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Journal of Cereals and Oilseeds

Full Length Research Paper

Combining ability analysis in sunflower (*Helianthus annuus* L.) genotypes

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Eight sunflower inbred lines were crossed in 8×8 diallel fashion (without reciprocal) and 28 F_1 were developed at Oilseed Research Centre (ORC), Bangladesh Agricultural Research Institute (BARI), Gazipur in Rabi season, 2018. All F_1 and their parents were planted in Rabi season 2019 to estimate general combining ability (GCA) and specific combining ability (SCA) effects for yield and yield attributes. The highly significant mean squares for genotypes for all the studied characters indicating wide variability in the parental materials. The highly significant GCA effects for stem diameter, days to maturity, number of seeds/head, 1000-seed weight and SCA effects for days to 50 flowering, days to maturity, head diameter, number of seeds/head, 1000-seed weight and seed yield were observed. The greater ratio of GCA/SCA implies the predominance of additive gene effect for all the studied characters. The parents, P1, P2, P3, P6 and P8 were found as good general combining parents for short duration, early maturity, lodging resistant, and 1000 seed weight. Crosses with the best SCA effects for some characters were found from the interaction of low × low, high × low, low × high or high × average combining parents. Further investigation on superiority and stability of good combining parents and hybrids over different years and locations is needed.

Key words: Sunflower, Griffing' method, general combining ability (GCA), specific combining ability (SCA).

INTRODUCTION

Edible oil is one of the major energy sources of our diet. Bangladesh faces lack of edible oil since long been ago and the area under cultivation of oilseed crops are decreasing day by day due to several reasons (Miah, 2014). Consequently, a lion share of the edible oil requirement of our country is fulfilling through import by using a huge amount of foreign currency every year. This big gap of edible oil requirement and supply in our country can be reduced by increasing area under oilseed crop cultivation as well as cultivating high yielding oilseed crops with high edible oil, early maturity, biotic and abiotic stress resistant varieties. However, in Bangladesh, the area under oilseed crop cultivation is not possible to increase due to limited land resources. The potential

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alternative would be the introduction of new oilseed crops to increase the yield and minimize the demand and supply gap of edible oil. Sunflower (*Helinths annus*), is an oilseed crop belongs to family Compositae originated from temperate region of North America. It has been domesticated as an oil crop in Russia in the early 18th century. Among the oilseed crops sunflower ranked 4th for edible oil production in the world (Masvodza et al., 2014) after soybean, palm and rapeseed. However, as an oilseed crop, sunflower has been introduced and begun to cultivate in Bangladesh since 1975 on a small scale (Habib et al., 2017). Compared to other oilseed crop, sunflower possesses several advantages. As for example, short duration (90-110 days) and high yield potential with higher % of edible oil, having tolerance to drought and salt (Ahmad et al., 2012) with wider adaptability to different soil and climatic conditions (Sunil and Khan, 2013). Therefore, the country's edible oil production can be increased by cultivating sunflower in between two rice crops, marginal and saline prone fallow land.

Commercial cultivation of sunflower in Bangladesh started with the composite varieties namely BARI Surjamukhi-2 and Kironi. These varieties were developed by ORC, BARI, Gazipur. Lodging tendency due to tallness and lower yield are the major constrains for the expansion of these varieties to the farmer's field. Farmer prefer hybrid sunflower variety as hybrids are stable, self-fertile, high yielding as well as uniform at maturity (Seetharam, 1979; Kaya and Atakisi, 2004). However, in Bangladesh there is no local high yielding sunflower hybrid variety for cultivation. The imported hybrid seeds are expensive which increase the production cost and most of the farmers cannot afford to obtain hybrid seeds every year. Besides, sometimes imported seeds do not give desired oil yield due to acclimatization in local climatic condition. Hence, development of local synthetic or hybrid variety with high achenes yield, lodging resistance and uniform maturity is the burning issue of the day.

Information regarding the general and specific combining ability of the parents and crosses, respectively are important to formulating breeding strategy (Vikas et al., 2015). Diallele mating designs provide useful genetic information for breeding programs, such as GCA and SCA to help in selecting appropriate breeding design and strategies (Johnson and King, 1998). Diallele mating design and Griffing's approaches are the most frequently used tools in various oleaginous crops including rapeseeds (Machikowa et al., 2011; Rameeh, 2011).

