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Combining ability analysis of early maturing maize (*zea mays.L*) inbred lines in central rift valley of Ethiopia

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Abstract- The current study was conducted using 105 hybrids resulted from diallel crosses of 15 early maturing maize inbred lines crossed in diallel mating system (Griffing's Method IV, Model I) along with three standard checks evaluated using Alpha-Lattice Design with two replications during the 2011 main cropping season at Melkassa Agricultural Research Center. The objective of the study was to determine combining ability of elite early maturing maize inbred lines for grain yield and yield related traits. ANOVA showed that mean squares due to entries were highly significant for all studied traits except anthesis-silking interval, ears per plant and number of rows per ear, which indicates the existence of sufficient genetic variability and potential for selection and improvement of the traits. The mean squares due to general combining ability (GCA) were significant for all the traits whereas mean squares due to specific combining ability (SCA) were significant only for grain yield, days to anthesis, days to silking and plant height. Both or either parents, P12 and P15 showed positive and significant GCA effects for grain yield, ear length, ear diameter, number of kernel rows per ear and number of rows per ear, and were good general combiners for the mentioned traits. Moreover, most hybrids with good SCA effects for grain yield contain these lines as one of their parents. Parents, P2 and P5 showed negative and significant GCA effects for days to anthesis, days to silking, plant height and ear height. Further research should be conducted over years and locations to identify an early maturing variety.

Index Terms- maize, combining ability, early maturity, inbred lines.

I. Introduction

Maize is one of the most important crops in the world and eastern and southern Africa. It is used as a human food, livestock feed, different alcoholic and non alcohol drinks, building material, and as fuel. It is also used to produce medicinal products such as glucose as well as an ornamental plant (Osborne and Beerling, 2006).

In the country, during the 2011/12 cropping season, 2.1 million hectares of land was covered with maize with an estimated production of about 6.1 tons (CSA, 2012). However, the national average yields 2.9 tons/ha (CSA, 2012) is still far below the world average 5.1 tons/ha, (FAOSTAT, 2011). Such low grain yield of maize is attributable to several production constraints, which include lack of improved varieties for different agro-ecological regions, diseases and insect pests, moisture stress, poor cultural practices, excessive plant height, drought and low soil fertility (Pswarayi and Vivek, 2007).

Furthermore advancement in yield of maize requires continuous development and release of higher yielding and well adapted varieties having better advantage over the existing commercial varieties. To achieve this, information regarding the nature of combining ability of a wide array of available inbred lines to be used in the hybridization program and gene actions is imperative.

Systematic mating methods such as diallel design Griffing (1956) can helps to achieve this goal and easily provide information about GCA and SCA effects of parents involved in the crosses, grouping of materials into different heterotic patterns and also to estimate the type of gene action involved in the expression of yield and yield related traits.

In Ethiopia, combining ability studies using diallel crosses of maize inbred lines were conducted by several researchers. Among researchers, Dagne (2008), Yoseph (1998) and Shewangizaw (1983) reported significant GCA and SCA for most characters of maize inbred line crosses. However, very limited research efforts have been made so far on the combining ability of inbred lines adapted to drought stress areas of Ethiopia, and no work has been done at all on identification of testers for this ecology.

Therefore, the current study is designed with the following objectives. Studying the combining ability of elite early maturing maize inbred lines for grain yield and yield related traits. Determining general and specific combining ability among early maturing maize inbred lines.

II. MATERIALS AND METHODS

The experiment was conducted in 2011 main cropping season at the Melkassa Agricultural Research Centre (MARC) of the Ethiopian Institute of Agricultural Research (EIAR). The experimental materials consisted of a total of 108 entries which comprised of 105 single crosses developed from 15 x 15 diallel crosses (excluding the reciprocal crosses and parental inbred lines), two standard checks namely; (Melkassa-2 and BH-543) and one pre-release candidate hybrid (MH130). The experiment was laid out in 9 x 12 Alpha-Lattice Designs (Patterson and Williams, 1976) with two replications. The plots were over sown with two seeds per hill which later thinned to one every 25 cm in two rows of 4.25 m length spaced 75 cm apart, with net plot area of 3.19 m^2.

Data were recorded either on plot basis or from five plants or ears randomly taken from the rows of each plot. Data Collected on plot basis and using random sample of 5 plants or ears from each plot. Genotypes were considered as fixed effects while replications and blocks within replications were considered as random effects. Further analyses were carried out for traits that showed statistically significant differences among the hybrids to estimate combining ability using modification of the DIALLEL-SAS program (Zhang and Kang, 1997). The checks were excluded from the analysis during the combining ability analysis. Griffing (1956) Method IVand Model I (fixed) diallel analysis, which involves F_1 hybrids only was used to estimate components of variance due to general combining ability (GCA) and specific combining ability (SCA).

III. RESULTS AND DISCUSSION

Mean squares due to entries were significant (P<0.01) for all traits except for anthesis-silking interval, ears per plant and number of kernel rows per ear (Table 1). Further partitioning of the sum of squares due to entries into that of hybrids, checks and hybrids versus checks indicated that mean squares due to hybrids were either highly significant or significant for all traits studied except for anthesis-silking interval, ears per plant and number of kernels per ear. In line with current study, Bullo (2010) found significant mean squares due crosses for grain yield and ear diameter while highly significant mean squares due to crosses for days to silking, days to anthesis, plant height, ear height, ear length, number of kernel per row, days to maturity and thousand kernel weight. Checks showed non-significant effects for all traits studied except for days to anthesis and days to silking. Significant differences (P<0.01 or P<0.05) were observed for hybrids versus checks for grain yield, days to anthesis, days to silking, plant height and days to maturity (Table1).

Table 1: Mean squares for grain yield and yield related traits in 15 x 15 diallel crosses of early maturing maize inbred lines and three standard checks evaluated at Melkassa in 2011.

