Journal of Applied Biosciences 57: 4198– 4207

ISSN 1997–5902

Combining ability analysis among Sudanese and IITA maize germplasm at Gezira Research Station

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Original submitted in on 23rd July 2012. Published online at www.m.elewa.org on 30th September 2012.

ABSTRACT

Objective: A study was conducted to estimate combining ability among four introduced drought tolerant maize (*Zea mays* L.) inbred lines and five local open pollinated varieties (OPVs) in Line x Tester mating design.

Methodology and results: The experiment was arranged in 5 x 5 alpha lattice with three replications conducted at Gezira Research Station (GRS), Sudan, in 2008 and 2009. Significant differences were detected among hybrids for all measured traits. Combining ability analysis showed that non-additive gene effects were important for inheritance of all traits except ear length which was controlled by additive gene effects. General combining ability (GCA) had the highest contribution to total variation of plant height, ear height, and grain yield, whereas specific combining ability (SCA) had the highest contributions to days to 50% anthesis. Among the testers, Pop10 was the best general combiner for grain yield across the two years. (Mugtama-45 x Pop10), (Hudeiba-1 x Pop10) and (Giza-2 x 1824) exhibited significant SCA effects for grain yield. Regression of grain yields of hybrids and OPVs on their ear length revealed that grain yield accounted for 62% of the total variability. The top-cross hybrids had higher grain yields and relatively longer ears than the local OPVs.

Conclusion and application: This study suggests that Pop10 was the best general combiner for grain yield and could be used for developing hybrids in the Sudan.

Keywords: drought tolerant; combining ability; top-cross hybrids; Line x tester

INTRODUCTION

Maize is a promising cereal crop in Sudan with the potential usefulness for both human beings and livestock (Salih *et al.,* 2008). It ranks the fourth important cereal crop in Sudan after sorghum, wheat and pearl millet. Although maize is emerging as an important cereal crop in Sudan, the vast majority of farmers still practice recycling seeds of open pollinated varieties (OPVs) without continuous maintenance measures. Some of the farmers believe that there is a small or no difference in yield between hybrids and OPVs and instead rely on saved seeds from their own harvest or obtain from other farmers. Farmers who grow maize and retain the seed from year to year are growing OPVs of their own selection (landraces). An estimated 95% of maize area in Sudan is being planted under routine recycled OPVs. Recycling of maize varieties would lead to seed contamination, loss of vigour and consequently reduction in yield potential (Setimela and Kosina, 2006). Pixley and Bänziger (2004) assessed the yield reduction of cultivar types incurred by planting recycled seeds relative to fresh seeds of cultivar types across locations. Their studies showed that the effect of planting recycled seeds was negligible (5%) for OPVs, severe for hybrids (> 30%) and intermediate in top-cross hybrids (16%).

Although an OPV seed may be recycled for a maximum of three seasons without significant yield loss (≤ 10%), the longer the farmer recycles OPV seed, the greater the risk of contamination by pollen from neighbouring fields, and consequently deterioration of the variety (Setimela and Kosina, 2006). The key in maintenance of seed quality of an improved OPV is an isolation distance of 300 m from the nearest maize field to avoid adulterations. This aims at maintaining yield potential among other preferred agronomic traits. The grain of an OPV may be saved for replanting if it is grown in isolation from other maize varieties, or harvested from the middle of the field.

