Role of combining ability and heterosis in improving achene yield of *Helianthus annuus*: An overview

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Abstract: Sunflower is an important oil seed crop, used for the manufacturing of vegetable ghee and margarine. It can also be used as bird seed and animal feed. When sunflower seed integrated into soil it can recover the soil fertility because, it is a good source of calcium, nitrogen and potassium. Sunflower is highly cross pollinated crop and is ideally suited for heterosis and combining ability exploitation. In sunflower, heterosis breeding evolved successfully as the detection of cytoplasmic male sterility source. Combining ability analysis, heterosis and heritability, for various traits like days to 50% flowering, days to maturity, plant height, head diameter, number of whorls per head, number of sterile achenes per head, achene length, achene thickness, 100 achene weight, achene yield per plant, oil contents, protein contents, oleic acid, palmitic acid and linoleic acid has been evaluated by various sunflower breeders and researchers. The present review article will provide informations, which may be helpful in future breeding program for the improvement of achene yield and oil contents, and also leads towards the development of varieties and hybrids of sunflower with high achene yield and oil quality.

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Introduction

Fats and oils are the highest and the cheapest source of calories for humans therefore is a major constituent of daily diet but Pakistan is consistently deficient in its production. Local production of edible oil in Pakistan is not adequate to meet more than 30% of total domestic requirement, resultantly; the large quantity of edible oil is met through imports. Total availability of edible oil during 2010-11 was 1.7 million tones, whereas, the local production was 696 thousand tones which is 25% of the total availability and the remaining 75% was met through imports (Anonymous, 2010-11). Domestic production of edible oil can be increased by a) increasing the area under oilseed cultivation, b) increasing per acre seed yield of oilseeds and c) increasing seed oil contents and improving seed oil quality. The area of oilseeds cultivation in Pakistan which is 8230 thousand hectares (Anonymous, 2010-11) generally cannot be increased because of hard competition with major food/fodder crops. Currently seed yield per acre in Pakistan is not supporting farmers' community as cost/benefit ratio of oilseeds does not match with other food crops. It is a major domain of plant breeding where breeders can contribute by evolving high seed yield of oilseed crops varieties. Similarly breeders can also contribute increasing seed oil contents and oil quality. Sunflower oil is mostly free of toxic/anti-nutritional elements but breeders can enhance oil quality in oilseeds so that these oils could be freely used in the kitchen. Among the non-traditional oilseed crops, sunflower has shown the great potential under our agro-ecological environment. It is most important oilseed crop and is widely grown for edible oil in different countries of the world. Sunflower is a short duration crop (90-110 days) and can be grown profitably twice a year under irrigated as well as rainfed conditions. The cultivated sunflower scientifically is *Helianthus annuus* L. that belongs to family Asteraceae. It is a diploid specie (2n = 2x = 34) that belongs to the sub tribe Helianthinae, subfamily Asteroideae. The genus Helianthus includes 12 annual and 36 perennial species.

