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Combining Ability of Maize (*Zea mays* L.) Inbred Lines for High Potential Areas of West Gojam, Ethiopia

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ABSTRACT

Maize (*Zea mays* L.) is one of the most important cereal crop cultivated globally. The development of inbred lines and hybrids is among the most widely used breeding strategies in maize. Choice of promising germplasm with good combining ability is a key to the development of high yielding maize varieties. Hence, the study was carried out with the objectives of determining the general and specific combining abilities of maize inbred lines and identifying crosses with higher grain yield and other important characteristics. The experiment consisted of thirty crosses and three popular standard hybrids were laid out in alpha lattice design with two replications during the 2018 cropping season at Adet and the data were analyzed using SAS software. There was a significant difference ($p<0.05$) among genotypes for all the traits except number of kernels per row and ear length. Mean squares for general combining ability of lines were significantly different at 1% and 5% probability levels for all evaluated traits, whereas specific combining ability was significantly different at 5% probability only for days to maturity, ear height, harvest index and thousand kernel weight. Among the tested inbred lines, L4 was the best combiner followed by L11 for grain yield with the general combining ability effects of 2867.73 and 488.70, respectively. L11 x T2 was the best cross for grain yield with the specific combining ability of 1035.67. Therefore, the crosses (L4 × T1) and (L4 × T2) as well as L11 x T2 can be utilized for developing high yielding hybrid varieties.

Keywords: GCA, Hybrid, SCA, Tester.

INTRODUCTION

Maize (*Zea mays* L., 2n=2x=20) is one of the most important cereal crops in the world following wheat and rice. It is widely used for food, feed, fuel and fiber in many parts of the world. According to the report of FAO (2019), 197 million hectares of land was covered by maize and produced 1,134 million tons of maize grain in the 2017 production season.

Maize is one of the major fundamental cereal crops for food security in Ethiopia in general and in Amhara region in particular. Based on (CSA, 2020), the amount of maize grain produced is 96.4 million quintals in the country on 2.3 million hectares and 22.6 million quintals in the region on 0.53 million hectares and 1.2 million quintals in West Gojam on 40 thousand hectares of land coverage. The current national productivity average per hectare is 4.24 tonnes per hectare while 4.27 tonnes per hectare and 3.03 tonnes per hectare in Amhara region and in West Gojam, respectively (CSA, 2020). In different countries, the productivity of maize ranges from 6 to 10 t ha^{-1}. For example, the national average grain yield per hectare of the USA, Canada, Germany, Brazil and China is 10.7, 9.63, 9.59, 5.70, and 6.32 tonnes per hectare, respectively (FAO, 2019). Lack of high yielding varieties, biotic and abiotic stresses and the poor adoption of improved technologies by the predominantly small-scale maize farmers are the major reasons for low maize productivity (Mosisa et al., 2011). This indicates the need to develop high yielding hybrid maize varieties that perform well under biotic and abiotic stress conditions. In order to achieve this, potentially suitable parents and superior combinations must be identified. Hybrid development in Ethiopia has been highly

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effective in increasing maize yields since the commercialization of the hybrids in the country. Increased yields are in part due to improved agronomic practices and increased inputs, but increased yields could not have been realized without genetic improvements (Tsedeke et al., 2015).

Enhancement of maize production and productivity can be achieved by identifying elite parent materials that could be used to develop high yielding varieties, and by forming a broad-based source population serving the breeding program. Line x tester mating design is a modified form of top cross scheme for inbred lines evaluation. Line x tester mating design provides reliable information on the general and specific combining ability effects of parents and their hybrid combinations in applied breeding programs (Kempthorne, 1957). The design has been widely used in maize breeding by several workers and continues to be applied in quantitative genetic studies in maize (Sharma et al., 2004).

Combining ability analysis is an important genetic tool used to the estimates of general combining ability (GCA) of parents and specific combining ability (SCA) of crosses and facilitated selection of the desired parents and crosses (Ahmed et al., 2017). To enhance hybrid formation, information on the combining abilities of inbred lines is extremely important. It is always mandatory for any breeding program to generate such information for any new batch of inbred lines. However, there is little information on the combining ability of the fifteen inbred lines used in the present study. Therefore, the objective of this study was to evaluate the general and specific combining ability of maize inbred lines and identify crosses with higher grain yield and other important yield-related traits.

MATERIALS AND METHODS

Description of the study area:

