Journal of Agricultural Science; Vol. 10, No. 3; 2018
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Combining Ability for Grain Yield Performance among CIMMYT Germplasm Adapted to the Mid-Altitude Conditions

Casper Nyaradzai Kamutando[1,2], Cosmos Magorokosho[2] & Shorai Dari[1]

[1] Department of Crop Science, University of Zimbabwe, Harare, Zimbabwe

[2] International Maize and Wheat Improvement Center (CIMMYT), Harare, Zimbabwe

Correspondence: Shorai Dari, Department of Crop Science, University of Zimbabwe, P.O. Box MP167, Mt Pleasant, Harare, Zimbabwe. Tel: 263-772-961-616. E-mail: shoraidari@yahoo.co.uk

Received: November 8, 2017 Accepted: January 7, 2018 Online Published: February 15, 2018
doi:10.5539/jas.v10n3p253 URL: https://doi.org/10.5539/jas.v10n3p253

The research was financed by the DTMA project.

Abstract

The International Centre for Maize and Wheat Improvement (CIMMYT) develops maize (*Zea mays* L.) inbred lines and hybrids yearly that have several breeding and commercial attributes. However, no genetic analysis has been done on the recently developed inbred lines for yield performance under drought and low-N stress. The objectives of this study were to identify lines with positive general combining ability (GCA) effects for grain yield under stress environments and to identify the best single-cross hybrids with the highest specific combining ability (SCA) effects. Analysis of variance combined across sites showed significant mean squares for genotypes, locations and genotype by environment interaction (GEI) for grain yield. GCA_{lines}, SCA and components of interaction effects were significant across sites. Additive genetic variance was more important than dominance variance in determining yield performance across locations indicating that selection based on grain yield under drought and low-N stress can be effective. Average grain yield across the eight locations ranged from 1.61 t ha^{-1} to 10.63 t ha^{-1} while narrow sense heritability for grain yield was 52.6% across sites and was slightly lower under managed drought and low-N stress. The testers CL115807 and CL106622 showed positive and significant GCA effects for yield performance under drought and low-N stress respectively. The best tester across all sites was CL115793 and line CZL0713 had consistently positive GCA effects for grain yield across sites. CML536 × CL115802 and CML312 × CL106508 were the best single crosses under low nitrogen stress sites while hybrid CML312 × C323-45 showed the highest positive SCA effects across sites. In conclusion, our results show that CIMMYT has new lines that have desirable adaptive attributes when grown under drought and low nitrogen stress environments in the mid-altitude region; hence these can be adopted for hybrid, synthetic and OPV formation.

Keywords: *Zea mays* L., grain yield, specific combining ability, general combining ability, genotype × environment interaction, managed drought stress, low nitrogen stress

1. Introduction

Drought and low-N stresses are factors that largely limit maize production in tropical environments (Bänziger et al., 1999; Edmeades et al., 1999; Bänziger & Diallo, 2001; Diallo et al., 2001). Yield declines are also being noticed in the productive mid-altitude eco-zones of central and southern Africa (Diallo et al., 2001). The mid-altitude zone falls within the altitudinal range of between 1000 and 1800 masl and it is characterized by rainfall of more than 500mm and mean temperature of 21.5 °C. The social-economic constraints, such as high inorganic fertilizer costs and lack of credit for small scale farmers (Diallo et al., 2001) are further worsening the bio-physical constraints that are hampering maize production. Hence development of maize hybrids that can adapt to these stresses is important (Hoisington, 2001; Betrán et al., 2003; Bänziger et al., 2004).

Abiotic stress tolerance is one of the most studied traits at CIMMYT, especially tolerance to drought (Hoisington, 2001). Plants vary in their ability to withstand abiotic stresses, both between species and within populations of single species. It is crucial to understand the genetic basis of hybrid performance under these stresses, in order to design appropriate breeding strategies (Betrán et al., 2003). One of the most challenging traits to breed for, among abiotic stresses is drought tolerance, due to its unpredictable nature (Hoisington, 2001).

Selection for grain yield under severe drought stress has often been considered inefficient (Bolanos et al., 1992), because the estimate of heritability for grain yield has been found to decline as yield fell. But, these authors recommended the use of secondary traits as an option to increase selection efficiency under these conditions, since they have adaptive values, high heritability, and are easy to measure.

Diallo et al. (2001) carried out a study to develop hybrid maize varieties that are tolerant to low-N and drought. In the study, drought tolerant inbred lines developed by CIMMYT-Harare in collaboration with CIMMYT-Mexico were crossed with two stress resistant testers (CML 202 and CML 206) during the 1997/98 minor season. The crosses were evaluated at seven sites, alongside local checks in 1999 under both stressed and unstressed conditions. The selected best single cross hybrids were crossed with other testers (CML 78 and CML 384) in 2000 and the resulting three-way hybrids were evaluated in 2001. Grain yield and secondary traits such as anthesis-silking interval, leaf senescence and number of ears plant^{-1} were used to select the most promising materials. The study identified eight drought and low-N tolerant three-way hybrids which yielded 24, 15 and 64% more than the best hybrid checks under optimum, low-N and drought stress conditions, respectively.

Betrán et al. (2003) also did a study to evaluate a group of tropical white inbred lines for grain yield performance, combining abilities and stability under optimal, drought and low-N stress conditions. They found heterosis to increase with the intensity of drought stress. Significant interactions were observed for combining abilities under low-N and high N. The type of gene action appeared to be different under low N and high-N, with additive effects more important under drought and dominance effects more important under low-N. The importance of additive effects increased with intensity of drought stress. The results suggested the need to incorporate drought tolerance in both parental lines to achieve acceptable hybrid performance under severe drought.

CIMMYT-Zimbabwe recently developed maize inbred lines that can adapt to the mid-altitude conditions through the pedigree breeding method. The lines have desirable adaptive attributes under low-N, drought, and in agronomically favorable conditions (optimal environments). But the combining ability of the new lines with the old CIMMYT lines is not known, yet this information is important to the breeders as a decision making tool in hybrid development, population and tester formation. Hence, the objectives of this study were to identify lines with positive and significant GCA and SCA effects for grain yield under stress environments and to identify the best single-cross hybrids with the highest SCA effects.