Genotype	df	GY	DA	DS	ASI	PH	EH	EPP	CR
Replication	1	0.11	2.24	0.38	0.78	310.56	66.67	0.07	0.09
Incomplete Blocks (rep)	22	1.09	3.6	4.07	0.54	294.87	156.87	0.02	0.1
Entry	107	1.67**	32.97**	30.78**	0.58	533.34**	262.81**	0.02	0.31**
Hybrids	104	1.54**	27.82**	26.09**	0.58	501.63**	256.68**	0.02	0.30**
Checks	2	0.82	90.50**	85.17**	0.17	929.17	429.17	0.01	0.01
Hybrids vs Check	1	16.89*	453.51**	409.76**	1.4	3039.86*	567.61	0.04	0.88
Error	**85**	0.48	2.07	2.16	0.56	97.21	113.03	0.02	0.08
Grand mean		5.11	63.28	64.96	1.68	200.93	70	1.08	2.41
Minimum		1.31	55.5	56.5	0.59	155	45	0.79	1.5
Maximum		8.05	80	81	3	247.5	102.5	1.47	4
LSD (5%)		1.38	2.86	2.92	1.49	19.6	21.14	0.31	0.56
F-test		**	**	**	Ns	**	**	Ns	**
SE (m)		0.7	1.44	1.47	0.75	9.86	10.63	0.16	0.28
R-square		0.84	0.96	0.95	0.59	0.9	0.78	0.56	0.85
CV (%)		13.61	2.27	2.26	44.67	4.91	15.19	14.6	1.5

Normally Melkassa-2 is expected to be earlier as the variety was released for drought prone areas because of its earliness. Such early types of varieties are appropriate in area with short rainy season so as to escape moisture stress encountering during grain filling stage or late in the season. Anthesis-silking interval ranged from 0.59 to 3.00 with a mean of 1.68. The highest anthesis-silking interval of 3.0 days was recorded for the hybrids P1X x P5, P3 x P5 and P5 x P12 whereas P1 x P3 (0.5) had the lowest value of anthesis-silking interval (table 1). Hybrids with the longer anthesis-silking interval are undesirable for grain yield production as the male and female parents do not synchronize well. On the other hand, materials with shorter anthesis-silking interval are suitable for grain production as the male and female flowers of such materials nick perfectly.

Table 1: *Continued …*

Genotype	Df	DM	EL	ED	KPR	RPE	KPE	TKW
Replication	1	163.63	35.85	0.01	57.04	0.02	12911.57	13247.26
Incomplete Block (rep)	22	7.82	3.08	5.91	13.68	1.29	2619.56	1058.48
Entry	107	20.31**	5.04**	18.71**	26.85**	4.15	9788.34**	2533.6**
Hybrids	104	18.33**	4.80**	18.30**	27.33*	4.22*	9903.41	2455.3**
Checks	2	31.50	6.5	37.67	1.17	0.67	882.00	4856.6
Hybrids vs Checks	1	203.85*	27.08	23.43	28.29	3.83	15633.74	6035.00
Error	85	8.88	2.80	11.08	17.16	2.84	7297.70	625.89
Grand mean		108.50	15.94	45.18	33.93	12.94	439.49	272.68
Minimum		91.50	12.50	39.00	22.50	10.00	270.00	168.20
Maximum		119.50	20.50	56.52	42.00	17.00	679.00	360.10
LSD (5%)		5.92	3.33	6.62	8.24	3.35	169.85	49.74
F-test		**	**	**	*	*	Ns	**
SE (m)		2.98	1.67	3.33	4.14	1.69	85.45	25.02
R-square		0.78	0.74	0.70	0.70	0.66	0.65	0.86
CV (%)		2.75	11.20	7.37	12.21	13.03	19.44	9.17

*P<0.05, **P<0.01, ASI=anthesis-silking interval, CR= common rust, DA=days to anthesis, DM=days to maturity, DS=days to silking, ED=ear diameter (cm), EH=ear height (cm), EL=ear length (cm), EPP=number of ear per plant, GY=grain yield (t ha-^{1}), KPE=number of kernel per ears, KPR=number of kernel per row, PH=plant height (cm), RPE=number of kernel rows per ears, and TKW=thousand kernel weight (g).

For all the entries, plant height was in the range of 155 cm (P4 x P8) to 247.5cm (P7 x P15) with the mean value of 201.25 cm. In the current study, most of the hybrids (67%) had shorter plant height than the shortest check (MH 130). Short maize varieties are desirable since they have good potential for lodging resistance. Ear height ranged from 45 (P1 x P6) to 102.5 (P6 x P15), with average of 73.75 cm (table 1).

3.1. Yield and yield components

Among all the entries grain yield ranged from the lowest as low as 1.31 t/ha (P4 x P8) to as high as 8.05 t/ha (P7 x P15) with a mean of 5.11 t/ha. Hybrids, P7 x P15 (8.05 t/ha), P12 x P15 (7.92 t/ha) and P3 x P15 (6.84 t/ha) showed higher grain yields in that order. More than 47% of the 105 F_1s yield higher than the grand mean (5.11 t/ha) and the two high-yielding hybrids (P7 x P15 and - P12 x P15) out yielded the best check (CML440/ CML445 / ZIMLINEK ATBCI-24 ♯) or MH 130 (7.34 t/ha) by 10% and 8% respectively (Table 1). Birhanu (2009) found the highest grain yield of 14.07 t/ha and the lowest grain yield of 4.90 t/ha in test crosses of maize inbred lines evaluated at Bako, Hawassa and Jimma Research Centers.

Thousand kernel weight ranged from 168.20g (P4 x P8) to 360.10g (P2 x P13). Number of ears per plant ranged from 0.79 (P4 x P8) to 1.47 (P11 x P12. Ear length ranged from 12.5cm (P4 x P10) to 20cm (P4 x P15).Hybrids with longer ear length indicated that they have inherent genetic potential for longer ear length. Similarly, ear diameter ranged from 39.0 mm (P4 x P8) to 56.52 (P1 x P5). Hybrids with wide ear diameter indicated that they have inherent genetic potential for wider ear diameter. Number of kernel rows per ear varied from 10 (P5 x P6, P6 x P9, P6 x P10, P6 x P13 and P11 x P14) to 17 (P7 x P12). The range of number of kernels per row varied from 22.50 (P2 x P5) to 42.00 (P4 x P15). Mean number of kernel per ear was 439.49 with a range of 270.00 to 679.00 (table 1).