Sunflower in Pakistan is cultivated on 443.2 thousand hectares with the seed production of 643 thousand tones and oil production of 244 thousand tones (Anonymous, 2010-11). It is a rich source of edible oil that contains high oil contents (40-45%). From health point of view it is considered as good quality oil because it has high mono and polyunsaturated fatty acids viz., oleic and linoleic acids that comprises 90% of total fatty acids (Rai, 2002). The presence of soluble vitamins viz., A, D, E and K makes the oil of premium quality that is good for heart patient (Evertt *et al*. 1987; Shaker et al., 2015). Sunflower is used for the manufacturing of vegetable ghee and margarine. It can also be used as bird seed and animal feed. When sunflower seed integrated into soil it can recover the soil fertility because, it is a good source of calcium, nitrogen and potassium (Robert *et al*. 1993). Sunflower is highly cross pollinated crop and is ideally suited for heterosis exploitation. In sunflower, heterosis breeding evolved successfully as the detection of cytoplasmic male sterility source (Leclercq, 1969) and fertility restoration (Kinman, 1970) that gave the required vigor to commercial hybrid seed production. By the public and private sectors, most of the hybrids have been released for commercial cultivation. In heterosis breeding programme, the selection of inbreds with good combining ability is very important for superior hybrid production. The heterosis magnitude determined by the combining ability of inbreds. The estimation of general and specific combining ability helps to identify the potential parents in superior hybrid production for achene yield and oil contents. The line x tester analysis is an efficient method to assess the large number of inbreds and it provides the information on the relative importance of general and specific combining ability effects to understand the genetic basis of important plant characters viz., plant height, head diameter, stem diameter, achene weight, achene yield and oil contents etc. The general combining ability (GCA) of line means the average value of its performance in hybrids when crossed with other lines (Ali et al., 2013a,b; Ali et al. 2014a,b; Ahsan et al., 2013; Naseem et al., 2015a,b; Saeed et al. 2014). Various statistical approaches including additive and dominant gene action, genetic advance, broad sense and narrow sense heritability, genotypic and phenotypic correlation, regression and path coefficient provides an opportunity to plant breeder for selecting suitable breeding program for crop yield improvement (Fawad et al., 2015; Ali et al., 2014c,d;Khan et al., 2015; Sajjad et al., 2015; Naseer et al., 2015a,b; Waseem et al., 2014) . The specific combining ability (SCA) means the performance of individual hybrids (Fick and Miller, 1997).

Review of literature

Khan *et al*. (1993) concluded that the combination of ORI-8 with RHA-274 expressed high heterosis over both mid and better parents. Dedio (1993) reported heterosis for oil contents, karnal contents and karnal oil contents. Heterotic effect of 47g/kg for achene oil contents, 44g/kg for karnal oil contents and 24g/kg for karnal contents were observed. Javed and Aslam (1995) found that the line CMS-HA-89 was the best general combiner for seed yield, oil content and 100 achene weight. The restorer RHA-271 was a good general combiner and the combination CMS-HA-277 × RHA-271 was the best specific combiner for seed yield. Khurana *et al*. (1996) reported that the lines CMS-7-1A, EC-68415 bulk and EC-68415 were good combiners for seed yield. Female lines CMS-234 A and CMS-207A and male line EC-68415 showed good general combining ability effects for earliness. The combination CMS-7-1A × EC-6815 was the best for seed yield and specific combining ability effects among the hybrids. Bajaj *et al.* (1997) reported the significance of additive genetic effects in the inheritance of days to maturity, plant height, and 100 achene weight and oil contents. They observed that female parents CMS-234A, CMS-2073A and CMS-10A and male parents RHA- 856, P-13R, P184-R14 were the best general combiners for different yield related traits. Gangappa *et al.* (1997) reported that the parental lines RHA-99 RTNBr, RHA-284, RHA-299 and CMS-302 have genes for earliness. The combination CMS-852 × RHA-99 RTNBR was the best for days to 50 per cent flowering. The female lines CMS-207 and CMS-852 and male lines RHA-6D-5-3-6 and RHA-21Br transmitted genes for higher seed yield. Combinations CMS-302 × RHA-273 and CMS-234 × RHA-284 were the best specific combiners for seed yield and oil content respectively.

Kandalkar (1997) reported that seed yield was governed by both additive and non-additive genetic effects. The male line Morden was good general combiner for achene yield and the combinations Sun IB6 × Morden and Sun IB1 × Surya had significant specific combining ability effects. Shekar *et al.* (1998) reported that the combination CMS-335A x RHA-274 produced early flowering hybrids and the line CMS 234A produced late flowering hybrids with the same restorer line. The combination CMS 234A × RHA 83 was better in average than checks in both achene yield and oil yield. Singh *et al.* (1999) reported the predominance of non-additive genetic effects for achene yield, oil content, palmitic acid, stearic acid and linoleic acid in a line × tester analysis of 30 hybrids. The CMS-234A and inbred line 187-333 were good general combiners for both seed yield and oil content. The combination 86A3 × 68-3 was the best for seed yield and oil contents.

