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Comparative performance of elite inbred lines with alien cytosterile sources and their corresponding hybrids in sunflower (*Helianthus annuus* L.)

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Abstract

The effect of cytoplasm on the mean performance of inbreds and their corresponding hybrids for seed yield and its contributing traits was investigated in the present study. There was no significant difference found between the inbreds based on cytosterile sources E002 (*H. annus*), ARG 3 (*H. argophyllus*) and PET 1 (*H. petiolaris*) for oil content, oil yield and seed yield indicating that under DS 2 nuclear genetic background all the three alloplasmic lines were on par for these traits. Similarly, for the performance of hybrids, both the cytosterile sources E002 and ARG 3 were equally efficient in the expression of traits *viz*., stem diameter, 100 seed weight, volume weight, hull content and seed yield but showed significant variations for days to 50% flowering, plant height, head diameter, days to maturity, seed filling percentage, oil content and oil yield. However, for *per se* performance for traits showing significant variation, E002 cytoplasm based hybrids were superior over ARG 3 cytoplasm based hybrids. Even for mid parent heterosis and heterobeltiosis both cytosterile sources influenced traits under consideration with the positive influence of E002 cytoplasm on MPH and BPH for all the traits except plant height and head diameter.

Key words: Sunflower, cytoplasmic male sterility, hybrids, seed yield.

INTRODUCTION

The synthesis of hybrids with high heterotic effect in Sunflower became possible after the discovery of the first CMS source by Leclercq (1969) and subsequent identification of genes for fertility restoration by Kinman (1970), Enns *et al.* (1970), Leclercq (1971) and Vranceanu and Stoenescu (1971). In India, the first ever CMS based sunflower hybrid BSH-1 was released from the University of Agricultural Sciences, Bangalore (Seetharam *et al*., 1980) which provided the required fillip to expand sunflower cultivation in the country as hybrids are preferred over varietal populations because of their uniformity in growth, high productivity in terms of total seed yield and oil yield. But the use of single cytosterile source PET 1 in the commercial hybrid production has resulted in the genetic uniformity for the cytoplasmic background in the crop. Prevalence of genetic uniformity of this kind over a large area could result in the genetic vulnerability of hybrids if the cytoplasm becomes susceptible to new strains of diseases or pests similar to that happened in maize when 'Texas' cytoplasm become susceptible to *Helminthosporium maydis* in the USA (Tatum, 1971). Among several strategies available to overcome this problem, diversification of CMS sources is possibly the cheapest and most effective method. Cytoplasmic genes of plants including mitochondrial and chloroplast genes of plants are known to play a vital role in various metabolic processes. Apart from male sterility, cytoplasmic genes show influence on agronomic traits as reported in sunflower (Sunitha and Shadakshari, 2018 and Gouri Shankar *et al*., 2006), rice (Young and Virmani, 1990 and Rosamma and Vijayakumar, 2007), chilli (Haritha, 2011 and Neelavva, 2012), sorghum (Reddy *et al.,* 2009 and Aruna *et al.,* 2013) and pearl millet (Chandrashekar *et al.,* 2007 and Yadav, 1999). So it becomes imperative to understand the interaction between alien cytoplasm and nuclear genes and the impact of this interaction on seed yield and its contributing traits before utilization of these CMS sources in hybrid seed production. Therefore in the present study, in order to compare and understand this impact, isonuclear alloplasmic lines having cytosterile sources from *H. argophyllus* and *H.annuus* were developed and *per se* performance of inbreds and their corresponding hybrids were compared for seed yield and its corresponding traits.

MATERIALS AND METHODS

Isonuclear alloplasmic lines in DS2 nuclear genetic background were developed by repeated backcrossing for six generations with DS2 as the recurrent parent and *H. argophyllus, H. annuus* and *H. petiolaris* as cytosterile donor parent to compare them for their *per se* performance of seed yield and its component traits. These alloplasmic lines derived from *H. argophyllus* (ARG 3) (**Fig. 1**) and *H. annuus* (E002) (**Fig. 2**), were crossed with ten restorers *viz*., GKVK-3, RHA 6D-1, RHA 95-C-1, LTRR 822, M-17R, MR-1, RHA-272-II, X-15-NB-10, GKVK-2 and RHA-93 to obtain 20 experimental hybrids at the experimental field of Zonal Agricultural Research Station, University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra, Bangalore. Hybrids along with isonuclear alloplasmic lines were evaluated in *Kharif,* 2016 and *Rabi/Summer,* 2016-17. Observations were recorded in each entry on randomly selected five plants for characters *viz*., days to 50 per cent flowering, plant height (cm), stem diameter (cm), head diameter (cm), days to maturity, seed filling (%), 100 seed weight(g), hull content (%), volume weight (g/100ml), seed yield (kg/ha), oil content (%) and oil yield (kg/ha). The significance of differences between isonuclear alloplasmic lines for their *per se* performance was determined using CD value.

Paired 't' test was used to test the significance of differences among hybrids for their *per se* performance. The significance of differences among hybrids for their *per se* performance was considered as evidence for the presence of cytoplasmic effects on hybrid mean performance.