3.2. Combining Ability Estimates

General combining ability (GCA) and specific combining ability (SCA) mean squares were significant at (P<0.05 or P<0.01) for grain yield, days to anthesis, days to silking, and plant height (Table 2). These suggest the importance of both GCA and SCA effects in determining the inheritance of these traits. General combining ability mean squares were significant for all traits except number of kernel rows per ear. The ratio of GCA variance to SCA variance showed that days to anthesis, days to silking, plant height, ear height, days to maturity and thousand kernel weight are more than a unity so additive gene action is important for controlling these traits.

Similarly, several workers reported the importance of both additive and non-additive gene actions in determining the inheritance of grain yield. Vasal *et al.* (1993a), Mandefro (1998), Jemal (1999), Leta *et al*. (1999), Habtamu (2000), Dagne (2002), Bayisa *et al*. (2008), Glover *et al*. (2005), Dagne *et al*. (2007, 2008), Birhanu (2009) and Bello and Olaoye (2009) found the importance of both additive and non-additive gene actions in controlling grain yield. In addition, Dagne *et al* (2010) found significant differences for SCA mean squares for grain yield, days to anthesis and plant height in the study made with a factorial cross among six locally developed lines and seven CIMMYT inbred lines which confirms with the current study.

Table 2: Mean squares due to general and specific combining ability for grain yield and related traits evaluated at Melkassa, 2011.

Traits	SGCA	SSCA	GCA (df 14)	SCA (df 90)	Error (df 85)	(GCA/SCA)	E (M.S.) GCA	E (M.S.) SCA
GY	69.58	109.8	4.97**	1.22**	0.24	0.30	0.29	0.98
DA	2784.04	550.8	198.86**	6.12**	1.04	2.92	14.83	5.08
DS	2568.58	540.0	183.47**	6.00**	1.08	2.77	13.65	4.92
PH	42824.88	16677.9	3058.92**	185.31**	48.61	1.62	221.05	136.70
EH	17128.58	12240.9	1223.47*	136.01	56.52	1.05	83.65	79.49
DM	1114.96	935.1	79.64*	10.39	4.44	0.90	5.33	5.95
EL	204.40	308.7	14.60*	3.43	1.40	0.42	0.86	2.03
ED	840.84	1155.6	60.06*	12.84	5.54	0.50	3.63	7.30
KPR	1288.00	1713.6	92.00	19.04	8.58	0.54	5.61	10.46
RPE	200.34	235.8	14.31*	2.62	1.42	0.75	0.90	1.20
TKW	202753.46	73409.4	14482.39*	815.66	312.95	2.09	1051.29	502.71

*$p \leq 0.05$; **$p \leq 0.01$; DA=days to anthesis, DM=days to maturity, DS=days to silking, ED=ear diameter (mm), EH=ear height (cm), EL=ear length (cm), GY=grain yield(t ha^{-1}), KPE=number of kernel per ear, KPR=number of kernel per row, PH=plant height (cm), , RPE=number of kernel rows per ears, and TKW=thousand kernel weight (g), E. (M.S) =expected mean squares, SGCA= sum of square due to general combining ability, SSCA= sum of square due to specific combining ability, GCA/SCA = ratio of GCA variance to SCA variance.

3.3. Estimates of general combining ability (GCA) effects

Estimates of GCA effects of each of the parental inbred lines for various traits with their respective standard errors are presented in (Table 3). The results were presented and discussed for each trait as follows. Hybrids evaluated in this study manifested considerable variation in general combining ability effects in all studied yield and yield related traits, which is in line with the study of Dagne (2008).

3.3.1. Phenology and growth parameters

Days to anthesis

General combining ability effects for days to anthesis were positive and highly significant for parents; P4, P8, P9, P14 and P15, indicating that these lines had tendency for lateness in their hybrid progenies. On the other hand, in bred lines P1, P5, P6, P10, P11and P12, exhibited negative and highly significant GCA effects for the trait and were found to be the most suitable parents for earlier anthesis (table 3).

Days to silking

Positive and highly significant GCA effects for days to silking were observed for parents, P4, P8, P9, P14 and P15. In contrast negative and highly significant GCA effects were obtained for parents, P1, P5, P6, P10 and P11. Days to silking follow the same trends with days to anthesis, in which parents with positive and significant GCA effects are considered as poor general combiners while those with negative and significant GCA effects are considered good general combiners in breeding for early maturing variety for short rainy season and dry areas (table 3).

Plant height

Parents, P2, P4, P5 and P10 showed negative and highly significant GCA effects for plant height and were the best general combiner and the most suitable parent in breeding for short plant stature. On the other hand, parents, P9, P13 and P15 exhibited positive and highly significant GCA effects for plant height and were poor combiners as they showed the tendency to increase plant height, which causes susceptibility to lodging (table 3).

Ear height

Parental lines, P1 and P5 exhibited negative and highly significant GCA effects, indicating these lines were good general combiners whereas P9, P14 and P15 showed positive and significant GCA effects, indicating poor general combining ability of the lines for the trait under study (table 3).

Days to maturity

GCA effect for days to maturity was negative and highly significant only for parental line- P4, indicating that this line was the earliest maturing parent. In contrary parents, P9, P14 and P15 exhibited positive and highly significant GCA effects for days to maturity- showing the tendency of these parents to enhance lateness (table 3).

3.3.2. Grain yield and yield components

Grain yield

Among all the parental inbred lines, positive and highly significant GCA effects for grain yield were exhibited by P12 and P15, indicating that these parents were good general combiners for grain yield. On the other hand, P4 and P5 showed negative and highly significant GCA effects for grain yield while P8 exhibited negative and significant GCA effects, indicating that these lines were poor general combiners for grain yield.

