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Combining ability of selected maize (*Zea mays* L.) inbred lines for major diseases, grain yield and selected agronomic traits evaluated at Melko, South West Oromia region, Ethiopia

Gemechu Nedi[1*], Leta Tulu[2], Sentayehu Alamerew[3] and Dagne Wakgery[4]

[1]Ambo University, P. O. Box, 19, Ambo, Ethiopia.
[2]Holeta Agricultural Biotechnology Research Center, Holeta, Ethiopia.
[3]College of Agriculture and Veterinary Medicine, Jimma University, P. O. Box, 370, Jimma, Ethiopia.
[4]International Livestock Research Institute, CIMMYT, Ethiopia.

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The genetic potentials of resistance to turcicum leaf blight (TLB), grey leaf spot (GLS), and common rust (CR) disease, grain yield and selected agronomic trait were studied in 45 F1 hybrids from a half diallel following Griffing's Model 1, Method 4. The 45 hybrids excluding parents were evaluated in 5 × 9 alpha lattice designs with three replications. The study was carried out at Jimma Agricultural Research Center during 2015 cropping season with the objective to evaluate combining ability for turcicum leaf blight, grey leaf spot, common rust disease, grain yield and selected agronomic trait in maize inbred lines. For analysis of variance, days to 50% anthesis, days to 50% silking, turcicum leaf blight, grey leaf spot, common rust disease severity index, days to maturity and grain yield data were collected. Mean square due to general combining ability (GCA) was highly significant (P ≤ 0.01) for all traits, while specific combining ability (SCA) mean square was non-significant except for grain yield, days to 50% tasseling, days to 50% of silking, and days to maturity. This study showed the importance of additive types of gene action in controlling the inheritance of the traits. Among ten inbred lines, L7 and L10 were best combiners for GLS tolerance with the highest negative value of GCA effects and inbred line L7 was the best combiner for TLB and CR tolerance with the highest negative value of GCA effect. Inbred lines L2 and L9 were best combiner for grain yield with the highest positive GCA effect value. Therefore, maize breeding program can engage in hybridization and synthetic variety formation based on the information of inbred lines with high negative value GCA effect for diseases tolerant and high GCA for grain yield.

Key words: Combining ability, general combining ability (GCA), inbred lines, specific combining ability (SCA).

INTRODUCTION

Maize (*Zea mays*) is the third most important cereal crop in the world after rice and wheat in production and it is stable food crop in Ethiopia. It is believed to have originated in Mexico and to have been introduced to Ethiopia in the 1600s to 1700s (McCann, 2005). It is cultivated in a wider range of environments than wheat and rice, because of its greater adaptability (Koutsika-Sotiriou, 1999).

In Ethiopia, maize grows under a wide range of environmental conditions between 500 and 2400 m above sea level. The mid-altitude sub-humid agro-ecology is the most important maize producing environment in Ethiopia (Kebede et al., 1993). Therefore, maize production in Ethiopia is constrained by a number of abiotic and biotic stress factors, including pests and diseases (northern leaf blight, gray leaf spot, maize streak virus, rust and downy mildew) (Dagne et al., 2004).

Turcicum leaf blight (TLB), caused by the fungi *Exserohilum turcicum* is one of the widely distributed and economically very important diseases of maize production in the country. The infection appears during both off- and main-seasons, but it is more serious during the main-season in constantly wet and humid areas (Mosisa et al., 2012). According to Tewabech et al. (2012), the northern corn leaf blight (*E. turcicum*) has been reported to cause the highest grain yield loss of 50 and 16.4% loss of 1000 kernel weight on the susceptible cultivar.

The other leaf diseases including grey leaf spot (*Cercospora zeae-maydis* Tehon & Daniels) and common leaf rust (*Puccinia sorghi* Schr.) are also the most important infectious diseases of maize in the country. The disease incidence ranges from 95 to 100% in areas with constant moisture and high humidity and the yield loss can reach up to 70% (Tewabech et al., 2012).

To use inbred lines in hybrid breeding program, evaluation of inbred lines based on per se performance such as yield, disease tolerance and other character, and test cross performance, is the most common. For that reason, combining ability tests must be employed to choose individual inbred lines with potential for hybrid performance (Stoskopf et al., 1999). The diallel cross design proposed by Griffing (1956) is the first approach to testing combining ability, to know the type of gene action from the parent lines.

