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Genetic analysis for grain yield and yield related traits in maize (*Zea mays* L.) inbred lines in line × tester mating design

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Maize is one of the most important cereal crop widely grown in the world. Maize crosses along with similar maturing checks were evaluated at Hawassa in 2015-2016 cropping season to understand the nature of gene action governing yield and its attributes through line × tester analysis and to study genetic contribution of line, tester and the interaction of line × tester to total variation. The experiment was done by using α-lattice design 6 × 11 arrangement. Cross L_{31}×T_2 showed the highest mean grain yield than both checks. The result showed that, lines played an important role towards days to anthesis, days to silking, ear length, number of rows per cob and number of kernels per row, indicating predominance of maternal lines. Based on analysis of genetic variance, traits variance due to specific combining ability (σ^2_{SCA}) was higher than variance due to general combining ability (σ^2_{GCA}) indicated, non-additive gene action was important than additive gene action in the inheritance of these traits. These best cross combinations could be effectively utilized in maize breeding for the improvement of yield components and thus their incorporation in further breeding program is suggested.

Key words: Additive, non-additive, cross, genotypes, line × tester, yield.

INTRODUCTION

Maize is one of the most important cereal crops in the world after wheat and rice. Maize is nutritionally, an important crop used as food and feed. It is a source of industrial materials for the production of fuel, oil, starch, syrup; gluten, alcohol, glucose, ethanol and many more products. Its cultivation extends over a wide range of geographical and environmental conditions ranging from 58°N to 40°S. Portuguese traders introduced maize to Ethiopia in 16^{th} or 17^{th} century (Haffnagel, 1961). Currently, in Ethiopia, maize is one of the most important cereal crops grown in almost all parts of the country. The popularity of maize in Ethiopia is partly because of its high value as a food, fodder and source of fuel for rural area. Approximately, 88% of maize produced in Ethiopia is consumed as food, both as green and dry grain (Abate et al., 2015). The total annual production and productivity of maize in Ethiopia exceeds all other cereal crops except Tef in area coverage (Mosisa et al., 2011).

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Objective of maize breeding programs is evaluation of best yielding and adaptive. Improvement of varieties (genotypes) needs deep genetic information. Breeders conducted a genetic analysis for yield and yield related traits of genotypes. In fact, maize has been subjected to extensive genetic studies than any other crop (Hallauer and Miranda, 1988). Several biometrical techniques were used to study genetic analysis of quantitative traits. Among them, line × tester is suggested by Kempthorne (1957) and is used to breed both self and cross pollination plants. This method of efficient study on large number of lines provides reliable estimates of genetic components, estimates of specific combining ability (SCA), general combining ability (GCA) and gene action governing quantitative traits.

Therefore, the current study aimed to understand the nature of gene action governing yield and its attributes through line × tester analysis and to study genetic contribution of line, tester and the interaction of line × tester and total variation.

MATERIALS AND METHODS

Experimental materials and design

Hawassa is situated at 7°4′N and 38°31′E latitude and longitude, respectively, at an altitude of 1700 m.a.s.l. in the central rift valley of Ethiopia. Sixty-four crosses were developed by crossing 32 inbred lines with two testers in line × tester mating design (Kemperton, 1957). Inbred lines (32) were coded as L_1, L_2…L_{32} and two testers CML-144 (F2) -21-2-2-1- 1/CML144 and CML-144 (F2) -15-2-2-2-1/CML159 were coded as T_1 and T2. Sixty-four crosses were planted along with similarly maturing checks BHQPY-545 and BH-546 at Hawassa. The experiment was planted by using α-lattice design 6×11 arrangement (Patterson and Williams, 1976) with two replications. Each block comprises of 11 units having 5.1 m long and 9.75 m width with the spacing of 0.75 m between rows and 0.30 m between plants. All cultural practices were performed as per required (Table 1a).

Data like days to maturity (DM), field weight, seed moisture content and thousand kernel weight (TKW) were collected plot bases while data like plant height (PH), ear height (EH), ear length (EL), number of rows per ear (NRPE), ear diameter (ED) and number of kernels per row (NCPR) were collected on plant bases. Biomass (BM) and grain yield (GY) was calculated by using the following formula:

$$\text{Grain yield (t ha}^{-1}\text{)} = \frac{\text{Fresher weigh} \times (100\text{-MC}) \times 0.8{*}17 \times 10{,}000}{n \times 85 \times 3.85 \times 100\ \text{kg}}$$

Where: MC = moisture content of grain at harvest, 0.8 = shelling percentage, 85 = standard moisture content of grain, n = number of plants harvested, 17 = total number of plants in a plot, 10000 = area of hectare in square meters.

Data analysis

All data obtained were subjected to SAS computer software to test the significance genotypes (Gomez and Gomez, 1984). Genetic parameter analysis and proportional contribution of line tester and line × tester were done only for tr.

