.47
19	4546 × DSF 2A × DSR-23	40.09	7.84	10.61	161.00	−12.65	−8.16
20	4546 × DSF 2A × DSR-35	36.20	−2.62	−0.12	127.49	−30.84	−27.28*
21	4546 × DSF 2A × DSR-37	39.32	5.76	8.47	125.91	−31.69*	−28.18*
22	4546 × DSF 2A × DSR-66	32.00	−13.92	−11.71**	123.18	−33.17*	−29.74*
23	4546 × DSF 2A × DSR-107	39.78	7.01	9.75	121.99	−33.82*	−30.42*

Table 11: (continued)

SI No	Crosses	Oil content (%)			Oil yield (kg ha $^{-1}$)		
		F_1 mean	% Heterosis over		F_1 mean	% Heterosis over	
			KBSH-53	C Champ		KBSH -53	C. Champ
24	4546 × DSF 2A × DSR-132	43.50	17.01**	20.02**	264.83	43.67**	51.06**
25	CMS 7-1-1 A × DSR-13	38.36	3.19	5.84	193.37	4.90	10.30
26	CMS 7-1-1 A × DSR-19	43.05	15.8**	18.78**	247.84	34.46**	41.37**
27	CMS 7-1-1 A × DSR-23	43.34	16.58**	19.58**	234.97	27.48**	34.03*
28	CMS 7-1-1 A × DSR-35	44.37	19.35**	22.42**	274.06	48.68**	56.33**
29	CMS 7-1-1 A × DSR-37	44.00	18.35**	21.40**	275.53	48.93**	56.59**
30	CMS 7-1-1 A × DSR-66	38.83	4.45	7.13	204.58	10.99	16.69
31	CMS 7-1-1 A × DSR-107	41.29	11.07	13.92*	232.67	26.22*	32.72*
32	CMS 7-1-1 A × DSR-132	39.87	7.25	10.00	227.95	23.66	30.02*
33	CMS-853A × DSR-13	38.84	4.47	7.15	153.98	−16.46	−12.17
34	CMS-853A × DSR-19	45.57	22.58**	25.73**	284.70	54.45**	62.39**
35	CMS-853A × DSR-23	45.07	21.24**	24.35**	278.95	51.33**	59.12**
36	CMS-853A × DSR-35	40.81	9.76	12.58*	168.67	−8.50	−3.79
37	CMS-853A × DSR-37	39.39	5.96	8.68	219.67	19.17	25.30
38	CMS-853A × DSR-66	36.44	−1.98	0.54	189.25	2.67	7.95
39	CMS-853A × DSR-107	30.69	−17.44	−15.33*	107.54	−41.66**	−38.66**
40	CMS-853A × DSR-132	34.56	−7.03	−4.65	187.21	1.56	6.78
C1	KBSH-53	37.17			184.33		
C2	Cauvery champ	36.24			175.31		

*Significance at 1%. **Significance at 5% .

Table 12: Promising hybrids with maximum seed yield and its component traits in sunflower.

Traits	CMS 853A × DSR-19	CMS 7-1-1 A × DSR-37	CMS 853A × DSR-23	CMS 7-1-1 A × DSR-35	4546 × DSF 2A × DSR-132	KBSH-53 (check)	Cauvery champ (check)
SPAD at 45 DAS	41.78	36.63	39.02	37.80	40.40	37.46	37.10
SPAD at 60 DAS	45.18	45.85	45.00	45.20	44.75	32.46	32.10
DFF	58.00	54.00	58.00	59.00	56.00	72.00	75.00
DM	96.00	103.00	99.00	99.00	97.00	107.00	121.00
PH (cm)	125.90	114.10	123.40	91.10	107.20	75.9	79.70
HD (cm)	9.47	9.42	9.70	9.20	9.01	5.74	5.89
TW (g)	4.40	4.77	4.46	4.51	4.62	3.49	3.47
Yl ha^{-1} (kg)	624.00	624.00	619.00	618.50	607.50	496.5	486.53
OC (%)	45.57	44.00	45.07	44.37	43.50	37.17	36.24
OY (kg ha^{-1})	284.70	275.53	278.95	274.06	264.83	184.33	175.31

DFF, days to 50% flowering; DM, days to maturity; PH, plant height; HD, head diameter; TW, test weight; Yl/ha, seed yield per hectare; OC, oil content; OY, oil yield.

Thakur (1992), Naresh et al. (1996) and Gangappa et al. (1997). All the combinations except 4546A × DSF-2A × DSR-37 and 4546A × DSF-2A × DSR-66 exhibited significant positive heterosis over KBSH-53 and 35 combinations exhibited significant positive heterosis over cauvery champ. The maximum heterosis for plant height was recorded by CMS-1030 A × DSR-37 over the checks KBSH-53 (122.79%) and cauvery champ (112.17%).

The hybrid combinations involved both positive and negative heterotic values. Out of 40 hybrids, 29 hybrids exhibited significant positive heterosis over KBSH-53 and 25 hybrids exhibited significant positive heterosis over cauvery champ. Similarly the maximum heterosis 36.8 and 37.4% was recorded in CMS 7-1-1 A × DSR-37 over KBSH-53 and cauvery champ. These results were in line with the report of Harini (1992)

The crosses CMS 7-1-1 A × DSR-37 and CMS-853A × DSR-19 recorded highest positive heterosis of 25.68% heterosis over KBSH-53 and 28.25 heterosis percent over cauvery champ. In sunflower, Similar results with heterosis in both the direction for seed yield per hectare was reported by Madrap and Makne (1993) and Seetharam et al. (2001). Similarly CMS-853A × DSR-19 exhibited maximum heterotic 22 and 25% over KBSH-53 and cauvery champ, respectively for oil content. (Heterosis percent for all the traits is shown in Tables 7–11).

Top most desired hybrids showing better performance with respect to yield along with the per se performance is shown in Table 12. Among the 40 crosses, CMS 7-1-1 A × DSR-37, CMS 853A × DSR-19, CMS 853A × DSR-23, CMS 7-1-1 A × DSR-35 and 4546 × DSF 2A × DSR-132 exhibited maximum seed yield with heterosis percent ranging from 22 to 25%. These crosses further need to be evaluated in large scale and in multi location trials.

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