Diallel cross analysis also yields information on GCA and SCA of inbred lines. Combining ability analysis is one of the powerful tools in identifying the best combiners that may be used in crosses either to exploit heterosis or to accumulate productive genes. It also helps to understand the genetic architecture of various characters that enable the breeder to design effective breeding programs for future improvement of the existing materials (Sprague and Tatum, 1942). The combining ability could be used to provide information in the selection of elite inbred lines in order to establish the type of gene action, which controls the grey leaf spot resistance (Legesse et al., 2009).

Selection of inbred lines for hybrid breeding program has crucial role to produce hybrids which might perform better than the latest released commercial variety. Therefore, this study was under take to estimate general and specific combining ability in crosses of selected inbred lines and to identify inbred lines with better combining ability for grain yield and disease resistant traits for further use in breeding program.

MATERIALS AND METHODS

Experimental site

The experiment was carried out in the main cropping season of 2015 at Jimma Agricultural Research Centre (JARC) located at Melko. It is located in south western part of Oromia Region, 358 km from Addis Ababa and 12 km from Jimma Town. The center is located at 7°40' N' latitude and 36° E longitude at an altitude of 1753 m.a.s.l. The climate of the area is characterized as sub-humid with mean monthly maximum and minimum temperature of 26.3C and 11.6°C, respectively (IAR, 1997).

Experimental materials and management

Ten selected inbred lines (Table 1) were crossed in a half diallel following Griffing's Model 1, Method 4 (Griffing, 1956) and the resulting 45 F_1 hybrids (excluding parents) were evaluated in a 5 × 9 alpha lattice design (Patterson and Williams, 1976) in three replications. Each treatment was planted in two rows of 5.1 m length with spacing of 0.75 m between rows and 0.30 m between plants within the rows. The inbred lines used for crossing were selected in terms of resistance to major diseases (Grey Leaf Spot, Turccum Leaf Blight and Commun Rust). List of inbred lines is shown in Table 1.

Data collected

Ten plants were selected randomly in each plot and were labeled. These plants were measured individually and the mean value was recorded for the plot. The severity of major diseases such as grey leaf spot (GLS), TLB and common leaf rust (CR) was recorded on the whole plot using a 1 to 5 scale where 1=no symptoms, 2=moderate lesion below leaves subtending the ear, 3=heavy lesion development on and below the leaf subtending the ear with a few lesions above it, 4=severe lesion development on all but uppermost leaves may have few lesions and 5=all leaves dead. After the diseases were recorded; the severity of the disease was estimated using severity index formula (Wheeler, 1969):

$$\mathrm{DSI}\ \% = \frac{\textit{The sum of all disease rate plants multiplied under each scale}}{\textit{Total number of scored plants X Maximum disease scale}} X100$$

Grain yield was determined as weight of the total shelled grain after adjusting grain moisture to 12.5% and then converted to ton per hectare. Days to 50% anthesis was recorded as the number of days from planting to the day when 50% of the plant in a plot started

*Corresponding author. E-mail: gemenedi2017@gmail.com.

Table 1. List of parent inbred lines used in this study.

Lines code (Number)	Pedigree
1	[LZ-956343/LZ956003]-B-1-1-2-B-B/124-b(113)-3-1-1
2	Gibe1-91-1-1-1-1
3	CML444
4	DE78-Z-126-3-2-2-1-1-1(g)
5	30H83-3-5-1-1-1-1-1
6	CLM197
7	ILOO’E1-9-1-1-1-1-1
8	SZNYA99F2-7-2-1-1
9	30H83-7-1-5-1-1-1-1
10	SC-715-56-2-1-2-1-1

pollen shading. Days to 50% silking was recorded as the number of days from planting to the day when 50% of the plants in the plot had their silks emerged 2 to 3 cm above the sheath.

Data analysis

The statistical analysis of the data was carried out using SAS computer software version 9.2 (SAS, 2008) software. The plot based mean values for grain yield and other agronomic traits were subjected to analysis of variance (ANOVA) as described in Gomez and Gomez (1984). Analysis of combining ability was carried out as described in Griffing (1956). Significances of general combining ability and specific combining ability effects of the hybrids were determined by t-test using standard errors of GCA and SCA effect. The significance of GCA and SCA effects were tested by dividing the corresponding GCA and SCA effect values by their respective standard error and comparing the obtained t value with tabular t-value at error degree of freedom (Hailegebrial et al., 2015).