2. Materials and Methods

2.1 Planting Materials and Evaluation Sites

The study was a combining ability trial of hybrids developed using the North Carolina Design II mating design, where 30 male lines were crossed with eight (8) female lines (Table 1). The male lines are the elite lines that were developed for adaptability in the sub-Saharan African conditions. The female lines are common CIMMYT lines and they were used as testers in this study. The hybrids were developed by crossing using hand pollination. The 240 hybrids developed were planted alongside 10 checks: two checks from Seed Co (SC 727 and SC 633) and eight checks developed by CIMMYT (CML444 × CML536, CML395 × CML444, CML312 × 442, CML539 × CML 442, CML539 × CML197, CML312 × CML444, CML444 × CML197 and CML444 × CML489). The evaluations were done at eight sites in the 2012-2013 summer and winter seasons in Zimbabwe (Table 2). The sites used represent the areas where maize is mostly grown in Zimbabwe.

Table 1. The pedigrees of the males and females that were crossed using an NCII design in the 2012 rainy season in Zimbabwe

Parents	Name	Origin	Pedigree	Heterotic group
Male lines (ML)				
1	CL115808	MZ11B-242A SITE 1-10	[[(CML395/CML444)-B-4-1-3-1-B/CML444//[[TUXPSEQ]C1F2/P49-SR]F2-45-7-1-2-BBB]-2-1-2-2-BBB/[LZ956441/LZ966205]-B-3-4-4-B-5-B*5]-B-5-2-BBB	B
2	CL115789	MZ11B-242A SITE 1-18	[[[MSRXPOOL9]C1F2-176-4-7-X-1-B/CML206]-5-2-3-1-B*5/P501SRc0-F2-47-3-1-1-B]-B-3-1-1-B*4	A
3	CL115809	MZ11B-242A SITE 1-20	[[CML199/[EV7992#/EV8449-SR]C1F2-334-1(OSU8i)-6-3-Sn]-B-23-2-2-B*4/[CML442/CML197//[TUXPSEQ]C1F2/P49-SR]F2-45-7-3-2-BBB]-2-1-1-2-1-BBB]-B-3-1-BBB	A
4	CL106683	HA10A-123A SITE 1-106	[[CML312/[TUXPSEQ]C1F2/P49-SR]F2-45-3-2-1-BB//INTA-F2-192-2-1-1-1-B*4]-1-5-1-1-2-BB/[CML442/CML197//[TUXPSEQ]C1F2/P49-SR]F2-45-7-3-2-BBB]-2-1-1-1-2-BBB]-B-1-1-BB	A

Parents	Name	Origin	Pedigree	Heterotic group
5	CL115755	MZ11B-242A SITE 1-88	[[CML312/[TUXPSEQ]C1F2/P49-SR]F2-45-3-2-1-BB//INTA-F2-192-2-1-1-1-B*4]-1-5-1-1-2-BB/[CML442/CML197//[TUXPSEQ]C1F2/P49-SR]F2-45-7-3-2-BBB]-2-1-1-1-2-BBB]-B-1-1-BBB	A
6	CL115803	MZ11B-242A SITE 1-72	[[CML312/MAS[MSR/312]-109-3]-B-71-3-BBB/[CML390/CML206]-BB-2-4-B*4]-B-11-2-3-B*4	A
7	CL106868	HA10A-123B SITE 1-35	[[CML312/MAS[MSR/312]-109-3]-B-71-3-BBB/[CML390/CML206]-BB-2-4-B*4]-B-11-2-3-BBB	A
8	CL115804	MZ11B-242A SITE 1-74	[[CML390/CML206]-BB-2-4-B*4/MAS[MSR/312]-117-2-2-1-B*5]-B-14-1-1-B*4	A
9	CL106581	MZ11B-242A SITE 1-66	[[CML442/[TUXPSEQ]C1F2/P49-SR]F2-45-3-2-1-BB//COMPE2/P43-SR//COMPE2]FS#-20-1-1-B-1-BBB]-2-5-1-1-1-B/[CML442/CML197//[TUXPSEQ]C1F2/P49-SR]F2-45-7-3-2-BBB]-2-1-1-1-2-BBB]-B-3-1-BBB	A
10	CL115811	MZ11B-242A SITE 1-76	[[CML444/CML395//DTPWC8F31-1-1-2-2-BB]-4-2-2-2-2-BB/[MSRXPOOL9]C1F2-205-1(OSU23i)-5-3-X-X-1-B//EV7992/EV8449-3-2-2-2-B*5]-B-1-1-BBB	B
11	C326-29	HA09A-123 SITE 2-31	[[EV7992#/EV8449-SR]C1F2-334-1(OSU8i)-1-4-X-X-2-B/[SC/ZM605-1-2-5-2/CML395]-B-14-3-2-1-3-1/[[EV7992#/EV8449-SR]C1F2-334-1(OSU8i)-10-4(I)-X-X-B/[MSRXPOOL9]C1F2-205-1-3-1-2/CML202]-B-5-1-1-2-B-4)-1-4-3-2-B	B
12	CL115793	MZ11B-242A SITE 1-26	[[LZ956441/LZ966205]-B-3-4-4-B-5-B*5/[CML390/CML206]-BB-2-4-B*4]-B-1-1-1-BB	AB
13	CL115791	MZ11B-242A SITE 1-22	[[LZ956441/LZ966205]-B-3-4-4-B-5-B*5/[CML390/CML206]-BB-2-4-B*4]-B-4-1-1-B*4	AB
14	CL115807	MZ11B-242A SITE 1-6	[[LZ956441/LZ966205]-B-3-4-4-B-5-B*5/[CML390/CML206]-BB-2-4-B*4]-B-4-1-2-B*4	AB
15	CL106689	HA10A-122B SITE 1-3	[[LZ956441/LZ966205]-B-3-4-4-B-5-B*5/[CML390/CML206]-BB-2-4-B*4]-B-4-1-3-B*4	AB
16	C323-45	HA09A-122 SITE 1-46	[CML444/DRB-F2-60-1-1-1-BBB//[LZ956441/LZ966205]-B-3-4-4-B-5-B*7]-5-2-2-1-1-BBB	B
17	CL115801	MZ11B-242A SITE 1-64	[INTA-155-2-2-2-B-4-B/CML390]-B-3-7-1-2-1-B	A
18	CL115802	MZ11B-242A SITE 1-68	[MAS[206/312]-23-2-1-1-B*5/[CML390/CML206]-BB-2-4-B*4]-B-5-1-4-B*4	A
19	CL115799	MZ11B-242A SITE 1-54	[MAS[206/312]-23-2-1-1-B*5/[CML390/CML206]-BB-2-4-B*4]-B-5-2-3-B*4	A
20	CL115795	MZ11B-242A SITE 1-40	[MAS[206/312]-23-2-1-1-B*5/[CML390/CML206]-BB-2-4-B*4]-B-5-2-4-B*4	A
21	CL115810	MZ11B-242A SITE 1-28	[MAS[206/312]-23-2-1-1-B*5/MAS[MSR/312]-117-2-2-1-B*5]-B-10-1-BBB	A
22	CL115800	MZ11B-242A SITE 1-56	[MAS[MSR/312]-117-2-2-1-B*5/ZM621A-10-1-1-1-2-B*7]-B-10-1-BBB	A
23	CL106631	MZ11B-242A SITE 1-36	[P501SRc0-F2-4-2-1-1-B/[CML442/CML197//[TUXPSEQ]C1F2/P49-SR]F2-45-7-3-2-BBB]-2-1-1-1-2-BBB]-B-4-1-1-B*4	A
24	CL106622	MZ11B-242A SITE 1-38	[P501SRc0-F2-47-3-2-1-B/[CML442/CML197//[TUXPSEQ]C1F2/P49-SR]F2-45-7-3-2-BBB]-2-1-1-1-2-BBB]-B-11-1-2-B*4	A
25	CL106508	HA10A-121B SITE 1-26	[WEEVIL/CML312]-B-18-3-1-B*5	A
26	CL115797	MZ11B-242A SITE 1-50	[Z97SYNGLS(B)-F2-188-2-1-2-B*4/P502SRC0-F2-1-3-1-1]-B-1-1-2-B*4	B
27	CL115798	MZ11B-242A SITE 1-52	[Z97SYNGLS(B)-F2-188-2-1-2-B*4/P502SRC0-F2-1-3-1-1]-B-5-2-1-B*4	B
28	CL106851	HA10A-123B SITE 1-17	[ZM621A-10-1-1-1-2-B*7/[TS6C1F238-1-3-3-1-2-#-BB/[EV7992#/EV8449-SR]C1F2-334-1(OSU8i)-10-7(I)-X-X-X-2-BB-1]-1-1-2-1-1-BBB]-B-4-2-1-BBB	A
29	CL115792	MZ11B-242A SITE 1-24	[ZM621A-10-1-1-1-2-B*7/MAS[MSR/312]-117-2-2-1-B*5]-B-7-1-BBB	A
30	CL106527	HA10A-127 SITE 1-16	SYN[N3-SR]F2(BalBulk)-174-1-2-2-1-BBB	A
Female lines (ML)				
1	CZL0713		[SYN-USAB2/SYN-ELIB2]-12-1-1-1-B*7	B
2	CML312		CML312	A
3	CML395		CML395	B
4	CML442		CML442	A
5	CML444		CML444	B
6	CML536		CML536	A
7	CML537		CML537	A
8	CZL052		ZM523B-29-2-1-1-B*7	B