Table 1: Pedigree of genotypes

Entry No.	Pedigree	Designation
1	CML161/CML165-3-1-1-2//CML395/CML202	L1 x T1
2	CML161/CML165-3-1-1-2// CML442/CML312	L1 x T2
3	CML395/CML202//142-1e-4-2-1-1/// CML395/CML202	L2 x T1
4	CML395/CML202//142-1e-4-2-1-1/// CML442/CML312	L2 x T2
5	CML161/CML165-3-1-1-4// CML395/CML202	L3 x T1
6	CML161/CML165-3-1-1-4// CML442/CML312	L3 x T2
7	JJ/PA4-3-1-2-3// CML395/CML202	L4 x T1
8	JJ/PA4-3-1-2-3// CML442/CML312	L4 x T2
9	CML161/CML165-4-1-1-3// CML395/CML202	L5 x T1
10	CML161/CML165-4-1-1-3// CML442/CML312	L5 x T2
11	CML161/CML165-3-3-2-2// CML395/CML202	L6 x T1
12	CML161/CML165-3-3-2-2// CML442/CML312	L6 x T2
13	CML161/CML165-3-3-2-1// CML395/CML202	L7 x T1
14	CML161/CML165-3-3-2-1// CML442/CML312	L7 x T2
15	CML161/CML165-3-1-1-3// CML395/CML202	L8 x T1
16	CML161/CML165-3-1-1-3// CML442/CML312	L8 x T2
17	KULENI- 5-3-2-1// CML395/CML202	L9 x T1
18	KULENI- 5-3-2-1// CML442/CML312	L9 x T2
19	MTB/99-7-3-2-1// CML395/CML202	L10 x T1
20	MTB/99-7-3-2-1// CML442/CML312	L10 x T2
21	KULENI- 5-3-2-3// CML395/CML202	L11 x T1
22	KULENI- 5-3-2-3// CML442/CML312	L11 x T2
23	KULENI-5-6-1-3// CML395/CML202	L12 x T1
24	KULENI-5-6-1-3// CML442/CML312	L12 x T2
25	HORA-4-1-2-1// CML395/CML202	L13 x T1
26	HORA-4-1-2-1// CML442/CML312	L13 x T2
27	GUTO- 6-2-1-3// CML395/CML202	L14 x T1
28	GUTO- 6-2-1-3// CML442/CML312	L14 x T2
29	CML161/CML165-4-1-1-1// CML395/CML202	L15 x T1
30	CML161/CML165-4-1-1-1// CML442/CML312	L15 x T2
31	BH-540	Check
32	BH-660	Check
33	AMH-851	Check
Tester1(T1)	IP NVA.BCO.(S/D) x NPH-2H,IF32-B-I-B-I-2-BBBBBB/ ZSR923s.4BULK-6-1-b-b	CML395/CML202
Tester2(T2)	IM37WfZM607IbF37ar-2-3lr...Z.X)...Z.X.1-8BB/88951lO f'2.2.2·1·1....	CML442/CML312

Table 2: Mean squares due to source of variations for grain yield and related traits

Source	DF	Mean squares							
		DA	**DS**	**DM**	**PH**	**EH**	**PA**	**EA**	**HI**
Rep	1	26.73**	42.56**	0.55^{ns}	1316.77**	45.17^{ns}	0.24^{ns}	0.03^{ns}	46.57**
Block	4	1.94^{ns}	7.11**	77.68**	610.23**	749.18**	0.29*	0.12^{ns}	12.40*
Genotype	32	11.96**	11.65**	17.62**	584.06**	493.00**	0.22*	0.36**	12.76**
Error	28	1.68	1.26	3.43	94.68	57.17	0.098	0.14	4.00
CV(%)		1.37	1.17	1.06	3.59	5.14	17.27	20.13	5.31

Table 2 Continued

Source of var.	DF	Mean squares						
		TKWT	**EPP**	**KRE**	**NKR**	**EL**	**ED**	**GY**
Rep	1	363.69^{ns}	0.02^{ns}	0.01^{ns}	9.81^{ns}	1.17^{ns}	0.01^{ns}	0.14^{ns}
Block	4	6405.21**	0.08**	0.79^{ns}	17.66*	4.15*	0.10**	8.96**
Genotype	32	3878.46**	0.06**	2.53**	3.95^{ns}	2.01^{ns}	0.059**	2115051.05**
Error	28	921.04	0.02	0.59	4.69	1.20	0.02	537732.00
CV (%)		7.22	9.69	5.39	6.15	5.65	2.50	7.48

*=significant at 0.05 probability level, **=significant at 0.01 probability level, DF=degree of freedom, DA=days to anthesis, DS = days to silking, DM = maturity of date, PH = plant height (cm), EH = ear height (cm), PA = plant aspect, EA = ear aspect, HI = harvest index (%), TKWT = thousand kernel weight (gram), EPP = ear per plant (number), KRE = number of kernel row per ear (number), NKR = number of kernel per row (number), EL = ear length (cm), ED = ear diameter (cm) and grain yield (kg/ha).

The experiment was conducted at Adet Agricultural Research Center (AARC) in 2018 main cropping season. The center represents the best agro-ecology of maize growing areas of Gojam, North West Ethiopia. AARC is located at a longitude from 37° 28' 38" to 37°29' 50" E and latitude from 11°16' 19" to 11°17' 28" N with an average altitude of 2240 meters above sea level. It is located about 450 km from the national capital, Addis Ababa and 42 km from Bahir Dar via Mota town. The center has a moderate and favorable climate with temperatures ranging from 10.81°C to 25.55°C and annual rainfall of 1432 mm in 2018 cropping season. The type of soil is nitisol with pH of 5.43.

Planting materials:

Thirty three entries including three standard checks (BH540, AMH 851 and BH-660) and thirty test crosses were developed by L x T mating design from fifteen inbred lines with two testers (CML395/CML202 and CML442/CML312)) in 2017 main cropping season (Table1). The lines were S4 generation, originally developed by Adet Research Center through selfing from improved maize varieties; the testers were originally developed by CIMMYT and widely used to identify the combining ability of newly generated maize inbred lines.

Experimental design and trial management:

The experiment was laid out in alpha-lattice design with two replications. Each plot comprised of two rows of 5.1 m long with the spacing of 0.75 m between rows and 0.30 m between plants respectively. Fertilizers were applied as NPS and urea at the rate of 69.16 P_2O_5 and 119.22 N. All P_2O_5 and one-third of N were applied as basal at planting, while the remaining two-thirds of N was applied at knee height. Hoeing and weeding were done throughout the entire growing season as required.

Statistical analysis and procedures:

Data were recorded on days to 50% anthesis, days to 50% silking, days to 50% maturity, number of ears per plant, thousand kernel weight, plant aspect, ear aspect, grain yield, harvest index, plant height, ear height, number of kernel rows per ear, number of kernels per row, ear length and ear diameter. The collected data were then subjected to analysis of variance using SAS 9.2 software.

