Combining Ability of Transitional Highland Maize Inbred Lines

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Abstract: Information on the combining ability of highland maize (Zea mays L.) germplasm is of great value for future hybrid development programs. Such a study has been poorly exploited in the highland areas of Ethiopia, due to limited research efforts in previous years. This study was conducted to determine the combining ability of highland maize inbred lines. The crosses were made from five lines and three testers using line by tester. The resulting crosses and their parents were evaluated at Kulumsa and Ambo in 2003, following recommended cultural practices. The combined analysis of variance showed that the mean squares due to genotypes were significant for all traits, except for thousand kernel weight and shelling percentage. B.T.Z.T.R.L.137-B-2-1-B X 142-1-e followed by B.T.Z.T.R.L-71-B-3-3-B X 142-1-e and B.T.Z.T.V.C-283-B-1-1-B X 144-7-b were the three top-yielding crosses. B.T.Z.T.V.C-283-B-1-1-B and B.T.Z.T.V.C-43-B-2-2-B manifested a high positive SCA effect with F-7215, implying these two lines combine well with F-7215. B.T.Z.T.R.L.137-B-2-1-B manifested negative SCA with F-7215, indicating that they could have a similar genetic background. The mean squares due to GCA of lines, testers and SCA of crosses were significant for ear height, ear length and grain yield B.T.Z.T.R.L.137-B-2-1-B and 142-1-e had high GCA for grain yield. The maximum SCA effect for grain yield was obtained from B.T.Z.T.R.L.137-B-2-1-B X 142-1-e and B.T.Z.T.R.L-71-B-3-3-B X 142-1-e. Generally, the magnitude of mean squares due to GCA of lines was higher than that of the SCA in most of the cases, indicating that additive gene actions were more important than non-additive with regard to inheritance of the traits studied.

Keywords: Combining Ability; Gene Action; Heterotic Pattern; *Zea mays*

1. Introduction

Maize is cultivated in all major agro-ecological zones in Ethiopia up to 2400 m.a.s.l. The high altitude moist areas including the highland transition and true highland, is next to mid-altitude in maize area and production. In highland areas, maize is the first crop grown and is a popular "hunger breaking crop" when it is harvested and consumed green (Twumasi *et al*., 2002). It is estimated that high altitude covers 20% of the land devoted to maize cultivation and 30% of small-scale farmers in the area depend on maize production for their livelihood. However, highland maize improvement research in Ethiopia has generally lagged behind that of other agro-ecologies. Attempts were made to develop suitable varieties for the highland areas of the country and, as a result, some parental lines and populations were developed. (Twumasi *et al*., 2002).

The development of appropriate maize varieties for highland areas would increase maize production and productivity in these areas. Such varietal development necessitates the use of effective selection methods for grain yield and other desirable traits. A suitable means to achieve this goal is the use of line-by-tester analysis, a system whereby the progeny performance can be statistically separated into components related to general combining ability (GCA) and specific combining ability (SCA) and thus elucidating the nature of gene action (Kempthorne, 1957). Combining ability analysis is one of the powerful tools in identifying the better combiners which may be hybridized to exploit heterosis and to select better crosses for direct use or further breeding work (Singh and Chaudhary, 1985).

The use of line-by-tester analysis would easily provide information about the combining ability of parents and also helps to estimate the type of gene action involved in the expression of grain yield and related traits (Zambezi, 1986). Although such genetic studies have been made in maize for other potential areas, little effort has been made to gather information for highland areas. Therefore, this study was initiated with the objective of determining the combining ability of transitional highland maize inbred lines.

2. Materials and Methods

The experiment was carried out at the Kulumsa and Ambo Research Centers during the 2003 cropping season. Geographically, Kulumsa lies at 8^{0}5'N latitude, 39^{o}10'E longitude with an altitude of 2200 m.a.s.l and is located in a tepid to cool, moist plain agro-ecological zone. The average rainfall at the research center is 830mm per annum. The mean maximum and minimum temperatures are 23.2^{o}c and 10^{o}c, respectively. The soils are luvisol/eutric nitosols with good drainage. Ambo is located at 8^{o}57'N latitude, 38^{o}7'E longitude and at an altitude of 2225 m.a.s.l. It is in a moist, tepid to cold mid-highland agroecological zone. The area receives an average annual rainfall of 850mm. The soil type of the experimental field is vertisol.