However, there is scare report on combining ability analysis in sunflower in Bangladesh. So far, this is the first time initiative on combining ability analysis in sunflower utilizing diallel mating with different parents in a set of half diallel crosses in Bangladesh. Therefore, this study has been undertaken with the view to find out the parents with good general combining ability as well as

superior hybrids for further breeding program.

MATERIALS AND METHODS

Plant material and F_1 development

The experiment was carried out in the research field at ORC, BARI, Gazipur during Rabi seasons of 2017-18 and 2018-19. Eight genetically diverse inbred lines of sunflower namely P1 (P-S-2-OP1), P2 (P-SP2-OP3), P3 (P-S-2-OP6), P4 (P-SP2-OPa), P5 (P-S-2-OP4), P6 (P-S-2-OP2), P7 (P-S-2-OP8) and P8 (P-S-2-OPb) were used in this study.

The parental lines were sown in 2 rows × 2 m long plot, maintaining plant to plant and row to row distances 25 and 50 cm, respectively in the Rabi season 2017-2018. 8×8 single crosses (diallel crosses) were made in all possible combination (excluding reciprocals) among the inbred lines and 28 crosses were developed for further study. All the F_1s and their parents were grown in a randomized complete block design (RCBD) in the research field of ORC, BARI Gazipur in the next rabi season (2018-2019) to record data on morphological and yield attributes. Seeds were sown in 2 rows × 4 m long plot, where plant to plant distance was 25 cm and row to row distance was 50 cm. Fertilizers such as NPKS were applied at 25:35:55:18 kg/ha, respectively from urea, TSP, MP and gypsum. During the final land preparation, half amount of urea and full amount of other fertilizers were applied and remaining half amount of urea were applied during flower primordial initiation stage as top dress. For optimum plant growth, all the agronomic practices namely weeding, thinning, hoeing, top dressing of fertilizer, irrigation, insect and diseases management were followed as required.

Data recording and statistical analysis

From ten randomly selected plants, data on days to 50 flowering, days to maturity, plant height (cm), stem diameter (cm), head diameter (cm), number of seeds per head, seed weight per head (g), and 1000 seed weight (g) were taken. Diallel analysis was performed to determine the general and specific combining ability effects following Griffing's Model I (fixed effect model) and Method 2 (parents + one set of cross) (1956) by using PBTools software program.

RESULTS

Analysis of variance

Analysis of variance for different characters of sunflower is presented in Table 1. It appears that there was significant variation among the genotypes for all the characters studied. The variances due to genotypes were partitioned into the variances due to parents (P), F_1s and parents vs. F_1s. The variance due to parents were significant for days to 50 flowering, stem diameter, number of seeds/head, seed yield/head and 1000 seed weight. The rest characters showed non-significant variation among the parents. The variances due to F_1 exhibited significant variation for most of the studied characters except for the characters stem diameter and 1000 seed weight. The variances parents vs. F_1s showed significant variation for the characters seed yield/head

Table 1. Analyses of variance (mean square) for different characters for parents and their F_1 in a diallel cross of sunflower.

Source of variation	df	DF	DM	PH(cm)	SD(CM)	HD(CM)	SH	YHG	1000SWG
Block	2	0.0001	0.0007*	0.0184	0.0136**	0.0134	0.0557	0.0362	0.0046
Genotype	35	0.0005**	0.0004**	0.0574*	0.0043*	0.0206*	0.1737**	0.0749**	0.0107**
Parents (P)	7	0.0010**	0.0002	0.0135	0.0056*	0.0069	0.1398**	0.0643**	0.0300**
F_1	27	0.0004**	0.0005**	0.0662**	0.0039	0.0246**	0.1771**	0.0671**	0.0035
P Vs F_1	1	0.0002	0.0001	0.1269	0.0056	0.0097	0.3199**	0.3592**	0.0696**
Error	70	0.0001	0.0002	0.0369	0.0027	0.0131	0.0773	0.0273	0.0028

DF: Days to 50 flowering, DM: Days to maturity, PH: Plant height (cm), SD: Stem diameter (cm), HD: Head diameter (cm), SH: number of seeds/head, and YH: seed yield/head (g) and SW: 1000 seed weight (g). **Significance at p=0.01 and ns=non-significant.

