Vikrant Tyagi* and S. K. Dhillon

Relationship between Crop Growth Parameters and Seed Yield in *CMS* Analogues in Sunflower

Abstract: Nine new *cms* analogues on the base of diversified *cms* sources were developed and evaluated for morphological, agronomic, physiological and biochemical traits, including the field resistance to the prevalent diseases of sunflower under Punjab conditions. As a result of this study, the most prospective *cms* analogues were designated for future use in hybrid breeding programme. The results revealed that selection for tall plants with large head size and high chlorophyll content may be associated with high grain yield as well as oil content and high oleic acid content in sunflower. Leaf dry weight, biological yield, harvest index, specific leaf weight and relative leaf water content had direct positive effect on grain yield. The harvest index, specific leaf weight/plant, leaf area index and leaf area had indirect effects (through leaf dry weight) on grain yield. These traits are advocated as selection criteria for grain yield improvement in sunflower.

Keywords: *cms* analogues, agronomic traits, physiological traits, fatty acids and path analysis

DOI 10.1515/helia-2014-0024
Received September 23, 2014; accepted February 6, 2015

Introduction

Sunflower is an important oilseed crop widely adopted and accepted for its high-quality edible oil. Its seeds contain high oil content ranging from 35% to 50% (Skoric and Marinkovic, 1986). Sunflower introduced in India in 1970s, has

***Corresponding author: Vikrant Tyagi,** Department of Plant Breeding & Genetics, Punjab Agricultural University, Ludhiana, Punjab, India 141004, E-mail: vikranttyagi97@gmail.com
S. K. Dhillon, Department of Plant Breeding & Genetics, Punjab Agricultural University, Ludhiana, Punjab, India 141004, E-mail: sklb-pbg@pau.edu

acquired the status of an important commercial oilseed crop and has spread across a number of climatic and geographical regions because of its day length neutrality, wider adaptability and responsiveness to added inputs. Sunflower, being a highly cross-pollinated crop is ideally suited for exploitation of heterosis. Sunflower hybrids are object of breeding attention because of their agronomic and economic advantages over varieties (high productivity, high oil content, uniformity, etc.). The central component of sunflower hybrid development is cytoplasmic male sterility (cms). The synthesis of hybrids with high heterotic effect became possible after the discovery of the first *cms* source by P. Leclercq (1968) and detection of fertility restoration genes by M. Kinman (1970) that gave the required impetus to commercial hybrid seed production. At present only one cms source, i.e. PET-1 is being widely used for sunflower hybrid breeding programme. Such cytoplasmic uniformity poses a potential risk for hybrid sunflower production. The utilization of different cytoplasmic backgrounds in hybrid development will improve general variability of the sunflower and lessen the threats of epiphytotics.

Sunflower breeding programme aims at developing cultivars with high grain yield and oil yield potential. Further, yield being a complex character, is a function of several component traits and their interaction with environment. Therefore, it is important to measure the mutual relationship between various plant attributes and determine the component characters, on which selection procedure can be based for direct and indirect genetic improvement of crop yield. In this context, the present work was undertaken to study the relationship between different morphological, physiological and quality attributes of the newly developed *cms* analogues for their further use in strengthening the hybrid breeding programme.

Materials and methods

The development of the *cms* analogues was initiated in the year 2007 under field conditions in Department of Plant Breeding and Genetics, PAU, Ludhiana. Nine interspecific crosses (F_1's) representing diversified *cms* sources *viz.* CMS ARG-2 (*Helianthus argophyllus*), CMS ARG-3 (*H. argophyllus*), CMS ARG-6 (*H. argophyllus*), CMS PKU-2 (*Helianthus annuus* wild), CMS E002-91 (*H. annuus* wild), CMS PRUN-29 (*Helianthus praecox ssp runyonii*), DV-10 (*Helianthus debilis ssp vestitus*), PHIR-27 (*H. praecox ssp hirtus)* and CMS X (Unknown source) along with one common maintainer line NC41B were obtained from Directorate of Research, Hyderabad. All the *cms* analogues belong to mid-oleic types. To obtain *cms* analogues the F_1 derivatives were crossed with their common maintainer line NC-41B followed by repeated backcrossing. Both spring (January to July) and off seasons (August to December) were exploited for attempting back crosses. The phenotypic uniformity with respect to morphological characters within these *cms* analogues was obtained in BC_6F_1/BC_7 F_1 progenies. The obtained nine *cms* analogues along with one common maintainer a total of ten lines were grown in the field in a plot measuring 9×3 m^2 during spring season 2011 in a randomized block design with three replications and evaluated for morphological, agronomic, physiological and quality traits. The data were recorded for days to 50% flowering and days to maturity on per plot basis; plant height, head diameter, number of leaves per plant and chlorophyll content on ten random plants in the field; for relative leaf water content, leaf water potential, leaf dry weight, leaf area, specific leaf weight and leaf area index on five random plants; and for 100 grain weight, oil content and fatty acid composition the representative sample of harvested grain was used. Oil content was estimated using Nuclear Magnetic Resonance (NMR) and fatty acids were estimated using gas liquid chromatography (GLC). Further, the maturity period of these lines coincided with high temperatures (>35°C) and heavy rains (275.9 mm) in the month of June 2011 which resulted in occurrence of head rot disease (*Sclerotinia sclerotiorum*); therefore, the data were also recorded for head rot incidence on these *cms* analogues.