Naik *et al.* (1999) found the predominance of dominant genetic effects in the inheritance of days to 50 percent flowering, number of leaves per plant, achene yield per plant and harvest index, whereas the predominance of over dominant effects for plant height, leaf area index, head diameter, 100 achene weight and oil contents. Ansaril *et al*. (1999) found that the appearance of negative heterosis was more frequent than positive heterosis and heterobeltiosis for most of the combinations. The significant and positive heterosis for head diameter followed by achene yield and plant height was the highest. The combinations CMS-232 x RHA-229 and HO-1A x RHP-44 may be included in future breeding program of sunflower. Ashok *et al.* (2000) reported predominance of additive genetic effects for the inheritance of all the traits studied except 100 achene weight and oil contents. The parents 338A, 62A, RHA-855, RHA-273 and RHA-299 were found good general combiners and the combinations 338A × RHA-296 and 338A × RHA-855 were found the best for heterosis and specific combining ability. Jayalakshmi *et al*. (2001) reported that the inbred lines RGP240, RGP18-4, RGP307, RGP81-1, RGP515-3 and RGP257 had high oil contents and oil yield. They also reported that these inbred lines may be utilized for heterosis breeding by developing cytoplasmic genetic male sterile and restore lines after estimating the combining ability. Singh *et al.* (2002) reported heterosis of 30.08 percent over better parent for oil content, 13.17 percent for palmitic acid, 8.94 percent for stearic acid, 77.42 percent for oleic acid and 278.01 percent for achene yield whereas not any of the combination was found superior than better parent for linoleic acid, as the oleic acid increasing the linoleic acid was decreases.

Khan *et al.* (2003) reported the significant genetic differences among the hybrids for plant height, number of leaves per plant, head diameter, number of achenes per plant, number of achenes per head and achene yield per hectares. The combination TS-4 x TR-11 showed heterosis for plant height, head diameter and oil contents and the combinations TS-4 x TR-11, TS-17 x TR-120 and TS-18 x TR-120 were the best hybrids for future breeding. Devindra and Singh (2003) reported that the female x male interactions were significant for all the traits studied except achene weight. The variance of specific combining ability was high with respect to the variance of general combining ability that showed the dominance of non-additive genetic effects for days to maturity, days to 50 percent flowering, plant height, head diameter, number of leaves per plant, number of achenes per plant, achene weight, achene yield per plant and oil contents. Sharma *et al.* (2003) reported the importance of additive genetic effects in the inheritance of head diameter, achene yield per plant and oil contents. A significant female × male × environment interaction for general and specific combining ability was observed for all traits studied excluding oil contents. The female lines CMS-44B and CMS-10B and the male lines IL-IP 234, IL-IP-238 and IL-M-197 were found to be the best general combiners. Farrokhi (2003) reported that the restorer lines R-43, R-72, R-82, R-217, R-231, R-256, R-103, R-87, R-55, R-45 and R-46 had high general combining ability values for achene yield and oil contents. He reported that both additive and non additive effects were involved in the evaluation of the genetic effects for plant height, growth duration, head diameter, 1000 achene weight, achene yield and oil contents.