General combining ability (GCA) and specific combining ability (SCA) of lines were computed for parameters that showed significant differences among crosses following line by tester analysis as suggested by Kempthorne (1957). Significances of GCA and SCA effects of the lines and hybrids, respectively were determined by t-test using standard errors of GCA and SCA effects. The main effects due to lines and testers were considered as GCA effects while LxT interaction effects were represented as the SCA.

gi = Yi - Y

gj = Yj – Y

Sij = Yij - Yi - Yj +Y

Where, gi = GCA effect for i^{th} line;S_{ij} = SCA effect of the ij^{th} cross; gj =GCA effect for j_{th}testers; Yi = the mean performance of i^{th} line with all testers; Yj = the mean performance of j_{th} tester with all lines; Yij = the mean performance of hybrid from j^{th}

Table 3: Mean squares of general combining ability (GCA) of lines and specific combining ability (SCA) of L x T for yield and yield related traits.

Source of var.	DF	Mean squares						
		DA	DS	DM	PH	EH	PA	EA
Rep (r)	1	21.76**	36.44**	1.47	1258.04**	43.19	0.26	0.00
Block (b)	4	11.41**	9.51**	22.31**	487.10**	231.27*	0.16	0.25
GCA Line	14	12.57**	13.90**	19.26**	704.30**	396.40**	0.27**	0.29*
Tester(T)	1	78.76**	60.69**	0.23	824.36	2215.54**	0.51	2.13
SCA (L x T)	14	3.07	2.96	5.91*	98.85	143.96*	0.10	0.32
Error	25	1.65	1.17	3.62	104.23	63.83	0.093	0.12
CV (%)		1.36	1.12	1.08	3.79	5.48	17.30	18.64
R^2		0.88	0.91	0.87	0.86	0.89	0.75	0.79

Table 3: (Continued)

Source of var.	DF	Mean squares					
		HI	TKWT	EPP	KRE	ED	GY
Rep (r)	1	54.68**	49.33	0.04			292778.08
Block (b)	4	3.72	5440.31**	0.05*	1.46	0.08**	5452712.46**
GCA Line	14	14.93**	4149.06**	0.08**	2.72**	0.07**	2628667.45**
Tester(T)	1	2.99	8606.71**	0.47**	1.71	0.02	250124.19
SCA (L x T)	14	5.60*	910.84*	0.02	0.64	0.02	847751.36
Error	25	4.02	867.21	0.02	0.60	0.02	580456.30
CV (%)		5.27	7.13	9.93	5.40	2.42	7.76
R^2		0.79	0.84	0.84	0.78	0.81	0.87

*=significant at 0.05 probability level, **=significant at 0.01 probability level, DF = degree of freedom, DA = days to anthesis, DS = days to silking, DM = days to maturity, PH = plant height (cm), EH = ear height (cm), PA = plant aspect, EA = ear aspect, HI = harvest index (%), TKWT = thousand kernel weight (gram), EPP = ear per plant (number), KRE = number of kernel row per ear, ED = ear diameter (cm) and grain yield (kg/ha).

tester and i^{th} line; Y = the overall mean performance of hybrids.

RESULTS

Days to anthesis, days to silking, days to maturity, plant height, ear height, ear aspect, harvest index, thousand kernel weight, ear per plant, number of kernel row per ear, ear diameter and grain yield were significantly different at p<0.01 and plant aspect was significantly different at P<0.05. However, the number of kernels per row and ear length were not significantly (p>0.05) different (Table 2). The mean performance of crosses revealed that among the crosses, CML395/CML202//142-1e-4-2-1-1///CML442/CML312(91.5 days), CML161/CML165-4-1-1-3//CML442/CML312 (91.5 days), and CML161/CML165-3-3-2-1//CML442/CML312 (91.5 days) were earlier in days to anthesis while CML161/CML165-3-3-2-1//CML442/CML312 (93.0 days) were earlier in days to silking but all crosses were late as compared to AMH 851 and earlier than BH 660 in days to anthesis and silking and some crosses were late as compared to BH 540 in days to anthesis and silking (Table 4).Three-way cross JJ/PA4-3-1-2-3//CML442/CML312 produced the highest grain yield (12682.2kg ha^{-1}) followed by JJ/PA4-3-1-2-3//CML395/CML202 (12680.7kgha^{-1}) with overall mean of 9805.8 kgha^{-1}. These three way crosses had better performance in grain yield compared to BH 540 (9038.2 kg ha^{-1}), BH 660 (11310.2 kg ha^{-1}) and AMH 851(8830.8 kg ha^{-1}) whereas lower yield was recorded in CML161/CML165-4-1-1-3//CML442/CML312 (8227.3 kg $ha\text{-}^{1}$) (Table 4).

General combining ability (GCA):

GCA effect analysis revealed that CML395/CML202//142-1e-4-2-1-1 and CML161/CML165-4-1-1-3 were exhibited negative and significant GCA effect for days to anthesis whereas CML395/CML202//142-1e-4-2-1-1,JJ/PA4-3-1-2-3,CML161/CML165-4-1-1-3,CML161/CML165-3-3-2-2,CML161/CML165-3-3-2-1, and CML161/CML165-3-1-1-3 showed negative and significant GCA effect for days to silking (Table 5). Inbred lines CML395/CML202//142-1e-4-2-1-1, KULENI- 5-3-2-3 and HORA-4-1-2-1 had positive and significant GCA effects for plant and ear height whereas CML395/CML202//142-1e-4-2-1-1 and CML161/CML165-4-1-1-3 showed negative GCA effects for plant and ear height (Table 3).