Table 2. The eight sites used for the evaluation of the maize hybrids that were planted in the summer and winter seasons of 2012-2013

Site No.	Site name	Site management	Season of planting	†GIS position	Altitude (masl)	Mega-environment	∫Natural region	Annual rainfall (mm)
1	Agricultural Research Trust Farm (ART Farm)	Optimum environment	Summer	17°26′S, 31°05′E	1480	A	IIa	750-1000
2	Devonia Farm (DV)	Optimum environment	Summer	17°40′S, 31°17′E	1 308	B	IIb	750-1000
3	Gwebi Variety Testing Station (G-Opt.)	Optimum environment	Summer	31°32′E, 17°41′S	1448	A	IIa	750-1000
4	CIMMYT-Harare Station (H-LN)	Low nitrogen	Summer	17°49′S, 31°01′E	1 480	A	IIa	750-1000
5	Gwebi Variety Testing Station (G-LN)	Low nitrogen	Summer	31°32′E, 17°41′S	1448	A	IIa	750-1000
6	Seed Co Kadoma Station (KD)	Random drought	Summer	18°20′S, 30°97′E	1 149	C	III	650-800
7	Chiredzi research Station (CH)	Managed drought	Winter	20°S, 33°E	455	E	IV	<450
8	Save Valley Research Station (SV)	Managed drought	Winter	20°S, 33°E	455	E	IV	<450

Note. † Geographic information system (GIS); ∫ Source: Nyamapfene, 1991.

2.2 Experiment Setup and Agronomic Management

The hybrids were grown in one-row plots at an inter-row spacing of 0.75 m and an intra-row spacing of 0.25 m at all sites. The experiments were grown using a 10 × 50 alpha (0, 1) lattice design (Patterson & Williams, 1996). Two hundred and fifty (250) entries, replicated twice with 50 blocks per replication were planted, but the hybrids were randomized differently at the eight sites. The trials were initially planted at two seeds per hole then later thinned to one plant per station at four weeks after crop emergence (4 WACE) to achieve a plant population of 53 000 plants/ha.

Maize fertilizer (7% N, 6% P, 6% K) was applied as a basal fertilizer at 400 kg ha^{-1} at the sites. But, the low-N sites did not receive any form of top-dressing fertilization. Basal fertilizer was broadcasted by a vicon and disked into the soil before planting. All sites, excluding the low-N sites received two applications of 200 kg ha^{-1} AN (ammonium nitrate) each as top dressing. The first split application was done at four (4) weeks after crop emergence and the second application was done at eight (8) weeks after crop emergence.

The experiments at the CIMMYT-Zimbabwe station, Agricultural Research Trust Farm, Devonia Farm, Gwebi Variety Testing Station and Seed Co Kadoma Station were all rainfed and were planted in the main summer season in 2012. The experiments at Save Valley and Chiredzi Research Stations were planted in the winter season in 2013. These experiments only received four circles of irrigation and the total amount of water received by the plants ranged from between 200 to 250 mm. Irrigation was terminated at a time when the plants were left with about 50 days to shed pollen.

Karate (Labda cyhalomethrin) was mixed with 200 litres of water and was applied in the field at the rate of 100 ml per hectare before sowing to control ants, termites and other soil pests. Hand weeding was the predominant form of weed control at all sites, however selective application of paraquat at the rate of 1.5 l ha^{-1} was also done at all sites. Stalk borer (*Buseola fusca*) was controlled by applying Thiodan 1% granules at a rate of 3 kg ha^{-1} granules into the funnel of each plant at four weeks and eight weeks after crop emergence.

2.3 Data Collection and Statistical Analysis

The traits that were recorded in this study were: grain yield: GY (shelled grain weight per plot adjusted to 12.5% grain moisture and converted to tons per hectare), male flowering date: MF (measured as number of days after planting when 50% of the plants shed pollen), female flowering dates: FF (measured as number of days after planting when 50% of the plants produce silk pollen), anthesis-silking interval: ASI (calculated as the difference between MF and FF), and grain moisture: MOI (percent water content of grain as measured at harvest).