Table 2. Analysis of variance (mean square) for combining ability of different characters in sunflower

Source of variation	df	DF	DM	SD(CM)	HD(CM)	SH	YHG	1000SWG
GCA	7	5.14^{ns}	18.31**	0.002**	0.008^{ns}	0.0108**	0.040^{ns}	0.007*
SCA	28	4.68**	5.28**	0.001^{ns}	0.005**	0.045**	0.021**	0.003**
Error	70	0.90	3.10	0.000	0.003	0.025	0.009	0.001
GCA:SCA		1.09	3.46	2.0	1.6	2.39	1.90	2.33

DF: Days To 50 flowering, DM: Days to maturity, SD: Stem diameter (cm), HD: head diameter (cm), SH: number of seeds/head, and YH: seed yield/head (g) and SW: 1000 seed weight (g). * and **Significance at p=0.05 and p=0.01, respectively and ns=non-significant.

and 1000 seed weight.

Table 2 shows the general combining ability (GCA) and specific combining ability (SCA) mean square and significant GCA effects were found for days to maturity stem diameter (cm), number of seeds per head as well as 1000-seed weight. A non-significant GCA effects was found for the characters days to 50 flowering, head diameter (cm) and yield per head. The characters, days to 50 flowering, days to maturity, head diameter (cm), number of seeds per head, 1000-seed weight and yield per head showed highly significant SCA effects. While non-significant SCA effect was found for stem diameter (Table 2). Besides, from the results of ratio of the components, greater GCA/SCA ratio was recorded for all the characters (Table 2).

General combining ability (GCA) effects of the parents

Table 3 shows the GCA effects of the parental lines. From the result, significantly negative GCA effects were found in the parent P1 for the character days to 50 flowering, and days to maturity and in the parents P2 and P4 for days to maturity. Negative and non-significant GCA effects were recorded in parents P2, P5 and P7 for days to maturity parameters. Significant and positive GCA effects were found for stem and head diameter in the parents P2 and P8. Among the eight evaluated

parents, significantly positive GCA effects was recorded in the parents P2 and P8 (for head diameter), in the parents P1 and P8 (for number of seeds/head), in the parents P2, P3 and P6 (for 1000-seed weight) and in the parents P1, P2 and P8 (for seed yield /head) (Table 3).

Specific combining ability (SCA) effects of the crosses

Table 4 shows the SCA effects of the crosses for different characters. Out of 28 crosses, significant but negative SCA effects for days to 50 flowering and days to maturity were found in seven (P1×P2, P1×P3, P1×P5, P1×P8, P3×P7, P6×P8 and P7×P8) and four (P1×P4, P1×P8, P2×P4 and P7×P8) cross combinations, respectively.

SCA effects of stem diameter were found significant and positive in four ((P1×P6, P2×P6, P5×P6 and P6×P8)) cross combinations. Among 28 crosses, a total of three (P1×P6, P2×P5, and P2×P7), four (P1×P5, P2×P3, P2×P6, and P6×P8) and eight crosses (P1×P3, P1×P4, P1×P5, P1×P6, P3×P8, P4×P7 and P6×P7) showed positively significant SCA effects of number of seeds per head, 1000-seed weight and yield per head, respectively.

Cross combinations with highest SCA effects, mean performance and their parents GCA effects

The parents used in this study have been grouped into

Table 3. Estimates of GCA effects of the parents for different characters in sunflower.

Parents	DF	DM	SD(CM)	HD(CM)	SH	YHG	1000SWG
P1	-0.933[**]	-2.75[**]	0.006[ns]	0.018[ns]	0.102[**]	0.068[**]	-0.037[**]
P2	-0.700[**]	-0.18[ns]	0.018[*]	0.033[**]	-0.114[**]	0.047[*]	0.043[**]
P3	-0.233[ns]	0.08[ns]	-0.014[*]	-0.015[ns]	-0.033[ns]	-0.018[ns]	0.017[*]
P4	-0.533[*]	0.95[*]	-0.015[*]	-0.012[ns]	-0.020[ns]	-0.011[ns]	-0.009[ns]
P5	0.033	-0.68[ns]	0.006[ns]	0.011[ns]	0.063[ns]	-0.017[ns]	-0.020[**]
P6	0.766[**]	0.88[*]	-0.015[*]	-0.048[**]	-0.169[ns]	-0.104[ns]	0.023[**]
P7	0.666[**]	-0.05[ns]	-0.011[*]	-0.017[ns]	0.043[ns]	-0.002[ns]	-0.003[ns]
P8	0.933[**]	1.75[**]	0.026[**]	0.030[**]	0.126[**]	0.097[**]	-0.013[ns]
S.E.(Gi) ±	0.281	0.521	0.007	0.015	0.047	0.028	0.009
LSD(5)	0.66597	1.23477	0.01659	0.03555	0.11139	0.06636	0.02133
LSD(1)	0.9835	1.8235	0.0245	0.0525	0.1645	0.098	0.0315