For harvest index, inbred lines KULENI-5-3-2-1 and GUTO-6-2-1-3 showed positive and significant GCA effects and on the other hand CML161/CML165-3-3-2-1 and KULENI-5-6-1-3 exhibited negative and significant GCA effects (Table 5). CML395/CML202//142-1e-4-2-1-1 and

Table 4: Mean performance of thirty-three genotypes (30 three-way cross and 3 hybrid checks) for fifteen traits

Entry	DA	DS	DM	PH (cm)	EH (cm)	PA	EA
L1 x T1	95.0^{a-g}	97.0^{b-g}	175.5^{def}	282.8^{b-f}	150.6^{c-h}	1.75^{ab}	1.75^{abc}
L1 x T2	92.5^{e-h}	94.0^{gh}	172.5^{f}	274.5^{b-h}	130.8^{g-j}	1.75^{ab}	2.25^{abc}
L2 x T1	92.0^{fgh}	94.5^{fgh}	172.0^{f}	252.0^{f-i}	148.3^{c-i}	1.75^{ab}	1.50^{bc}
L2 x T2	91.5^{gh}	94.0^{gh}	176.0^{d-g}	245.0^{hi}	124.2^{ij}	1.25^{b}	2.25^{abc}
L3 x T1	98.0^{abc}	99.0^{a-d}	171.0^{f}	273.2^{b-h}	156.6^{b-f}	2.00^{ab}	1.50^{bc}
L3 x T2	95.0^{a-g}	97.0^{b-g}	171.5^{f}	279.0^{b-g}	148.8^{c-i}	1.50^{ab}	2.75^{ab}
L4 x T1	94.5^{b-g}	96.0^{d-h}	175.0^{def}	282.5^{b-f}	157.9^{b-e}	1.75^{ab}	1.25^{c}
L4 x T2	93.0^{d-g}	94.5^{fgh}	175.0^{def}	290.0^{b-e}	158.4^{b-e}	1.50^{ab}	1.75^{abc}
L5 x T1	93.0^{d-g}	96.0^{d-h}	173.0^{f}	271.9^{b-h}	129.0^{g-j}	2.50^{a}	1.75^{abc}
L5 x T2	91.5^{gh}	94.5^{fgh}	172.5^{f}	236.5^{i}	117.3^{j}	2.00^{ab}	2.25^{abc}
L6 x T1	94.5^{b-g}	96.0^{d-h}	179.5^{a-e}	283.7^{b-f}	163.0^{bcd}	2.00^{ab}	2.25^{abc}
L6 x T2	92.5^{e-h}	94.0^{gh}	173.5^{ef}	269.0^{b-h}	146.4^{c-i}	1.75^{ab}	2.00^{abc}
L7 x T1	94.0^{c-g}	94.5^{fgh}	180.5^{a-d}	267.8^{b-i}	146.5^{c-i}	2.00^{ab}	2.00^{abc}
L7 x T2	91.5^{gh}	93.0^{hi}	175.5^{def}	258.8^{d-i}	132.6^{f-j}	2.00^{ab}	2.25^{abc}
L8 x T1	95.5^{a-g}	95.5^{d-h}	171.0^{f}	279.0^{b-g}	165.5^{bc}	1.50^{ab}	2.00^{abc}
L8 x T2	94.0^{c-g}	95.0^{e-h}	177.0^{b-f}	274.8^{b-h}	153.8^{c-g}	1.75^{ab}	1.75^{abc}
L9 x T1	96.0^{a-f}	97.5^{a-g}	172.0^{f}	272.8^{b-h}	140.7^{c-j}	1.50^{ab}	1.50^{bc}
L9 x T2	92.0^{gh}	95.0^{e-h}	174.0^{ef}	258.0^{e-i}	126.2^{hij}	1.50^{ab}	2.00^{abc}
L10 x T1	97.0^{a-d}	98.5^{a-e}	174.5^{def}	263.5^{b-i}	136.2^{e-j}	1.25^{b}	1.25^{c}
L10 x T2	96.0^{a-f}	98.5^{a-e}	175.0^{def}	263.0^{b-i}	135.5^{e-j}	1.75^{ab}	2.00^{abc}
L11 x T1	97.5^{abc}	100.0^{abc}	174.5^{def}	291.5^{bc}	179.7^{ab}	1.50^{ab}	2.00^{abc}
L11 x T2	94.5^{b-g}	96.0^{d-h}	175.0^{def}	275.5^{b-h}	138.3^{d-j}	1.25^{b}	2.00^{abc}
L12 x T1	95.5^{a-g}	98.0^{a-f}	181.5^{abc}	269.5^{b-h}	141.5^{c-j}	2.00^{ab}	2.25^{abc}
L12 x T2	96.5^{a-e}	98.0^{a-f}	182.0^{ab}	273.0^{b-h}	149.2^{c-h}	1.50^{ab}	1.75^{abc}
L13 x T1	98.5^{ab}	100.5^{ab}	176.0^{c-f}	290.4^{bcd}	161.7^{bcd}	2.25^{ab}	1.50^{bc}
L13 x T2	96.0^{a-f}	100.0^{abc}	172.5^{f}	295.0^{b}	163.6^{bc}	2.00^{ab}	1.75^{abc}
L14 x T1	96.0^{a-f}	97.0^{b-g}	175.0^{def}	253.7^{f-i}	151.3^{c-g}	1.75^{ab}	1.75^{abc}
L14 x T2	93.0^{d-g}	94.0^{gh}	174.0^{ef}	252.5^{f-i}	133.1^{f-j}	1.75^{ab}	3.00^{a}
L15 x T1	95.0^{a-g}	97.5^{a-g}	171.0^{f}	258.5^{d-i}	151.7^{c-g}	2.50^{a}	1.50^{bc}
L15 x T2	95.5^{a-g}	96.5^{c-h}	176.5^{b-f}	247.5^{ghi}	129.8^{g-j}	1.75^{ab}	1.25^{c}
BH 540	96.5^{a-e}	97.0^{b-g}	176.5^{b-f}	277.5^{b-g}	160.2^{b-e}	2.25^{ab}	2.00^{abc}
BH 660	99.0^{a}	101.0^{a}	184.0^{a}	325.5^{a}	194.6^{a}	2.50^{a}	1.00^{c}
AMH851	88.5^{h}	90.0^{i}	182.0^{ab}	259.5^{c-i}	129.5^{g-j}	2.25^{ab}	2.00^{abc}
Mean	94.58	96.35	175.36	271.13	147.05	1.82	1.87
CV	1.37	1.17	1.06	3.59	5.14	17.27	20.13
R^2	0.90	0.93	0.90	0.89	0.92	0.76	0.75
F. Test	**	**	**	**	**	*	**