Genetic parameter analysis

$$\sigma^2\text{GCA}=\frac{MSl-\frac{MSlxt}{rt}+MSt-\frac{MSlxt}{lr}}{rtl}$$

$$\sigma^2\text{SCA}=MSt-\frac{MSlxt}{r}$$

The ratio of σ²GCA to σ²SCA was expressed as $\frac{\sigma^2\text{GCA}}{\sigma^2\text{SCA}}$

Additive variance

σ²l=[Ms(l)-Mse]/rt=1/2σ²A   σ²A=2σ²l

σ²t=[Ms(t)-Mse]/rl=1/2σ²A   σ²A=2σ²t

σ²A=[2σ²l+2σ²t]/2=σ²l+2σ²t

σ²D=dominance variance

σ²lt=[Ms(l×t)-Mse]/r= σ²D

Average degree of dominance (ā) was calculated according to the following equation:

$\bar{a}=\sqrt{2}\sigma^2\text{D}/\sigma^2\text{A}$

if ā = 0 no dominance

if ā = <1> 0 partial dominance

if ā = 1 complete dominance

if ā > 1 over dominance

Where: σ²GCA = variance of general combining ability, σ²SCA = variance of specific combining ability, MSl = mean square of line, MSt = mean square of tester, MSl×t = mean square of line × tester, l = line, t = tester, r = replications.

Proportional contribution of line, tester and line × tester to total variation in hybrid combinations

The percentage contribution of lines (females), testers (males) and line × tester to the hybrids were calculated according to Abuali et al. (2016):

Percentage contribution of line $=\frac{SS\ (l)}{SS\ (c)}x100$

Percentage contribution of tester $=\frac{SS\ (t)}{SS\ (c)}x100$

Percentage contribution of Line ×Tester $=\frac{SS\ (L\times T)}{SS\ (c)}x100$

Where, SS (c) = sum square of cross, SS (l) = sum square line, SS (t) = sum square tester, SS (L×T) = sum square of line × tester, l = line, t = tester, r = replications.

RESULTS AND DISCUSSION

Genetic parameters analysis

The analysis of variance showed that, there was a significance difference between genotypes for all traits. The analysis of variance indicated that, sufficient genetic variability is present among genotypes for all characters (Table 1b). Variance due to SCA ($σ^2_{SCA}$) was higher than variance due to general combining ability ($σ^2_{GCA}$) and the ratio of $σ^2_{GCA}$ to σ²SCA was less than one for traits like days to anthesis, days to silking, days to maturity, ear diameter, thousand kernel weight, grain yield and cob per plant which indicate, non-additive gene action was more important than additive gene action in the inheritance of these traits (Table 1). Non additive gene action is not easily fixable, implies that best hybrids were not easily identified for the following traits. Similarly, Atanaw et al. (2010) reported that, non-additive gene effects were important than additive gene effect for grain yield. Also, Kamara et al. (2014) found similar result for ear diameter and thousand kernel weight. $σ^2_{GCA}$ was larger than $σ^2_{SCA}$ in plant height, ear length, number of rows per cob, number of kernels per row and biomass which indicates the additive gene action played the great role in governing the inheritance of these traits than non-additive gene action (Table 1). Additive gene action is easily fixable, implying that, best hybrids were easily identified for the following traits. Alamnie et al. (2007) and Panhwar et al. (2008) reported that, additive gene effects were more important than non-additive gene effects for plant height and number of kernels per row. The result was pact with that of Sharma et al. (2004) who found preponderance of additive genetic effects in the control of traits like plant height, ear length, number of rows per cob, number of kernels per row and biomass. Similar result has been reported by different researchers (Irshad-El-Haq et al., 2010; El-Badawy, 2012; Aminu et al., 2014) for grain yield.

The value of additive gene effects was more than the value of dominance gene effect for plant height, ear length, number of kernels per row, number of rows per cob, while the value of dominance gene effects was higher than the value of additive gene effects for days to anthesis, days to silking, days to maturity, ear height, ear diameter, thousand seed weight and grain yield (Table 1). The average degree of dominance was more than one for days to anthesis, days to silking, days to maturity, ear height, ear diameter, thousand seed weight and grain yield, indicating these traits were under control of the over dominance gene effect, whereas the average dominance was zero for traits like plant height, ear length, number of kernels per row, number of row per cob indicate there was no dominance for the traits (Table 1).

Mean performance of genotypes (crosses and check)