The meteorological data as recorded at Meteorological Observatory, Punjab Agricultural University, Ludhiana, during crop season of 2011 (February 2011–June 2011) have been presented in Table 1. Maximum and minimum air temperature ranged between 41.8 °C and 6.8 °C with maximum value in the month of May and June and minimum in month of February. Relative humidity ranged from 38.7 % to 97.0 %, maximum being in the month of February and minimum in May. Total rain fall received during the crop season was 391.8 mm out of which 275 mm rainfall was recorded in the month of June only. When the day temperature reaches near 35 °C or above, in subtropical condition of India it is considered as high temperature conditions for this crop.

The data recorded was statistically analysed following standard procedures for the estimation of correlations and path coefficient among crop growth parameters and seed yield. Genotypic and phenotypic correlation coefficients were estimated among the traits following the method given by Kown and Torrie (1964). Path coefficients were determined following Dewey and Lu (1957) to study direct and indirect effects of different morphological traits under study on the seed yield.

Table 1: Weekly meteorological data of Ludhiana (2011) during crop season.

Month/dates	Temperature			Relative humidity (%)			Rain-fall (mm)	Sunshine (hrs)	Evaporation (mm)
	Max	Min	Mean	M	E	Mean			
4–11 February	21.8	10.3	16.1	95	66	81	8.2	5.4	15.7
12–18	19.7	10.7	15.2	92	74	83	35.6	3.9	11.6
19–25	21.0	8.7	14.9	97	67	82	0.4	5.0	1.8
26 February–4 March	20.6	10.5	15.6	93	69	81	6.5	4.1	13.6
5–11 March	24.8	9.8	17.3	95	55	75	0.0	10.1	23.1
12–18	29.3	14.0	24.7	94	56	75	0.0	8.4	3.9
19–25	30.4	14.4	22.4	91	47	69	0.0	10.1	4.5
26 March–1 April	31.7	16.3	24.0	83	42	63	0	9.9	33.5
2–8 April	31.0	14.6	22.8	74	22	48	0.0	9.3	41.6
9–15	33.1	17.4	25.3	75	28	52	2.6	6.4	34.9
16–22	32.4	16.7	24.5	74	28.5	56	22.1	9.1	34.2
23–29	**38.0**	21.7	29.9	59	27.1	43	0.0	10.2	63.2
30 April–6 May	**38.9**	24.3	31.6	51	27.6	47	18	9.1	61.4
7–13 May	**39.6**	24.0	31.3	52	27.1	39	0.0	10.2	60.2
14–20	**41.8**	25.7	**34.0**	51	28.1	38.7	0.0	9.8	**68.8**
21–27	**37.4**	24.4	30.9	67	41.7	54.3	**22.4**	6.4	48.6
28 May–3 June	**36.3**	24.1	30.7	73	45.9	59.4	**32.3**	**10.5**	54.1
4–10	**38.7**	26.5	32.6	63	41.0	52.0	**20.0**	**11.2**	**66.3**
11–17	**36.7**	26.1	31.4	78	53.0	65	**148.6**	7.6	42.6
18–24	35.2	26.1	30.3	88	60	74.1	**75.1**	5.6	25.5

Note: Bold values signifies the Highest rain fall in mm during crop season which is very favorably environment for head rot (for mm); Recorded maximum temperature during crop season (for max).

Results and discussion

The analysis of variance revealed significant differences among the *cms* analogues for all the traits. Since these *cms* analogues have same nuclear genotype, these differences in the performance of these analogues with respect to different traits can be attributed due to differences in cytoplasmic genes/factors from different sources.

This indicates that there was significant amount of phenotypic variability and all the genotypes differ with regard to the morpho-physiological and biochemical characters that opened a way to proceed for further improvement through simple selection. Mean values for days to 50% flowering varied between 68 and 79 days while days to maturity ranged from 92 to 100 (Table 2). Likewise plant height varied from 60.66 to 122.00 with an average of 81.20 cm, head diameter from 9.16 to 24.16 cm and seed yield ranged from 12.00 to 42.67 g and other physiological traits also had a wide range. A wide range for oil and quality parameters was recorded *viz*. oil (24.00–34.40%), Palmitic acid (5.10–6.90%), Stearic acid (1.00–5.60%), Oleic acid (40.80–58.00%), Linoleic acid (29.00–45.30%) and Linolenic acid (0.60–1.00%) in these analogues.