JJ/PA4-3-1-2-3 had positive and significant GCA effects for thousand kernel weight and inbred lines CML161/CML165-4-1-1-1 and JJ/PA4-3-1-2-3 had significant positive GCA effects for ears per plant whereas CML395/CML202//142-1e-4-2-1-1, CML161/CML165-3-3-2-2 and KULENI- 5-3-2-1 showed significant negative GCA effects for ears per plant (Table 5). In the case of the number of kernel row per ear, inbred line KULENI-5-6-1-3 showed positive and significant GCA effect whereas CML161/CML165-3-3-2-1 and CML161/CML165-4-1-1-1 exhibited negative and significant GCA effect. CML161/CML165-3-1-1-2,CML395/CML202//142-1e-4-2-1-1and CML161/CML165-3-1-1-4 showed positive and significant GCA effects for ear diameter whereas CML161/CML165-3-3-2-1, CML161/CML165-3-1-1-3 and HORA-4-1-2-1 displayed negative and significant GCA effects for ear diameter (Table 5). GCA effect for grain yield of parental lines ranged between 1282.91 (CML161/CML165-3-1-1-4) to 2867.73 (JJ/PA4-3-1-2-3).

Specific combining ability (SCA):

SCA effect analysis revealed that CML161/CML165-3-3-2-2//CML442/CML312 and CML161/CML165-3-1-1-3//CML395/CML202 had significant negative SCA effect whereas CML161/CML165-3-3-2-2//CML395/CML202 and CML161/CML165-3-1-1-3//CML442/CML312 showed significant positive SCA effects for days to maturity (Table 6). Only crosses KULENI-5-3-2-3//CML442/CML312 and KULENI-5-3-2-3//CML395/CML202 displayed negative and positive significant SCA effect for ear height, respectively (Table 6). For

Table 4: (Continued)