NOTE: DF: Days To 50 flowering, DM: Days to maturity, SD: Stem diameter (cm), HD: head diameter (cm), SH: number of seeds/head, YH: seed yield/head (g) and SW: 1000 seed weight (g). * and **Significance at p=0.05 and p=0.01, respectively and ns=non-significant.

high or good, medium or average, and low or poor combiners based on the parents GCA effects. The parents which showed significant GCA effects in desirable direction were categorized as high or good combiners. Parents were categorized as medium or average combiners when they showed non-significant GCA effects in desirable direction and parents with undesirable GCA effects were categorized as low or poor combiner. In the present study, higher SCA effects in desirable direction in a single cross combining all characters were not found. However, significant and desirable SCA effects for some crosses with some characters were found from the combination of low and low, low and high, high and low, and/or high and average combiner parents (Table 5).

DISCUSSION

Yield of sunflower may be increased by cultivating high yielding hybrids. Genetically diverse parental materials are a pre-requisite for developing high yielding hybrid. In this study diversity of the parental materials are confirmed by the highly significant mean squares of all the tested parameters except for days to maturity, plant height and stem diameter. Similar results of highly significant genotypic variability due to mean squares were also reported in cucumber (Olfati et al., 2012). Although the parents depicted non-significant variation for days to maturity, plant height and stem diameter but they gave variation in F_1 generation when the parents were crossed. This confirmed that parents did not show significant variation at phenotypic level but there were really allelic variation for which significant variations were obtained in F_1 generations. The significant variation due to parents vs. F_1s for the characters seed yield/head and 1000 seed weight in this study might implies the average

heterosis of the F_1s over their parents.

Successful breeding program are achieved through selections of suitable parental materials. For sunflower crop improvement, genetic divergence, additive and/or dominant gene actions, and combining ability are the most important parameters (Sher et al., 2009). The GCA variance and SCA variance indicates the additive gene effects and non-additive gene effects, respectively (Griffings, 1956; Baker, 1978). The significant GCA and SCA estimates in this study perhaps an indication of both additive and non-additive gene effects had dominated role in expression of the tested parameters. However, greater GCA/SCA ratio is an indication of predominance of GCA effects over SCA for inheritance of all tested parameters in the present study. These results agree with other researchers who found greater GCA variance than SCA variance in sunflower (Kaya and Atakisi, 2004; Mijic et al., 2008). High GCA/SCA ratio of head diameter, acne and oil yield in sunflower (Thitiporn et al., 2011), plant and ear height and days to maturity in maize (Ivy and hawlader, 2000) was reported. Rukundo et al. (2017) reported high GCA/SCA ratio for sweet potato root yield and storage dry matter content and opined that additive gene effects are important over non-additive gene effects.

The estimates of GCA effects are the important criteria for selecting superior parents of desirable traits. Short duration sunflower hybrids, synthetic and/or composite varieties are the preference of sunflower growers as such varieties could reduce the risk of diseases and insect-pest incidence as well as adverse climatic condition. In sunflower breeding, the main focus is to develop high yielding open pollinated or hybrid variety with short growing cycle (Sher et al., 2009). Hence, the parents P1, P2, P4, P5 and P7 which showed significant but negative GCA effects of days to flowering or maturity in this study could be considered as good general combiner for

Table 4. Estimates of SCA effect of the crosses for different characters in sunflower.