Relationship among various characters

In general, genotypic correlation coefficients were higher than their corresponding phenotypic correlation coefficients indicating a fairly strong inherent relationship among the traits. The lower estimates of phenotypic correlation indicated that the relationships were affected by environment at phenotypic level. Such environmental influence in reducing the correlation coefficients in rice was also reported by Chaudhary and Singh (1994). Efforts were made to study correlations among various characters in these *cms* analogues which are presented in Table 3. The perusal of the table indicated that the grain yield was highly significant positively correlated with chlorophyll content ($r = +0.705$) and biological yield ($r = +597$) and had significant positive association with oil content ($r = +0.428$) a positive but non-significant correlation of ($r = +0.365$) was observed between grain yield and days to flowering. Days to maturity showed highly significant positive association with plant height ($r = +0.508$) and linoleic acid ($r = +0.692$). Number of leaves per plant had highly significant positive relationship with 100 grain weight ($r = +0.534$), plant height ($r = +0.807$), oil percent ($r = +0.661$), oleic acid ($r = +0.512$) and biological yield ($r = +0.508$). Plant height was highly significant positively correlated with head diameter ($r = +0.694$), oil content ($r = +0.739$), oleic acid ($r = +0.696$) and biological yield ($r = +0.815$). Head diameter

Table 2: Mean performance of *cms* analogues for morphological and physiological characteristics in sunflower.

S. N.	Genotypes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	**CMS-XA × NC-41B**	68	95	22.67	3.60	82.00	17.50	37.44	74.10	115.55	2.43	13.35	5.12	26.00	6.10	4.00	51.40	36.10	0.80	335.33	4.06	13.67
2	**E002-91A × NC-41B**	69	98	18.00	4.90	88.33	23.83	37.07	64.68	66.74	1.40	7.71	3.71	27.22	5.50	1.00	58.00	32.80	0.70	648.33	2.52	16.33
3	**PKU-2A × NC-41B**	71	94	16.33	4.33	60.67	20.33	35.85	88.26	28.57	0.60	3.30	1.75	29.63	5.70	3.40	51.90	36.10	0.80	291.33	6.17	18.00
4	**ARG-2A × NC-41B**	72	93	18.67	4.00	70.00	15.17	37.15	69.87	22.35	0.47	2.58	1.20	28.40	5.40	4.90	52.00	34.60	0.70	630.00	5.61	35.33
5	**ARG-3A × NC-41B**	69	97	22.33	4.87	**110.00**	**24.17**	40.41	70.32	58.79	1.24	6.79	2.63	**32.00**	5.10	3.80	**56.60**	32.80	0.90	840.00	5.08	42.67
6	**ARG-6A × NC-41B**	68	92	20.67	4.40	66.67	18.00	37.81	75.65	22.57	0.47	2.61	1.10	27.50	6.20	5.60	51.20	36.80	0.60	335.33	7.13	**24.00**
7	**DV-10A × NC-41B**	79	101	21.00	3.73	87.33	15.33	40.22	61.84	49.57	1.04	5.73	2.37	33.60	5.60	4.00	55.70	29.00	1.00	581.67	5.92	34.47
8	**PHIR-27A × NC-41B**	76	99	17.00	3.10	63.33	16.33	41.14	56.83	17.00	0.36	1.96	1.00	25.20	6.90	4.40	40.80	45.30	1.00	226.67	13.02	29.50
9	**PRUN-29A × NC-41B**	69	100	**29.00**	**5.83**	**122.00**	**23.33**	36.46	63.65	38.58	0.81	4.46	1.33	**35.40**	5.60	2.80	**57.60**	31.70	1.00	681.67	2.98	**20.33**
10	**NC-41B**	71	97	17.33	4.50	51.67	9.17	32.26	78.52	14.77	0.60	1.71	0.82	24.00	5.50	4.40	47.70	39.90	0.90	53.33	22.33	12.00
Mean		71	97	20.30	4.33	80.20	18.32	37.58	70.37	43.45	0.94	5.02	2.10	28.90	5.76	3.83	52.29	35.51	0.84	462.37	7.48	24.63
Range	**Min.**	68	92	16.33	3.10	51.67	9.17	32.26	56.83	14.77	0.36	1.71	0.82	24.00	5.10	1.00	40.80	29.00	0.60	53.33	2.52	12.00
	Max.	79	101	29.00	5.83	122.00	24.17	41.14	88.26	115.55	2.43	13.35	5.12	35.40	6.90	5.60	58.00	45.30	1.00	840.00	22.33	42.67

Notes: 1. Days to 50% flowering, 2. Days to maturity, 3. No. of leaves/plant, 4. 100 grain wt. (g), 5. Plant height (cm), 6. Head diameter (cm), 7. Chlorophyll cont. (%), 8. Relative leaf water cont. (%), 9. Leaf dry wt. (g), 10. Leaf area (m^2), 11. Leaf area index, 12. Specific leaf wt./plant, 13. Oil cont. (%), 14. Palmitic acid, 15. Stearic acid, 16. Oleic acid, 17. Linoleic acid, 18. Linolenic acid, 19. Biological yield, 20. Harvest index and 21. Grain yield.