RESULTS AND DISCUSSION

Comparison of per se performance of isonuclear alloplasmic lines for seed yield and its contributing traits: The mean performance of isonuclear alloplasmic lines pooled over seasons are presented in **Table 1**. With reference to days to 50% flowering, the *per se* performance of inbreds based on CMS E002 (56.0 days) and ARG 3 (54.75 days) was on par but significantly early than PET 1 (58.25 days). Similar observations were recorded for days to maturity too wherein PET 1 (90.25 days) matured later than E002 (86.00 days) and ARG 3 (84.75 days). The tested inbreds were on par for plant

Fig 1. Cytosterile line ARG 3

Fig 2. Cytosterile line E002

Table 1. Comparison of *per se* performance of isonuclear alloplasmic lines for seed yield and its contributing traits

Character	*Per se* performance of alloplasmic lines carrying DS2 nuclear background			
	E002	ARG 3	PET-1	CD @ P=0.05
Days to 50% flowering	56.00	54.75	58.25	1.96
Plant height(cm)	133.37	137.89	135.60	11.77
Head diameter(cm)	13.46	12.36	12.34	2.16
Stem diameter (cm)	1.83	2.05	1.87	0.15
Days to maturity	86.00	84.75	90.25	3.59
100 seed weight (g)	3.72	4.02	4.12	0.39
Volume weight (g/100ml)	40.41	43.99	40.77	1.99
Seed yield (kg/ha)	681.64	714.56	754.12	113.18
Hull content (%)	29.13	26.38	26.61	0.96
Seed filling per cent	88.90	93.87	91.99	1.98
Oil content (%)	37.01	36.89	35.82	1.27
Oil yield (kg/ha)	252.60	263.88	270.46	48.52

height and head diameter but for stem diameter, ARG 3 (2.05 cm) had a thicker stem compared to E002 (1.83 cm) and PET 1 (31.87 cm). Inbreds based on CMS PET 1 had significantly higher seed weight (4.12 g) than E002 (3.72 g), while ARG 3 was on par with them. For volume weight ARG 3 (43.99 g/100 ml) was significantly superior to E002 (40.41 g/100 ml) and PET 1 (40.77 g/100 ml). Significantly lower hull content was found in inbreds based on ARG 3 (26.38 %) and PET 1 (26.61%) compared to E002 (29.13%). Higher seed filling per cent of 93.87 and 91.99 was observed in ARG 3 and PET 1 compared to 88.90 per cent for E002.

There was no significant difference between the inbreds for oil content, oil yield and seed yield indicating that under DS 2 nuclear genetic background all the three alloplasmic lines were on par for these traits. However, these lines can be used in the development of hybrids with their added advantage of earliness and to widen the cytoplasmic base of the hybrids. These results are in agreement with Patil (2003), Gouri Shankar *et al*. (2006) and Sunitha and Shadakshari (2018).

Comparison of per se performance of alloplasmic hybrids: The male sterile cytoplasm showed significant influence on the performance of hybrids for days to 50% flowering and days to maturity which was evident from significant differences between overall mean values (**Table 2**). For days to 50% flowering, the overall mean of the hybrids based on cytosterile source E002 (57.28) was significantly lower than the ARG 3 (58.80) based hybrids as indicated by $p<0.05$. Similarly, for days to maturity, hybrids based on E002 (89.83) matured significantly earlier than those based on ARG 3 (91.25) indicating the cytosterile source E002 favoring earliness in sunflower hybrids. Considering plant height, hybrids based on cytosterile source E002 (155.76 cm) had tall plants compared to those based on ARG 3 (150.08 cm). The significant differences between hybrids were present in three of the ten nuclear genetic backgrounds indicating that the cytoplasm did have a significant influence on *per se* performance for plant height and as medium stature plants are preferred in sunflower, cytosterile source ARG 3 can be considered over E002 as a donor for the trait. Tyagi *et al*. (2020) also observed variations in the performance of alien cytoplasm based hybrids in Sunflower.

The cytoplasm showed significant influence on the performance of hybrids for head diameter, hybrids based on cytosterile source E002 (13.93 cm) had wider head diameter than those based on ARG 3 (58.80) and thus E002 cytosterile source can be utilized as a donor for this trait. For stem diameter, cytosterile sources in only two of the ten nuclear genetic backgrounds registered significant differences for *per se* performance between E002 and ARG 3 based hybrids. The E002 hybrids as a group did not show significant differences with their corresponding ARG 3 group of hybrids which is evident from the non-significant difference between their overall means for this trait. While, both the cytosterile sources were equally efficient for *per se* performance of 100 seed weight, volume weight and hull content as the overall mean of E002 based hybrids and ARG 3 based hybrids were comparable. Comparable results corresponding to these traits were also noted in the studies of Gouri Shankar *et al.* (2006) and Tyagi and Dhillon (2017).