Hybrids showed higher grain yield in the current study contain inbred lines P12 and P15 as one parent while the lowest mean grain yield was obtained by hybrids having parent 4 as one parent (Table 3). This study result indicated that P12 and P15 were the best general combiners for grain yield; the lines could be more effectively used in hybrid and synthetic variety development programs.

Ear diameter

Parental lines P1, P12 and P15 showed positive and highly significant GCA effects for ear diameter, indicating good general combining ability of the lines for the trait. On the other hand, negative and highly significant GCA effects for the trait were exhibited by parents P4, P6 and P9, indicating- poor general combining ability for the trait (table 3).

Number of kernel per row

Parents, P4, P13 and P15 had positive and negative GCA effects for number of kernel per row depicting good general combiner for the trait while parents P2, P5, P7 and P10 had negative and highly significant GCA effects indicating, that these lines had undesirable characters for number of kernel per row (table 3).

Number of rows per ear

Number of row per ears showed positive and highly significant GCA effects for parents P1, P7 and P12, indicating good general combining ability of these lines for the trait. On the other hand, parents P5, P6, P9 and P14 showed negative and highly significant GCA effects indicating, poor general combining ability for the trait (table 3).

Thousand kernel weight

Thousand kernel weight showed positive and highly significant GCA effects for parents P2, P5, P9, P10 and P14 and hence the lines were best general combiners whereas parental lines, P1, P4 and P7 showed negative and highly significant GCA effects, indicating that these lines were poor general combiners for thousand kernel weight. In the current study some of the parents were good general combiners while some others were poor general combiners for the traits studied. Even though, parents combining ability effect differ in any crossing programs, similar results were also reported by Vasal *et al*. (1993a, 1993b), Mandefro (1998) and Dagne (2002), Bullo (2010) who studied combining ability of maize inbred lines and populations for various traits (table 3).

3.4. Estimates of specific combining ability (SCA) effects

The estimate of specific combining ability effects (SCA) for the 105 different hybrids in respect of the traits studied are presented in (Table 4). Hybrids evaluated in this study manifested considerable variation in specific combining ability (SCA) effects in all studied yield and yield-related traits, which is in line with the study of Mandefro and Habtamu (2001) and Dagne (2002), Dagne (2008), Dagne (2010).

3.4.1. Phenology and growth parameters

Days to anthesis and silking

For days to anthesis and silking, hybrids P4 x P8, P9 x P14, P12 x P15, P5 x P15 and P1 x P10 manifested positive and highly significant SCA effects while P4 x P14, P10 x P12, P1 x P4 and P1 x P2 showed negative and highly significant SCA effects, indicating that crosses with high SCA effects had a tendency to enhance late maturity which is not desirable while crosses that had lower SCA exhibit a tendency to enhance early maturity (table 4).

Days to maturity

Hybrids, P2 x P4 showed negative and highly significant SCA effects for days to maturity followed by P8 x P14 and P13 x P15 which showed negative and significant SCA effects, indicating; early maturity of the hybrids (table 4). In line with current study, Pswarayi and Vivek (2007) reported that an earlier maturing variety, owing to its shorter life cycle, is predisposed to lower yield than a later maturing variety which has the opportunity to draw on nutrients and photosynthesize over a longer period.

Plant height

Hybrids, P3 x P7, P4 x P8, P4XP11 and P3 x P8, P4 x P10, P7 x P15 and P9 x P11 exhibited positive and significant SCA effects for plant height, which is undesirable as tallness contributes to susceptibility to lodging. On the other hand, hybrids P2 x P3 showed negative and significant SCA effects for the same trait, indicating the better specific combinations of this hybrid for plant height, which is desirable as short statured plants are mostly lodging tolerant (table 4).

Ear height

Hybrids P1 x P6, P2 x P15, P4 x P8 and P6 x P10 showed negative and highly significant SCA effects for ear height. Ear height for hybrids P1 x P3, P4 x P7, P6 x P12 and P9 x P11 showed positive and highly significant SCA effects. In contrast hybrids P3 x P6, P4 x P8, P5 x P7, P9 x P14, P12 x P14 and P13 x P15 showed negative and highly significant SCA effects (table 4).

3.4.2. Grain yield and yield components

Grain yield

In the current study, only about 10.48% of the hybrids manifested significant SCA effects for grain yield. Highest SCA effects for grain yield was recorded for P4 x P8 followed by P3 x P7 and P12 x P15, indicating that the hybrids were best specific combinations for higher grain yield. On the other hand, negative and significant SCA effects were exhibited by P9 x P14, P5 x P12 and P5 x P10, indicating they were poor specific combinations for grain yield.

The fact that hybrids P4 x P8 and P3 x P7 resulted from poor x poor inbred lines combinations (Table 4) showed that the hybrids performed better than what would be expected from the GCA effects of their respective parents. Therefore, the hybrids could be selected for their specific combining ability for grain yield improvement. When high yielding specific combinations are desired, especially in hybrid maize development, SCA effects could help in the selection of parental material for hybridization.

Ear length

Out of all the hybrids evaluated P4 x P6, P5 x P10 and P14 x P15 showed positive and highly significant SCA effects for ear length while P1 x P8, P3 x P6, P5 x P12 and P6 x P15 depicted negative and significant SCA effects indicating that these hybrids had poor specific combination for ear length.

Ear diameter

Hybrids P1 x P4, P1 x P5, P5 x P6, P7 x P13 and P8 x P12 showed positive and highly significant SCA effects followed by P2 x P7, P4 x P6 and P9 x P10 which showed positive and significant SCA effects for ear diameter, which is desirable for larger ear diameter whereas hybrids P5 x P12, P10 x P15 and P13 x P15 depicted negative and significant SCA effects (table 4).