Crosses	DF	DM	SD(CM)	HD(CM)	SH	YHG	1000SWG
P1×P2	-2.4778**	1.063 ^{ns}	0.0015^{ns}	-0.042 ^{ns}	0.163 ^{ns}	-0.0781 ^{ns}	-0.015 ^{ns}
P1×P3	-3.2778**	-0.537 ^{ns}	0.0145 ^{ns}	0.046 ^{ns}	-0.011 ^{ns}	0.0591 ^{ns}	0.058**
P1×P4	-0.9778 ^{ns}	-3.070**	0.0070 ^{ns}	0.037 ^{ns}	0.105 ^{ns}	0.0534 ^{ns}	0.059**
P1×P5	-2.5444**	-1.770 ^{ns}	-0.0278 ^{ns}	-0.038 ^{ns}	-0.017 ^{ns}	0.1557*	0.046*
P1×P6	1.7222**	0.329 ^{ns}	0.0384*	0.068 ^{ns}	0.348**	0.1014 ^{ns}	0.053*
P1×P7	-0.5111 ^{ns}	0.596 ^{ns}	0.0115	0.016 ^{ns}	0.048 ^{ns}	0.0436 ^{ns}	0.037 ^{ns}
P1×P8	-2.7778**	-2.537**	-0.0215 ^{ns}	-0.031 ^{ns}	-0.197 ^{ns}	-0.0208 ^{ns}	0.036 ^{ns}
P2×P3	2.8222**	-2.103	0.0208^{ns}	0.061 ^{ns}	0.071 ^{ns}	0.2256**	-0.008 ^{ns}
P2×P4	2.4556**	-2.970**	0.0022^{ns}	0.037 ^{ns}	0.159 ^{ns}	0.0153 ^{ns}	-0.002 ^{ns}
P2×P5	0.2222 ^{ns}	-0.337 ^{ns}	0.0271^{ns}	0.019 ^{ns}	0.247*	0.1096 ^{ns}	0.025 ^{ns}
P2×P6	-0.8444 ^{ns}	1.429 ^{ns}	0.0417*	0.062 ^{ns}	-0.607**	0.1865**	0.006 ^{ns}
P2×P7	1.9222**	1.029 ^{ns}	0.0013^{ns}	0.055 ^{ns}	0.229*	-0.33636**	-0.004 ^{ns}
P2×P8	-0.6778 ^{ns}	-0.437 ^{ns}	-0.0274^{ns}	0.002 ^{ns}	0.211 ^{ns}	-0.1491*	-0.057**
P3×P4	0.6556 ^{ns}	0.096 ^{ns}	0.0243 ^{ns}	0.076**	0.067 ^{ns}	-0.0781 ^{ns}	0.005 ^{ns}
P3×P5	1.4222*	0.729 ^{ns}	-0.0218 ^{ns}	-0.057 ^{ns}	-0.123 ^{ns}	0.0450 ^{ns}	0.060**
P3×P6	0.0222 ^{ns}	0.163 ^{ns}	-0.058**	-0.137**	-0.120*	-0.0042 ^{ns}	-0.050*
P3×P7	-1.8778**	2.763*	-0.0075 ^{ns}	0.001 ^{ns}	-0.179 ^{ns}	0.1646*	-0.012 ^{ns}
P3×P8	0.1889 ^{ns}	-0.370 ^{ns}	-0.0061^{ns}	0.015 ^{ns}	0.116 ^{ns}	-0.1118 ^{ns}	0.044*
P4×P5	0.3889 ^{ns}	-0.803 ^{ns}	0.0248 ^{ns}	0.043 ^{ns}	0.129 ^{ns}	0.0614 ^{ns}	0.016 ^{ns}
P4×P6	-0.0111 ^{ns}	-1.703 ^{ns}	-0.0707**	-0.202**	-0.221*	0.0748 ^{ns}	0.008 ^{ns}
P4×P7	1.0889 ^{ns}	0.229 ^{ns}	0.0044 ^{ns}	-0.024 ^{ns}	0.051 ^{ns}	0.1274 ^{ns}	0.048*
P4×P8	0.4889 ^{ns}	8.429**	-0.0207 ^{ns}	-0.029 ^{ns}	0.031 ^{ns}	-0.0601 ^{ns}	-0.048*
P5×P6	1.7556**	0.929 ^{ns}	0.0069**	0.043 ^{ns}	0.181 ^{ns}	0.0526 ^{ns}	-0.038 ^{ns}
P5×P7	1.5222*	0.529 ^{ns}	0.0171^{ns}	0.028 ^{ns}	0.135 ^{ns}	0.0453 ^{ns}	0.026 ^{ns}
P5×P8	0.9222 ^{ns}	-1.603 ^{ns}	-0.0226 ^{ns}	-0.021 ^{ns}	-0.162 ^{ns}	0.0251 ^{ns}	0.027 ^{ns}
P6×P7	-0.2111 ^{ns}	-0.370 ^{ns}	0.0056^{ns}	0.008 ^{ns}	0.129 ^{ns}	-0.1572*	0.055**
P6×P8	-2.4778**	0.496 ^{ns}	0.0415**	0.092*	0.203 ^{ns}	0.2210**	-0.009 ^{ns}
P7×P8	-2.3778**	-3.237**	-0.0519**	-0.088*	-0.175 ^{ns}	0.0647 ^{ns}	0.011 ^{ns}
S.E.(ij) ±	0.861	1.597	0.022	0.046	0.144	0.086	0.027
LSD (5)	1.76505	3.27385	0.0451	0.0943	0.2952	0.1763	0.05535
LSD (1)	2.37636	4.40772	0.06072	0.12696	0.39744	0.23736	0.07452