The experimental materials consisted of twenty-four genotypes which include five lines, three testers (142-1-e, 144-7-b and F-7215), fifteen test-crosses and a check

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(Table 1). The parental lines and testers were obtained from CIMMYT- Mexico, where they were developed to enrich highland germplasm as they are well-adapted to the highlands (up to 2200 m.a.s.l), mature early and are capable of surviving frost that usually comes late in the season, and screened for adaptation at Ambo. The testers' characterstic show large genetic differences between test crosses and are used to evaluate a series of lines which were parents of some of the released maize hybrids in Ethiopia and Eastern Africa.

Table 1. Designation and pedigree of lines and testers of maize.

Designation	Pedigree
L_1	B.T.Z.T.R.L-71-B-3-3-B
L_2	B.T.Z.T.V.C-283-B-1-1-B
L_3	B.T.Z.T.V.C-43-B-2-2-B
L_4	B.T.Z.T.R.L-137-B-2-1-B
L_5	B.T.Z.T.R.L-8-B-2-1-B
T_1	142-1-e (Ecuador-573)
T_2	144-7-b (Ecuador-573)
T_3	F-7215 (Kitale-Syn.II)
BH-660 (Check**)**	(F-7215 x A-7033) x 142-1-e

The test crosses were generated by a LxT mating design at Ambo in 2001/2. Since this design has an advantage over diallel procedure. To determine the performance of lines in hybrid combinations, a single diallel procedure is not practical because a large number of crosses is required for only a few lines. Therefore, for a preliminary hybrid evaluation, the breeder needs to determine the relative GCA of new lines using common testers. Moreover, the use of testers with common heteroic classes provides the best means of allocating inbred lines into different groups.

The experiment was laid out in randomised complete block design with two replications. A spacing of 75 cm between rows and 30 cm between plants was used. Thirty-four plants were grown by planting two seeds in each hill and then thinning to one seedling per hill four weeks after emergence. All other crop management practices were carried out as per the recommendations for each location. Data were collected according to days to tasseling, days to silking, days to maturity, grain yield, plant height, ear height, number of ears per plant, ear length, ear diameter, 1000 kernel weight, number of kernel rows per ear, number of kernels per row and shelling percentage. Grain yield per hectare was calculated using a shelling percentage of 80%, adjusted to 12.5% moisture.

The analysis of variance was computed, first for each location separately (data not shown), and then combined across locations using SPAR-1 and AGROBASE-99 computer software packages. The combined analysis across locations was computed for characters that showed significant difference among the genotypes at either of the locations after testing for homogeneity of error variance by using variance ratio. The environments were considered as random, while the genotypes were considered as fixed effects. Furthermore, line-by-tester analysis for combining ability was executed for traits that exhibited significant differences among crosses (Dabholkar, 1992).

The mathematical model for combining ability analysis of combined analysis is:

$$Y_{ijk} = \mu + r_k + g_i + g_j + S_{ij} + l_k + (gl)_{ik} + (gl)_{jk} + (sl)_{ij} + e_{ijk}$$

Where, Y_{ijk} = The value of a character measured on cross of line i by tester j in k^{th} replication

μ = Population mean

r_k = Effect of k^{th} replication

g_i = General combining ability (gca) effect of i^{th} line

g_j = General combining ability (gca) effect of the j^{th} tester

S_{ij} = Specific combining ability (sca) of i^{th} line and j^{th} tester such that S_{ij} equal to S_{ji}