Table 3: Phenotypic correlations among different morphological, physiological and quality parameters.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1																				
2	0.443*																			
3	−0.299	0.342																		
4	−0.535**	0.141	0.534**																	
5	−0.242	0.508**	0.807**	0.570**																
6	−0.411*	0.159	0.400*	0.508**	0.694**															
7	0.357	0.276	0.114	−0.372*	0.334	0.323														
8	−0.419*	−0.701**	−0.283	0.113	−0.410*	−0.132	−0.601**													
9	−0.322	0.104	0.341	−0.040	0.418*	0.344	0.179	−0.049												
10	−0.336	0.109	0.315	−0.031	0.371*	0.264	0.085	−0.006	0.991**											
11	−0.322	0.104	0.341	−0.040	0.418*	0.344	0.179	−0.049	1.000**	0.991**										
12	−0.289	0.065	0.152	−0.096	0.315	0.351	0.167	−0.013	0.974**	0.964**	0.974**									
13	0.127	0.408*	0.661**	0.500**	0.739**	0.487**	0.290	−0.226	0.061	−0.001	0.061	−0.037								
14	0.198	0.008	−0.207	−0.570**	−0.371*	−0.189	0.304	−0.242	−0.100	−0.129	−0.100	−0.094	−0.440*							
15	0.173	−0.462*	−0.125	−0.475**	−0.440*	−0.557**	0.073	0.196	−0.372*	−0.363	−0.372*	−0.442*	−0.230	0.312						
16	−0.298	0.164	0.512**	0.676**	0.696**	0.579**	−0.032	0.013	0.401*	0.373*	0.401*	0.382*	0.669**	−0.713**	−0.524**					
17	0.029	−0.220	−0.507**	−0.488**	−0.650**	−0.413*	−0.080	0.051	−0.375*	−0.341	−0.375*	−0.340	−0.751**	0.688**	0.378*	−0.915**				
18	0.423*	0.692**	0.270	−0.089	0.309	−0.067	0.187	−0.378*	−0.055	−0.038	−0.055	−0.129	0.328	0.066	−0.083	−0.086	0.037			
19	−0.111	0.260	0.508**	0.462*	0.815**	0.673**	0.435*	−0.388*	0.293	0.220	0.293	0.257	0.715**	−0.557**	−0.387*	0.767**	−0.746**	0.018		
20	0.223	−0.005	−0.463*	−0.264	−0.633**	−0.749**	−0.410*	0.161	−0.532**	−0.426*	−0.532**	−0.519**	−0.579**	0.206	0.402*	−0.670**	0.665**	0.222	−0.745**	
21	0.365	0.103	0.073	−0.148	0.299	0.158	0.705**	−0.394*	−0.172	−0.238	−0.172	−0.202	0.428*	−0.165	0.301	0.114	−0.223	0.162	0.597**	−0.222

Notes: 1. Days to 50% flowering, 2. Days to maturity, 3. No. of leaves/plant, 4. 100 grain wt. (g), 5. Plant height (cm), 6. Head diameter (cm), 7. Chlorophyll cont. (%), 8. Relative leaf water cont. (%), 9. Leaf dry wt. (g), 10. Leaf area (m^2), 11. Leaf area Index, 12. Specific leaf wt./plant, 13. Oil Cont. (%), 14. Palmitic acid, 15. Stearic acid, 16. Oleic acid, 17. Linoleic acid, 18. Linolenic acid, 19. Biological yield, 20. Harvest index and 21. Grain yield.
Critical value of "*r*" at 5% = 0.3673 and that at 1% = 0.4706.