The significant difference in *per se* performance for seed yield was observed between hybrids in only one nuclear genetic background. Seed yield ranged from 1795.69 kg/ha (E002 x RHA 272-II) to 2035.97 kg/ha (E002 x M-17-R) for E002 cytosterile source, while it ranged from 1630.41 kg/ha (ARG 3 x RHA 272-II) to 2070.69 kg/ha (ARG 3 x GKVK-3) for ARG 3 based hybrids. The overall mean of these two groups of hybrids showed uniformity for seed yield with $p>0.05$ indicating that both cytosterile sources were equally contributing to seed yield. The number of seeds filled per head is a very important trait influencing seed yield in sunflowers. In the present study, seven of the 10 nuclear genetic backgrounds registered significant differences for *per se* performance between hybrids differing in their male sterility cytoplasms. The E002 based hybrids as a group were significantly superior for this trait compared to the ARG 3 group of hybrids for seed filling percentage which is evident from the significant difference between overall means of E002 (91.07%) and ARG 3 (87.59%) based hybrids confirming the positive influence of E002 cytosterile sources on seed filling percentage. For oil content, the E002 group of hybrids and their corresponding ARG 3 group of hybrids manifested significant differences which is evident from the significant difference between overall means of E002 (35.13%) and ARG 3 (31.99 %) based hybrids. The cytosterile source E002 differed significantly with respect to its *per se* performances in all the nuclear genetic backgrounds except one confirming the significant influence of cytosterile sources on *per se* performance for this trait. On the expected lines, cytosterile source from E002 had significantly better oil yield as it was having higher oil content too when compared with ARG 3 cytosterile source. Similar results were reported by Nanda (2005), Haritha (2011) and Neelavva (2012) in chilli and Sunitha and Shadakshari (2018) and Sharma and Shadakshari (2021) in sunflower.

Comparison of mid-parent heterosis (MPH) and heterobeltiosis (BPH) of hybrids based on two cytosterile sources (E002 and ARG 3): The significant differences between isonuclear alloplasmic hybrids for mid parent heterosis (MPH) and better parent heterosis (BPH) for day to 50% flowering were present in eight and all of the ten nuclear genetic backgrounds respectively (**Table 3**). Similarly, for days to maturity, significant differences were observed for both MPH and BPH. These

Table 2. Comparison of *per se* performance of hybrids based on two cytosterile sources (E002 & ARG 3) for seed yield and component traits.

Nuclear genetic background	Days to 50% flowering					Plant height (cm)				
	E002	ARG 3	Diff.	t value	P value	E002	ARG 3	Diff.	t value	P value
E002/ARG 3 x GKVK-3	61.50	64.00	-2.50	3.87	0.031	164.90	150.98	13.93	1.79	0.170
E002/ARG 3 x RHA 6D-1	57.25	60.00	-2.75	3.66	0.035	162.70	155.20	7.50	1.54	0.221
E002/ARG 3 x RHA 95-C-1	58.75	61.00	-2.25	2.63	0.078	171.15	157.65	13.50	5.19	0.014
E002/ARG 3 x LTRR-822	59.50	61.00	-1.50	1.73	0.182	161.05	154.93	6.13	3.79	0.032
E002/ARG 3 x M-17-R	54.75	56.50	-1.75	7.00	0.006	154.33	151.98	2.35	0.96	0.409
E002/ARG 3 x MR-1	56.50	56.25	0.25	0.33	0.761	152.13	150.33	1.80	0.62	0.580
E002/ARG 3 x RHA 272-II	54.75	56.50	-1.75	3.65	0.035	149.30	152.35	-3.05	5.81	0.010
E002/ARG 3 x X-15-NB-10	57.00	58.75	-1.75	2.05	0.133	154.10	151.48	2.63	0.55	0.621
E002/ARG 3 x GKVK-2	56.50	55.75	0.75	1.19	0.319	150.40	139.75	10.65	2.92	0.061
E002/ARG 3 x RHA-93	56.25	58.25	-2.00	2.45	0.092	137.55	136.20	1.35	0.16	0.886
Mean	57.28	58.80	-1.53	5.797	<0.001	155.76	150.08	5.678	3.651	<0.001

Table 2 Contd...

Nuclear genetic background	Head diameter (cm)					Stem diameter (cm)				
	E002	ARG 3	Diff.	t value	P value	E002	ARG 3	Diff.	t value	P value
E002/ARG 3 x GKVK-3	13.90	13.95	-0.05	0.11	0.919	2.33	2.31	0.02	0.19	0.860
E002/ARG 3 x RHA 6D-1	13.83	14.18	-0.35	0.87	0.449	2.29	2.37	-0.08	1.43	0.249
E002/ARG 3 x RHA 95-C-1	14.68	14.50	0.18	1.48	0.235	2.41	2.32	0.09	6.97	0.006
E002/ARG 3 x LTRR-822	14.05	13.60	0.45	2.44	0.093	2.33	2.24	0.09	1.71	0.186
E002/ARG 3 x M-17-R	13.83	13.73	0.10	1.00	0.391	2.06	2.30	-0.24	4.11	0.026
E002/ARG 3 x MR-1	14.03	13.65	0.38	2.27	0.108	2.27	2.25	0.02	0.93	0.423
E002/ARG 3 x RHA 272-II	13.98	13.90	0.07	0.33	0.765	2.12	2.30	-0.18	1.77	0.176
E002/ARG 3 x X-15-NB-10	13.88	13.40	0.48	1.90	0.153	2.36	2.27	0.09	1.31	0.283
E002/ARG 3 x GKVK-2	13.50	12.60	0.90	1.45	0.242	2.20	1.87	0.33	13.11	0.001
E002/ARG 3 x RHA-93	13.65	13.43	0.23	0.68	0.547	2.21	2.14	0.06	0.89	0.437
Mean	13.93	13.69	0.24	2.280	0.028	2.26	2.24	0.02	0.712	0.481

Table 2 Contd...