RESULTS AND DISCUSSION

Analysis of variance (ANOVA)

ANOVA showed significant difference among genotypes for all character. It showed highly significant ($P \leq 0.01$) and significant ($P \leq 0.05$) mean squares due to GCA for all traits, while mean square due to SCA was non-significant except for days to tessiling, days to silking, maturity date and grain yield traits (Table 2). This suggests that significant difference exists among the materials with respect to combining ability and thus both additive and non-additive gene actions were important for the expression of the traits.

Mean squares due to GCA and SCA were highly significant ($P \leq 0.01$) for grain yield. This indicated that the importance of both additive and non-additive types of gene action in controlling this trait. But the ratio of GCA/SCA was greater than unity for the trait, indicating that this trait is pre-dominantly controlled by additive type of gene action. Similarly Wende (2013) and Tessema et al. (2014) reported more importance of additive gene action than non-additive gene action for grain yield in maize. Mean square due to GCA showed highly significant difference ($P \leq 0.01$) for grey leaf spot, turcicum leaf blight and common rust, whereas SCA revealed non-significant difference (Table 2). This showed that as the resistant genes controlled by additive types of gene action for Grey leaf spot, turcicum leaf blight, and common rust diseases in this study. Cumulative gene action plays an important role in developing grey leaf spot, turcicum leaf blight and common rust tolerant variety. Similarly, an experiment conducted by Legesse et al. (2009) showed non-significant SCA mean square for northern leaf blight (NLB) diseases in combining ability and heterotic grouping of highland transition maize inbred lines. But in other study, Dagne et al. (2008) and Nzuve et al. (2013) reported that the GLS resistant gene was controlled by both additive and non-additive types of gene action.

Mean squares due to GCA and SCA were highly significant ($P \leq 0.01$) for days to 50% anthesis, days to 50% silking and days to maturity (Table 2), indicating that days to 50% anthesis and days to 50% silking were governed by both additive and no-additive types of gene action. But additive type of gene action had preponderance to control days to 50% anthesis and days to 50% silking traits, since GCA/SCA ration was greater than unity. Study conducted by Abdel-Moneam et al. (2009), Shushay (2014) and Habtamu (2015) also indicated the importance of additive and non-additive gene action for this trait. In contrast to this, Melkamu et al. (2013a) and Alam et al. (2008) reported the predominance of non-additive types of gene action for this trait in maize combining ability studies that were done in inbred lines.

General combining ability effect

The estimates of GCA effects of the parents for different characters are shown in Table 3. A wide range of variability for GCA effects was observed among the parents for disease resistance and in other traits.

Table 2. Analysis of variance for TLB, GLS, CR, grain yield and selected agronomic traits of inbred lines by half diallel method, 2015.

SV	Df	Mean squares						
		GY (t/ha)	GLS (1-5)	TLB (1-5)	CR (1-5)	AD (day)	SD (day)	MD (day)
Cross	44	3.8**	95.5*	123**	76.4*	13.9**	12.6**	9.8**
GCA	9	8**	233.2**	196.6**	111.7*	71.3**	64.1**	29.2**
SCA	35	2.4*	71.7	117	71.4	3.5**	3.7**	7**
GCA/SCA		3.3	3.3	1.7	1.6	20.4	17.3	4.2
CV (%)		14.9	21.2	18.5	22.9	1.7	1.5	1.2
Error	90	1.3	60.7	60.3	52.4	1.7	1.5	3.7

*,**Significant and highly significant at 0.05 and 0.01, respectively. AD: Days to anthesis (day), CR: common rust (1-5 scale), Df: degree of freedom, GCA: general combining ability, GLS: grey leaf spot (1-5 scale), GY: grain yield per hector (ton/h), MD: maturity date (day), TLB: turcicum leaf blight (1-5scale), SCA: specific combining ability, SD: days to silking (day), SV: source of variation.

Table 3. Analysis of general combining ability effects for the ten inbred lines for GLS, TLB, CR, grain yield and selected agronomic traits, 2015.