Line × tester analysis was performed for grain yield across all sites, under optimum, managed drought, and low-N sites to obtain probability estimates of SCA and GCA of the parents. This analysis was done using R.2.11.1, which is embedded in the CIMMYT Fieldbook software (Bänziger & Vivek, 2007) and the following model was used:

$$c_{ijkp} = \mu + g_i + g_j + s_{ij} + E_p + r_k\ (E_p) + (gE)_{ip} + (gE)_{jp} + (sE)_{ijq} + e_{ijkp} \quad (1)$$

where, i = 1, 2, 3, … 8, j = 1, 2, 3, … 30, k = 1, 2, and c_{ijkp} represented the value of the progeny of a mating of the i^{th} line, the j^{th} tester, in the k^{th} replication, and in the p^{th} environment (site). The simple μ stands for grand mean, g_i is the GCA effect common to all progeny of the i^{th} line, g_j is the GCA effect common to all progeny of the j^{th} tester, s_{ij} is the SCA effect specific to the progeny of mating the i^{th} line and the j^{th} tester, E_p is the average effect of the p^{th} environment, r_k (E_p) is the effect of the k^{th} replication that was nested within the p^{th} environment, $(gE)_{ip}$ and $(gE)_{jp}$ are the interactions between the GCA effects and the environment, $(sE)_{ijq}$ is the interaction between the SCA effect and environment, and e_{ijkp} is the random experimental error. This model was adopted from Lee et al. (2005). Genetic effects, broad and narrow-sense heritability were calculated using the AGD-R software (Rodríguez et al., 2015).

The GCA and the SCA estimates were calculated according to Beil and Atkins (1967).

3. Results

3.1 Across Sites Analysis of Variance for Grain Yield

Results of the analysis of variance combined across sites revealed that entry mean squares were significant for grain yield. GCA_{lines}, SCA effects, entry × site interaction and components of interaction effects were also significant across sites (Table 3). The highest yielding early maturing hybrid was CZL0713 × CL11579 (6.26 t ha^{-1}). CML395 × CL106622 (6.03 t ha^{-1}) was the best performer within the intermediate maturing hybrid group, while CML444 × CL115797 (6.35 t ha^{-1}) showed highest performance among the late maturing hybrids, although its performance was surpassed by a commercial check hybrid SC 727 (6.65 t ha^{-1}) (Table 4). General combining ability (GCA) for the lines (old CIMMYT lines) and specific combining ability (SCA) was significant ($p < 0.001$) across sites, under optimum, managed drought, and low-N environments. There were significant interactions ($p < 0.001$) between GCA_{lines}, $GCA_{testers}$ and SCA with the environment (Table 3). Additive genetic variance was more important than dominance genetic variance, and at the same time, genotypic variance was more important than environmental variance for grain yield across sites, across managed drought, low nitrogen, and optimum sites. Grain yield performance was highly repeatable across all environments. Narrow-sense heritability slightly exceeded 50% across sites, but it was relatively low under managed drought sites (Table 3).

Table 3. Analysis of variance (ANOVA) for grain yield (t ha^{-1}) across eight sites, two managed drought and low nitrogen sites, and three optimum sites for the North Carolina design II crosses of 30 testers and eight (8) lines following line × tester analysis procedures

Source of variation	Across sites		Optimum sites		Managed drought stress		Low nitrogen stress	
	ᒍDF	ᑲMean Sq	DF	Mean Sq	DF	Mean Sq	DF	Mean Sq
Replication (Site)	8	6.595^{***}	3	1.969^{ns}	2	23.390^{***}	2	0.012^{ns}
Site	7	4037.605^{***}	2	1532.499^{***}	1	674.088^{***}	1	16.178^{***}
Entry	231	9.971^{***}	231	9.801^{***}	231	3.338^{***}	227	2.496^{***}
GCA_{lines}	7	52.937^{***}	7	43.246^{***}	7	17.908^{***}	7	13.651^{***}
$GCA_{testers}$	29	7.801^{***}	29	11.277^{***}	29	3.094^{***}	29	2.915^{***}
SCA	195	8.696^{***}	195	8.351^{***}	195	2.837^{***}	191	2.018^{***}
Site × Entry	1595	2.072^{***}	460	2.642^{***}	231	1.931^{***}	224	1.209^{ns}
GCA_{lines} × Site	49	6.298^{***}	14	6.151^{***}	7	4.779^{***}	7	2.734^{*}
$GCA_{testers}$ × Site	203	2.996^{***}	58	2.336^{ns}	29	4.673^{***}	29	1.683^{*}
SCA × Site	1343	1.786^{***}	388	2.577^{***}	195	1.43ns	188	1.085^{ns}
Residuals	1798	1.338	683	1.92	460	1.304	439	1.049
Line variance		0.096		0.200		0.107		0.095
Tester variance		0		0.081		0		0.007
Line × Tester variance		0.469		0.989		0.384		0.298
Genotype variance		0.553		1.241		0.42		0.393
Additive variance		2.210		4.966		1.678		1.571
Dominance variance		1.875		3.955		1.535		1.193
Environmental variance		0.112		0.403		0.351		0.253
Broad heritability		0.973		0.957		0.901		0.916
Narrow heritability		0.527		0.533		0.471		0.521

Note. ᒍ Degrees of freedom (DF); ᑲ Mean of squares (Mean Sq).

$^{*, **, ***, ns}$ Significant at 0.5, 0.01 and 0.001 significance levels and not significant, respectively.