The mean performances of genotypes are presented in Table 2. Top ten high yielding crosses relative to both checks were L31×T2 (8.68 t ha^{-1}), L8×T1 (8.25 t ha^{-1}), L26×T1 (7.70 t ha^{-1}), L23×T2 (7.56 t ha^{-1}), L12×T2 (7.04 t ha^{-1}), L16×T1 (7.00 t ha^{-1}), L23×T1 (7.00 t ha^{-1}), L21×T1 (6.93 t ha^{-1}), L21×T2 (6.91 t ha^{-1}) and L8×T2 (6.82 t ha^{-1}) (Table 2). The mean grain yield of check BHQPY-545 and BH-546 were 4.4 t ha^{-1} and 4.3 t ha^{-1}, respectively. Low yielding crosses in relation to checks were L2×T2 (4.24 t ha^{-1}), L6×T2 (3.59 t ha^{-1}), L7×T1 (4.37 t ha^{-1}), L9×T2 (4.03 t ha^{-1}), L11×T2 (3.81 t ha^{-1}), L14×T2 (3.67 t ha^{-1}), L17×T2 (2.88 t ha^{-1}), L20×T2 (3.93 t ha^{-1}), L25×T1 (3.88 t ha^{-1}), L26×T2 (3.82 t ha^{-1}) and L32×T1 (3.36 t ha^{-1}) (Table 2). The grain yield ranged from 2.88 t ha^{-1} (L17×T2) to 8.68 t ha^{-1} (L31×T2) with an overall mean of 5.55 t ha^{-1} (Table 1). Those crosses that had better mean values over standard checks indicate the possibility of obtaining promising hybrid variety with desirable traits. Highest mean number of days to maturity was obtained for cross L11×T1 (166 days), while the lowest mean number of days to maturity was recorded for cross L12×T2 (149.5 days). Three crosses L12×T2 (-5.5 days), L21×T2 (-4.5) and L27×T2 (-4.5 days) were early as compared to both standard checks BHQPY-545 and BH-546 (Appendix 2). Plant height for genotypes ranges from 165 (L2×T1) to 254 cm (L31×T2) with the mean 207.5 cm. Ear height for genotypes ranges from 95 ($L_7×T_2$) to 134 cm (L19×T2) with the mean of 110 cm (Table 2).

Proportional contribution of line, tester and line × tester

The proportional contribution of lines, testers and the interaction of line ×tester to the total variances are presented in Table 3. The result showed that, lines played an important role in days to anthesis, days to silking, ear length, number of rows per cob and number of kernels per row, indicating that predominant of maternal (lines) influence these traits and higher estimates of variance due to GCA (Table 3). The contribution of testers was low for all traits, which indicates higher estimates of variances due to SCA. The contribution of line × tester interactions played an important role in days to maturity, plant height, ear height, ear diameter, thousand kernel weight and grain yield, which indicate higher estimates of variances due to non-additive genetic effects and the importance of SCA. Shams et al. (2010) observed higher estimates of SCA variance due to line × tester. Aminu et al. (2014) also found the proportional contribution of line × tester was greater than tester for grain yield, plant height, ear height, thousand kernels weight and ear length of their study on combining ability and heterosis for phenologic and agronomic traits in maize (*Zea mays* L.) under drought conditions. In contrast, Shams et al. (2010) found proportional contribution of line × tester interaction was greater than line and tester for number of kernels per row and proportional contribution of tester was greater than line and the interaction line × tester in number of rows per

Table 1a. List of crosses and checks used in the experiment.

StockID	Pedigree	Code
BK152-1	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-4-1-1-1-1/CML144	L_1×T_1
BK152-2	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-4-1-1-1-1/CML159	L1×T2
BK152-3	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-4-2-2-1-1/CML144	L2×T1
BK152-4	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-4-2-2-1-1/CML159	L2×T2
BK152-5	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-4-3-2-1-1/CML144	L3×T1
BK152-6	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-4-3-2-1-1/CML159	L3×T2
BK152-7	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-1-1-1-1/CML144	L4×T1
BK152-8	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-1-1-1-1/CML159	L4×T2
BK152-9	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-1-1-1/CML144	L5×T1
BK152-10	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-1-1-1/CML159	L5×T2
BK152-11	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-1-1-2/CML144	L6×T1
BK152-12	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-1-1-2/CML159	L6×T2
BK152-13	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-1-2-1/CML144	L7×T1
BK152-14	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-1-2-1/CML159	L7×T2
BK152-15	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-2-2-1/CML144	L8×T1
BK152-16	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-2-2-1/CML159	L8×T2
BK152-17	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-3-1-1/CML144	L9×T1
BK152-18	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-3-1-1/CML159	L9×T2
BK152-19	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-3-2-1/CML144	L10×T1
BK152-20	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-15-2-3-2-1/CML159	L10×T2
BK152-21	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-17-3-1-1-1/CML144	L11×T1
BK152-22	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-17-3-1-1-1/CML159	L11×T2
BK152-23	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-17-3-1-2-1/CML144	L12×T1
BK152-24	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-17-3-1-2-1/CML159	L12×T2
BK152-25	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-17-3-2-1-1/CML144	L13×T1
BK152-26	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-17-3-2-1-1/CML159	L13×T2
BK152-27	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-21-2-2-1-1/CML144	L14×T1
BK152-28	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-21-2-2-1-1/CML159	L14×T2
BK152-30	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-48-1-1-1-1/CML144	L15×T1
BK152-31	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-48-1-1-1-1/CML159	L15×T2
BK152-32	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-48-2-1-1-1/CML144	L16×T1
BK152-33	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-48-2-1-1-1/CML159	L16×T2
BK152-34	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-50-3-1-1-1/CML144	L17×T1
BK152-35	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-50-3-1-1-1/CML159	L17×T2
BK152-36	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-50-3-1-2-1/CML144	L18×T1
BK152-37	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-50-3-1-2-1/CML159	L18×T2
BK152-38	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-61-1-2-1-1/CML144	L19×T1
BK152-39	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-61-1-2-1-1/CML159	L19×T2
BK152-40	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-61-1-2-1-2/CML144	L20×T1
BK152-41	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-61-1-2-1-2/CML159	L20×T2
BK152-42	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-61-2-1-1-1/CML144	L21×T1
BK152-43	BK02-Z-311-28(F2)-B-1 × CML-144(F2)-61-2-1-1-1/CML159	L21×T2
BK152-44	BK02-Z-311-28(F2)-B-1-1-1-1/CML144	L22×T1
BK152-45	BK02-Z-311-28(F2)-B-1-1-1-1/CML159	L22×T2
BK152-46	BK02-Z-311-28(F2)-B-1-1-2-1-1/CML144	L23×T1
BK152-47	BK02-Z-311-28(F2)-B-1-1-2-1-1/CML159	L23×T2
BK152-48	BK02-Z-311-28(F2)-B-1-1-2-2-1/CML144	L24×T1
BK152-49	BK02-Z-311-28(F2)-B-1-1-2-2-1/CML159	L24×T2
BK152-50	BLWBAM-QPM2006 F2 -15-2-1-1-1-1/CML144	L25×T1
BK152-51	BLWBAM-QPM2006 F2 -15-2-1-1-1-1/CML159	L25×T2