Number of kernel per row

With respect to number of kernel per row, hybrids P3 x P11 and P8 x P13 showed positive and significant SCA effects indicating the tendency of the hybrids to enhance this trait. P11 x P12 showed negative and highly significant SCA effects whereas P2 x P5, P4 x P7 and P7 x P8 depicted negative and significant SCA effects, indicating; the tendency of the hybrids combinations to decrease the trait (table 4).

Number of rows per ear

Number of row per ears showed positive and highly significant SCA effects for hybrids P4 x P5 and P5 x P7 followed by hybrids P1 x P4, P1 x P5, P6 x P15 and P8 x P12 which showed positive and significant SCA effects indicating the tendency of the hybrids to enhance this traits. Hybrid P5 x P12 showed negative and significant SCA effects indicating the ability of the hybrid to decrease number of row per ear (table 4).

Number of kernel per row

Number of kernel per row showed positive and highly significant SCA effects for hybrids P2 x P10, P3 x P11, P5 x P9, P5 x P14 and P12 x P13 followed by P1 x P8 which showed positive and significant SCA effects indicating tendency of the hybrids to enhance the traits. Hybrids P5 x P11 and P5 x P12 depicted negative and significant SCA effects indicating the ability of the hybrids to decrease the trait (table 4).

Thousand kernel weight

Among the hybrids evaluated in this experiment, P4 x P6 and P14 x P15 showed positive and significant SCA effects for thousand kernel weight, indicating the hybrids combined well to give higher thousand kernel weight and could be selected for their SCA to improve the trait. Hybrid P1 x P5 showed negative and significant SCA effects, indicating; the tendency of the hybrid to decrease the trait (table 4).

It was observed that some crosses involved good general combining parents produced hybrids, with poor specific combining ability for a given trait example grain yield, indicating parents with high GCA effects might not always give hybrids with high SCA effects. The possible explanation is that both lines used in the hybrid may have the same gene controlling the trait(s) studied and not able to take advantage of any additive gene action.

Table 3: General combining ability (GCA) effects for grain yield and yield related traits of 15 parental lines used in diallel cross in 2011 at Melkassa.

Inbred	GY	DA	DS	PH	EH	DM	CR	EL	ED	KPR	RPE	TKW
P1	-0.14	-1.17**	-1.03**	-4.48*	-7.28**	-1.07	-0.27**	0.99**	1.36**	0.84	0.78**	-26.43**
P2	-0.01	-0.67*	-0.65*	-11.83**	-0.94	-1.11	0.04	-0.2	-0.05	-1.77*	-0.06	22.03**
P3	0.12	0.48	0.47	-0.67	1.76	0.24	0.04	0.03	-0.33	0.19	0.09	-2.14
P4	-0.81**	1.25**	1.24**	-6.44**	-2.86	-3.38**	0.21**	-0.51	-1.92**	2.61**	0.71*	-51.76**
P5	-0.42**	-4.48**	-3.99**	-15.86**	-14.59**	0.35	0.12**	-0.62	1.26*	-3.58**	-0.14	18.88**
P6	0.14	- 2.02**	-1.99**	1.64	-2.67	-0.8	-0.09	0.38	-2.22**	0.69	-1.29**	5
P7	0.13	0.1	0.01	0.87	1.76	-0.3	0.02	-1.01**	-0.23	-2.01**	0.78**	-11.60*
P8	-0.31*	2.02**	1.97**	-1.83	-1.9	-0.53	0.12	-0.47	-1.27*	0.36	0.4	-31.23**
P9	-0.15	1.45**	1.27**	7.41**	6.76**	1.97**	0.19**	0.19	-1.82**	-0.24	-0.98**	23.74**
P10	0.07	-2.98**	-3.34**	-11.06**	-2.86	0.62	0.06	-1.01**	-0.35	-1.47*	-0.37	29.85**
P11	-0.15	-1.86**	-1.69**	-1.06	2.91	-0.65	-0.02	-0.62	-0.07	-1.2	-0.22	4.72
P12	0.23**	-0.82**	-0.46	3.37	-3.24	-0.76	0.003	0.3	2.77**	-0.16	1.32**	-11.02*
P13	0.28	-0.09	-0.07	7.98**	2.14	-0.68	-0.17**	1.26**	0.09	2.46**	-0.37	6.13
P14	-0.18	1.10**	0.85**	1.44	4.64*	1.70**	0.21**	-0.04	0.07	-0.12	-0.98**	28.04**
P15	1.21**	7.68**	7.43**	30.52**	16.37**	4.39**	-0.48**	1.30**	2.72**	3.42**	0.32	-4.21
SE(gi)	0.18	0.39	0.4	2.66	2.89	0.8	0.07	0.44	0.86	1.12	0.46	6.5
SE(gi-gj)	0.28	0.57	0.59	3.89	4.23	1.16	0.1	-0.27**	0.89	1.64	0.67	9.51

* and **, significant at P<0.05 and P<0.01**,** respectively. CR=common rust, DA=days to anthesis, DM=days to maturity, DS=days to silking, ED=ear diameter (mm), EH=ear height (cm), EL=ear length (cm), EPP=number of ear per plant, GY=grain yield (t ha^{-1}), KPE=number of kernel per ear KPR=number of kernel per row, PH=plant height (cm), RPE=number of kernel rows per ears, and TKW=thousand kernel weight (g).

On the other hand, parents which were considered poor combinations produced hybrids with good specific combination. This showed that good specific combinations for yield and other traits can be obtained from all possible combination of parents' i.e. good x good, poor x good and poor x poor combinations.

In general smaller (negative direction) SCA was considered desirable for traits like days to anthesis, days to silking, plant height, ear height, days to maturity and disease resistance while positive and significant SCA was desirable for traits like grain yield, ear length, ear diameter, number of kernel per row, rows per ears, kernel per ear and thousand kernel weight.

Accordingly, seven, six, three, four and fourteen hybrids showed good specific combinations for days to anthesis, days to silking, days to maturity, ear height and common rust in the negative direction respectively. Ear length, ear diameter, number of kernels row per row, number of kernels per ear and thousand kernel weight showed good specific combination in the positive direction for four, eight, two, five and five hybrids, respectively.