Table 4. Grain yield performance of top four early, intermediate and late maturing hybrids developed using the NCII mating design in the 2012 winter season that were evaluated in 2012-13 summer and winter seasons, alongside 10 check hybrids

		Grain yield (t/ha)								Across Sites			
Entry	**Name**	**ART Farm**	**Gwebi-opt**	**Devonia Farm**	**Harare-LN**	**Gwebi-LN**	**Kadoma**	**Chiredzi**	**Save Valley**	**Grain yield (t/ha)**	**Relative grain yield rank**	**Standard deviation**	**Anthesis date**
Early maturing hybrids													
24	CZL0713×CL115793	11.88	9.44	8.36	5.15	3.19	3.12	5.97	6.14	6.26	151	29	77.6
1	CML312×CL106851	11.22	8.94	10.57	4.50	3.17	2.17	3.56	6.70	5.98	133	31	77.4
80	CML312×CL115808	12.86	9.07	10.16	4.55	1.90	3.13	4.23	4.40	5.89	132	72	77.6
68	CML395×CL115801	13.27	9.50	8.44	2.83	1.96	2.60	4.19	4.97	5.47	118	58	77.3
Intermediate maturing hybrids													
140	CML395×CL106622	13.56	9.25	8.35	5.38	3.98	2.61	2.49	5.87	6.03	138	62	79.7
64	CML312×CL115801	12.37	9.11	7.70	4.46	2.76	3.00	3.63	6.02	5.71	132	39	79.3
40	CZL0713×CL106868	10.46	6.60	8.46	4.65	2.98	2.84	4.38	5.70	5.64	134	48	79.5
191	CML536×CL115802	12.51	10.87	7.74	4.72	4.57	2.16	3.03	6.41	5.88	136	52	81.2
Late maturing hybrids													
242	SC727	15.05	9.93	11.16	3.29	3.50	2.66	4.33	6.56	6.65	143	28	85.7
164	CML444×CL115797	14.26	12.43	8.06	4.36	6.05	1.63	4.29	5.79	6.35	146	45	82.6
149	CML444×CL115810	14.99	8.32	8.52	2.71	3.39	1.93	4.56	5.54	5.95	126	48	82.2
161	CML536×CL115797	10.84	10.93	8.50	4.01	3.26	2.29	3.87	5.33	5.44	125	33	82.3
Least significance differences (0.05)		**2.79**		**2.52**	**2.29**	**1.52**	**1.12**	**1.52**	**2.20**		**21**	**18**	

3.2 General Combining Abilities Effects for Grain Yield of Lines and Testers

The tester CL115807 showed positive and significant GCA effects for grain yield under managed drought sites. CL106622, showed positive and significant GCA effects under low-N environments. The best tester across the eight sites was CL115793 (Table 5). Line CZL0713 consistently showed positive GCA for grain yield in all the environments. However, this line only showed significant GCA effects for yield performance on the managed drought stress sites (Table 6).

Table 5. The GCA estimates for grain yield, their ranks and the significance levels across eight sites, three optimum sites, two drought sites, two low nitrogen sites and one random drought site of the male lines in hybrid combinations done using the NCII mating design in the 2012 winter season that were evaluated in 2012-13 summer and winter seasons

Tester	Across sites		Optimum sites		Managed drought stress		Low nitrogen stress		Random stress	
	˩GCA (ᒍt ha^{-1})	GCA rank	GCA (t ha^{-1})	GCA rank	GCA (t ha^{-1})	GCA rank	GCA (t ha^{-1})	GCA rank	GCA (t ha^{-1})	GCA rank
CL115808	-0.05565	18	-0.36355	21	0.412642	2	-0.33692	27	0.354856	2
CL115789	-0.04534	17	-0.27037	18	0.062726	11	0.084578	10	0.250603	4
CL115809	0.11516	11	0.856994	2	-0.43205	29	-0.2096	22	-0.25053	30
CL106683	-0.07671	19	-0.19654	16	-0.03749	17	0.250657	8	-0.17989	25
CL115755	0.140202	9	0.53396	6	-0.24623	23	-0.29617	23	-0.03238	15
CL115803	-0.17358	22	-0.20524	17	0.049749	12	-0.34937	28	0.096865	10
CL106868	0.00109	14	-0.3701	22	0.315098	4	-0.1889	21	0.271336	3
CL115804	-0.2904	25	-0.47673	27	-0.36816	26	-0.02961	15	0.173059	8
CL106581	-0.34942	27	-0.45114	26	-0.53963	30	-0.08801	18	-0.16652	23
CL115811	0.283099	4	0.852359	3	0.30773	5	-0.31154	26	-0.18565	26
C326-29	-0.41613	30	-1.01353	30	-0.40792	27	-0.04752	16	-0.17123	24
CL115793	0.535136*	1	0.91073	1	0.129915	9	0.585237	2	0.389085*	1
CL115791	-0.09846	21	-0.18515	15	0.039065	13	0.014754	14	-0.06936	16
CL115807	0.224155	7	0.204893	11	1.002102**	1	-0.29913	25	0.043114	14
CL106689	0.276705	5	0.432901	8	0.158957	8	0.388791	4	0.089939	12
C323-45	-0.37059	29	-0.43666	24	-0.13723	19	-0.44253	30	-0.23995	29
CL115801	0.131461	10	0.306775	10	0.382652	3	-0.29656	24	0.068598	13
CL115802	-0.35808	28	-0.48839	28	-0.13858	20	-0.37969	29	-0.22809	28
CL115799	-0.2901	24	-0.4133	23	-0.14912	21	-0.14349	19	-0.2252	27
CL115795	-0.23879	23	-0.44466	25	0.107422	10	-0.17873	20	-0.16318	22
CL115810	0.028382	12	0.022895	13	0.199017	6	0.060883	13	-0.09093	18
CL115800	-0.07869	20	-0.28293	19	0.026137	15	0.266283	6	-0.0951	20
CL106631	-0.04317	16	0.1657	12	-0.32355	25	0.076609	11	-0.07811	17
CL106622	0.265717	6	0.342686	9	0.007117	16	0.731758*	1	-0.10958	21
CL106508	-0.00038	15	-0.1204	14	-0.04352	18	0.063793	12	0.199002	6
CL115797	0.467589	2	0.653167	4	0.184655	7	0.361022	5	0.239843	5
CL115798	0.215313	8	0.468133	7	0.038962	14	-0.05737	17	0.151693	9
CL106851	0.002731	13	-0.31134	20	-0.21654	22	0.256984	7	0.193293	7
CL115792	-0.34011	26	-0.56854	29	-0.41308	28	0.086216	9	-0.09105	19
CL106527	0.405279	3	0.567032	5	-0.24776	24	0.421388	3	0.096005	11

Note. ˩ General combining ability (GCA); ᒍ Tonnes per hectar.