Nuclear Genetic background	Days to maturity					100 seed weight (g)				
	E002	ARG 3	Diff.	t value	P value	E002	ARG 3	Diff.	t value	P value
E002/ARG 3 x GKVK-3	93.75	97.50	-3.75	3.96	0.029	4.59	4.20	0.39	2.47	0.090
E002/ARG 3 x RHA 6D-1	90.00	97.50	-7.50	6.30	0.008	4.42	4.57	-0.15	3.26	0.048
E002/ARG 3 x RHA 95-C-1	91.75	94.50	-2.75	2.67	0.076	4.73	4.51	0.23	1.14	0.340
E002/ARG 3 x LTRR-822	93.25	90.00	3.25	2.60	0.080	4.50	4.47	0.03	0.10	0.925
E002/ARG 3 x M-17-R	85.50	88.00	-2.50	3.87	0.031	4.43	4.34	0.09	1.03	0.378
E002/ARG 3 x MR-1	89.50	88.50	1.00	1.10	0.353	4.76	4.34	0.42	2.55	0.083
E002/ARG 3 x RHA 272-II	87.00	87.75	-0.75	0.73	0.519	4.75	4.66	0.09	0.49	0.655
E002/ARG 3 x X-15-NB-10	89.50	91.50	-2.00	4.89	0.016	4.37	4.68	-0.31	3.07	0.054
E002/ARG 3 x GKVK-2	89.00	86.75	2.25	4.70	0.018	4.85	4.79	0.07	0.44	0.687
E002/ARG 3 x RHA-93	89.00	90.50	-1.50	0.81	0.477	4.27	4.98	-0.71	4.19	0.025
Mean	89.83	91.25	-1.425	2.564	0.014	4.57	4.55	0.02	0.198	0.844

Table 2 Contd...

Nuclear Genetic background	Volume weight (g/100ml)					Seed yield (kg/ha)				
	E002	ARG 3	Diff.	t value	P value	E002	ARG 3	Diff.	t value	P value
E002/ARG 3 x GKVK-3	43.61	43.36	0.25	0.19	0.862	1867.92	2070.69	-202.78	6.32	0.008
E002/ARG 3 x RHA 6D-1	40.84	42.11	-1.28	1.02	0.381	1829.19	1915.14	-85.94	1.18	0.324
E002/ARG 3 x RHA 95-C-1	43.06	43.44	-0.38	0.35	0.751	2002.64	1876.25	126.39	1.37	0.264
E002/ARG 3 x LTRR-822	36.78	38.17	-1.39	1.08	0.361	1856.80	1862.92	-6.11	0.07	0.951
E002/ARG 3 x M-17-R	47.02	45.86	1.16	0.87	0.447	2035.97	1848.80	187.17	1.43	0.248
E002/ARG 3 x MR-1	40.26	41.99	-1.73	0.96	0.410	2010.97	1973.47	37.50	1.64	0.200
E002/ARG 3 x RHA 272-II	41.80	41.99	-0.19	0.13	0.907	1795.69	1630.41	165.28	1.13	0.339
E002/ARG 3 x X-15-NB-10	41.68	41.22	0.46	0.31	0.777	1813.75	1788.75	25.00	0.32	0.767
E002/ARG 3 x GKVK-2	43.70	44.59	-0.89	0.49	0.652	1991.53	1872.08	119.45	2.07	0.130
E002/ARG 3 x RHA-93	41.53	41.77	-0.24	0.23	0.832	1949.30	1938.75	10.56	0.03	0.975
Mean	42.03	42.45	-0.42	1.021	0.313	1915.38	1877.73	37.65	0.934	0.356

Table 2 Contd...

Nuclear Genetic background	Hull content (%)					Seed filling percentage				
	E002	ARG 3	Diff.	t value	P value	E002	ARG 3	Diff.	t value	P Value
E002/ARG 3 x GKVK-3	29.62	29.97	-0.34	0.67	0.548	90.98	91.15	-0.17	0.13	0.903
E002/ARG 3 x RHA 6D-1	29.26	31.09	-1.82	5.93	0.010	93.54	90.04	3.50	3.97	0.029
E002/ARG 3 x RHA 95-C-1	31.87	32.73	-0.87	5.34	0.013	92.92	89.99	2.93	4.15	0.026
E002/ARG 3 x LTRR-822	28.76	31.16	-2.40	5.77	0.010	88.06	87.24	0.83	0.73	0.516
E002/ARG 3 x M-17-R	31.89	32.82	-0.93	2.88	0.064	91.71	88.57	3.14	12.18	0.001
E002/ARG 3 x MR-1	31.41	29.72	1.70	48.43	<0.001	92.22	88.29	3.92	4.68	0.018
E002/ARG 3 x RHA 272-II	31.58	30.78	0.80	0.65	0.563	82.83	81.61	1.22	1.69	0.189
E002/ARG 3 x X-15-NB-10	29.43	28.61	0.82	3.42	0.042	94.97	88.76	6.21	40.10	<0.001
E002/ARG 3 x GKVK-2	32.34	32.84	-0.50	3.13	0.052	91.75	84.78	6.97	32.03	<0.001
E002/ARG 3 x RHA-93	31.01	30.27	0.74	2.04	0.134	91.71	85.49	6.22	13.66	<0.001
Mean	30.72	30.99	-0.27	1.172	0.248	91.07	87.59	3.47	8.190	<0.001

Table 2 Contd...