DF: Days To 50 flowering, DM: Days to maturity, SD: Stem diameter (cm), HD: head diameter (cm), SH: number of seeds/head, YH: seed yield/head (g) and SW: 1000 seed weight (g). * and **Significance at p=0.05 and p=0.01, respectively and ns=non-significant.

developing early maturing short duration sunflower variety. Similar result was also reported by Shankar et al. (2007) and Vikas and Supriya (2017). Negative but significant GCA effects in sunflower were reported for days to 50 flowering (Kang et al., 2013; Saleem et al., 2014; Patil et al., 2017). Stem diameter is an important criterion for sunflower which prevents lodging tendency of plant in wind prone area. Hence, the parents (P2 and P8) which showed significant and positive GCA effects for stem diameter could be used for developing lodging resistant sunflower variety. Ahmad et al. (2012) was also reported significant GCA effect for stem diameter in sunflower. For achieving higher commercial yield in sunflower, head diameter, seeds per head, 1000-seed weight and yield per head play important role. In this study the parents (P1, P2, P3, P6 and P8) which showing

significant and positive GCA effects of these characters might be used for developing potential hybrid, synthetic and composite sunflower variety with higher commercial yield. Parents with good general combiners for yield attributing characters namely head diameter, seeds/head, yield/head were also reported in sunflower (Sawargaonkar and Ghodke 2008; Bhoite et al., 2018). In this study, the parents with good general combining ability might be a novel findings especially for the development of synthetic, composite or hybrid sunflower variety.

To identify the crosses with desirable characters, specific combining ability is one of the important genetic components in breeding program (Acquaah, 2007). Negative SCA effects of days to 50 flowering and maturity is the indication of early maturity which perhaps

Table 5. Crosses with maximum SCA effects, their mean performance and GCA effects of the parents.

Character	Desirable crosses	SCA effects	Mean	GCA effects	
				Female parent	Male parent
DF	P1 × P3	-3.2778[**]	65.33	High	Average
	P1 × P8	-2.7778[**]	67	High	Low
	P1 × P5	-2.5444[**]	66.33	High	Low
	P1 × P2	-2.4778[**]	65.66	High	High
	P3× P7	-1.8778[**]	68.33	Average	Low
DM	P7 × P8	-3.237[**]	102.33	Average	Low
	P1 × P4	-3.070[**]	99	High	Low
	P2 × P4	-2.970[**]	101.66	Average	Low
	P1 × P8	-2.537[**]	100.33	High	Low
SD(CM)	P2 × P6	0.0417[*]	1.88	High	Low
	P1 × P6	0.0384[*]	1.75	Average	Low
	P5 × P6	0.0069[**]	1.55	Average	Low
HD(CM)	P6 × P8	0.092[*]	16.83	Low	High
SH	P1 × P6	0.348[**]	411.96	High	Low
	P2 × P5	0.247[*]	390.41	Low	Average
	P2 × P7	0.229[*]	453.2	Low	Average
YHG	P2 × P3	0.2256[**]	23.06	High	Low
	P6 × P8	0.2210[**]	34	Low	High
	P2 × P6	0.1865[**]	15.92	High	Low
	P1 × P5	0.1557[*]	19.96	High	Low
1000SWG	P3 × P5	0.060[**]	74.33	High	Low
	PI × P3	0.058[**]	71	Low	High
	P6 × P7	0.055[**]	77.66	High	Low
	P1 × P6	0.053[*]	71	Low	High
	P3 × P8	0.044[*]	73	High	Low