Table 4: Estimates of specific combining ability (SCA) effects for grain yield and related traits of 15 x 15- diallel crosses of maize inbred lines evaluated at Melkassa in 2011.

Crosses	GY	DA	DS	PH	EH	CR	ED	DM	EL	KPR	RPE	TKW
P1xP2	-0.447	-2.176*	-2.027*	8.538	3.599	0.049	-1.412	-0.137	0.841	1.531	0.363	-17.892
P1xP3	0.096	-0.330	-1.643	-2.615	3.407	-0.451**	-0.097	1.016	0.130	0.110	-0.791	27.526
P1xP4	-0.564	-2.099*	-1.412	-4.346	3.022	0.126	-5.072**	0.632	0.648	0.187	-2.407*	17.553
P1xP5	-0.097	0.132	0.819	0.077	2.253	0.223	8.772**	-0.599	0.764	1.879	2.24*	-38.997*
P1xP6	0.108	-0.830	-0.681	-2.423	-14.670*	-0.066	1.273	-0.945	1.764	5.140	0.592	24.248
P1xP7	-0.108	0.555	0.319	0.846	3.407	0.069	-1.311	0.555	-0.352	-2.198	-0.484	-12.272
P1xP8	-0.872	0.032	0.957	-1.462	-10.440	0.223	-2.520	0.286	-2.390*	1.456	-1.099	10.952
P1xP9	0.072	-0.791	-0.951	6.808	-1.593	-0.104	-1.470	1.286	-0.044	-0.467	-0.714	10.931
P1xP10	0.011	3.632**	4.165**	-4.731	0.522	-0.470**	0.533	-1.868	0.148	-0.236	-0.330	4.244
P1xP11	0.016	1.016	1.011	-2.231	4.753	-0.143	0.820	-1.599	-0.236	1.990	1.515	-13.674
P1xP12	-0.380	0.978	0.780	5.846	15.906*	0.338	0.320	-0.984	-0.159	-1.544	-0.022	-10.684
P1xP13	-0.153	0.247	0.396	6.231	-1.978	0.011	-0.218	1.440	1.379	-3.159	0.670	-12.593
P1xP14	0.062	0.055	-0.027	0.269	0.522	0.126	0.268	0.555	-0.813	-0.582	0.285	5.437
P1xP15	-0.377	-1.522	-1.604	-10.808	-8.709	0.069	0.113	0.363	-1.659	-4.121	-0.022	5.222
P2xP3	0.072	-0.830	-0.027	7.231	12.060	-0.008	0.262	-1.945	-0.698	-4.271	1.055	-26.296
P2xP4	0.027	0.401	-0.297	-2.000	-3.324	-0.431**	1.976	-12.330**	-0.659	3.802	-0.560	-6.909
P2xP5	-0.871	1.132	1.434	2.423	8.407	0.415**	-1.629	2.440	-2.044	-6.005*	-0.714	5.846
P2xP6	0.044	0.170	0.934	-5.077	1.484	0.126	4.262*	1.593	-1.044	0.725	0.440	-5.854
P2xP7	1.103*	-0.945	-1.566	8.192	7.060	-0.489**	-0.452	2.093	0.841	1.418	1.361	18.671
P2xP8	-0.936	-0.368	-0.027	0.885	-6.786	0.165	1.013	0.324	0.802	-0.429	0.747	-9.535
P2xP9	0.043	-0.791	-0.335	-8.346	-10.440	-0.162	-2.151	1.824	-0.352	-1.852	-0.868	1.374
P2xP10	-0.483	0.632	0.280	5.115	6.676	0.223	-0.383	-1.330	-0.159	-0.621	-0.484	-16.523
P2xP11	0.017	-1.484	-1.374	-14.885	-6.593	0.049	3.129	1.440	0.456	-0.890	0.363	41.554*
P2xP12	-0.309	2.978**	0.896**	-4.308	-7.940	0.030	-3.377	-0.445	0.033	0.571	-0.176	-18.591
P2xP13	0.003	0.747	1.011	13.577	14.176*	-0.297	0.620	1.978	0.571	2.456	-0.484	55.460**
P2xP14	-0.052	-1.945*	-1.912	2.615	1.676	-0.181	0.096	0.593	0.879	2.033	0.132	-0.311
P2xP15	-0.921	1.478	2.011	-13.962	-20.055*	0.511**	-1.953	-0.099	0.533	1.495	-1.176	-20.995
P3xP4	-0.250	-1.253	-1.412	-10.654	-8.516	0.068	1.451	-0.676	0.610	0.341	1.286	34.475
P3xP5	-0.005	-1.022	-0.181	6.269	5.714	-0.085	-0.050	0.093	0.225	-0.467	0.868	10.604
P3xP6	0.017	-0.484	-0.681	-11.231	-3.709	0.126	-0.274	-0.253	-2.275*	-4.236	0.286	9.035
P3xP7	2.229*	1.901	2.319*	-25.462**	-10.632	0.761**	0.217	-1.253	1.110	-0.044	1.791	-16.466
P3xP8	0.622	-1.522	-2.143*	17.231*	3.022	0.165	3.378	2.478	3.071**	4.610	0.593	-1.772
P3xP9	0.136	0.055	-0.451	-2.000	-8.132	-0.162	-1.497	3.022	-0.082	-1.313	-0.022	-19.943
P3xP10	-0.512	0.478	0.665	1.462	-3.516	0.223	-2.019	0.176	-0.890	-2.082	-0.637	0.450
P3xP11	-0.520	0.363	0.111	-1.038	0.714	0.049	1.333	-0.407	1.225	6.148*	0.209	-3.088
P3xP12	0.354	-1.176	-0.720	4.538	1.868	0.030	-1.462	-1.291	0.302	-0.890	0.670	5.327
P3xP13	0.396	0.093	-0.104	-0.077	-3.516	-0.047	-0.770	0.632	-2.159	3.495	0.363	-5.662
P3xP14	0.026	2.401*	2.473*	3.962	8.984	-0.181	-2.019	2.747	-1.352	-2.429	-0.022	-8.447
P3xP15	0.142	1.324	1.896	12.385	2.253	-0.489**	1.547	1.055	0.802	1.033	-0.330	-5.742
P4xP5	0.022	0.209	0.649	4.538	5.330	-0.008	-0.220	-0.791	1.764	4.610	2.516**	-27.864
P4xP6	0.552	-0.753	0.049	17.038*	0.907	-0.297	4.746*	1.363	2.764**	2.341	0.670	44.577*
P4xP7	-0.454	1.632	1.149	-9.692	-8.516	0.088	0.702	2.363	-0.851	-5.967*	-0.407	-11.219
P4xP8	2.638**	6.709**	6.588**	-37.000**	-19.863**	1.242**	-2.933	0.093	-1.890	-3.813	-0.022	-22.899
P4xP9	0.111	-1.714	-1.720	1.269	8.984	-0.085	-1.617	-0.907	-0.544	-0.236	0.362	8.345