Kaya and Atakisi (2004) evaluated 25 sunflower hybrids at three locations for combining ability and reported that the combination 2453-a × R-1001 was the best for plant height, 1000-achene weight, days to flowering, days to physiological maturity, head diameter and hectoliter weight.. Parameshwari *et al.* (2004) reported the dominance of non-additve genetic effects for days to 50 percent flowering, plant height, head diameter, 100 achene weight and oil contents. They also observed that none of the female and male lines had good combining ability for achene yield. Seneviratne (2004) reported a wide range of variability for most of the characters viz., plant height, days to maturity, head diameter, number of filled achenes, achene yield, number of unfilled achenes and oil contents. He observed the positive selection differential for plant height, head diameter, achene yield and oil yield whereas the days to maturity and oil contents had negative selection differential values. Achene yield and oil yield had high values of phenotypic and genotypic covariance and plant height, head diameter, 100 achene weight and oil contents had moderate values. Achene yield, 100 achene weight, days to 50% flowering, days to maturity, plant height, head diameter and oil yield had high heritability. High genetic advance was also observed for head diameter and oil yield.

Khan *et al*. (2004) reported highly significant genetic differences for head weight, achene weight per head, 1000 achene weight and harvest index among the inbred lines and hybrids, whereas non significant genetic differences for filled achene weight per head were observed. The combinations TS-17 x TR-120 and TS-18 x TR-120 showed the highest levels of heterosis for head weight per plant (184 and 183% respectively), achene weight per head (322.3 and 292.7% respectively), filled achene weight per head (302.7 and 295.5% respectively) and the combination TS-4 x TR-11 showed the maximum heterosis for 1000 achene weight (104.6%) and harvest index (128.6%). Gatto *et al*. (2005) reported significant general combining ability variance for achene yield, oil yield, plant height and 1000 achene weight. The CMS226 showed positive general combining ability effects and OL9 negative general combining ability effects for all traits. Non significant general combining ability effects for oil content and oil yield were observed for plant height and 1000 achene weight. The positive and negative values were observed in restorer (RHA) population. Kaya (2005) found that the combination 2453-A x 2644-R was the best for combining ability analysis of achene yield, oil yield, oil contents and hull to seed ratio. Female lines 2453-A, 0704, HA89 and BAH-8-A and male lines R-1001 and 2644-R have high oil contents and achene yield. The restorer lines 2644-R and 2280-R had high oil percentage Masood *et al*. (2005) observed heterosis for traits viz., head size, achene yield per plant, number of achenes per plant, 100 achene weight, achene yield and oil contents. The highest heterosis was observed for head size (32.88%) and for achene yield (1.29%). Significant parental effects were observed for achene yield, number of achenes per plant and oil contents and non significant effects were observed for head size, achene yield per plant and 100 achene weight. High heterosis was observed for all the traits except head size and number of achenes in those combinations where parents were phenotypically different. Uttam *et al.* (2005) reported that the combinations CMS 338A × RHA 265 and CMS 91A × RHA 271 had high heterosis for earliness and achene yield per plant.

Devi *et al*. (2005) reported that achene yield and its components were predominantly governed by non additive genetic effects and the combinations 9AK x 21R, 10A x 21R and 8A x 22R had the highest heterosis and specific combining ability effects. Most of the heterotic combinations involved parents with low x low and high x low general combining ability effects. Ahmad *et al*. (2005) reported highly significant heterosis in F_1 hybrids ranging from 102 – 309% and 46.3 – 163.9% for achene yield and leaf area respectively. Leaves per plant showed low level of heterosis in F_1 hybrids. The parent RHA- 822 was found to be the best general combiners. Jan *et al*. (2005a) reported that the general combining ability, specific combining ability and reciprocal effects were significant for all traits studied excluding days to maturity. The specific combining ability effects had higher magnitude than that of general combining ability effects that showed the contribution of non additive genetic effects. GCA: SCA ratio also showed the dominance of non additive genetic effects for achene yield, ARI and GUL were the best combiners.