Table 1a. Contd.

BK152-52	BLWBAM-QPM2006 F2 -15-2-1-1-2-1/CML144	L26×T1
BK152-53	BLWBAM-QPM2006 F2 -15-2-1-1-2-1/CML159	L26×T2
BK152-54	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-1-2-1-1/CML144	L27×T1
BK152-55	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-1-2-1-1/CML159	L27×T2
BK152-56	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-1-2-1-2/CML144	L28×T1
BK152-57	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-1-2-1-2/CML159	L28×T2
BK152-58	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-2-1-1-1/CML144	L29×T1
BK152-59	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-2-1-1-1/CML159	L29×T2
BK152-60	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-2-2-1-1/CML144	L30×T1
BK152-61	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-2-2-1-1/CML159	L30×T2
BK152-62	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-2-2-1-2/CML144	L31×T1
BK152-63	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-2-2-1-2/CML159	L31×T2
BK152-64	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-3-1-1-1/ CML144	L32×T1
BK152-65	(CML-142 × 144-7-b(F2) × 144-7-b(F2) × 144-7-b)-B-12-1-3-1-1-1/CML159	L_{32}×T_2
Checks	BHQPY-545	BHQPY-545
	BH-546	BH-546

Table 1b. Analysis of variance for phenological, growth parameters and yield of maize in maize crosses.

Source Variation	df	DA (days)	DS (days)	DM (days)	PH (cm)	EH (cm)	EL (cm)	NRPC (no)	NCPR (no)	ED (cm)	TSW (g)	GY (t/ha)
Replication	1	1.09^{ns}	0.61^{ns}	3.66^{ns}	1.94	303.03*	1.91^{ns}	0.02^{ns}	17.89^{ns}	0.03^{ns}	37.12^{ns}	0.69^{ns}
Block with in replication	5	9.10**	10.5**	14.8**	813.9**	376.5**	9.87**	0.60^{ns}	9.81^{ns}	0.17^{ns}	4687^{ns}	3.02*
Genotypes	65	6.05**	6.00**	14.96**	442.11*	115.2**	5.91**	0.54*	13.52*	0.13**	4824**	2.94**
Error	60	3.12	2.73	3.82	290.34	73.43	3.01	0.32*	8.55	0.09	50	1.58
σ^2_{GCA}		0.11	0.08	0.37	2.47	1.25	0.05	0.0001	0.12	0.01	88.9	0.06
σ^2_{SCA}		5.53	1.83	31.5	-210.8	26.9	-1.84	-0.29	-1.97	0.41	4952	4.01
$\sigma^2_{GCA}/\sigma^2_{SCA}$		0.02	0.04	0.01	-0.01	0.05	-0.03	0	-0.06	0.02	0.02	0.01
σ^2_A		0.43	0.31	1.49	9.89	5.01	0.2	0.01	0.47	0.02	355.93	2.39
σ^2_D		22.12	7.32	126	-843.2	107.6	-7.36	-1.19	-7.88	1.66	19808	1.6
ā		10.1	6.91	13.01	0	6.55	0	0	0	13.71	10.55	1.16

**Highly significant at P<0.01,* significant difference at P<0.05, ns=non-significant, DA=days to anthesis, DS = days to silking, DM = days to maturity, PH = plant height, EH = Ear height, EL=ear length, NRPC = number of rows per cob, NCPR = number of kernel per row, ED = ear diameter, TSW = thousand seed weight, GY = grain yield, (blk/R) = incomplete blocks with in replication, σ^2_{GCA} = variance of general combining ability, σ^2_{SCA} = variance of specific combining ability, σ^2_A = additive variance, σ^2_D = dominance variance, ā = average degree of dominance.

cob in maize using line × tester method.