Table 6. The GCA estimates for grain yield, their ranks and the significance levels across eight sites, three optimum sites, two drought sites, two low N sites and one random drought site of the female lines in hybrids combinations done using the NCII mating design in the 2012 winter season that were evaluated in 2012-13 summer and winter seasons

Line	Across sites		Optimum sites		Managed drought stress		Low nitrogen stress		Random stress	
	˩GCA (ᒍt ha^{-1})	GCA rank	GCA (t ha^{-1})	GCA rank	GCA (t ha^{-1})	GCA rank	GCA (t ha^{-1})	GCA rank	GCA (t ha^{-1})	GCA rank
CZL0713	0.430908	2	0.234753	3	0.767395*	1	0.453042	1	0.275023	1
CML312	-0.2037	6	-0.21452	6	-0.27228	6	-0.14515	6	0.1368	3
CML395	0.241804	3	0.382169	2	0.011313	4	0.311238	2	0.160814	2
CML442	-0.33016	7	-0.52075	7	0.146424	3	-0.53538	8	-0.29157	8
CML444	0.435143	1	0.863635	1	0.28971	2	0.199979	4	-0.05294	5
CML536	0.035095	4	0.157417	4	-0.29543	7	0.229147	3	-0.15636	6
CML537	-0.4563	8	-0.66207	8	-0.45585	8	-0.36929	7	-0.16308	7
CZL052	-0.11755	5	-0.18892	5	-0.17801	5	-0.08057	5	0.082836	4

Note. ˩ General combining ability (GCA); ᒍ Tonnes per hectar.

3.3 Specific Combining Ability Effects for Grain Yield of Lines Versus Testers

The estimates of the SCA effects were summarized in Table 7. Line CML 537 showed the highest positive and significant SCA effects with the tester, CL106683 and, CML 312 showed the second highest positive and significant SCA effects with C323-45 under optimum environments. Under managed drought sites, the highest, positive and significant SCA effects were noted on combination between CML 312 and C323-45, followed by combination between CML 536 and CL106622. The best single-crosses under low nitrogen sites, with positive and significant SCA were CML 536 × CL115802 and CML 312 × C323-45. CML 312 × C323-45 is the single-cross hybrid that showed the highest positive and significant SCA across sites, with SCA effects of 1.462 t ha^{-1} (Table 7).

Table 7. The best 20 hybrid combinations that were crossed using the NCII mating design and evaluated in 2012-13 summer and winter seasons with the highest SCA effects for grain yield across the eight sites: three optimum sites, two drought sites, two low N sites and one random drought site

Across sites				**Optimum sites**				**Managed drought stress**			
Line	**Tester**	**SCA mean**	**SCA (t ha^{-1})**	**Line**	**Tester**	**SCA mean**	**SCA (t ha^{-1})**	**Line**	**Tester**	**SCA mean**	**SCA (t ha^{-1})**
CML312	C323-45	5.679	1.476*	CML312	C323-45	9.675	2.398*	CML312	CL106851	5.168	1.747*
CML537	CL106683	5.682	1.438*	CML537	CL106683	9.454	2.385*	CML536	C323-45	5.153	1.677*
CML537	CL115755	5.899	1.438*	CML444	CL115802	10.343	2.040	CZL052	CL115810	5.546	1.615*
CML536	CL115802	5.804	1.349*	CML444	CL115799	10.352	1.974	CML312	CL106581	4.713	1.615*
CML536	CL106851	6.067	1.252	CZL052	CL106683	9.508	1.966	CML537	CL106683	4.995	1.579*
CML395	CL106527	6.637	1.213	CML312	CL115808	9.266	1.917	CML312	CL106622	5.146	1.502
CML536	C323-45	5.613	1.172	CML536	CL115811	10.800	1.863	CZL052	CL115809	4.547	1.247
CML537	CL115811	5.659	1.055	CML537	CL115809	9.951	1.828	CZL0713	CL115791	5.898	1.182
CML312	CL106851	5.609	1.033	CML536	C323-45	9.432	1.784	CML312	CL115755	4.547	1.156
CML537	CL106581	5.000	1.029	CML537	CL106581	8.576	1.762	CML442	CL115792	4.744	1.101
CML444	CL115802	5.865	1.010	CML537	C323-45	8.523	1.694	CML536	CL115807	5.715	1.099
CML312	CL115808	5.527	1.009	CML312	C326-29	8.290	1.590	CML537	CL115811	4.859	1.097
CML536	CL115798	6.017	0.99	CML536	CL115802	9.177	1.581	CML395	CL106581	4.472	1.091
CML444	CL115799	5.904	0.982	CML537	CL115811	9.688	1.57	CML442	CL106683	5.104	1.086
CML312	C326-29	5.104	0.947	CML312	CL115793	10.15	1.526	CML444	CL115803	5.287	1.039
CML312	CL115801	5.648	0.943	CML536	CL106868	9.148	1.433	CML442	CL115795	5.191	1.028
CML536	CL115811	6.023	0.928	CML395	C323-45	9.303	1.43	CML536	CL106508	4.563	0.992
CML312	CL106581	5.139	0.915	CZL0713	CL115810	9.57	1.384	CZL052	CL115755	4.476	0.991
CML537	CL115809	5.33	0.893	CML537	CL115808	8.269	1.367	CML444	CL115802	5.052	0.991
CML536	CL106868	5.705	0.892	CML312	CL106851	8.747	1.345	CZL0713	CL115793	5.786	0.979

Table 7. Continued

Low nitrogen stress				Random stress			
Line	**Tester**	**SCA mean**	**SCA (t ha^{-1})**	**Line**	**Tester**	**SCA mean**	**SCA (t ha^{-1})**
CML536	CL115802	4.399	2.248**	CML312	CL115801	2.316	1.158**
CML312	C323-45	3.436	2.186*	CML444	CL115791	1.731	1.02*
CML444	CL115797	4.542	2.989*	CML537	CL115791	1.604	1.02*
CML536	CL106868	3.991	2.439*	CML536	CL115802	1.446	0.861*
CML442	CL115804	3.23	2.599	CML444	CL115793	2.079	1.478*
CML312	CL115791	3.636	2.643	CML442	C323-45	1.208	0.849*
CML537	CL115793	3.937	3.213	CML536	CL115792	1.412	0.998
CML395	CL106622	4.713	3.36	CML395	CL106631	1.741	1.011
CML312	CL106689	3.882	3.017	CML395	CL106683	1.616	0.909
CML312	CL115808	3.114	2.291	CML537	CL115798	1.616	1.241
CML536	CL115799	3.637	2.485	CML395	CL115801	1.853	1.158
CZL0713	CL115795	3.817	2.449	CZL052	CL115799	1.434	0.864
CZL0713	CL115800	4.257	2.894	CML395	CL106622	1.615	0.98
CML312	CL106527	3.808	3.05	CZL052	CL115809	1.367	0.839
CML444	CL106508	3.791	2.692	CML536	CL106868	1.649	1.360
CML312	CL106622	4.104	3.34	CML537	CL106581	1.197	0.923
CML536	CL115800	3.984	2.894	CML312	C326-29	1.491	0.918
CML537	CL106631	3.171	2.705	CML395	CL106508	1.868	1.288
CML536	CL106527	4.096	3.05	CML395	CL115803	1.763	1.186
CML395	CL115791	3.763	2.643	CZL052	CL115795	1.423	0.926

Note. Specific combining ability (SCA); Tonnes per hectar.