Nuclear Genetic background	Oil content (%)					Oil yield (kg/ha)				
	E002	ARG 3	Diff.	t value	P value	E002	ARG 3	Diff.	t value	P value
E002/ARG 3 x GKVK-3	35.15	31.47	3.68	58.92	<0.001	657.16	652.15	5.01	0.62	0.581
E002/ARG 3 x RHA 6D-1	36.32	32.43	3.89	64.83	<0.001	665.87	622.68	43.19	1.61	0.205
E002/ARG 3 x RHA 95-C-1	33.92	34.11	-0.20	39.00	<0.001	680.31	641.69	38.62	1.24	0.303
E002/ARG 3 x LTRR-822	36.43	31.48	4.95	30.94	<0.001	677.05	587.99	89.06	2.76	0.070
E002/ARG 3 x M-17-R	33.76	33.26	0.50	1.79	0.172	687.48	615.58	71.90	1.68	0.192
E002/ARG 3 x MR-1	34.94	32.22	2.72	11.23	0.002	703.22	636.91	66.31	6.96	0.006
E002/ARG 3 x RHA 272-II	35.25	31.89	3.36	14.00	<0.001	633.73	519.86	113.87	2.23	0.112
E002/ARG 3 x X-15-NB-10	37.85	31.84	6.01	32.95	<0.001	687.00	570.56	116.43*	3.54	0.038
E002/ARG 3 x GKVK-2	35.34	32.90	2.44	65.00	<0.001	705.41	617.20	88.22	4.31	0.023
E002/ARG 3 x RHA-93	32.31	28.35	3.96	16.14	<0.001	631.00	553.98	77.02	0.85	0.456
Mean	35.13	31.99	3.13	10.79	<0.001	672.82	601.86	70.96	5.644	<0.001

differences were mostly in a negative direction indicating that E002 cytosterility based hybrids flowered and matured significantly earlier than ARG 3 based hybrids, confirming that the cytoplasm did have a significant influence on MPH and BPH for days to maturity.

For plant height, significant differences between crosses for MPH and BPH were observed and these differences were in a positive direction which indicates that the cytoplasm have significant influence on MPH and BPH for plant height as hybrids based on cytosterile source ARG 3 were of significantly low stature. Among the E002 cytoplasm based hybrids, MPH for stem diameter ranged from 10.56 to 29.09 per cent, while it ranged from 5.47 to 27.67 per cent for BPH. For this trait, the difference in MPH and BPH were significant in a positive direction except in one nuclear genetic background indicating that E002 cytoplasm had a significant positive influence on higher MPH and BPH for stem diameter.

For 100 seed weight the MPH and BPH of hybrids differed significantly in seven and six nuclear genetic backgrounds respectively. Except for one nuclear genetic background these differences were in the positive direction leading to the conclusion that cytoplasmic influence on MPH and BPH of hybrids for 100 seed weight was significant.

Significant differences between isonuclear alloplasmic hybrids for MPH and BPH were present in seven and four nuclear genetic backgrounds, respectively for volume weight. These differences were in a positive direction indicating that E002 cytosterility based hybrids had significantly higher volume weight than ARG 3 based hybrids.

In the present study, MPH for seed yield ranged from 146.91 (E002 x RHA 95-C-1) to 322.40 per cent (E002 x RHA 93) for E002 cytosterile source, while it ranged from 126.72 per cent (ARG 3 x RHA 95-C-1) to 305.64 per cent (ARG 3 x RHA 93) for ARG 3 based hybrids. Same hybrids had the highest and lowest BPH for seed yield but in lower magnitude. Similar results for high heterosis for seed yield in Sunflower were also observed by Ailwar *et al*., (2020) and Lakshman *et al*., (2020). Significant differences in MPH and BPH performance for seed yield were observed between hybrids in six and seven nuclear genetic backgrounds respectively in a positive direction while negative in one nuclear genetic background. Hence it can be inferred that positive cytoplasmic effect/nuclear interaction in E002 cytoplasm based hybrids was present leading to higher MPH and BPH.

The MPH and BPH of E002 based hybrids were lower for hull content which is desirable in this case. The differences were significant in a negative direction indicating the usefulness of E002 cytoplasm in producing hybrids with low hull content.

E002 cytosterile source has higher MPH compared to ARG 3 based hybrids for seed filling percentage as indicated by a significant difference in all the nuclear genetic backgrounds. While, for BPH these differences were significant in eight nuclear genetic backgrounds in a positive direction confirming the favourable effect of E002 cytosterile source on seed filling percentage.

The cytosterile source E002 differed significantly with respect to its MPH and BPH in most of the nuclear genetic backgrounds for oil content. The E002 group of hybrids and their corresponding ARG 3 group of hybrids manifested significant differences for oil content. Further, E002 analogs showed superiority over the ARG 3 group of hybrids. Clear influence of cytosterile sources on MPH and BPH for oil content was observed.