Conclusion

The analysis of variance showed sufficient genetic variability among genotypes for all characters. σ²SCA was greater than σ²GCA for traits like days to anthesis, days to silking, days to maturity, ear diameter, thousand kernel weight, grain yield. σ²GCA was larger than σ²SCA in plant height, ear length, number of rows per cob, number of kernels per row and biomass. The proportional contribution of line is greater than tester and the interaction of line × tester for traits like days to anthesis, days to silking, ear length, number of rows per cob and number of kernels per row. The proportional contribution of line × tester is greater than line and tester for days to maturity, plant height, ear height, ear diameter, thousand kernel weight and grain yield.

CONFLICT OF INTERESTS

The author declares that there is no conflict of interest.

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Table 2. Mean performance of maize 64 crosses and 2 checks for phenological, growth parameters, grain yield and yield related traits of maize (*Zea mays* L.) in southern Ethiopia, Hawassa.

Crosses	DA (days)	DS (days)	DM (days)	PH (cm)	EH (cm)	EL (cm)	NRPC (no.)	NCPR (no.)	ED (cm)	TW (g)	GY (t ha^{-1})
$L_1 \times T_1$	77.5^{ab}	79.5^{ab}	156.5^{b-g}	209^{b-e}	112^{b-g}	17.8^{a-i}	14.2^{a-g}	35.2^{b-g}	4.53^{a-g}	303^{b-j}	5.74^{a-m}
L1×T2	74.5^{a-h}	77^{a-f}	154.5^{c-i}	194^{d-f}	100^{d-g}	16.0^{d-j}	15.4^{a}	36.2^{a-g}	4.80^{a-g}	290^{b-j}	5.19^{c-m}
L2×T1	75.5^{a-f}	78^{a-e}	158^{b-e}	165^{f}	95^{g}	14.6^{h-j}	13.2^{e-g}	33.3^{c-g}	4.53^{a-g}	293^{b-j}	4.45^{d-m}
L2×T2	73^{a-k}	75^{c-f}	158.5^{b-d}	224^{a-e}	120^{a-e}	17.5^{a-g}	14.0^{a-g}	35.9^{a-g}	4.57^{a-g}	303^{b-j}	4.24^{d-m}
L3×T1	77^{a-c}	80^{a}	156.5^{b-g}	193^{d-f}	103^{d-g}	16.9^{b-i}	14.0^{a-g}	37.6^{a-f}	4.65^{a-g}	253^{d-j}	5.24^{c-m}
L3×T2	73^{c-j}	75^{c-f}	157.5^{b-e}	195^{d-f}	109^{b-g}	16.2^{d-j}	14.2^{a-g}	36.4^{a-g}	4.34^{b-g}	285^{b-j}	5.25^{c-m}
L4×T1	72^{e-g}	74.5	157^{b-f}	209^{b-e}	113^{a-g}	17.5^{a-g}	13.9^{b-j}	38.0^{a-f}	4.55^{a-g}	295^{b-j}	5.56^{b-m}
L4×T2	76^{a-e}	78^{a-e}	153.5^{c-i}	201^{c-f}	108^{b-g}	17.5^{a-g}	13.9^{b-j}	38.7^{a-e}	4.54^{a-g}	285^{b-j}	5.73^{a-m}
L5×T1	73.5^{b-g}	75^{c-f}	154.5^{c-i}	215^{a-e}	113^{a-g}	16.5^{d-j}	13.9^{b-j}	35.3^{b-g}	4.78^{a-g}	288^{b-j}	6.06^{a-l}