P4xP10	1.130*	0.709	0.396	14.731*	13.599	-0.201	-0.379	2.940	-1.852	-2.005	-0.253	-11.232
P4xP11	0.615	-0.407	-0.758	22.231**	12.830	-0.124	1.463	2.709	1.264	0.225	0.593	5.660
P4xP12	0.324	-0.945	-1.489	0.308	-11.016	-0.393*	1.082	1.842	-0.659	-2.813	0.055	1.635
P4xP13	-0.929	2.024	2.626**	0.692	8.599	0.280	0.640	1.747	-0.621	1.071	-0.253	-22.419
P4xP14	0.966	-4.368**	-4.297**	12.231	-1.401	-0.354*	-1.760	1.863	-0.313	0.148	-1.637	16.091
P4xP15	0.613	-0.445	-0.374	-9.346	-0.632	0.088	-0.079	-0.830	0.341	2.110	0.055	-25.794
P5xP6	0.029	-0.522	-1.220	-3.538	-4.863	0.049	-4.785**	0.132	1.979	2.533	-1.484	-17.174
P5xP7	0.318	1.063	1.980	2.231	0.714	-0.066	-3.688	0.132	0.764	4.725	-2.560**	30.231
P5xP8	0.244	-1.560	-1.181	12.423	9.368	-0.412*	0.357	0.863	-1.275	-2.621	-0.176	28.910
P5xP9	0.543	-1.484	-1.489	-4.308	0.714	-0.489**	0.863	0.863	-0.929	-1.044	1.208	-21.756
P5xP10	-0.988*	-0.060	-0.874	-10.846	-7.170	0.646**	0.310	-3.291	2.264*	1.187	0.593	-18.723
P5xP11	0.897	-0.176	-0.527	-3.346	-12.940	-0.027	2.928	1.978	-0.621	-3.082	-0.560	16.389
P5xP12	-1.379*	-1.2143	-0.758	-12.769	-1.786	0.703**	-4.138*	-2.907	-2.544*	-3.621	-2.099*	10.304
P5xP13	0.358	-0.445	-0.643	7.615	-4.670	-0.624**	-1.496	0.016	-1.005	0.364	-0.407	17.635
P5xP14	0.183	-0.637	-0.566	-3.346	-2.170	-0.508**	-0.940	-1.868	0.302	2.341	0.209	0.145
P5xP15	-0.456	3.786**	2.857**	2.577	1.099	0.184	3.716	1.940	0.456	-0.698	1.801	4.450
P6xP7	1.32**	0.401	0.380	2.231	-11.209	0.396*	-1.218	-0.214	-1.736	-2.544	0.593	-24.999
P6xP8	0.394	1.978*	1.819	12.423	9.945	-0.201	2.003	1.017	-0.275	1.110	-0.022	-12.874
P6xP9	-0.507	0.055	0.511	5.692	8.791	-0.027	1.578	1.516	0.571	1.187	-0.637	33.595
P6xP10	0.357	-2.022*	-2.374*	6.654	-14.093*	0.357*	-1.769	-3.137	-0.736	-3.082	-1.253	4.848
P6xP11	-0.543	-0.137	-0.527	-5.846	2.637	-0.066	-0.667	-2.368	1.979	0.648	0.593	-20.295
P6xP12	-0.769	1.024	1.742	-7.769	6.291	0.165	-3.227	-0.753	0.956	0.610	-0.945	-6.185
P6xP13	0.378	0.593	0.857	-9.885	0.907	-0.412*	-0.980	-0.330	0.495	3.495	-1.253	3.866
P6xP14	-0.172	-1.099	-0.066	1.654	-1.593	-0.048	0.811	0.286	-0.698	-4.429	0.363	0.116
P6xP15	-0.546	-0.176	-0.643	0.077	19.176**	-0.104	-1.753	0.093	-3.544**	-3.467	2.050*	-32.904
P7xP8	0.298	-0.637	-0.681	-4.308	8.022	-0.066	-2.236	-1.484	-1.390	-5.198*	-1.099	-10.980
P7xP9	0.132	-1.060	-0.989	-1.038	-0.632	-0.143	-2.560	0.016	0.456	0.879	-0.714	-0.466
P7xP10	-0.804	-1.637	-1.374	-7.577	-3.516	-0.008	2.102	-1.137	-0.352	-1.390	1.670	-7.053
P7xP11	-0.464	0.147	1.473	7.423	10.714	0.069	-1.595	0.632	-0.236	0.341	0.516	-3.431
P7xP12	-0.185	0.209	0.242	0.500	-0.632	-0.201	1.694	-2.253	-1.159	-1.198	1.878	-3.661
P7xP13	0.061	-0.522	-0.643	3.385	-3.516	-0.027	5.101**	-1.830	1.879	4.687	1.670	-2.980
P7xP14	0.176	-1.714	-1.566	7.423	6.484	0.088	1.762	1.786	1.187	5.264	0.286	37.330*
P7xP15	1.638**	-1.291	-1.143	15.846*	2.253	-0.470**	1.483	0.593	-0.159	1.225	-1.022	7.295
P8xP9	0.268	-1.984*	-1.951	-3.346	-1.978	0.011	-1.215	-1.753	0.918	4.133	-1.330	7.863
P8xP10	0.027	-0.560	-0.335	5.115	7.637	-0.104	2.748	1.093	0.610	4.464	1.055	5.786
P8xP11	0.446	-2.176	-1.489	0.115	1.868	-0.027	-2.090	-1.637	-0.275	-0.005	-0.099	-3.282
P8xP12	-0.380	-0.214	-0.220	-4.308	-1.978	-0.297	3.994**	0.978	1.302	5.956*	2.163*	10.468
P8xP13	-0.448	-0.945	-0.604	8.577	7.637	-0.374*	0.792	0.401	-0.159	-6.259	1.055	15.105
P8xP14	0.072	-1.137	-1.027	-4.885	-9.863	-0.258	-2.603	-4.484*	0.648	-1.082	-1.330	-26.875
P8xP15	-0.243	0.286	0.396	-1.462	3.717	-0.150	-0.687	0.824	0.302	-1.621	-0.637	9.134