The highest MPH and BPH for oil yield were manifested in the cross E002 x GKVK 2 followed by E002 x RHA 93 in E002 cytosterility based hybrids while for ARG 3 analog the highest was observed in cross combination ARG 3x GKVK 2 followed by ARG 3 x MR-1. The differences in MPH and BPH of E002 and ARG 3 analogs were significantly different in all the nuclear genetic backgrounds except one. Similar to oil content, E002 cytosterile based hybrids showed superiority over the ARG 3 group of hybrids indicating the influence of cytosterile sources on MPH and BPH for oil yield.

Overall, both the cytosterile sources were equally efficient in the expression of traits *viz*., stem diameter, 100 seed weight, volume weight, hull content and seed yield but showed significant variations for days to 50% flowering, plant height, head diameter, days to maturity, seed filling percentage, oil content and oil yield. However, for *per se* performance for traits showing significant variation, E002 cytoplasm based hybrids were superior over ARG 3 cytoplasm based hybrids. Apparently for MPH and heterobeltiosis both cytosterile sources influenced traits under consideration with the positive influence of E002 cytoplasm on MPH and BPH for all the traits except plant height and head diameter. The results provided strong evidence for the role of male sterility inducing cytoplasm effects on the expression of hybrids. The results obtained in the present study are in confirmation with the earlier works of Patil *et al*. (2003), Tyagi and Dhillon (2017) and Tyagi *et al*. (2020) in sunflower. The differential responses of isonuclear alloplasmic hybrids on *per se* performance could be not only due to the influence of cytoplasm *per se*, but also due to its interaction with restorers. However, it is difficult to discern the effects of the cytoplasm *per se* and cytoplasm x nuclear genotype interaction.

Table 3. Comparison of mid-parent heterosis and heterobeltiosis of hybrids based on two cytosterile sources (E002 & ARG 3)

Nuclear genetic background	Days to 50 per cent flowering (%)						Plant height (%)					
	MPH			BPH			MPH			BPH		
	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.
E002/ARG 3 x GKVK-3	2.29	7.56	-5.27**	9.82	16.89	-7.07**	27.08	14.36	12.72**	30.72	19.68	11.04**
E002/ARG 3 x RHA 6D-1	-3.17	2.56	-5.73**	2.23	9.59	-7.36**	19.68	12.29	7.39**	22.00	12.55	9.45**
E002/ARG 3 x RHA 95-C-1	1.08	6.09	-5.01**	4.91	11.42	-6.51**	22.57	11.10	11.47**	28.33	14.33	14.00**
E002/ARG 3 x LTRR-822	2.59	6.32	-3.73**	6.25	11.42	-5.17**	20.46	13.95	6.51**	20.76	15.60	5.16**
E002/ARG 3 x M-17-R	-3.95	0.22	-4.17**	-2.23	3.20	-5.43**	14.87	11.25	3.62*	15.72	12.30	3.42
E002/ARG 3 x MR-1	-0.66	0.00	-0.66	0.89	2.74	-1.85*	20.85	17.31	3.54*	28.48	26.96	1.52
E002/ARG 3 x RHA 272-II	-4.58	-0.44	-4.14**	-2.23	3.20	-5.43**	19.82	20.08	-0.26	28.87	31.51	-2.64
E002/ARG 3 x X-15-NB-10	1.79	6.09	-4.30**	1.79	7.31	-5.52**	13.52	9.76	3.76*	15.55	9.85	5.70**
E002/ARG 3 x GKVK-2	0.89	0.68	0.21	0.89	1.83	-0.94	26.00	14.90	11.10**	42.75	32.64	10.11**
E002/ARG 3 x RHA-93	1.58	6.39	-4.81**	2.74	6.39	-3.65**	16.50	13.18	3.32*	33.83	32.52	1.31
Mean	-0.21	3.55	-3.76	2.51	7.40	-4.89	20.14	13.82	6.32	26.70	20.79	5.91
SEM ±			0.622			0.674			1.356			1.641
CD @ P=0.05*			1.306			1.417			2.849			3.448
CD @ P=0.01**			1.790			1.941			3.903			4.724