Theoretically, it is known that the first generation seed of top-cross hybrids yield more than OPVs. Smale and Phiri (1998) recommended that maize breeders working for areas where farmers normally recycled seeds should consider use of inbred lines in improving maize genotypes. Non-conventional hybrids involving at least one non-inbred parent are cheaper and easier to produce, but typically offer lower yield potential than conventional hybrids using two or more inbred parents. Since many farmers in Sudan recycle their seeds, therefore, use of non-conventional hybrids such as top cross and variety cross that are less sensitive to inbred depression could be one way of enhancing yield stability. This approach also allows exploitation of heterosis with relatively little inbreeding depression when seeds are recycled. Meseka *et al*. (2002) used some maize collections in Sudan for varietal crosses at Gezira Research Farm (GRF) and found that some local OPVs such as VAR 113 released in 1970s had good combining ability in hybrid combination with yield advantage of 8% over their parent OPVs. Correjado and Magulama (2008) compared top-cross hybrids with their parental OPVs and found that the top-crosses had yield advantage of 17% over their parental OPVs. They also observed significant differences among the top-cross hybrids with yield ranging from 3.8 to 6.2 t ha^{-1}. These studies (Meseka *et al*., 2002; Pixley and Bänziger, 2004; Correjado and Magulama, 2008) suggested that moving from recycled OPVs to varietal cross and top-cross hybrids will increase the productivity of maize in Sudan. The cheap seed price for non-conventional hybrids as compared to conventional hybrids will be of an advantage for the majority resource poor farmers in Sudan.

Although some maize hybrids (PAN-6064, PAN-6068) introduced by PANNAR Seed Company (Ltd) in Sudan through the Agricultural Research Corporation (ARC) and released for use in 1999 and others (PAN-6026, PAN-6568, PAN-6966) released in 2009, none of these hybrids are adopted by farmers. There are several factors that led to the lack of adoption which include the lack of sustainable supply of seeds in good time, high cost of hybrid seed, and unavailability of parent materials with ARC and the local Seed Companies in Sudan. These factors and others related to management of single-cross maize hybrids compelled the majority of farmers to rely on local maize varieties. Most of the local varieties in the Sudan are named after locations where they are commonly grown (Meseka, 2000). Some of these local varieties include Dallenge (in Nuba Mountains), Sennar and Damazin (in Sennar and Southern Blue Nile States).

Until recently, most farmers all over the world widely believed that the yield advantage of hybrids is expressed only with good management (Heisey *et al*., 1998), under optimum conditions. Others urged that under conditions of low fertility or in presence of abiotic stresses (heat, drought, water logging), hybrids perform more poorly than OPVs or even local varieties (Friis-Hansen, 1989). Most of these instances involve hybrids that were either introduced without adequate testing to ensure their suitability for local production conditions or developed using only exotic germplasm which were not well-adapted to the local environment. Maize hybrids developed from well-adapted germplasm are profitable and can significantly out-yield local varieties or improved OPVs even when grown in marginal production environments under low levels of management (Heisey *et al*., 1998), typically of resource poor farmers in Sudan. Estimates of combining ability are useful in determining the breeding value of maize germplasm and the appropriate procedures to use in a breeding program. Line x Tester analysis provides information about general and specific combining abilities of parents which help in estimating various types of genetic effects. This study was conducted to (i) evaluate combining ability of Sudanese open pollinated maize varieties with IITA inbred lines for grain yield and other agronomic traits; and (ii) compare yield performance of top-cross with their parental open pollinated varieties.

MATERIAL AND METHODS

Site: The experimental site was Gezira Research Farm (GRF) at the Gezira Research Station (GRS), Wad Medani (14º 25/ N, 33º 80. 29/ E). The soil is typically of central clay plains characterized by its high heavy cracking clay soil of the order Vertisols. The soil is low in organic matter content (0.6%) and pH ranging from 7.7 to 8.3. GRF is generally flat with 0.01% gradient from south to north and tilted from east to west (Adam *et al*., 1983).

Genetic materials: The genetic materials comprised of five local maize varieties grown by farmers in Sudan for more than a decade and four drought tolerant maize inbred lines introduced from the International Institute of Tropical Agriculture (IITA) in Nigeria (Table 1).

Table 1: Parents of top-cross hybrids, type of germplasm, their important attributes and sources of origin.