l_k = Effect of l^{th} location

(gl) = GCA x location interaction effect of i^{th} line

(gl) = GCA x location interaction effect of j^{th} tester

$(Sl)_{ijk}$ = SCA x location interaction of i^{th} line and j^{th} tester

e_{ijk} = Experimental error for ijk^{th} observation

3. Results and Discussions

3.1. Analysis of Variance and Genotypic means

The combined analysis of variance showed highly significant ($P \leq 0.01$) mean squares due to genotypes for all characters studied, except for thousand kernel weight and shelling percentage. Mean squares due to parents were significant for days to maturity, ear height, ear length and the number of kernels per row, showing that the parents had differences for these traits (Table 2). The mean of testers was higher than that of lines in yield and other traits, except shelling percentage (Table 4). This revealed that lines were relatively earlier in tasselling and maturity than the testers. Significant ($P \leq 0.01$) differences were observed among crosses for ear height, ear length and grain yield, indicating varied performance of different cross combinations. L_4xT_1 followed by L_1xT_1 performed better in grain yield and most other traits. On the other hand, the difference between parents versus crosses was siginificant for all traits except days to maturity and shelling percentage (Table 2). Parental genotypes are late in tasselling and silking compared to their F_1 hybrids. Thus, crosses are more vigorous, mature earlier and produce a high yield than their parents. Generally, crosses involving L_4 as parent showed a better performance in most of the traits followed by L_3 crosses.

The interaction between genotypes and location (G x L) was highly significant ($P \leq 0.01$) for grain yield and shelling percentage, indicating that the performances of the genotypes were not consistent for these two traits. Significant interaction effects of parent x location were observed for thousand kernel weight. This revealed that the parents showed general adaptation across the locations for most of the traits considered in this study. However, a non-significant interaction effect of crosses with location (Crosses x Loc) was observed for all traits, indicating that crosses performed uniformly across locations. The parents vs. crosses component interact significantly with location for traits like ear length and 1000 kernel weight. Generally, the traits which showed significant GxL interaction had a differential genotypic response to variable environmental conditions and this resulted in change in the ranks of genotypes and limited the identification of superior genotypes for both locations. This revealed the location specificity of the genotypes tested.

3.2. Combining Ability

In the combined analysis of variance, mean squares due to GCA of lines, testers and SCA of crosses were significant for ear height, ear length and grain yield, indicating the role of additive and non-additive gene action in the inheritance of these characters (Table 2). This has breeding implications, since hybridization methods such as multiple crossing and/or reciprocal recurrent selection, which exploit both additive and non-additive gene effects simultaneously, could be useful in genetic improvement of the characters studied. However, for most of the traits, the variance ratio (∂^2GCA/∂^2SCA) was greater than unity revealing the predominace of additive gene action in the inheritance of these traits. Several studies involving the inheritance of various quantitative traits in maize have revealed the importance of additive gene actions (Stangland *et al.*, 1983, Shewangizaw, 1985; Zambezi *et al.*, 1986 and Vasal *et al.*, 1992). This showed that parents with good GCA and per se performance were used to predict the performance of crosses. Hence, these parents can be crossed to develop high-yielding composites that can be used directly or for further breeding work (Allard, 1960).

Estimates of GCA and SCA effects for various traits combined over location are presented in Table 3. For grain yield, none of the lines revealed significant GCA effect, implying that the inbred lines were not developed based on their GCA for yield. However, high positive and desirable GCA effects were revealed by L_4 and L_5 indicating the potential advantage of the lines for the development of high-yielding hybrids. For ear height, L_1 and L_3 showed GCA effects in a negative direction, implying the tendency of the lines to reduce ear height. L_4 was the poorest combiner for ear height and ear length as it showed positive and negative significant GCA effects respectively. L_3 showed a positive and highly significant GCA effect for ear length suggesting that this line was a good combiner for increasing ear length. Mandefro and Habtamu (1999) reported similar results for these traits. Estimates of the general combining ability effects of testers showed that T_3 exhibit negative and significant GCA effects while T_1 manifested positive and significant GCA effects for all traits studied. Moreover, T_2 showed a positive and significant GCA effect for ear length and grain yield. The result suggested that T_3 had a tendency to reduce ear placement and decrease ear length and grain yield while the reverse is true for other testers. Those parents in crosses which have a negative general combining effects for plant and ear height, appeared to be good general combiners in reducing the problem of lodging due to wind and other stresses. Hence, parents such as L_3, L_1 and T_3 could serve the purpose of breeding for lodging tolerance.