Trait Lines	GY (t/ha)	GLS (1-5)	TLB (1-5)	CR (1-5)	AD (day)	SD (day)	MD (day)
L1	-0.4	-2.3	4.1*	2.3	-1.4**	-0.9**	0.3
L 2	0.8**	2	-3	-1	1.1**	1.1**	0.3
L 3	0.1	4.6**	4.4*	3.6*	-2.1**	-2**	-1**
L 4	-0.2	-0.2	-0.4	1.3	-3.1**	-3.2**	-1.4**
L 5	-1**	-1.3	-1.5	-0.1	0.7*	0.4	2.1**
L 6	-0.6*	3.8*	2.3	1.6	1.0**	1**	0.8*
L 7	0.5*	-3.5*	-4.3*	-3.3*	-0.2	-0.3	-0.9*
L 8	-0.4	-0.3	0.5	-1.3	1.3**	1.3**	-0.1
L 9	0.7**	-2.5	-1.6	-0.8	0.2	0.6*	-1**
L 10	0.5*	-4.8**	-0.5	-2.3	2.5**	2**	0.9*
SE	0.2	1.5	1.7	1.4	0.3	0.2	0.4

*,**Significant and highly significant at 0.05 and 0.01, respectively. AD: Days to anthesis (day), CR: common rust, GLS: grey leaf spot, GY: grain yield per hectar (ton/ha), MD: maturity date (day), SD: days to silking (day), TLB: turcicum leaf blight.

General combining ability effect varied among lines in all the disease severity percentage; this means that there is a genetic variation between the lines. Usually, lines with negative and significant GCA effect values are good general combiner for disease tolerant variety development; whereas lines with positive and significant GCA effects values are poor general combiner. Inbred lines L7 and L10 showed negative and significant GCA effects for grey leaf spot, while only line L7showed negative and significant GCA effects for turcicum leaf blight and common rust disease as well. This indicates that these lines 7 and 10 have potential for tolerance to grey leaf spot disease and diseases useful in breeding program to develop resistant variety. Lines L3 and L6, for example, exhibited positive and significant GCA effects for grey leaf spot, turcicum leaf blight and common rust traits and line 1 for grey leaf spot; therefore, they might contribute diseases susceptible alleles in the synthesis of new varieties. The results of this study are in agreement with the findings from Dagne et al. (2008), Legesse et al. (2009) and Girma et al. (2015).

Four inbred lines (L2, L7, L9 and L10) were found to be the best general combiners for grain yield as these lines had showed significant and positive GCA effects (Table 3). Inbred lines with positive and significant GCA effects are desirable parents for hybrid development as well as for developing synthetic varieties as they may contribute favorable alleles in the synthesis of new varieties. Inbred lines L5 and L6 had negative and significant GCA effects indicating that these inbred lines were poor combiners for grain yield. Lines with positive and significant GCA effects have potential to form high yielding cross combinations with different number of lines. The results of this study are also in agreement with the findings of Dagne et al. (2007) and Tessema et al. (2014). Similarly, Legesse et al. (2009) and Amiruzzaman et al. (2010) reported negative and positive significant GCA effects for grain yield, respectively.

Among the ten inbred lines, eight exhibited significant GCA effects for days to anthesis, but only three lines (L1, L3 and L4) revealed negative and significant GCA effects which is important in developing early flowering hybrids in areas having short growing period. The five lines L2, L5, L6, L8 and L10 showed positive and significant GCA effects, which are undesirable for this trait (Table 3). Only three lines (L1, L3 and L4) revealed negative and significant GCA effects, whereas five lines (L2, L6, L8, L9 and L10) showed positive and significant GCA effects (Table 3) for days to 50% silkings trait. Inbred lines with negative and significant GCA effects are best general combiner for days to 50% silkings trait in breeding program as they are used to develop early maturing variety in low moisture areas and the reverse is true for areas receiving rainfall for longer periods.

Inbred lines with positive and significant GCA effects for days to silking had the tendency to increase late maturity, indicating that they could be used in breeding program to develop late mature varieties in long rain season receiving area. Similarly, negative and positive GCA effects were also reported by Dagne et al. (2008) and Girma et al. (2015). Lines L3, L4, L7 and L9 revealed negative and significant GCA effects; this indicated that they are the best general combiners for this trait in breeding program to develop early mature varieties. Nowadays, parent with negative and significant GCA effect for days to anthesis and days to silking are desirable in maize breeding, for areas with early termination of rain in Ethiopia to develop early mature varieties. Inbred lines L5, L6 and L10 displayed positive and significant GCA effects for days to maturity which are not desirable for drought stress areas. Similar results were reported by Habtamu (2015) for days to maturity.