Entry	HI (%)	TKWT(g))	EPP	KRE	NKR	EL(cm)	ED(cm)	GY(kg/ha)
L1 x T1	38.06^{a-e}	370.19^{fg}	1.24^{cde}	14.5^{a-e}	38.22^{a}	19.7^{a}	5.24^{abc}	9696.6^{b-f}
L1 x T2	40.89^{ab}	399.94^{b-g}	1.33^{a-e}	15.9^{ab}	33.58^{a}	18.9^{a}	5.17^{a-d}	10085.7^{b-f}
L2 x T1	38.93^{a-d}	472.61^{a-e}	1.33^{a-e}	13.9^{b-e}	33.35^{a}	17.6^{a}	5.23^{a-d}	10023.7^{b-f}
L2 x T2	38.34^{a-d}	477.95^{abc}	1.03^{e}	14.2^{b-e}	33.32^{a}	19.4^{a}	5.20^{a-d}	9723.9^{b-f}
L3 x T1	38.06^{a-e}	394.79^{b-g}	1.44^{a-e}	14.7^{a-e}	34.78^{a}	18.6^{a}	5.07^{a-f}	8500.1^{def}
L3 x T2	38.66^{a-d}	392.81^{b-g}	1.14^{de}	14.8^{a-e}	35.76^{a}	19.6^{a}	5.38^{a}	8561.6^{def}
L4 x T1	37.46^{a-e}	384.06^{c-g}	1.74^{a}	13.2^{c-f}	36.16^{a}	17.9^{a}	4.98^{a-f}	12680.7^{a}
L4 x T2	37.32^{a-e}	509.46^{a}	1.51^{a-d}	14.3^{a-e}	36.38^{a}	19.3^{a}	5.26^{ab}	12682.2^{a}
L5 x T1	39.90^{abc}	414.05^{a-g}	1.48^{a-d}	13.3^{c-f}	33.92^{a}	18.9^{a}	5.07^{a-f}	9117.7^{b-f}
L5 x T2	38.07^{a-e}	372.60^{fg}	1.36^{a-e}	14.3^{a-e}	32.82^{a}	17.8^{a}	4.93^{b-f}	8227.3^{f}
L6 x T1	41.11^{a}	413.34^{a-g}	1.25^{cde}	14.0^{b-e}	35.77^{a}	20.6^{a}	5.03^{a-f}	10754.8^{a-e}
L6 x T2	35.54^{a-e}	449.58^{a-f}	1.14^{de}	13.6^{b-f}	37.92^{a}	20.5^{a}	5.05^{a-f}	8873.4^{b-f}
L7 x T1	37.33^{a-e}	423.51^{a-f}	1.69^{ab}	13.5^{b-f}	36.68^{a}	19.3^{a}	4.82^{c-f}	11062.0^{abc}
L7 x T2	34.32^{a-e}	451.89^{a-f}	1.25^{cde}	13.5^{b-f}	34.38^{a}	21.2^{a}	4.97^{a-f}	9018.3^{b-f}
L8 x T1	37.94^{a-e}	380.04^{c-g}	1.49^{a-d}	13.5^{b-f}	36.24^{a}	18.9^{a}	4.83^{c-f}	9597.2^{b-f}
L8 x T2	41.70^{a}	404.81^{b-g}	1.21^{cde}	15.1^{a-e}	36.70^{a}	20.9^{a}	5.01^{a-f}	9677.1^{b-f}
L9 x T1	41.47^{a}	380.64^{c-g}	1.27^{b-e}	15.0^{a-e}	33.38^{a}	17.3^{a}	5.12^{a-e}	9061.6^{b-f}
L9 x T2	40.52^{ab}	469.57^{a-f}	1.02^{e}	14.9^{a-e}	34.90^{a}	21.2^{a}	5.21^{a-d}	8343.3^{ef}
L10 x T1	35.34^{a-e}	423.32^{a-f}	1.43^{a-e}	14.3^{a-e}	34.24^{a}	18.3^{a}	5.19^{a-d}	10876.5^{a-d}
L10 x T2	39.47^{a-d}	384.41^{c-g}	1.32^{a-e}	15.9^{ab}	36.26^{a}	20.1^{a}	5.02^{a-f}	9387.6^{b-f}
L11 x T1	35.16^{a-e}	376.03^{d-g}	1.35^{a-e}	14.9^{a-e}	35.38^{a}	18.8^{a}	5.17^{a-d}	9311.4^{b-f}
L11 x T2	37.83^{a-e}	424.74^{a-f}	1.37^{a-e}	14.5^{a-e}	35.82^{a}	20.4^{a}	5.17^{a-d}	11293.5^{ab}
L12 x T1	33.50^{cde}	389.81^{c-g}	1.36^{a-e}	16.8^{a}	36.86^{a}	19.0^{a}	5.11^{a-e}	9583.6^{b-f}
L12 x T2	33.71^{cde}	447.68^{a-f}	1.14^{de}	15.7^{abc}	34.74^{a}	19.9^{a}	5.03^{a-f}	10854.1^{a-d}
L13 x T1	35.53^{a-e}	390.69^{c-g}	1.60^{abc}	13.6^{b-f}	35.78^{a}	19.2^{a}	4.85^{b-f}	9101.0^{b-f}
L13 x T2	36.71^{a-e}	418.52^{a-f}	1.33^{a-e}	13.9^{b-e}	34.42^{a}	20.1^{a}	4.81^{def}	9573.9^{b-f}
L14 x T1	40.69^{ab}	318.46^{g}	1.49^{a-d}	14.9^{a-e}	36.82^{a}	18.4^{a}	5.00^{a-f}	9680.6^{b-f}
L14 x T2	39.89^{abc}	388.28^{c-g}	1.23^{cde}	15.4^{a-d}	35.38^{a}	19.7^{a}	5.26^{ab}	9748.5^{b-f}
L15 x T1	38.31^{a-d}	400.54^{b-g}	1.74^{a}	12.9^{def}	32.16^{a}	19.1^{a}	4.84^{b-f}	8827.5^{c-f}
L15 x T2	39.73^{a-d}	463.06^{a-f}	1.57^{a-d}	14.1^{b-e}	35.92^{a}	19.2^{a}	5.12^{a-e}	10487.1^{a-f}
BH 540	39.07^{a-d}	476.38^{a-d}	1.32^{a-e}	13.0^{def}	32.16^{a}	18.4^{a}	4.74^{f}	9038.2^{b-f}
BH 660	33.12^{d}	509.02^{a}	1.44^{a-e}	12.6^{ef}	36.32^{a}	21.9^{a}	4.82^{c-f}	11310.2^{ab}
AMH851	31.59^{e}	492.62^{ab}	1.31^{a-e}	11.2^{f}	35.44^{a}	19.7^{a}	4.66^{f}	8830.8^{c-f}
Mean	37.73	420.16	1.36	14.24	35.21	19.39	5.04	9805.8
CV	5.31	7.22	9.69	5.39	6.15	5.65	2.50	7.48
R^2	0.82	0.85	0.83	0.84	0.61	0.71	0.84	0.87
F. Test	**	**	**	**	Ns	Ns	**	**

*=significant at 0.05 probability level, **=significant at 0.01 probability level, DF = degree of freedom, DA = days to anthesis, DS = days to silking, DM = maturity of date, PH = plant height (cm), EH = ear height (cm), PA = plant aspect, EA = ear aspect, HI = harvest index (%), TKWT = thousand kernel weight (gram), EPP = ear per plant (number), KRE = number of kernel row per ear, NKR = number of kernel per row, EL = ear length (cm), ED = ear diameter (cm) and grain yield (kg/ha).

harvest index, CML161/CML165-3-3-2-2//CML395/CML202 had significantly positive SCA effects whereas CML161/CML165-3-3-2-2//CML442/CML312 had significantly negative SCA effects. JJ/PA4-3-1-2-3//CML442/CML312 showed positive and significant SCA effects for thousand kernel weights whereas cross JJ/PA4-3-1-2-3//CML395/CML202 displayed negative and significant SCA effects (Table 6). The SCA value of grain yield ranged from -1035.67 (KULENI-5-3-2-3//CML395/CML202) to 1035.67 (KULENI-5-3-2-3//CML442/CML312).