In this study, crosses manifested considerable variation in SCA effect for different traits. For grain yield, SCA estimates revealed that L_4xT_1 was the best specific combiner as it showed positive and significant SCA. Three other crosses, L_1xT_1, L_2xT_2 and L_2xT_3, were also good as specific combiners. Thus, these crosses could be selected for their specific combining ability to improve grain yield. Similarly, Yoseph (1998), Girma (1991) and Shewangizw (1985) reported on the significance of SCA effects and concluded that the predominance of non-additive genetic variance exists in the case of yield. Seven crosses showed a positive SCA effect while one cross, (L_3xT_3), manifested a significant SCA effect in an undesirable direction for ear length. Thus, L_2xT_3 (0.71) and L_3xT_3 (-0.76) were the best and worst specific combiners for this trait. Eight of the 15 crosses exhibited negative SCA effects out of which L_4xT_3 and L_5xT_1 showed a negative and significant SCA effect for ear height, indicating the crosses have a good specific combination for shorter ear placement (Table 3).

Heterotic combinations between inbred lines and testers for grain yield showed that all the lines except L_4, manifested positive SCA with T_3, indicating that these lines combined well with the Kitale heterotic pool, themselves belonging to the Ecuador gene pool. L_4 exhibited negative SCA with T_3 and can be assigned to the Kiatle heterotic pool (Table 3). This revealed that the testers manifested the tendency of discriminating lines into heterotic groups. Generally, most of the parents involved in the selected crosses were high x high general combiners. In such cross combinations, practising selection in advanced populations or using such lines in multiple crosses enable an improvement in grain yield potential.

Table 2. Line by tester ANOVA pooled over locations for yield and other traits of maize.

Sources of Variation	df	Mean Squares							
		DM	EH	EL	KRE	NKR	GY	TKW	SHP
Location	1	3372.3**	0.19**	6.69	9.98*	58.72	7065200.0	12159.80*	1121.0*
Replication/Loc	4	9.74	0.007	1.06	0.76	50.85	54316.6	1526.90	157.39
Genotypes	22	75.97**	0.41**	42.06**	2.14**	223..9**	23178972.2**	9891.10	276.2
Parents	7	156.61**	0.27**	32.5**	1.76	90.48**	3890830.0	1426.10	223.09
Parents vs Cross	1	13.27	6.18**	662.69**	22.18**	4254.7**	436816700.2**	16908.0**	263.20
Crosses	14	31.88	0.08**	65.43**	0.98	21.06	6832448.0**	3219.70	169.80
Lines(gca)	4	39.20	2.01**	4.75*	0.64	28.15	3320213.3**	21089.21	262.29
Testers(gca)	2	12.43	0.16*	28.52**	0.61	10.16	30284830.0*	236.28	51.58
Lines x testers(sca)	8	30.02	0.03*	1.49*	0.54	13.86	2434862.0*	2684.99	188.10
Genotype x Loc	22	27.50	0.03	1.76	0.74	13.17	17331893.9**	7661.59	1533.6**
Parents x Loc	7	17.30	0.01	1.89	1.18	14.16	1678846.0	4780.50*	482.70
Parent vs cross x loc	1	2.15	0.0008	7.64*	0.19	33.23	1306128.0	51297.0**	435.40
Crosses x Loc	14	34.40	0.02	1.33	0.56	11.23	1790866.0	5985.30	213.80
Lines x Loc	4	62.81	0.00078	2.12 **	0.12	11.60	19809920.1**	16519.1**	541.4**
Testers x Loc	2	33.10	0.0100	0.68	0.94	6.52	58086.4	2070.50	73.09
(Lines x testers) x Loc	8	20.20	0.00026	0.94	0.67	12.33	2128998.0**	1697.08	85.36
Pooled Error	132	22.98	0.018	1.51	0.65	12.98	1746192.0	1635.60	163.40

**, ** Significant at 0.05 and 0.01 prob. level., respectively, df = degree of freedom, Loc = location, DM = Days to maturity, EH= Ear height, EL = Ear length, KRE = Number of kernel rows per ear, NKR = Number of kernels per row, GY= Grain Yield, TKW = Thousand Kernel weight, SHP = Shelling percentage*

Table 3. Estimates of general and specific combining ability effects for yield and other traits across locations of maize in 2003.