recorded significant positive correlation with oil content ($r = +0.487$), oleic acid ($r = +0.579$) and biological yield ($r = +0.673$). Oil content was positively associated with oleic acid concentration ($r = +0.669$), biological yield ($r = +0.715$) and grain yield ($r = +0.428$) and negatively associated with linoleic acid ($r = -0.751$) and harvest index ($r = -0.579$). Earlier studies by Tyagi *et al.* (2013) have also recorded significant positive correlation between days to flowering, days to maturity, plant height, chlorophyll content, oil content and biological yield involving 18 inbreds of sunflower including these *cms* analogues. This indicates that selection for easily observable traits like, numbers of leaves/plant, 100 grain weight, plant height and large head size may be associated with high oil content and high oleic acid composition of the sunflower oil. Selection for tall plant type having larger head diameter and high numbers of leaves/plant, 100 grain weight, chlorophyll content and biological yield may be suitable for enhancing the grain yield in sunflower. Based on mean performance of these analogues with respect to different traits as presented in Table 2, the *cms* analogues *viz*: PRUN-29A having high value for plant height (122.00 cm), 100 grain weight (5.80 g) and oil content (35.40%); moderate values for seed yield and (20.33 g/plant) and oleic acid (57.60%) and ARG-3A having medium tall plant height (110.00 cm), large head diameter (24.16 cm), high grain yield (42.67 g/plant), oil content (32.00%) and oleic acid (56.60%) may be designated as potential new sources for use in the sunflower improvement programme for development of high yielding hybrids having high oil content with better quality oil. ARG-3A has earlier also been reported as the most diverse and desirable under normal irrigated environment (Tyagi *et al.* 2013).

Path analysis

Simply working out correlations between the yield and its components may not be very informative with respect to determining the functional relation between components from diverse hierarchy. The analytical method of path coefficients analysis permits the decomposition of the correlations between two variables (X and Y) in a sum of the direct effect of X on Y, and the effects of X on Y via other independent variables.

Genotypic correlation was partitioned into direct and indirect effects through various yield contributing characters to investigate the selection criteria in sunflower breeding (Table 4). Path analysis revealed highest direct effect of leaf dry weight (+3.257) followed by biological yield (+1.851), harvest index (+0.956), specific leaf weight (+0.621) and relative leaf water content (+0.503) on grain yield as recorded at phenotypic level. The highest direct effect on grain