L5×T2	73.5^{b-g}	75.5^{b-f}	157^{b-f}	246^{ab}	121^{a-d}	19.7^{a-e}	13.4^{d-f}	35.5^{b-g}	4.78^{a-g}	353^{a-g}	6.07^{a-l}
L6×T1	76.5^{a-d}	78.5^{a-d}	159^{bc}	207^{b-f}	113^{a-g}	15.5^{e-j}	13.6^{c-j}	33.9^{c-g}	4.63^{a-g}	258^{c-j}	6.49^{a-k}
L6×T2	77.5^{ab}	79.5^{ab}	156.5^{b-g}	191^{ef}	99^{e-g}	12.5^{j}	13.6^{c-j}	33.2^{c-g}	4.13^{g}	208^{ij}	3.59^{k-m}
L7×T1	74^{a-i}	76.5^{a-f}	155^{b-i}	192^{ef}	101^{d-g}	16.1^{d-j}	12.8^{g}	31.1^{fg}	4.55^{a-g}	263^{c-j}	4.37^{d-m}
L7×T2	77^{a-c}	79^{a-c}	156.5^{b-g}	211^{b-e}	95^{g}	17.6^{a-g}	14.6^{a-e}	37.9^{a-f}	4.70^{a-g}	293^{b-j}	5.67^{b-m}
L8×T1	76^{a-e}	78.5^{a-d}	157.5^{b-e}	235^{a-d}	123^{a-c}	19.5^{a-e}	14.4^{a-f}	39.2^{a-e}	5.07^{ab}	340^{a-g}	8.25^{ab}
L8×T2	73^{c-j}	75^{c-f}	158^{b-e}	213^{a-e}	113^{a-g}	19.6^{a-e}	14.0^{a-g}	37.4^{a-f}	4.79^{a-g}	338^{a-h}	6.81^{a-g}
L9×T1	75^{a-g}	77^{a-f}	158.5^{b-d}	203^{c-f}	100^{d-g}	16.1^{d-j}	14.9^{a-c}	34.5^{c-g}	4.62^{a-g}	308^{b-j}	5.53^{b-m}
L9×T2	77^{a-c}	78.5^{a-d}	154.5^{c-i}	189^{ef}	113^{a-g}	15.1^{f-j}	13.6^{c-j}	34.9^{c-g}	4.34^{b-g}	230^{g-j}	4.03^{e-m}
L10×T1	75.5^{a-f}	78^{a-e}	164^{a}	202^{c-f}	109^{b-g}	17.4^{a-g}	14.4^{a-f}	37.1^{a-g}	4.29^{c-g}	260^{c-j}	4.39^{d-m}
L10×T2	74.5^{a-h}	76.5^{a-f}	153.5^{c-i}	198^{c-f}	106^{b-g}	17.7^{a-g}	14.0^{a-g}	37.5^{a-f}	4.78^{a-g}	280^{b-j}	5.92^{a-l}
L11×T1	78^{a}	80^{a}	166^{a}	192^{ef}	99^{e-g}	16.2^{d-j}	13.4^{d-f}	35.4^{a-g}	4.78^{a-g}	330^{a-i}	5.86^{a-l}
L11×T2	75.5^{a-f}	77.5^{a-f}	156.5^{b-g}	185^{ef}	103^{d-g}	14.1^{ij}	14.4^{a-f}	34.4^{a-g}	4.17^{d-g}	200^{j}	3.81^{l-m}
L12×T1	74.5^{a-h}	76.5^{a-f}	157.5^{b-e}	225^{a-e}	119^{a-e}	18.2^{a-g}	14.0^{a-g}	36.1^{a-g}	4.89^{a-e}	343^{a-g}	6.58^{a-j}
L12×T2	75^{a-g}	77^{a-f}	149.5i	222^{a-e}	117^{a-f}	18.8^{a-g}	13.9^{b-j}	40.2^{ab}	4.75^{a-g}	338^{a-h}	7.00^{a-e}
L13×T1	71.5^{fg}	74^{ef}	158^{b-e}	199^{c-f}	109^{b-g}	16.7^{c-j}	14.6^{a-e}	37.4^{a-f}	4.90^{a-d}	315^{b-j}	6.61^{a-j}
L13×T2	73^{b-j}	75^{c-f}	152^{h-j}	215^{a-e}	115^{a-g}	18.4^{a-g}	13.6^{c-j}	36.9^{a-g}	4.86^{a-f}	383^{a-c}	5.22^{c-m}
L14×T1	75.5^{a-f}	78^{a-e}	158^{b-e}	224^{a-e}	108^{b-g}	17.2^{a-g}	13.2^{e-g}	37.6^{a-f}	4.69^{a-g}	338^{a-d}	5.49^{b-m}
L14×T2	77^{a-c}	79^{a-c}	157^{b-f}	197^{d-f}	113^{a-g}	14.6^{h-j}	13.9^{b-j}	33.2^{c-g}	4.08^{g}	213^{h-j}	3.67^{j-m}
L15×T1	71.5^{fg}	74^{ef}	152^{h-j}	201^{c-f}	106^{b-g}	16.3^{d-j}	14.6^{a-e}	32.8^{d-g}	4.79^{a-g}	303^{b-j}	5.17^{c-m}