Jan *et al.* (2005b) reported that the general combining ability, specific combining ability and reciprocal effects were significant for all traits studied, but the reciprocal effects were non-significant for days to maturity. The specific combining ability effects had higher magnitude with non additive genetic effects than that of general combining ability effects. The GCA: SCA ratio also showed the dominance of non additive genetic effects. For all traits studied, the inbred lines TF-11, ARI and TF-4 were good general combiner. ARI and GUL were the best combiners for achene yield. The combination TF-335 x ARI showed early days to 50% flowering and maturity. Additive and non additive variances were involved in the expression of physiological traits. Jan *et al.* (2005c) reported that heterosis magnitude of F_1 over mid parent was 1.29% and 3.73% for achene yield in direct and reciprocal crosses respectively and for oil contents 31.19 and 5.71% in direct and reciprocal crosses respectively was observed. More heterosis was found in hybrid combinations where parents were different. Habib *et al*. (2006) reported that the combinations ORI-3 x RL-84, ORI-29 x RL-84 and ORI-3 x RL-77 had the highest increase over mid and better parent for 100 achene weight and head diameter. Hladni *et al*. (2006) reported that the hybrids NS-GS-4 and NS-GS-5 had highly significant positive and negative general combining ability values for oil contents. The combination NS-GS-6 x RHA-R-PL-211 had a highly significant positive specific combining ability values for oil contents. Mijic *et al*. (2006) reported that the combinations 5A x 302B and 101A x 103B were the best for 1000 achene weight. Lines L-5 and L 103 were good general combiners for 1000 achene weight. Both additive and dominant variances were obtained for 1000 achene weight.

Habib *et al.* (2007) reported that the combination ORI-6 x RL-69 and ORI-6 x RL-77 had the highest heterosis and heterobeltiosis for days to flower initiation. The combination ORI-20 x RL-77 showed the highest increases over mid and better parent for flowering period. The combination ORI-20 x RL-77 showed the highest positive heterosis and heterobeltiosis values for plant height and the combination ORI-3 x RL-77 showed the highest positive heterosis over mid and better parent for achene yield. Shankar *et al*. (2007) reported that for most of the traits viz., seed yield, oil yield, early maturity, head diameter, stem diameter, number of filled seeds per head, seed filling percentage and 100 seed weight the combination PF-400A × P-356R was the most promising. ARM243B was good general combiner for achene yield, oil yield, oil contents, head diameter, number of filled seeds per head and 100 seed weight, and R272-1 and R-17 were good male parents for achene yield and oil yield. Khan *et al.* (2008a) observed high heritability for 1000 achene weight, number of achenes per head, oil contents and achene yield at two locations. The combinations TS-335 x TR-5, TS-11 x TR-3, TS-11 x TR-6023 and TS-4 x TR-5 were recommended for commercial and further use in plant breeding programs. Khan *et al*. (2008b) reported that the combinations TS-4 × TR-5, TS-11 × TR-3, TS-11 x TR-6023 and TS-335 x TR-5 had greater specific combining ability effects for achene yield. They found that the specific combining ability effects had higher magnitude than the general combining ability effects. Predominance of non-additive genetic effects was also shown by GCA: SCA ratio. Mijic *et al*. (2008) reported that OS-1 × OS-6B combination had the highest specific combining ability effects for grain yield, oil yield and oil contents and OS-1 line has the highest general combining ability effects for grain yield and oil contents. The additive and genetic variance for all traits was greater than dominant and environmental variance respectively. Sawargaonkar and Ghodke (2008) reported that the combinations J/6 × NDR-1, 6D-1R × DMLT-1Y, NDR-1 × LR-451 and 6D-IR × DMLT-1Y had the best general combining ability effects and high mean performance respectively for seed yield per plant, oil contents, 100-achene weight and head diameter. Tavade *et al*. (2009) found that ID-3/147 R was the best general combiner for seed yield per plant and oil contents. The combinations 298R × ID-3/147 and 274R × BC-3-IR were the best for seed yield and oil contents respectively. Karasu *et al*. (2010) found that the non-additive effects were the most effective than other type of polygenetic effects. The gene action was changed across the years, for example additive gene action was significant for number of achenes per head and 1000-achene weight in one year but not in the second. All the hybrids showed positive significant hetrobeltiosis for seed yield and general and specific combining ability ratio was greater than 1. Aslam *et al*. (2010) reported that the combination 291RGI x TS-335 had the highest negative heterotic effects and the combination TS-18 x R-25 had positive heterosis for C18:2 and negative heterosis for C 20:0. They concluded that the mid and high parent heterotic effects improve oil quality and was suggested to use in sunflower breeding programs. Ghaffari *et al.* (2011) observed significant differences among the hybrids for all traits studied excluding head diameter, the variance of cytoplasmic male sterile lines was greater than restorer lines that showed the possible existence of some maternal effects on achene yield and oil yield. Life cycle duration, 100 achene weight, number of achenes per head and achene yield were under the control of both additive and dominant effects. However the plant height and oil contents were controlled by additive effects, life cycle duration and achene yield were controlled by dominant effects and plant height was controlled by complete dominant effects. The combination R23 × CMS78 was identified as superior in early maturity with high oil contents and achene yield. Restorer line R21 and cytoplasmic male sterile line CMS356 had greater and stronger effect on their hybrids. Nasreen *et al*. (2011) observed the highest genetic distance and the existence of maximum genetic variability in CMS-HARI-1 x RHA- 854 and CMS-64 x C-206R combinations for achene yield and its components, this study could be used in varietal improvement programs through heterosis breeding. Nooryazdan *et al*. (2011) reported additive genetic effects for days to 50 percent flowering, branching and plant height. The positive correlation between general combining ability and *per se* performance of genotypes was observed for all traits studied excluding achene yield and oil contents.