Table 4: Direct and indirect effects of path coefficient in sunflower *cms* analogues.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	GP	**0.162**	0.037	−0.108	0.150	0.089	−0.002	0.130	−0.211	2.226	0.479	−2.483	−0.190	0.024	0.060	0.036	−0.016	0.010	−0.045	−0.205	0.256	**0.398***
	PP	**0.181**	0.035	−0.105	0.160	0.084	0.015	0.095	−0.211	−1.049	0.392	0.870	−0.179	0.023	0.057	0.030	−0.007	0.007	−0.041	−0.205	0.213	**0.365**
2	GP	0. 076	**0.078**	0.125	−0.038	−0.198	0.001	0.100	−0.354	−0.710	−0.153	0.791	0.040	0.083	−0.005	−0.100	0.009	−0.044	−0.069	0.490	−0.011	**0.110**
	PP	0.080	**0.080**	0.120	−0.042	−0.177	−0.006	0.074	−0.353	0.340	−0.128	−0.281	0.040	0.074	0.002	−0.080	0.004	−0.053	−0.068	0.482	−0.005	**0.103**
3	GP	−0.052	0.029	**0.334**	−0.147	−0.321	0.002	0.039	−0.142	−2.351	−0.448	2.621	0.114	0.128	−0.051	−0.022	0.028	−0.103	−0.024	0.950	−0.495	**0.087**
	PP	−0.054	0.027	**0.352**	−0.160	−0.282	−0.014	0.030	−0.142	1.109	−0.367	−0.920	0.094	0.120	−0.059	−0.022	0.013	−0.123	−0.026	0.939	−0.443	**0.072**
4	GP	−0.094	0.011	0.191	**−0.257**	−0.238	0.003	−0.128	0.060	0.282	0.045	−0.314	−0.064	0.098	−0.171	−0.098	0.037	−0.101	−0.001	0.865	−0.281	**−0.156**
	PP	−0.096	0.011	0.188	**−0.300**	−0.199	−0.018	−0.099	0.057	−0.131	0.036	0.108	−0.060	0.091	−0.163	−0.082	0.017	−0.118	0.009	0.855	−0.253	**−0.147**
5	GP	−0.038	0.041	0.287	−0.164	**−0.373**	0.004	0.111	−0.217	−2.879	−0.527	3.209	0.206	0.148	−0.114	−0.096	0.039	−0.132	−0.026	1.524	−0.690	**0.314**
	PP	−0.043	0.040	0.284	−0.171	**−0.349**	−0.025	0.089	−0.206	1.363	−0.433	−1.130	0.196	0.134	−0.106	−0.076	0.017	−0.158	−0.030	1.508	−0.605	**0.299**
6	GP	−0.074	0.011	0.150	−0.147	−0.281	**0.005**	0.123	−0.071	−2.463	−0.387	2.746	0.236	0.104	−0.066	−0.130	0.034	−0.091	0.007	1.321	−0.844	**0.182**
	PP	−0.074	0.012	0.141	−0.152	−0.242	**−0.036**	0.086	−0.066	1.120	−0.308	−0.928	0.218	0.088	−0.054	−0.097	0.014	−0.100	0.007	1.245	−0.716	**0.157**
7	GP	0.065	0.024	0.040	0.102	−0.129	0.002	**0.322**	−0.310	−1.224	−0.118	1.364	0.110	0.058	0.086	0.020	−0.001	−0.015	−0.021	0.826	−0.450	**0.753****
	PP	0.064	0.022	0.040	0.111	−0.117	−0.012	**0.267**	−0.303	0.583	−0.099	−0.483	0.104	0.053	0.087	0.013	−0.001	−0.019	−0.018	0.805	−0.392	**0.704****
8	GP	−0.070	−0.056	−0.097	−0.031	0.165	−0.001	−0.204	**0.490**	0.326	0.008	−0.363	−0.010	−0.041	−0.071	0.039	0.001	0.010	0.038	−0.709	0.172	**−0.406**
	PP	−0.076	−0.056	−0.100	−0.034	0.143	0.005	−0.160	**0.503**	−0.158	0.007	0.131	−0.008	−0.041	−0.069	0.034	0.000	0.012	0.037	−0.717	0.154	**−0.393**
9	GP	−0.054	0.008	0.117	0.011	−0.161	0.002	0.059	−0.024	**−6.684**	−1.365	7.452	0.634	0.011	−0.030	−0.077	0.022	−0.074	0.005	0.532	−0.560	**−0.175**
	PP	−0.058	0.008	0.120	0.012	−0.146	−0.012	0.048	−0.025	**3.257**	−1.156	−2.700	0.605	0.011	−0.029	−0.065	0.010	−0.091	0.005	0.542	−0.509	**−0.172**
10	GP	−0.056	0.008	0.109	0.008	−0.142	0.001	0.028	−0.003	−6.621	**−1.377**	7.382	0.627	−0.001	−0.038	−0.075	0.020	−0.068	0.003	0.400	−0.449	**−0.243**
	PP	−0.060	0.008	0.111	0.009	−0.130	−0.009	0.023	−0.003	3.226	**−1.167**	−2.675	0.599	0.000	−0.037	−0.063	0.009	−0.083	0.004	0.408	−0.408	**−0.238**
11	GP	−0.054	0.008	0.117	0.011	−0.160	0.002	0.059	−0.024	−6.684	−1.365	**7.452**	0.634	0.011	−0.030	−0.077	0.022	−0.074	0.005	0.532	−0.560	**−0.175**
	PP	−0.058	0.008	0.120	0.012	−0.146	−0.012	0.048	−0.024	3.257	−1.156	**−2.700**	0.605	0.011	−0.029	−0.064	0.010	−0.091	0.005	0.542	−0.509	**−0.172**
12	GP	−0.047	0.004	0.059	0.026	−0.118	0.002	0.055	−0.008	−6.538	−1.333	7.289	**0.648**	−0.006	−0.030	−0.093	0.021	−0.068	0.012	0.469	−0.548	**−0.207**
	PP	−0.052	0.005	0.054	0.029	−0.110	−0.013	0.045	−0.007	3.173	−1.125	−2.630	**0.621**	−0.007	−0.027	−0.077	0.009	−0.083	0.013	0.476	−0.496	**−0.201**
13	GP	0.021	0.035	0.232	−0.136	−0.301	0.003	0.101	−0.108	−0.409	0.004	0.455	−0.022	**0.184**	−0.124	−0.048	0.037	−0.154	−0.031	1.331	−0.622	**0.449***
	PP	0.023	0.032	0.233	−0.150	−0.258	−0.017	0.078	−0.114	0.198	0.001	−0.164	−0.023	**0.181**	−0.126	−0.040	0.017	−0.182	−0.032	1.324	−0.553	**0.428***
14	GP	0.036	−0.001	−0.064	0.163	0.158	−0.001	0.103	−0.130	0.736	0.194	−0.820	−0.073	−0.085	**0.269**	0.066	−0.041	0.144	−0.005	−1.076	0.218	**−0.208**
	PP	0.035	0.000	−0.073	0.171	0.130	0.007	0.081	−0.122	−0.327	0.150	0.271	−0.058	−0.080	**0.286**	0.054	−0.018	0.167	−0.007	−1.032	0.197	**−0.165**
15	GP	0.029	−0.038	−0.037	0.125	0.178	−0.003	0.031	0.095	2.544	0.511	−2.835	−0.299	−0.044	0.088	**0.202**	−0.029	0.075	0.010	−0.721	0.426	**0.307**
	PP	.0 031	−0.037	−0.044	0.143	0.153	0.020	0.020	0.098	−1.211	0.424	1.003	−0.274	−0.042	0.089	**0.173**	−0.013	0.092	0.008	−0.717	0.384	**0.300**
16	GP	−0.051	0.013	0.182	−0.183	−0.278	0.003	−0.008	0.005	−2.780	−0.533	3.099	0.256	0.132	−0.210	−0.114	**0.052**	−0.188	0.013	1.433	−0.738	**0.105**
	PP	−0.054	0.013	0.180	−0.203	−0.243	−0.021	−0.008	0.007	1.307	−0.435	−1.083	0.237	0.121	−0.204	−0.091	**0.025**	−0.222	0.008	1.419	−0.641	**0.113**
17	GP	0.007	−0.017	−0.175	0.132	0.251	−0.002	−0.024	0.026	2.538	0.476	−2.829	−0.226	−0.145	0.197	0.077	−0.050	**0.196**	−0.002	−1.379	0.699	**−0.247**
	PP	0.005	−0.017	−0.178	0.146	0.227	0.015	−0.021	0.026	−1.220	0.398	1.012	−0.211	−0.136	0.197	0.066	−0.023	**0.243**	−0.004	−1.381	.6363	**−0.222**
18	GP	0.099	0.073	0.106	−0.002	−0.128	−0.001	0.091	−0.249	0.432	0.058	−0.483	−0.105	0.076	0.020	−0.027	−0.009	0.004	**−0.075**	0.049	0.276	**0.200**
	PP	0.076	0.055	0.095	0.027	−0.108	0.002	0.050	−0.190	−0.180	0.044	0.149	−0.080	0.059	0.019	−0.014	−0.002	0.009	**−0.098**	0.034	0.213	**0.161**
19	GP	−0.018	0.021	0.175	−0.122	−0.313	0.004	0.147	−0.192	−1.958	−0.304	2.183	0.167	0.135	−0.159	−0.080	0.041	−0.149	−0.002	**1.814**	−0.786	**0.603****
	PP	−0.020	0.020	0.179	−0.139	−0.285	−0.024	0.116	−0.195	0.954	−0.257	−0.791	0.160	0.130	−0.159	−0.067	0.019	−0.181	−0.002	**1.851**	−0.712	**0.597****
20	GP	0.039	0.000	−0.158	0.069	0.246	−0.004	−0.139	0.081	3.587	0.593	−3.999	−0.340	−0.110	0.056	0.082	−0.037	0.131	−0.020	−1.366	**1.044**	**−0.244**
	PP	0.040	0.000	−0.163	0.079	0.221	0.027	−0.110	0.081	−1.733	0.498	1.437	−0.322	−0.105	0.059	0.070	−0.017	0.161	−0.022	−1.379	**0.956**	**−0.221**