Table 3 contd…

Nuclear genetic background	Head diameter (%)						Stem diameter (%)					
	MPH			BPH			MPH			BPH		
	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.
E002/ARG 3 x GKVK-3	8.19	13.41	-5.22**	3.31	12.86	-9.55**	20.88	13.36	7.52*	14.78	12.80	1.98
E002/ARG 3 x RHA 6D-1	11.63	19.75	-8.12**	2.75	14.68	-11.93**	15.08	12.72	2.36	6.26	9.98	-3.72
E002/ARG 3 x RHA 95-C-1	10.86	14.26	-3.40**	9.07	17.31	-8.24**	26.34	14.85	11.49**	21.11	13.17	7.94*
E002/ARG 3 x LTRR-822	15.59	17.17	-1.58	4.42	10.03	-5.61**	29.09	16.82	12.27**	27.67	9.27	18.40**
E002/ARG 3 x M-17-R	22.02	27.29	-5.27**	2.75	11.04	-8.29**	13.83	19.66	-5.83*	12.74	12.07	0.67
E002/ARG 3 x MR-1	18.76	21.20	-2.44*	4.24	10.44	-6.20**	28.43	19.68	8.75**	24.38	9.76	14.62**
E002/ARG 3 x RHA 272-II	11.49	15.95	-4.46**	3.86	12.46	-8.60**	10.56	13.05	-2.49	5.47	11.95	-6.48
E002/ARG 3 x X-15-NB-10	5.43	6.24	-0.81	3.12	4.16	-1.04	26.54	14.54	12.00**	23.88	10.49	13.39**
E002/ARG 3 x GKVK-2	19.26	16.96	2.30*	0.33	1.94	-1.61	24.72	-0.40	25.12**	20.27	-9.02	29.29**
E002/ARG 3 x RHA-93	26.95	31.55	-4.60**	1.45	8.62	-7.17**	20.49	10.17	10.32**	20.16	4.39	15.77**
Mean	15.02	18.38	-3.36**	3.53	10.35	-6.82**	21.60	13.45**	8.15	17.67	8.49	9.19*
SEM ±			0.913			1.072			2.746			3.524
CD @ P=0.05*			1.919			2.252			5.769			7.404
CD @ P=0.01**			2.628			3.086			7.903			10.146

Table 3 contd…

Nuclear genetic background	Days to maturity (%)						100 Seed weight (%)					
	MPH			BPH			MPH			BPH		
	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.
E002/ARG 3 x GKVK-3	1.76	6.56	-4.80**	9.01	15.04	-6.03**	24.93	9.74	15.19**	23.34	4.29	19.05**
E002/ARG 3 x RHA 6D-1	0.28	9.40	-9.12**	4.65	15.04	-10.39**	24.32	23.26	1.06	18.89	13.61	5.28
E002/ARG 3 x RHA 95-C-1	2.66	6.48	-3.82**	6.69	11.50	-4.81**	36.30	24.36	11.94**	27.23	12.00	15.23**
E002/ARG 3 x LTRR-822	6.27	3.30	2.97*	8.43	6.19	2.24	17.35	12.17	5.18	13.93	11.12	2.81
E002/ARG 3 x M-17-R	-3.66	-0.14	-3.52**	-0.58	3.83	-4.41**	30.81	22.76	8.05*	19.02	7.88	11.14**
E002/ARG 3 x MR-1	0.28	-0.14	0.42	4.07	4.42	-0.35	32.87	16.18	16.69**	28.04	7.88	20.16**
E002/ARG 3 x RHA 272-II	-2.25	-0.71	-1.54	1.16	3.54	-2.38	24.62	17.54	7.08*	21.74	15.71	6.03
E002/ARG 3 x X-15-NB-10	3.02	6.09	-3.07*	4.07	7.96	-3.89**	0.22	3.65	-3.43	-12.69	-6.54	-6.15
E002/ARG 3 x GKVK-2	2.89	1.02	1.87	3.49	2.36	1.13	40.45	32.63	7.82*	30.53	18.95	11.58**
E002/ARG 3 x RHA-93	3.94	6.47	-2.53*	4.40	6.78	-2.38	29.11	44.03	-14.92**	14.79	23.80	-9.01**
Mean	1.52	3.83	-2.31	4.54	7.67	-3.13*	26.10	20.63	5.47	18.48	10.87	7.61*
SEM ±			1.107			1.164			2.966			3.111
CD @ P=0.05*			2.326			2.446			6.232			6.536
CD @ P=0.01**			3.186			3.351			8.536			8.957

Table 3 contd…

Nuclear genetic background	Volume weight (%)						Seed yield (%)					
	MPH			BPH			MPH			BPH		
	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.
E002/ARG 3 x GKVK-3	3.97	-0.86	4.83**	0.30	-1.43	1.73	194.47	218.18	-23.71**	174.03	189.78	-15.75**
E002/ARG 3 x RHA 6D-1	-1.91	-3.01	1.10	-4.70	-4.28	-0.42	208.77	214.53	-5.76	168.35	168.01	0.34
E002/ARG 3 x RHA 95-C-1	4.14	0.71	3.43**	1.84	-1.25	3.09*	146.91	126.72	20.19**	112.92	99.49	13.43*
E002/ARG 3 x LTRR-822	-11.59	-12.03	0.44	-14.05	-13.23	-0.82	173.60	168.00	5.60	172.40	160.71	11.69*
E002/ARG 3 x M-17-R	19.09	11.13	7.96**	16.34	4.25	12.09**	292.67	245.60	47.07**	198.69	158.73	39.96**
E002/ARG 3 x MR-1	-1.20	-1.29	0.09	-2.01	-4.55	2.54	251.05	234.88	16.17*	195.02	176.18	18.84**
E002/ARG 3 x RHA 272-II	-2.14	-5.65	3.51**	-7.14	-6.72	-0.42	185.72	152.80	32.92**	163.44	128.17	35.27**
E002/ARG 3 x X-15-NB-10	1.47	-3.84	5.31**	-0.14	-6.30	6.16**	163.09	153.42	9.67	160.17	150.33	9.84
E002/ARG 3 x GKVK-2	6.44	4.06	2.38**	4.79	1.35	3.44*	288.38	253.73	34.65**	192.17	161.99	30.18**
E002/ARG 3 x RHA-93	-2.94	-6.31	3.37**	-8.04	-7.52	-0.52	322.40	305.64	16.76*	185.97	171.32	14.65*
Mean	1.53	-1.71	3.24**	-1.28	-3.97	2.69*	222.71	207.35	15.36*	172.32	156.47	15.85**
SEM ±			0.762			1.265			6.508			5.241
CD @ P=0.05*			1.602			2.658			13.673			11.011
CD @ P=0.01**			2.194			3.642			18.730			15.089