4. Discussion

Adequate genetic variability is important to make selection progress in breeding programs targeting improved grain yield under both stress and non-stress environments. However, Weitholter et al. (2008) suggested that selection is mostly effective for qualitative traits that are highly heritable. The significant genotypic variation for grain yield performance observed in this study indicates that, good progress can be made in selecting for improved grain yield under drought and low-N stress environments. Studies done by Turi et al. (2007) and Salami et al. (2007) also showed significant genotypic variation for grain yield under both stressed and unstressed environments. Voichita et al. (2011) suggested that if genetic variation exists amongst maize inbred lines, the scenario suggests that those inbred lines could be useful in a maize-breeding program.

GEI mean squares for grain yield were significant and a study done by Beyene et al. (2011) also identified significant mean squares for GEI. The significant variation for GEI effects for grain yield suggest that these CIMMYT lines and hybrids should be tested in contrasting environments in multi-locational trials to identify the most stable line regarding drought and low-N tolerance. This point is supported by Anley et al. (2013) who coined that significant GEI interactions indicates inconsistency in genotypic performance across testing environments, and suggested that the genotypes have to be tested in several testing locations in order to select stable genotypes.

The highly significant site effect on grain yield under drought and low-N stress environments suggested that selection for improved maize grain yield has to be carried out for specific drought and low-N sites. These results are in-line with findings of Badu-Apraku et al. (2014) who reported highly significant location effect for maize grain yield measured under two *Striga*-free environments. Bänziger et al. (2004) suggested the need to do selections under carefully managed high priority abiotic stress sites, indicating that this initiative can significantly increase yields in a highly variable drought-prone environment. However, an experiment done by Miti et al. (2010) under low nitrogen soils showed a low heritability estimate (0.38) for grain yield indicating that selection based on grain yield under low-N was ineffective.

The results showed that the new CIMMYT lines have desirable adaptive attributes when grown under common environmental stresses prevalent in the mid-altitude climatic region: drought and low-N soils. This was confirmed by the importance of additive genetic effects for grain yield performance and the moderate heritability of this trait in these environments. Moderate to large genetic variance and also low to high heritability estimates indicates the presence of sufficient residual genetic variation in a population, which makes further improvement for the trait concerned possible (Badu-Apraku, 2007; Rajesh et al., 2013). These new CIMMYT lines can be used as parental lines in breeding and hybridization programs targeting production of maize that is adapted to drought and low-N stress environments. For example, CL115807 showed to be a good line to use when making hybrids that are tolerant under drought. On the other hand, CL106622 is also the best line to use in the formation of low-N tolerant hybrids. However for breeders who aim to develop varieties with stable performance across all environments, they can choose CL115793 that showed the highest positive GCA effects across environments.

In order to produce good hybrids and synthetics in maize breeding, there is always need to make good decisions in the choice of parents, since the parental attributes affects the performance of these breeding products. GCA is a very important factor when making these decisions (Pswarayi & Vivek, 2008; Singh et al., 2013). Hence, the identification of those many lines with positive GCA effects for GY across sites, under optimum, managed drought, low-N and random stress sites random stress sites are important. According to Anwar et al. (2011), this information will be useful to select best lines to use when making hybrids, synthetic and open pollinated varieties (OPV's) that are adapted to the targeted environments. The identified low-N and drought stress adapted genotypes will increase maize productivity under these stress environments, thereby lessening problems of hunger and poverty that are predominant in sub-Saharan Africa.

Pingali and Pandey (2001) indicated the importance of doubling maize production from the period of the year 2000 to the year 2020, in an endeavor to offsetting the high demands that are being caused by increasing population sizes, especially in developing countries and the increased demands for feed and biofuels globally. Hence, the new knowledge generated regarding the breeding value of the new CIMMYT lines will be useful in the development of desirable cultivars (Masny et al., 2008; Amiruzzaman et al., 2011; Singh et al., 2013).

The study also identified CML 312 as the best CIMMYT common line when breeding for drought and low-N adaptability. Its hybrid combinations with CL106851, CL106508 and C323-45 showed the best specific combining abilities in most stress environments. This information is important for maize breeders that are involved in breeding for stress adaptability in sub-Saharan Africa.

5. Conclusion

The study has demonstrated that the new CIMMYT mid-altitude adapted lines have some levels of low-N and drought stress adaptability. However, these new lines need to be evaluated together with the old lines as these also have the desirable adaptive attributes in the stressed environments. The best single crosses identified in this study can also be considered as single-cross testers or they can be further screened for grain yield stability across several environments and seasons, in an endeavor to facilitate their release as new hybrids.

Acknowledgements

The authors are grateful to the DTMA project, CIMMYT staff and collaborators for the financial and technical support.

References

Amiruzzaman, M., Aslam, M. A., Pixley, K. V., & Rohman, M. M. (2011). Heterosis and Combining Ability of CIMMYT's Tropical × Sub-tropical Quality Protein Maize Germplasm. *International Journal of Sustainable Agriculture, 3*(3), 76-81. https://doi.org/10.2135/cropsci1992.0011183X003200060036x

Anley, W., Zeleke, H., & Dessalegn, Y. (2013). Genotype × Environment Interaction of Maize (*Zea mays* L.) Across North Western Etheopia. *Journal of Plant Breeding and Crop Science, 5*(9), 171-181. https://doi.org/10.5897/JPBCS2013.0406

Anwar, J., Akbar, M., Hussain, M., Asghar, S., Ahmad, J., & Owais, M. (2011). Combining Ability Estimates for Grain Yield in Wheat. *J Agric Res, 49*(4), 437-445.

Badu-Apraku, B. (2007). Genetic Variances and Correlations in an Early Tropical while Maize Population after Three Cycles of Reccurent Selection for Striga Resistance. *Maydica, 52*, 205-217.