Parent	General combining abilities			Specific combining abilities								
	EH	EL	GY	EH			EL			GY		
				T1	T2	T3	T1	T2	T3	T1	T2	T3
L_1	-0.10	0.19	-260.67	-0.01	0.02	-0.01	-0.22	-0.27	0.49	785.93	-1084.97*	299.05
L_2	0.00	0.27	60.86	-0.03	-0.05	0.07	-0.55	-0.15	0.71	-859.54*	454.39	405.15
L_3	-0.05	0.49**	-124.57	0.02	0.03	-0.05	0.58	0.18	-0.76*	-700.71	325.09	375.62
L_4	0.08*	-0.76**	190.41	0.11*	-0.02	-0.09*	0.58	-0.12	-0.46	957.94*	263.41	-12221.40**
L_5	0.04	-0.19	133.97	-0.09	0.02	0.08	-0.39	0.36	0.02	-183.61	42.08	141.53
T_1	0.06*	0.47**	884.23**									
T_2	0.04	0.82**	520.15*									
T_3	-0.10*	-1.29**	-1404.38**									
SE. (M)	0.02	0.16	207.98									
S.E. (F)	0.03	0.22	294.13									
SE(d)gi-gj (line)	0.18	0.73	87.21									
SE(d)gi-gj (tester)	0.15	0.61	73.56									
SE				0.04	0.04	0.04	0.32	0.32	0.32	415.96	415.96	415.96
SE (Sij-Skl)				0.25	0.25	0.25	1.05	1.05	1.05	0.82	0.82	0.82

**, ** = *, ** Significant at 0.05 and 0.01 prob. level, respectively, S.E. = Standard error, EH = Ear height, EL = Ear length, GY = Grain Yield*

Table 4. Mean of different traits of maize pooled over five locations.