Specific combining ability (SCA) effect

ANOVA for specific combining ability effects was carried out for traits which revealed significant mean squares due to specific combining ability. The estimated SCA effects of the crosses for grain yield and selected agronomic characters are shown in Table 4. Among the forty five crosses, only five hybrids (L3 × L7, L5 × L6, L6 × L7, L8 × L9, and L9 × L10) revealed significant SCA effects for grain yield (Table 4). Among forty five crosses, only the hybrid L6 × L7 exhibited positive and significant SCA effect for grain yield; this indicated that this cross has good specific combinations for grain yield. On the other hand, most of the hybrids showed positive SCA effects for grain yield. Such cross combination could be effectively exploited in maize hybrid breeding program, since there are dominance or epistasis gene effects. On other hand, L3 × L7, L5 × L6, L8 × L9, and L9 × L10 exhibited negative and significant SCA effects for grain yield which is an undesirable feature for this trait, as these crosses revealed reduced grain yield performance. The result of this study is in conformity with the findings of Dagne et al. (2008) and Hailegebrial et al. (2015), who also indicated positive and negative SCA effects for grain yield.

Among the forty five crosses, eight hybrids showed significant SCA effects for days to 50% anthesis (Table 4). Hybrids L1 × L3, L1 × L9, L2 × L10, L4 × L10, and L7 × L8 showed negative and significant SCA effects for the character desirable for drought stress area. Hybrid L7 × L8 (-2.6 days) showed maximum negative and significant SCA effect indicating that this combination increases early maturity of maize in breeding program. Hybrids L2 × L7, L3 × L8 and L7 × L10 exhibited positive and significant SCA effects which could be used in late mature maize variety development breeding program especially in long rain season area, because the highest positive SCA effect hybrid L7 × L10 for days to 50% anthesis exhibited also the highest grain yield (9.2 t/ha).

The maximum SCA effect is 2.2 days for days to 50% silking (L3 × L8), whereas the earliest SCA effect is -2.6 days for days to 50% silking of L7 × L8. Hybrids L1 × L3, L1 × L9, L2 × L10, L3 × L4 and L7 × L8 revealed negative and significant SCA effects for days to 50% silking, whereas L1 × L2, L1 × L8, L3 × L8 and L3 × L10 exhibited positive and significant SCA effects (Table 4). Negative and significant SCA effect for days to 50% silking is desirable in breeding programs to develop early mature maize variety, while positive and significant SCA effect for days to 50% silking is desirable to develop late mature variety. The results of this study are inconsistent with finding of Legesse et al. (2009). In contrast to this, Melkamu et al. (2013b) reported that none of the hybrids showed significant SCA effects for days to silking, since all the tested hybrids had similar days to 50% silking; this is because there is no more SCA effect variation within crosses for days to 50% silking.

Among forty five crosses, only eight hybrids revealed significant SCA effects for days to maturity (Table 4). Hybrids L1 × L2, L1 × L10, L5 × L6 and L5 × L10 exhibited negative and significant SCA effects, whereas hybrids L1 × L6, L2 × L10, L3 × L4 and L6 × L10 showed positive and significant SCA effects. The SCA effects revealed by the earliest hybrid cross (L1 × L2) for days to maturity showed only a seven-day difference as compared to the latest hybrid cross (L1 × L6). Even if crosses with negative and significant SCA effects was desirable at area receive short rain season, but most of the crosses, positive and significant SCA effects revealed the highest grain yield than crosses with negative and significant SCA effect hybrid in this study. This indicates that for long rain season, areas late mature maize variety is preferable. Hybrid with medium and long maturity time appeared resistant to the three common maize disease studied. Similarly, Dagne et al. (2008) reported positive and negative SCA effect for days to maturity in combining ability of maize inbred lines for grain yield and reaction to grey leaf spot disease. On the other hand, Girma et al. (2015) reported that crosses with negative and significant SCA effects for days to maturity can be exploited in hybrid breeding program in maize research for reduced maturity dates, while crosses with positive and significant

Table 4. Analysis of specific combining ability effects for grain yield and other traits, 2015.