DISCUSSION

Combining ability analysis is associated with additive genetic effects while SCA is associated with non-additive genetic effects (Falconer & Mackay, 1996). GCA mean squares due to lines were highly significant for all parameters studied. The SCA mean squares of the line x tester were significant only for days to maturity, ear height, harvest index and thousand kernel weight. The existence of significant differences for traits indicates the presence of inherent variation among the materials and hence, selection is possible. Significant GCA and SCA mean squares indicate the contribution of both additive and non-additive gene action in controlling the expression of traits. The predominance of GCA sums of squares to SCA sums of squares indicates the relative importance of additive gene action to non-additive gene action while the predominance of SCA sums

Table 5: Estimates of general combining ability (GCA) effects for maize inbred lines and testers

Lines	**DA**	**DS**	**DM**	**PH**	**EH**	**PA**	**EA**	**HI**	**TKWT**	**EPP**	**KRE**	**ED**	**GY**
1	-0.82	-0.88	-0.82	9.15	-4.91	-0.02	0.11	1.43	-27.85	-0.08	0.76	0.13*	77.40
2	-2.82**	-2.13**	-0.82	-21.00**	-9.36*	-0.27	-0.02	0.59	62.37**	-0.18**	-0.39	0.14*	60.06
3	1.93**	1.62**	-3.57**	6.60	7.09	-0.02	0.23	0.31	-19.11	-0.07	0.31	0.15*	-1282.91**
4	-0.82	-1.13*	0.18	16.75**	12.54**	-0.14	-0.39*	-0.66	33.85*	0.26**	-0.69	0.05	2867.73**
5	-2.32**	-1.13*	-2.07*	-15.30**	-22.46**	0.48**	0.11	0.94	-19.59	0.06	-0.64	-0.07	-1141.24**
6	-1.07	-1.38*	1.68	6.85	9.09*	0.11	0.23	0.28	18.55	-0.17*	-0.64	-0.03	0.32
7	-1.82	-2.63**	3.18**	-6.20	-6.06	0.23	0.23	-2.22*	24.79	0.11	-0.94*	-0.18**	226.40
8	0.18	-1.13*	-0.82	7.40	14.04**	-0.14	-0.02	1.77	-20.49	-0.01	-0.14	-0.15*	-176.60
9	-0.57	-0.13	-1.82	-4.10	-12.16**	-0.27	-0.14	2.95**	12.19	-0.22**	0.51	0.09	-1111.28**
10	1.93**	2.12**	-0.07	-6.25	-9.76*	-0.27	-0.27	-0.64	-9.05	0.01	0.66	0.03	318.30
11	1.43*	1.62**	-0.07	14.00*	13.39**	-0.39*	0.11	-1.55	-12.53	0.00	0.26	0.10	488.70
12	1.43*	1.62**	6.93**	1.75	-0.26	-0.02	0.11	-4.44**	5.83	-0.11	1.81**	0.00	405.10
13	2.68**	3.87**	-0.57	23.20**	17.04**	0.36*	-0.27	-1.93	-8.31	0.11	-0.69	-0.24**	-476.31
14	-0.07	-0.88	-0.32	-16.40**	-3.41	-0.02	0.48**	2.24*	-59.54**	0.00	0.71	0.06	-99.21
15	0.68	0.62	-1.07	-16.50**	-4.86	0.36*	-0.52**	0.97	18.89	0.29**	-0.94*	-0.09	-156.48
SE	0.64	0.54	0.95	5.10	3.99	0.15	0.17	1.00	14.72	0.06	0.39	0.06	380.94
SEd	0.90	0.76	1.34	7.22	5.64	0.21	0.25	1.41	20.82	0.09	0.55	0.08	538.72
Testers	DA	DS	DM	PH	EH	PA	EA	HI	TKWT	EPP	KRE	ED	GY
1	0.9**	0.78**	-0.02	3.36	6.41**	0.1	-0.18**	-0.13	-17.44**	0.10**	-0.24	-0.03	44.58
2	-0.9**	-0.78**	0.02	-3.36	-6.41**	-0.1	0.18**	0.13	17.44**	-0.10**	0.24	0.03	-44.58
SE	0.23	0.20	0.34	1.86	1.45	0.05	0.06	0.36	5.37	0.02	0.14	0.02	139.09
SEd	0.33	0.28	0.49	2.63	2.06	0.07	0.09	0.51	7.60	0.03	0.20	0.03	196.71

*=significant at 0.05 probability level, **=significant at 0.01 probability level, DA = days to anthesis, DS = days to silking, DM = days to maturity, PH = plant height (cm), EH = ear height (cm), PA = plant aspect, EA = ear aspect, HI = harvest index (%), TKWT = thousand kernel weight (gram), EPP = ear per plant (number), KRE = number of kernel row per ear, ED = ear diameter (cm) and grain yield (kg/ha), SE = Standard error and SEd = Standard error difference.