Machikowa *et al*. (2011) reported general and specific combining ability for achene yield, head diameter, 1000 achene weight, plant height and oil contents. They observed that general combining ability was highly significant for 1000 achene weight and plant height. The general combining ability variance for achene yield, head diameter and oil content was higher than that of specific combining ability. The additive genetic effect for these traits was more important than non additive effect. The inbred line 5A showed the highest general combining ability effects for achene yield and oil contents and the combination 5A x 2A showed higher positive specific combining ability effects for 1000 achene weight and oil contents.

Hladni *et al*. (2011) reported significant differences for general combining ability and specific combining ability for number of achenes per head and 100 achene weights. A line NS-GS-5 showed highly significant positive general combining ability value and the combination NS-GS-5 x RHA-R-PL-2/1 showed highly significant specific combining ability value. GCA: SCA ratio showed the inheritance of non additive genetic variance. A line showed significant results for 100 achene weight and Rf tester showed significant results for number of achenes per head. A very strong inter dependence was obtained between achene yield and number of achenes per head and between achene yield and 100 achene weight. Andarkhor (2012) reported that male lines RF81-25 and RF81-30 had significant positive general combining ability effects for achene yield and 1000 achene weight respectively. The RF-13/1 had significant negative general combining ability effects for plant height. The combinations AF80-460/2/1/1 x RF81-25 and AF8-6937 x RF81-30 had significant positive specific combining ability effects for achene yield. Ramzan et al., (2015) found higher heritability and strong correlation among the achene and its attributing traits. Mumtaz et al., (2015) reported higher additive effect for grain and quality traits of brassica. Kanwal et al., (2015) found that plant height and 100 achene weight had positive and significant SCA effects for cross combination A-18 × G-79. The additive variances (σ^2A) was more for plant height, head diameter, 100 achene weight and achene yield per plant as compared to dominance variances (σ^2D) and high heritability was found in these traits. Heterosis and heterobiltosis of plant height, 100-acehne weight and achene yield/plant were found the most significant ($p^* < 0.01$) for cross combination A-18 × G-79. The present study results demonstrated that A-18 × G-79 hybrid has potential to obtain high yielding genotypes in arid/semiarid regions.

Conclusions

The achene yield of sunflower may be improved through the development of sunflower hybrids, through the use of combining ability and heterosis breeding program.

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