Table 3 contd…

Nuclear genetic background	Hull content (%)						Seed filling percentage (%)					
	MPH			BPH			MPH			BPH		
	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.
E002/ARG 3 x GKVK-3	8.92	16.04	-7.12**	17.25	18.60	-1.35	-1.19	-3.61	2.42*	-4.48	-4.30	-0.18
E002/ARG 3 x RHA 6D-1	16.28	30.66	-14.38**	38.03	46.63	-8.60**	3.59	-2.96	6.55**	2.00	-4.08	6.08**
E002/ARG 3 x RHA 95-C-1	13.49	22.58	-9.09**	17.91	24.08	-6.17**	1.27	-4.51	5.78**	-1.79	-4.89	3.10*
E002/ARG 3 x LTRR-822	-0.02	13.75	-13.77**	1.27	9.70	-8.43**	-2.05	-5.58	3.53**	-3.14	-7.06	3.92**
E002/ARG 3 x M-17-R	13.43	22.73	-9.30**	17.69	24.39	-6.70**	3.38	-2.87	6.25**	3.16	-5.64	8.80**
E002/ARG 3 x MR-1	15.04	14.61	0.43	23.30	16.64	6.66**	3.33	-3.75	7.08**	2.92	-5.94	8.86**
E002/ARG 3 x RHA 272-II	23.27	26.96	-3.69*	42.87	39.25	3.62	-9.44	-13.13	3.69**	-11.90	-13.20	1.30
E002/ARG 3 x X-15-NB-10	5.84	8.24	-2.40	11.13	8.44	2.69	3.99	-5.39	9.38**	1.29	-5.44	6.73**
E002/ARG 3 x GKVK-2	8.55	15.56	-7.01**	11.02	24.49	-13.47**	3.37	-7.08	10.45**	3.20	-9.68	12.88**
E002/ARG 3 x RHA-93	13.14	16.26	-3.12	20.72	17.82	2.90	1.80	-7.64	9.44**	0.48	-8.92	9.40**
Mean	11.79	18.74	-6.95**	20.12	23.00	-2.89	0.81	-5.65	6.46**	-0.83	-6.92	6.09**
SEM ±			1.536			2.111			0.862			1.284
CD @ P=0.05*			3.227			4.435			1.810			2.698
CD @ P=0.01**			4.221			6.078			2.480			3.697

Table 3 contd…

Nuclear genetic background	Oil content (%)						Oil yield (%)					
	MPH			BPH			MPH			BPH		
	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.	E002	ARG 3	Diff.
E002/ARG 3 x GKVK-3	-4.31	-14.19	9.88**	-5.03	-14.70	9.67**	181.50	172.76	8.74	160.16	147.14	13.02
E002/ARG 3 x RHA 6D-1	-2.63	-12.92	10.29**	-3.38	-13.73	10.35**	200.87	174.36	26.51**	163.60	135.97	27.63**
E002/ARG 3 x RHA 95-C-1	-12.01	-11.37	-0.64	-15.38	-14.89	-0.49	116.31	100.43	15.88**	169.32	70.47	98.85**
E002/ARG 3 x LTRR-822	-0.55	-13.92	13.37**	-1.57	-14.66	13.09**	172.12	131.09	41.03**	168.03	122.82	45.21**
E002/ARG 3 x M-17-R	-8.14	-9.35	1.21	-8.79	-9.85	1.06	260.52	213.54	46.98**	172.16	133.28	38.88**
E002/ARG 3 x MR-1	-7.78	-14.83	7.05**	-9.86	-16.88	7.02**	225.24	187.08	38.16**	178.39	141.36	37.03**
E002/ARG 3 x RHA 272-II	-7.32	-16.02	8.70**	-9.75	-18.35	8.60**	165.57	112.82	52.75**	150.88	97.00	53.88**
E002/ARG 3 x X-15-NB-10	-1.23	-16.79	15.56**	-4.49	-19.66	15.17**	159.68	111.17	48.51**	148.46	106.35	42.11**
E002/ARG 3 x GKVK-2	-4.09	-10.56	6.47**	-4.53	-10.83	6.30**	272.36	216.37	55.99**	179.26	133.89	45.37**
E002/ARG 3 x RHA-93	-14.96	-25.25	10.29**	-17.09	-27.24	10.15**	263.77	209.31	54.46**	149.80	109.93	39.87**
Mean	-6.30	-14.52	8.22**	-7.99	-16.08	8.09**	201.79	162.89	38.90**	164.01	119.82	44.19**
SEM ±			1.578			1.544			5.251			7.018
CD @ P=0.05*			3.315			3.244			11.032			14.745
CD @ P=0.01**			4.541			4.445			15.120			20.205

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