Badu-Apraku, B., Akinwale, R. O., & Oyekunle, M. (2014). Efficiency of secondary traits in selecting for improved grain yield in extra-early maize under *Striga*-infested and *Striga*-free environments. *Plant Breeding, 133*, 373-380. https://doi.org/10.1111/pbr.12163

Beil, G., & Atkins, R. (1967). Estimates of general and specific combining ability in F1 hybrids for grain yield and its components in grain sorghum, Sorghum vulgare Pers. *Crop Sci, 7*, 225-228. https://doi.org/10.2135/cropsci1967.0011183X000700030016x

Betrán, F. J., Beck, D., Bänziger, M., & Edmeades, G. O. (2003). Genetic analysis of inbred and hybrid grain yield under stress and non-stress environments in tropical maize. *Crop Sci, 43,* 807-817. https://doi.org/10.2135/cropsci2003.8070

Beyene, Y., Mugo, S., Mutinda, C., Tefera, T., Karaya, H., Ajanga, S., Shuma, J., … Kega, V. (2011). Genotype by Environment Interactions and Yield Stability of Stem borer Resistant Maize Hybrids in Kenya. *African Journal of Biotechnology, 10*(23), 4752-4758.

Bänziger, M., & Diallo, A. O. (2001). *Progress in developing drought and stress tolerant maize cultivars for Eastern and Southern Africa* (pp. 189-194). Seventh Eastern and Southern Africa Regional Maize Conference, February 11-15, 2001.

Bänziger, M., & Vivek, B. (2007). *Fieldbook: Software for Managing a Maize Breeding Program*. CIMMYT.

Bänziger, M., Edmeades, G. O., & Lafitte, H. R. (1999). Selection for drought tolerance increases maize yields across a range of nitrogen levels. *Crop Sci, 39*, 1035-1040. https://doi.org/10.2135/cropsci1999.0011183X003900040012x

Bänziger, M., Setimela, P. S., Hodson, D., & Vivek, B. (2004). Breeding for improved drought tolerance in maize adapted to Southern Africa. New directions for a diverse planet. *Proceedings of the 4th International Crop Science Congress*, Sept. 26-Oct. 1, 2004, Brisbane, Australia.

Bolanos, J., Edmeades, G. O., & Martinez, L. (1992). Eight circles of selection for drought tolerance in lowland tropical maize. III responses in drought-adaptive physiological and morphological traits. *Field Crops Research, 31*, 269-286. https://doi.org/10.1016/0378-4290(93)90066-V

Cochran, W. G., & Cox, G. M. (1957). *Experimental designs* (2nd ed., pp. xiv +617). Wiley, New York (Chapman and Hall, London).

Diallo, A. O., Kikafunda, J., Wolde, L., Odongo, O., Mduruma, Z. O., Chivatsi, W. S., Friesen, W. D. K., … Bänziger, M. (2001). *Drought and low nitrogen tolerant hybrids for the moist mid-altitude ecology of eastern Africa* (pp. 206-212). Seventh Eastern and Southern Africa Regional Maize Conference, February 11-15, 2001.

Edmeades, G. O., Balanos, J., Chapiman, S. C., Lafitte, H. R., & Banzinger, M. (1999). Selection improves drought tolerance in tropical maize populations: I. Gains in biomass, grain yield, and harvest index. *Crop Sci, 39*, 1306-1315. https://doi.org/10.2135/cropsci1999.3951306x

Hoisington, D. (2001). *Application of biotechnology to maize improvement: Past, present and future prospects* (pp. 7-11). Seventh Eastern and Southern Africa Regional Maize Conference, February 11-15, 2001.

Lee, E., Ahmadzadeh, A., & Tollenaar, M. (2005). Quantitative Genetic Analysis of the Physiological Processes underlying Maize Grain Yield. *Crop Science, 45*, 981-987. https://doi.org/10.2135/cropsci2003.0518

Masny, A., Mądry, W., & Żurawicz, E. (2008). Combining ability for important horticultural traits in medium-and late-maturing strawberry cultivars. *J. Fruit Ornam. Plant Res., 16*, 133-152.

Miti, F., Tongoona, P., & Derera, J. (2010). S_1 Selection of Local Maize Landraces for Low Soil Nitrogen Tolerance in Zambia. *African Journal of Plant Science, 4*(3), 67-81.

Nyamapfene, K. (1991). *Soils of Zimbabwe* (p. 179). Nehanda Publishers, Union Avenue, Harare.

Patterson, H. D., & Williams, E. R. (1996). A Class of Resolvable Incomplete Block Designs. *Biometrica, 63*, 83-92. https://doi.org/10.1016/0378-3758(88)90056-0

Pingali, P. L., & Pindey, S. (2001). Meeting World maize Needs: Technological Opportunities and for the Public Sector. In P. R. Pingali (Ed.), *CIMMYT 1999-2000 World Food Facts and Trends* (pp. 1-24). CIMMYT, Mexico.

Pswarayi, A., & Vivek, B. (2008). Combining Ability Amongst CIMMYT's Early Maturing Maize (*Zea mays* L.) Germplasm under Stress and Non-stress Conditions and Identification of Testers. *Euphytica, 162*(3), 353-362. https://doi.org/10.1007/s10681-007-9525-0

Rajesh, V., Kumar, S. S., Reddy, V. N., & Sankar, A. S. (2013). Studies on Genetic Variability and Genetic Advance Estimates in Newly Developed Maize Genotypes (*Zea mays* L.). *International Journal of Applied Biology and Pharmaceutical Technology, 4*(4), 242-245.

Rodríguez, F., Alvarado, G., Pacheco, A., Burgueñ, J., & Crossa, J. (2015). *AGD-R: Analysis of Genetic Designs*. CIMMYT.

Salami, A. E., Adegoke, S. A. O., & Adegbite, O. A. (2007). Genetic Variability among Maize Cultivars Grown in Ekiti-State Nigeria. *Middle-East Journal of Scientific Research, 2*(1), 9-13.

Singh, A., Shahi, J. P., & Langade, D. M. (2013). Combining Ability Studies for Yield and Its Related Traits in the Inbred Lines of Maize (*Zea mays* L.). *Molecular Plant Breeding, 4*(22), 177-188. https://doi.org/10.5376/mpb.2013.04.0022

Turi, N. A., Shah, S. S., Ali, S., Rahman, H., Ali, T., & Sajjad, M. (2007). Genetic Variability for Yield parameters in Maize (*Zea mays* L.) Genotypes. *Journal of Agricultural and Biological Science, 2*, 1-3.

Voichita, H. S. S., Rodica, P. O. P., Ioan, H. A. S., & Copandean, A. (2011). Genetic Variability in a Set of Early Maize Inbred Lines. *Bulletin UASUM Agriculture, 68*(1), 155-164.

Wietholter, P., Cruz de Melo Sereno, M. J., de Freitas Terra, T., Delmar dos Anjos e Silva, S., & Barbosa Neto, J. F. (2008). Genetic Variability in Corn Landraces from Southern Brazil. *Maydica, 53*, 151-159.

Copyrights