Notes: 1. Days to 50% flowering, 2. Days to maturity, 3. No. of leaves/plant, 4. 100 Grain wt. (g.), 5. Plant height (cm), 6. Head diameter (cm), 7. Chlorophyll cont. (%), 8. Relative leaf water cont. (%), 9. Leaf dry wt. (g), 10. Leaf area (m^2), 11. Leaf area Index, 12. Specific leaf wt./plant, 13. Oil Cont. (%), 14. Palmitic acid, 15. Stearic acid, 16. Oleic acid, 17. Linoleic acid, 18. Linolenic acid, 19. Biological yield, 20. Harvest index and 21. Grain yield; Diagonal bold values are direct effect on seed yield.

yield at genotypic level was exhibited by leaf area index (+ 7.45), followed by biological yield (+ 1.814), harvest index (+ 1.044), specific leaf weight (+ 0.648) and relative leaf water content (+ 0.490). Other traits also had positive direct effects on yield but these were quite low. Therefore, these cannot be generalized as traits for indirect selection for higher seed yield. In order to identify a trait as an indirect selection criterion for seed yield through path coefficient, the trait should have positive direct effect on seed yield as well as significant positive correlation with seed yield (Das and Taliaferro, 2009). The highest positive indirect effects on grain yield were recorded for the specific leaf weight/plant (+ 7.289), leaf area (+ 7.382), leaf dry weight (+ 7.452) and plant height (+ 3.209) through their impacts on leaf area index. The specific leaf weight/plant, leaf area, leaf dry weight and plant height had indirect effects (through leaf area index) on grain yield at genotypic level. While at phenotypic level the highest positive indirect effects on grain yield were obtained for the harvest index (+ 3.587), specific leaf weight/plant (+ 3.173), leaf area index (+ 3.257) and leaf area (+ 3.226) through their impacts on leaf dry weight. The harvest index, specific leaf weight/plant, leaf area index and leaf area had indirect effects (through leaf dry weight) on grain yield. Earlier, Farratullah *et al.* (2006) and Muhammad *et al.* (2007) had reported similar findings in sunflower. The results of the present study suggest that leaf dry weight, biological yield, harvest index, specific leaf weight and relative leaf water content are the main components affecting grain yield directly while plant height, head diameter, leaf area, leaf area index, specific leaf weight/plant and harvest index are affecting indirectly. These traits are advocated as selection criteria for grain yield improvement in sunflower.