Genotype	DT	DS	DM	PH	EH	EPP	ED	EL	KRE	NKR	GY	TKW	SHP
L_1	100.5	104.3	176.5	1.22	0.60	1.15	2.93	13.35	13.00	25.80	2376.67^{hij}	189.68	62.77
L_2	105.0	113.3	182.0	1.96	1.03	0.95	2.93	13.80	12.50	22.95	2026.73^{ij}	217.4	58.48
L_3	103.8	109.0	179.8	1.08	0.61	1.08	3.55	12.30	12.60	19.35	2311.37^{hij}	266.93	65.25
L_4	104.3	103.3	187.3	1.90	1.09	1.35	2.63	11.25	13.00	22.30	2517.26^{hij}	186.95	58.33
L_5	104.3	113.5	182.0	1.76	0.96	0.98	2.58	9.80	11.70	13.35	1412.84^{j}	209.10	64.55
T_1	102.3	104.5	192.3	2.08	1.29	1.10	3.05	17.50	12.30	27.45	3668.5^{fghij}	345.28	58.09
T_2	107.8	112.8	193.0	1.96	1.09	1.10	3.65	17.55	11.10	25.75	4484.69^{efghi}	337.88	59.98
T_3	106.5	112.5	191.0	2.04	1.23	0.90	3.35	15.85	11.90	27.03	3259.35^{ghij}	322.55	64.14
L_1 x T_1	99.0	99.8	187.3	2.60	1.51	1.55	4.93	20.00	14.10	36.03	8635.73^{ab}	300.53	80.24
L_1 x T_2	99.5	103.3	184.5	2.56	1.52	1.45	4.43	20.30	13.60	37.83	6400.75^{bcde}	281.38	76.42
L_1 x T_3	98.5	100.5	182.5	2.43	1.36	1.10	4.58	18.95	13.50	38.75	5860.24^{cdefg}	256.15	77.41
L_2 x T_1	102.0	107.8	187.5	2.54	1.56	1.75	4.28	19.75	12.75	37.15	7311.79^{abcd}	282.25	69.92
L_2 x T_2	100.8	107.5	183.5	2.57	1.52	1.63	4.83	20.50	13.20	41.08	8261.64^{abc}	262.88	75.56
L_2 x T_3	99.3	103.3	190.5	2.43	1.5	1.45	3.55	19.25	12.75	37.08	6287.87^{bcdef}	316.70	68.95
L_3 x T_1	99.3	100.5	186.5	2.63	1.56	1.75	5.10	21.10	13.70	35.73	7285.19^{abcd}	299.93	80.84
L_3 x T_2	101.8	105.3	190.3	2.53	1.54	1.68	5.10	21.05	13.10	33.65	7946.92^{abc}	284.70	64.11
L_3 x T_3	100.8	102.5	187.0	2.18	1.33	1.23	5.15	18.00	14.10	33.10	6072.91^{bcdef}	316.00	66.96
L_4 x T_1	99.3	101.5	183.0	2.85	1.77	1.93	4.63	9.85	13.40	37.13	9258.82^{a}	251.05	79.72
L_4 x T_2	100.5	105.3	186.3	2.64	1.62	1.75	4.00	19.50	12.70	40.60	8200.22^{abc}	314.90	78.19
L_4 x T_3	101.0	105.3	183.3	2.34	1.42	1.23	3.93	17.05	13.65	37.58	4790.92^{efgh}	264.65	87.52
L_5 x T_1	103.3	107.0	190.3	2.48	1.53	1.70	4.23	19.45	12.90	39.83	8060.83^{abc}	312.30	74.13
L_5 x T_2	100.0	103.0	188.5	2.75	1.63	1.88	3.95	20.55	12.90	37.30	7922.45^{bcdf}	284.05	66.75
L_5 x T_3	102.0	105.8	183.3	2.56	1.55	1.38	4.00	18.10	13.05	36.30	6097.36^{bcdef}	267.23	67.61
BH660	108.0	112.5	191.5	2.53	1.45	1.23	4.28	16.90	13.00	33.50	6358.87^{bcde}	250.60	60.74
Crosses	100.5	103.8	186.3	2.54	1.53	1.56	4.50	19.56	13.29	37.28	7226.24	286.31	74.29
Parents	104.3	109.1	172.9	1.75	0.99	1.08	3.08	13.93	12.26	23.00	2757.19	259.47	61.45
Lines	103.6	108.6	181.5	1.58	0.86	1.10	2.90	12.10	12.56	20.75	2128.97	214.01	61.876
Tester	105.5	109.9	158.8	2.03	1.20	1.03	3.40	16.97	11.77	26.74	3804.20	335.24	60.74
G.mean	102.3	105.9	186.2	2.28	1.34	1.39	3.98	17.57	12.94	32.36	5700.42	275.80	69.79
CV(%)	2.4	3.6	2.6	8.57	9.77	15.50	11.98	6.86	6.07	11.58	23.22	15.04	21.50
LSD(0.05)	4.9	7.8	9.7	0.39	0.26	0.43	0.96	2.43	1.58	7.54	2663.00	83.49	12.23

DT = Days to tasselling, DS = Days to silking, DM = Days to maturity, PH = Plant height, EH = Ear height, EPP= Number of ears per plant, ED = Ear diameter, EL = Ear length, KRE = Number of kernel rows per ear, NKR = Number of kernels per row, GY= Grain Yield, NN = Number of nodes, TKW = Thousand Kernel weight, SHP = Shelling percentage

4. Conclusions

The results of this study have demonstrated the importance of line by tester analysis in identifying parents with general and specific combining abilities that would help to develop hybrids with desirable traits for highland areas. L_4 and T_1 for grain yield, L_3 and T_2 for ear length, L_1 and T_3 for ear height had good general combining abilitiy estimates. These parents could therefore be used to improve the respective characters. Crosses such as L_4xT_1 and L_1xT_1 for grain yield and L_5xT_1 and L_4xT_3 for ear height were good in specific combining ability and can be used to develop hybrids for future use in maize breeding programs. Generally, crosses involving L_4 as the parent showed better performance in most of the traits, followed by L_3 crosses. The testers showed a tendency of allocating lines into heterotic groups. Thus, parental inbred lines can be selected from different heterotic groups so as to develop superior hybrids in most of the traits. In conclusion, parents with good GCA and *per se* performances can be crossed to develop high yielding composites that can be used directly for recommendation or further breeding work, whereas crosses with good SCA and high mean values can be promoted for further testing.

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