Crosses	GY (t/ha)	AD (day)	SD (day)	MD (day)
L1×L 2	0.1	1	1.4*	-2.4*
L 1×L 3	-0.1	-1.7*	-2.2**	-1
L 1×L 4	-0.4	1.2	1.2	-0.8
L 1×L 5	0.4	-0.6	-1.1	0.8
L 1×L 6	1	0.4	0.4	4.2**
L 1×L 7	-0.8	-0.06	-0.3	1
L 1×L 8	0.5	1	1.4*	-1.3
L 1×L 9	-0.03	-1.5*	-1.8*	1.3
L 1×L 10	-0.4	-0.1	1.1	-1.9*
L 2×L 3	0.07	-0.3	-0.6	0.7
L 2×L 4	-0.08	-0.02	-0.1	-0.9
L 2×L 5	-0.3	-0.02	0.3	0.2
L 2×L 6	-0.5	0.9	0.1	-0.4
L 2×L 7	-0.4	1.5*	1.1	-1.5
L 2×L 8	0.7	-0.4	-0.6	1.7
L 2×L 9	0.3	-0.2	-0.2	0.3
L 2×L 10	0.2	-2.4**	-1.3*	2.4**
L 3×L 4	0.7	-0.8	-1.6*	2.1*
L 3×L 5	0.5	-0.2	-0.3	0.5
L 3×L 6	-0.1	-0.5	-0.1	-1.8
L 3×L 7	-2.1*	0.7	0.9	-0.1
L 3×L 8	0.5	1.8*	2.2**	-0.6
L 3×L 9	0.5	0.3	0.3	0.9
L 3×L 10	0.1	0.6	1.5*	-0.6
L 4×L 5	-0.5	0.5	0.6	0.2
L 4×L 6	-0.02	-0.7	-1	-0.8
L 4×L 7	0.6	-0.6	0.7	-0.1
L 4×L 8	-0.5	0.8	0.6	-0.2
L 4×L 9	0.3	1.2	0.4	-0.3
L 4×L 10	0.07	-1.4*	-1	0.5
L 5×L 6	-2.8**	0.7	0.5	-1.9*
L 5×L 7	0.4	-0.3	0.5	0.7
L 5×L 8	0.7	0.2	-0.01	0.9
L 5×L 9	0.9	0.3	0.8	0.8
L 5×L10	1.1	-0.6	-1	-2.1*
L 6×L 7	1.6*	-1	-0.2	-0.9
L 6×L 8	0.9	-1	-0.6	1.3
L 6×L 9	0.1	-0.1	0.2	-1.8
L 6×L 10	-0.02	1	0.8	2*
L 7×L 8	-0.8	-2.6**	-2.6**	-1.1
L 7×L 9	0.9	0.1	0.3	1.2
L 7×L10	0.7	2.2**	-0.2	1
L 8×L 9	-2.1*	-0.4	-0.1	-0.7
L 8×L 10	-0.2	0.7	-0.2	0.1
L 9×L 10	-1.3*	0.4	-0.2	-1.6
SE	0.6	0.7	0.6	0.9

*,**Significant and highly significant at 0.05 and 0.01, respectively. AD: Days to anthesis (day), GY: grain yield (ton/ha), MD: maturity date, SD: days to silking (day), SE: standard error.

SCA effect for days to maturity are undesirable as these crosses showed a tendency to increase maturity date.

Conclusion

In this study, inheritance of grey leaf spot, turcicum leaf blight and common rust maize disease were controlled by additive type of gene action. This suggests the possibility of breeding through recurrent selection and backcrosses to incorporate candidate genes into susceptible parents. Of the ten inbred lines, only L7 and L10 showed negative and significant GCA effects for GLS disease, whereas only L7 manifested negative and significant GCA effect for TLB and CR disease, which is a desirable character to develop disease tolerant variety. This means that these parents had potential to cross with many other inbred lines to develop disease tolerant hybrids in breeding program.

Lines L2, L7, L9 and L10 had positive and significant GCA effects for grain yield, which mean that these parents could be used to improved grain yield in breeding programs. Among the F1 crosses, only L6 × L7showed positive and significant SCA effects for grain yield indicating its potential for use in future breeding program to develop hybrid variety. Most of the crosses also revealed positive SCA effects for grain yield; therefore, they might be used in hybrid variety development program. Generally, the results of this study could be exploited to develop disease tolerant and high yield varieties of maize particularly adapted to middle-altitude agro-ecology areas. The cross combinations with good performance in terms of disease resistant and grain yield were recommended for further evaluation in multi-location experiments to confirm their tolerance to diseases, yield superiority and stability.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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