Screening of *cms* analogues for diseases

Simultaneously the obtained cms analogues were tested for resistance to the prevalent disease *Sclerotinia sclerotiorum* (head rot) and stem breakage (Table 5). *Sclerotinia sclerotiorum* is an important fungal disease under Punjab conditions and it appears when high temperature (35°C and above) at the time of maturity in the month of May/June coincides with heavy rainfall. The rain water gets collected on the backside of head and head starts rotting. During the crop season, the maximum temperature at the time of anthesis (starting from mid April) and seed filling ranged from 36.3°C to 41.8°C. This high temperature coincided with heavy rainfall of 298.4 mm (from last week of May to third week of June) at the time of maturity of crop. These weather conditions were very much favourable for occurrence of *Sclerotinia sclerotiorum* (head rot). The

Table 5: Evaluation of sterile *cms* analogues for head rot and stem breakage.

***CMS* analogues**	**Head rot**	**Stem breakage**
NC41B	+	+
CMS-XA	+ +	–
E002-91A	+	–
PKU-2A	+	–
ARG-2A	+	–
ARG-3A	–	+
ARG-6A	–	+ +
DV-10A	+ + +	–
PHIR-27A	–	–
PRUN-29A	+	–

Notes: += Susceptible; + + = MOD. Susceptible; + + + = Highly Susceptible; – = Resistant.

screening of these analogues had been done under field condition (favourable environmental conditions) and any kind of artificial inoculation or infection technique were not used for screening. Here in this study the aim was to find, if any, cytoplasm from these alloplasmic lines offers resistance to this disease. Stem breakage at maturity is also an important character associated with yield losses. When the head starts maturing if the stem is not flexible enough it breaks down the top instead of bending thereby resulting in reduced yields. The majority of the lines were attacked by *Sclerotinia sclerotiorum* although the incidence varied. However, *cms* analogues ARG-3A, ARG-6A and PHIR-27A were free from disease. Stem breakage at maturity was maximum in ARG-6A while rest of the *cms* analogues did not show any stem breakage. NC-41B (control) was susceptible to head rot and stem breakage.

Acknowledgements: This study is a part of Ph. D. thesis ("Effect of Alien Cytoplasms on Heterosis and Combining Ability of Yield, Quality and Water Use Efficiency Traits in Sunflower (*Helianthus annuus* L.)"). I am thankful to Department of Science and Technology (DST), New Delhi, India for providing INSPIRE fellowship during this study. The authors are grateful to the Directorate of Oilseed Research, Hyderabad, India for providing the source material.

References

Arshad M., Kasif Ilias M., Ayub K.M., 2007. Genetic divergence and path coefficient analysis for grain yield traits in sunflower (*Helianthus Annuus* L) hybrids. Pakistan Journal of Botany 39 (6): 2009–2015.

Chaudhary, P.K., Singh R.P., 1994. Genetic variability, correlation and path analysis of yield components of rice. Madras Agricultural Journal 81(9): 468–470.

Das, M.K., Taliaferro C.M., 2009. Genetic variability and interrelationships of seed yield and yield components in switchgrass. Euphytica 167: 95–105.

Dewey, D.R., Lu K.H., 1957. A correlation and path coefficient analysis of components of crested wheat grass seed production. Agronomy Journal 51: 515–518.

Farratulla, F.-E.-A., Khalil I.H., 2006. Path analysis of the coefficients of sunflower (*Helianthus Annuus* L.) hybrids. International Journal of Agricultural and Biology 8(5): 56–60.

Kinman, M. 1970. New developments in the USDA and state experiment station sunflower breeding programs. *In*: Proc. 4th Int. Sunf. Conf., Memphis. Tennessee, USA, pp. 181–183.

Kown, S.H., Torrie J.H., 1964. Heritability and Interrelationship among traits of two soybean populations. Crop Science 4: 196–198.

Leclercq, P. 1968. Cytoplasmic male sterility in sunflower. *In*: Proc 3rd Int. Sunf. Conf., Krasnodar, pp. 40–45.

Skoric, D., Marinkovic R. 1986. Most recent results in sunflower breeding. *In*: Int. Symp. on Sunflower, Budapest, Hungary, pp. 118–119.

Tyagi, V., Dhillon S.K., Bajaj R.K., Kaur J., 2013. Divergence and Association Studies in Sunflower (*Helianthus Annuus* L. Helia 36 (58): 77–94.