L15×T2	75.5^{a-f}	78.5^{a-d}	155^{b-i}	220^{a-e}	116^{a-g}	17.7^{a-g}	13.8^{b-j}	39.0^{a-e}	4.72^{a-g}	315^{b-j}	6.82^{a-g}
L16×T1	72.5^{c-g}	77^{a-f}	155.5^{b-i}	199^{c-f}	105^{d-g}	18.7^{a-g}	13.8^{b-j}	37.4^{a-f}	4.97^{a-c}	358^{a-f}	7.04^{a-d}
L16×T2	75^{a-g}	77^{a-f}	154^{d-j}	211^{b-e}	119^{a-e}	17.1^{b-i}	13.9^{b-j}	36.3^{a-g}	4.64^{a-g}	253^{d-j}	4.88^{c-m}
L17×T1	75.5^{a-f}	78^{a-e}	157.5^{b-e}	219^{a-e}	115^{a-g}	19.6^{a-e}	14.6^{a-e}	38.9^{a-e}	5.22^{a}	370^{a-e}	6.71^{a-i}
L17×T2	75^{a-g}	77.5^{a-f}	156.5^{b-g}	204^{b-f}	119^{a-e}	17.2^{a-g}	13.9^{b-j}	34.2^{c-g}	4.39^{b-g}	278^{c-j}	2.88^{m}
L18×T1	72.5^{d-g}	75^{c-f}	152^{h-j}	212^{a-e}	111^{b-g}	17.6^{a-g}	14.0^{a-g}	35.1^{c-g}	4.77^{a-g}	300^{b-j}	5.53^{b-m}
L18×T2	72.5^{d-g}	74.5^{d-f}	158.5^{b-d}	217^{a-e}	108^{b-g}	17.4^{a-g}	14.4^{a-f}	32.4^{e-g}	4.63^{a-g}	340^{a-g}	6.23^{a-l}
L19×T1	75^{a-g}	78^{a-e}	156.5^{b-g}	195^{d-f}	101^{d-g}	15.8^{e-j}	13.9^{b-j}	34.0^{c-g}	4.62^{a-g}	268^{c-j}	5.27^{b-m}
L19×T2	75^{a-g}	77.5^{a-f}	155.5^{b-i}	224^{a-e}	134^{a}	15.4^{e-j}	13.2^{e-g}	36.2^{a-g}	4.30^{c-g}	253^{d-j}	5.46^{b-m}
L20×T1	72.5^{d-g}	74.5^{d-f}	157.5^{b-e}	213^{a-e}	110^{b-g}	18.4^{a-g}	13.6^{c-j}	38.1^{a-f}	4.39^{b-g}	270^{a-e}	5.79^{a-m}
L20×T2	76.5^{a-d}	79^{a-c}	155^{b-i}	197^{d-f}	108^{b-g}	15.8^{e-j}	13.9^{b-j}	36.2^{a-g}	4.33^{c-g}	228^{g-j}	3.93^{f-m}
L21×T1	74^{a-g}	76^{a-f}	150.5^{d-j}	204^{b-f}	111^{b-g}	18.4^{a-g}	14.4^{a-f}	36.1^{a-g}	4.93^{a-c}	368^{a-e}	6.93^{a-e}
L21×T2	73.5^{b-g}	76^{a-f}	154.5^{d-j}	213^{a-e}	99^{e-g}	21.0^{ab}	13.8^{b-j}	38.6^{a-e}	4.67^{a-g}	330^{a-i}	6.91^{a-f}
L22×T1	75.5^{a-f}	77.5^{a-f}	155^{b-i}	208^{b-e}	115^{a-g}	19.5^{a-e}	13.6^{c-j}	38.8^{a-e}	4.89^{a-e}	348^{a-g}	6.60^{a-j}
L22×T2	77^{a-c}	78.5^{a-d}	155.5^{b-i}	202^{c-f}	115^{a-g}	16.5^{d-j}	13.4^{d-f}	33.8^{c-g}	4.34^{b-g}	235^{f-j}	4.52^{d-m}
L23×T1	73.5^{b-g}	75^{c-f}	152^{h-j}	221^{a-e}	111^{b-g}	18.9^{a-g}	14.4^{a-f}	36.1^{a-g}	4.59^{a-g}	383^{a-c}	7.00^{a-e}
L23×T2	75.5^{a-f}	77.5^{a-f}	155.5^{b-i}	215^{a-e}	110^{b-g}	21.5^{a}	13.4^{d-f}	43.1^{a}	5.21^{a}	448^{a}	7.56^{a-c}
L24×T1	71.5^{fg}	74^{ef}	153.5^{c-i}	200^{c-f}	114^{a-g}	16.3^{d-j}	13.4^{d-f}	33.2^{c-g}	4.42^{b-g}	250^{e-j}	5.37^{b-m}
L24×T2	74.5^{a-h}	77^{a-f}	157.5^{b-e}	195^{d-f}	111^{b-g}	17.3^{a-g}	14.0^{a-g}	36.3^{a-g}	4.16^{e-g}	290^{b-j}	6.72^{a-h}