Table 6: Estimates of specific combining ability (SCA) effects of thirty crosses

Cross	DM	EH	HI	TWKT	GY
L1 x T1	1.52	3.49	-1.29	2.56	-239.15
L1 x T2	-1.52	-3.49	1.29	-2.56	239.15
L2 x T1	-1.98	5.64	0.43	14.77	105.34
L2 x T2	1.98	-5.64	-0.43	-14.77	-105.34
L3 x T1	-0.23	-2.51	-0.17	18.43	-75.33
L3 x T2	0.23	2.51	0.17	-18.43	75.33
L4 x T1	0.02	-6.66	0.20	-45.26*	-45.31
L4 x T2	-0.02	6.66	-0.20	45.26*	45.31
L5 x T1	0.27	-0.56	1.05	38.16	400.62
L5 x T2	-0.27	0.56	-1.05	-38.16	-400.62
L6 x T1	3.02*	1.89	2.92*	-0.68	896.13
L6 x T2	-3.02*	-1.89	-2.92*	0.68	-896.13
L7 x T1	2.52	0.54	1.63	3.25	977.27
L7 x T2	-2.52	-0.54	-1.63	-3.25	-977.27
L8 x T1	-2.98*	-0.56	-1.75	5.06	-84.56
L8 x T2	2.98*	0.56	1.75	-5.06	84.56
L9 x T1	-0.98	0.84	0.60	-27.02	314.55
L9 x T2	0.98	-0.84	-0.60	27.02	-314.55
L10 x T1	-0.23	-6.06	-1.93	36.89	699.83
L10 x T2	0.23	6.06	1.93	-36.89	-699.83
L11 x T1	-0.23	14.29*	-1.21	-6.91	-1035.67
L11 x T2	0.23	-14.29*	1.21	6.91	1035.67
L12 x T1	-0.23	-10.26	0.03	-11.49	-679.79
L12 x T2	0.23	10.26	-0.03	11.49	679.79
L13 x T1	1.77	-7.36	-0.46	3.53	-281.05
L13 x T2	-1.77	7.36	0.46	-3.53	281.05
L14 x T1	0.52	2.69	0.53	-17.47	-78.53
L14 x T2	-0.52	-2.69	-0.53	17.47	78.53
L15 x T1	-2.73	4.54	-0.58	-13.82	-874.37
L15 x T2	2.73	-4.54	0.58	13.82	874.37
SE	1.34	5.64	1.41	20.82	538.72
SEd	1.90	7.99	2.00	29.44	761.87

*=significant at 0.05 probability level, **=significant at 0.01 probability level, DM = days to maturity, EH = ear height (cm), HI = harvest index (%), TKWT = thousand kernel weight (gram) and grain yield (kg/ha), SE = Standard error and SEd = Standard error difference.

of squares implies the relative importance of non-additive gene action. However, mean squares due to SCA was non-significant for days to anthesis, days to silking, plant height, plant and ear aspect, ears per plant number of kernel row per ear,ear diameter and grain yield indicating that only additive gene actions contributed to the inheritance of these traits (Dabholkar, 1992).

The estimate of GCA effects of inbred lines is an important indicator of their potential for generating superior breeding genotypes. High positive GCA is desirable for grain yield, ears per plant, thousand kernel weight, number of kernel rows per ear, number of kernels per row, harvest index, ear length, ear diameter and thousand kernel weights while high negative effects are desirable for the other traits. In the current study, inbred lines that showed significant and negative general combining ability effects for days to anthesis and silking could be considered as good general combiners for developing early maturing hybrids to escape late coming disease and pest infestation as well as terminal moisture stress. This study agreed with Habtamu (2015) and Girma et al. (2015) who reported significant negative GCA effects of lines and suggested that lines with highly significant GCA effects in the negative direction could be used in breeding programs for early maturity. JJ/PA4-3-1-2-3 was the best general combiner for grain yield with significant and positive GCA effect and can be used for development of high yielding hybrids by contributing desirable alleles. Positive significant GCA effects for maize lines indicated that they are desirable parents for maize hybrid development and involvement in the maize breeding program as they can be good allele source in the process of varietal development. CML161/CML165-3-1-1-4 was the poorest general combiner for grain yield with significant and negative GCA effect followed by CML161/CML165-4-1-1-3 (-1141.24) and KULENI-5-3-2-1 (-1111.28) signifying that those lines were undesirable combiner for developing high yielding hybrids. Similar to this study, both positive and negative GCA effects were reported in maize by several investigators (Alamerew & Warsi, 2015).

The specific combining ability effect is an essential criterion to determine the usefulness of hybrids. SCA mean squares were not significant for most traits, including grain yield, except days to maturity, ear height, harvest index and thousand kernel weights indicating that non-additive genetic effects are less important. Consistent with this finding, Vasal et al. (1993) reported lack of non-additive gene action for grain yield and other agronomic traits. Baker (1978) indicated that when SCA mean squares are not significant, the performance of a single cross progeny can be adequately predicted on the basis of GCA effects. Among thirty crosses evaluated, none of the hybrids showed positive and negative significant SCA effect for grain yield but cross KULENI-5-3-2-3//CML442/CML312 relatively displayed better specific combiners for grain yield. The potential crosses should be tested further and released as new hybrids if their performance remains consistently high over seasons and locations. This result is in line with the previous finding of Amare et al. (2016) who reported non-significant SCA effect among hybrids for grain yield.

In conclusion, among the inbred lines, CML161/CML165-3-1-1-4 and JJ/PA4-3-1-2-3 were good general combiners for days to maturity and grain yield, respectively. Significant SCA effects were observed for some traits in some cross combinations. For instance, crosses CML161/CML165-3-3-2-2//CML442/CML312 and CML161/CML165-3-1-1-3//CML395/CML202; and JJ/PA4-3-1-2-3//CML442/CML312 were the best specific combiners for days to maturity and thousand kernel weight, respectively. These crosses could be included for further studies for the improvement of grain yield and related traits. No significant SCA effects exhibited for grain yield in the cross combinations, while cross KULENI-5-3-2-3//CML442/CML312 followed by CML161/CML165-3-3-2-1//CML395/CML202 and CML161/CML165-3-3-2-2//CML395/CML202 were relatively better specific combiners for grain yield. Cross combinations with desirable SCA effects and better yield performance would be tested in multi-location trial to identify better-performing cross among them.

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