Table 4: *Continued…*

Crosses	GY	DA	DS	PH	EH	CR	ED	DM	EL	KPR	RPE	TKW
P9xP10	-0.779	-0.984	-1.143	0.985	1.884	-0.181	4.308*	2.093	0.456	-1.119	1.440	2.935
P9xP11	-0.159	0.401	0.703	15.885*	3.214	0.146	0.891	0.863	0.571	-0.429	-0.714	28.057
P9xP12	0.4054	1.363	0.973	11.862	6.968	0.126	0.245	-0.522	0.648	1.533	-1.253	-6.028
P9xP13	0.051	-0.868	-0.912	-10.654	-1.016	0.549**	-0.188	-1.090	0.187	-3.082	1.040	-26.437
P9xP14	-2.639*	6.440**	6.165**	-9.115	-6.016	0.665**	3.073	-0.984	-0.005	2.495	1.050	-23.037
P9xP15	-0.367	1.363	1.788	-3.192	-0.247	-0.143	-0.261	-0.176	-1.852	-0.544	0.747	4.568
P10xP11	-0.805	0.342	1.819	-8.154	-9.670	-0.220	-1.552	0.209	-0.236	-0.198	-0.330	-4.440
P10xP12	0.449	-2.214*	-2.412*	9.923	13.984*	-0.489**	3.768	3.424	0.841	1.261	0.132	26.335
P10xP13	0.141	0.055	0.703	2.808	-7.901	-0.066	-0.170	-0.753	0.379	2.648	-0.176	7.246
P10xP14	-0.779	0.363	0.280	-10.654	-1.401	-0.201	-2.854	-0.137	0.187	-2.775	-0.560	-9.044
P10xP15	0.022	0.286	0.203	-4.731	4.368	0.492**	-4.64*	1.670	-0.659	4.387	-0.868	12.151
P11xP12	-0.547	-0.330	-0.066	-5.077	-8.786	0.088	-0.830	-2.407	-2.044	-6.505**	-0.022	-8.768
P11xP13	-0.275	-1.060	-0.951	-9.692	-4.670	0.261	-0.343	1.016	-0.505	-3.121	-0.330	-7.087
P11xP14	0.182	0.747	1.726	9.846	0.330	-0.124	-2.297	1.132	-2.198	1.956	-1.714	-36.967*
P11xP15	-0.709	-1.330	-0.451	-2.231	8.599	0.069	-1.191	-2.060	0.956	2.988	-0.022	7.370
P12xP13	0.424	0.901	0.319	-5.615	1.484	0.242	-2.923	0.632	0.791	3.444	1.868	0.750
P12xP14	0.829	0.709	0.896	2.823	-1.016	-0.143	0.937	1.747	0.579	3.418	0.747	4.504
P12xP15	2.021**	4.230**	-3.154*	-5.615	-15.115	-0.327	3.873	2.077	0.885	-1.654	1.692	-0.384
P13xP14	-0.739	-0.522	-0.989	-5.632	1.099	0.780**	3.035	-1.330	-1.082	-4.698	1.400	-12.755
P13xP15	-0.258	-0.599	-1.066	6.231	-5.632	-0.277	-3.100*	-4.022*	0.071	-0.736	-1.868	-13.155
P14xP15	-0.093	-0.291	0.489	2.769	4.368	0.538	2.691	-1.907	2.879**	-1.659	0.747	52.810**
SE(Sij)	0.65	1.34	1.38	9.18	10.00	0.24	2.75	1.53	2.96	3.88	1.58	22.45
SE(Sij-Sik)	0.96	1.97	2.03	13.48	14.66	0.36	4.04	2.24	4.34	5.69	2.32	32.94
SE(Sij-Skl)	0.92	1.89	1.94	12.90	14.04	0.34	3.86	2.15	4.15	3.85	2.22	31.54

*and **, significant at *$p \leq 0.05$,**$p \leq 0.01$ respectively, CR= common rust (scale 1-5), DA=days to anthesis, DM= days to maturity, DS= days to silking, ED=ear diameter (mm), EH= ear height (cm), EL=ear length (cm), GY=grain yield ($t\ ha^{-1}$), KPR= number of kernel per row, PH=plant height (cm), RPE=number of rows per ear and TKW= thousand kernel weight (g).

3.5. CONCLUSION

The main aim of any plant breeding program is to develop varieties with desirable agronomic traits and high yielding. To accomplish this, a breeding program should efficiently be planned with prior knowledge of the genetic constituent of complex traits like yield and its attributes. It is, therefore, necessary to examine the genetic architecture of various quantitative characters in relation to breeding behavior of the genetic material available. Desirable inbred lines with good GCA and crosses with good SCA identified in the current study could be exploited in future breeding activity after confirming the repeatability of current results over years and locations.

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