Table 2. Contd.

L25×T1	74.5^{a-h}	77^{a-f}	158^{b-e}	199^{c-f}	106^{b-g}	15.4^{e-j}	13.4^{d-f}	30.0^{g}	4.34^{b-g}	320^{b-j}	3.88^{g-m}
L25×T2	75^{a-g}	77^{a-f}	154^{d-j}	207^{b-f}	110^{b-g}	18.7^{a-g}	13.0^{fg}	38.5^{a-e}	4.80^{a-g}	338^{a-d}	5.97^{a-l}
L26×T1	73.5^{b-g}	75.5^{b-f}	153.5^{c-i}	240^{a-c}	117^{a-f}	20.2^{a-d}	14.4^{a-f}	40.4^{a-c}	4.89^{a-e}	378^{a-d}	7.70^{a-e}
L26×T2	74.5^{a-h}	76.5^{a-f}	158^{b-e}	186^{ef}	102^{d-g}	18.2^{a-g}	13.6^{c-j}	34.7^{c-g}	4.19^{d-g}	303^{b-j}	3.82^{h-m}
L27×T1	72^{e-g}	74^{ef}	157^{b-f}	215^{a-e}	109^{b-g}	16.8^{b-j}	14.0^{a-g}	39.8^{a-d}	4.55^{a-g}	278^{c-j}	4.44^{d-m}
L27×T2	71^{g}	73.5^{f}	150.5^{ij}	196^{d-f}	106^{b-g}	17.2^{a-g}	14.2^{a-g}	42.5^{ab}	4.44^{b-g}	253^{d-j}	5.48^{b-m}
L28×T1	75^{a-g}	77^{a-f}	154^{d-j}	215^{a-e}	114^{a-g}	19.4^{a-e}	14.0^{a-g}	40.5^{a-c}	4.63^{a-g}	295^{b-j}	6.24^{a-l}
L28×T2	73.5^{b-g}	75.5^{b-f}	156.5^{b-g}	206^{b-f}	107^{b-g}	16.3^{d-j}	15.1^{ab}	34.3^{c-g}	4.90^{a-d}	278^{c-j}	5.04^{c-m}
L29×T1	74.5^{a-h}	77^{a-f}	154.5^{c-i}	204^{b-f}	106^{b-g}	16.4^{d-j}	13.9^{b-j}	37.9^{a-f}	4.39^{b-g}	268^{c-j}	5.77^{c-m}
L29×T2	77.5^{ab}	79.5^{ab}	155.5^{b-i}	206^{b-f}	110^{b-g}	15.8^{e-j}	13.9^{b-j}	32.8^{d-g}	4.57^{a-g}	280^{b-j}	4.49^{d-m}
L30×T1	77.5^{ab}	77.5^{a-f}	157^{b-f}	199^{c-f}	97^{fg}	18.1^{a-g}	14.2^{a-g}	36.3^{a-g}	4.90^{a-d}	315^{b-j}	6.69^{a-i}
L30×T2	77.5^{ab}	79.5^{ab}	155.5^{b-i}	202^{c-f}	108^{b-g}	15.9^{d-j}	13.4^{d-f}	37.9^{a-f}	4.41^{b-g}	258^{c-j}	4.94^{c-m}
L31×T1	75.5^{a-f}	77.5^{a-f}	159.5^{b}	208^{b-e}	108^{b-g}	17.3^{a-g}	13.0^{fg}	38.1^{a-f}	4.68^{a-g}	305^{b-j}	5.39^{b-m}
L31×T2	76.5^{a-d}	78.5^{a-d}	155^{b-i}	254^{a}	127^{ab}	19.1^{a-e}	14.8^{a-d}	40.1^{a-d}	4.75^{a-g}	350^{a-g}	8.68^{a}
L32×T1	76^{a-e}	78^{a-e}	156.5^{b-g}	188^{ef}	118^{a-f}	14.9^{g-j}	13.4^{d-f}	32.0^{e-g}	4.41^{b-g}	240^{f-j}	3.36^{lm}
L32×T2	73.5^{b-g}	75.5^{b-f}	155^{b-i}	205^{b-f}	106^{b-g}	18.1^{a-g}	14.0^{a-g}	35.0^{c-g}	4.77^{a-g}	318^{b-j}	4.75^{c-m}
BH545QPY	72.5^{d-g}	74.5^{d-f}	155^{b-i}	227^{a-e}	120^{a-e}	20.9	13.2	37.1^{a-g}	5.00^{a-c}	405^{ab}	4.43^{d-m}
BH-546	74.5^{a-h}	77^{a-f}	155^{b-i}	216^{a-e}	112^{b-g}	16.5	14.0	36.6^{a-g}	4.53^{a-g}	263	4.33^{d-m}
CV	2.93	2.80	2.01	9.44	9.43	12.5	5.5	9.2	7.31	20.36	26.79
R-square	0.70	0.73	0.82	0.65	0.69	0.71	0.65	0.64	0.64	0.69	0.71
Grand (m)	74.7	76.8	155.8	207.5	110	17.3	13.9	36.4	4.62	299.8	5.58

Means with the same letter are not significantly different from each other. DA = days to anthesis, DS=days to silking, DM=days to maturity, PH=plant height, EH=Ear height, EL=ear length, NRPC=number of rows per cob, NCPR=number of kernel per row, ED=ear diameter, TSW=thousand seed weight, GY=grain yield, CV=coefficient of variance.

Table 3. Proportional contribution of line, tester and line × tester interaction to total variance for 11 traits of maize hybrids tested at Hawassa.

Source variation	DA (days)	DS (days)	DM (days)	PH (cm)	EH (cm)	EL (cm)	NRPC (no)	NCPR (no)	ED (cm)	TSW (g)	GY (t/ha)
Line (%)	58	55	38	46	44.7	60	52.3	63.1	42.2	47.9	44.2
Tester (%)	2.1	1.2	4.2	0.1	1.3	0	3.3	0.1	0	0.6	5.9
Line × Tester (%)	39.9	44	58	54	54	40	44.2	36.8	57.8	51.5	49.8

DA=days to anthesis, DS=days to silking, DM=days to maturity, PH=plant height, EH=Ear height, EL=ear length, NRPC=number of rows per cob, NCPR=number of kernel per row, ED=ear diameter, TSW=thousand seed weight, GY=grain yield.

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