DF: Days To 50 flowering, DM: Days to maturity, SD: Stem diameter (cm), HD: head diameter (cm), SH: number of seeds/head, YH: seed yield/head (g) and SW: 1000 seed weight (g). * and **Significance at p=0.05 and p=0.01, respectively and ns=non-significant.

results in timely vacation of land for next crop. In this study, out of 28 cross combinations, 7 and 4 cross showing significant but negative SCA effects for these characters, respectively. Therefore, these cross combinations could be used to develop early maturing sunflower hybrid. Similar results were also reported by Goksoy and Turan (2005); Gvozdenovic et al. (2005); Ortis et al. (2005) and Hladni et al. (2006).

The crosses with negative SCA effects of days to flowering and maturity would contribute favorable additive genes for earliness (Patil et al., 2017). In sunflower, stem diameter is an important lodging resistant trait, the greater the stem diameter the lesser chance of stem breakage. In this study, the cross combination (P1×P6, P2×P6, P5×P6, and P6×P8) with positive and significant

SCA effects for stem diameter could be used in developing hybrid with robust stem for reducing lodging tendency. High SCA effect for stem diameter was reported by previous researcher (Radhika et al., 2001; Jan et al., 2003). Yield is the ultimate objective of crop improvement program. In sunflower, the seed/head, yield/head and 1000 seed weight are important characters in determining the yield potential of this crop. From the present study among 28 crosses, three (P1×P6, P2×P5, and P2×P7), four (P1×P5, P2×P3, P2×P6 and P6×P8) and eight (P1×P3, P1×P4, P1×P5, P1×P6, P3×P5, P3×P8, P4×P7, and P6×P7) cross combination showed high positively significant SCA effects for these characters. Therefore, these cross combinations would be potential for developing high yielding sunflower hybrid.

For these characters, Jan et al. (2017) also reported positive and significant SCA effects in sunflower.

The significant desirable SCA effect in this study might be achieved due to the dominant and recessive allelic interaction of good or average and poor combining parents, respectively. Therefore, the crosses with significant SCA effect may be exploited for commercial purpose. Significant cross combination for yield attributing in sunflower involving parent with low, average or high combining ability were also documented in Ahmad et al. (2012); Jan et al., (2017) and Bhoite et al. (2018). In sunflower, many reports on combining ability were studied, however, in Bangladesh so far this is the first report on combining ability study on sunflower. Therefore, the crosses obtained in this study in desirable direction perhaps the indication of novel outcome of the research.

Conclusion

The current study focus that the evaluated parental materials possess enough genetic diversity which could be used in the future sunflower varietal development program. Inheritance of all the characters governed by additive gene effect was confirmed by the greater ratio of GCA than SCA. The parents with good general combining ability (P1, P2, P3, P6 and P8) in this study could be used to develop potential hybrid, synthetic and composite sunflower variety with higher commercial yield. Significant and negative SCA effects of the character days to 50 flowering and days to maturity found in seven (P1×P2, P1×P3, P1×P5, P1×P8, P6×P8 and P7×P8) and in four (P1×P4, P1×P8, P2×P4 and P7×P8) crosses, respectively. Three (P1×P6, P2×P5 and P2×P7) and five (P1×P5, P2×P3 P2×P6, P3×P7 and P6×P8) crosses showed positive and significant SCA effects for number of seeds per head and seed yield per head, respectively. Significant and positive SCA effect was also expressed for the character 1000-seed weight in eight (P1×P3, P1×P4, P1×P5, P1×P6, P3×P5, P3×P8, P4×P7 and P6×P7) crosses. In this study all desirable SCA effects were obtained by the interaction of dominant and recessive allele from a combination of low and low, low and high, high and low or high and average parents. The crosses with desirable SCA effects might be used to develop commercial sunflower hybrid.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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