Parent	Type	Attribute	Source
Hudeiba-1	Improved OPV	Good grain quality	ARC-Sudan
Hudeiba-2	Improved OPV	Good grain quality	ARC-Sudan
Giza-2	Introduced OPV	High yield	Egypt
Mugtama-45	Introduced OPV	Drought tolerant	Egypt
VAR 113	Local variety	Earl maturity	ARC
9006	Inbred line	Drought tolerant	IITA
Pop 10	Inbred line	Drought tolerant	IITA
1824	Inbred line	Drought tolerant	IITA
KU1409	Inbred line	Drought tolerant	IITA

These materials were planted during the rainy season of 2007 at GRS to generate 20 top-cross hybrids using Line x Tester design (Kempothorne, 1957). The same materials were planted in 2008 to increase seed of the top-cross hybrids for planting in 2009 main season.

Layout of experiment: The trial consisted of 20 top-cross hybrids and five parental local Sudanese OPVs making a total of 25 entries. Four parental inbred lines (testers) were excluded from the field evaluation due to their weak plant statues coupled with low performances that could not, reasonably, be compared with performances of OPVs and top-cross hybrids. The 25 entries were evaluated for two consecutive years at GRS during the rainy season in July 2008 and 2009. In each year, the experiment was arranged in 5 x 5 alpha lattice design (incomplete design) with three replications. Each replicate consisted of 5 incomplete blocks and 5 plots in each block. Each entry was planted on a two-row 5 m plot spaced 0.80 m between rows and 0.25 m between hills. Two seeds were shown in a hill and then thinned to one plant per hill three weeks after sowing to attain a population density of 53,333 plants ha^{-1}. Nitrogen fertilizer was applied in a split dose of 60 kg N ha^{-1} each at 21 and 37 days after sowing. Weeding was done manually at 15 and 35 days after plant emergence to keep the field weed free. Supplementary irrigation (furrow irrigation) was applied at the interval of every 10 to 12 days and reduced to seven days whenever there were no rains.

Data collection and analysis: Days to anthesis and silking were recorded as number of days from planting to when 50% of the plants within a plot were shedding pollen and had emerged silks of about 5 cm long from the shoot tip, respectively. Plant and ear heights were measured in centimeters (cm) as distance from the surface of ground to the first tassel branch and the node bearing the upper ear, respectively. Ear length was measured from the base to the tip of ear of five randomly selected ears in each plot. Hundred-kernel weight was recorded as the mass of a random sample of 100 kernels taken from the bulked threshed seeds of each plot. All ears harvested from each plot were shelled and used to determine percentage of grain moisture and grain weight. Grain yield adjusted to 12.5% moisture was computed from the shelled grain weight as shown in the equation below.

Grain yield (t ha^{-1}) = [GWT*(100 – MOIST%)/ 87.5] * (10000/Plot size)

Where
t ha^{-1} = grain yield converted into tons per hectare;
GWT = shelled grain weight measured in kilograms per plot;
MOIST = grain moisture content measure by using digital grain moisture analyzer;
87.5 = adjustment factor of grain moisture to 12.5%;
10,000 = conversion factor to an area of one hectare of a plot;
Plot size = actual plot size harvested measured in meters.

To test effect of year and the significance of genotype by year interactions, a combined data from two years (2008 and 2009) were subjected to analysis of variance (ANOVA) using a mixed model in SAS (SAS Institute, 2002), considering years and replications as random effects. Each year was considered a test environment. The ANOVA were performed with PROC GLM of SAS using a RANDOM statement with the TEST option. ANOVA was computed for the hybrids and the local OPVs to generate entry means. Adjusted means for incomplete block design were used to estimate general and specific combining ability effects. Line x Tester analysis was performed according to Kempothorne (1957). The hybrid component of variation was divided into variation attributable to Lines (females), Testers (males) and Line x Tester interaction. General and specific combining abilities for the studied traits were estimated according to Singh and Chaudhary (1985).

RESULTS

Combined analysis of variance for 25 genotypes showed highly significant differences among the genotypes for all the measured traits. Year of testing was the largest source of variation among genotypes for all the traits studied. Genotypes also showed significant interactions with year for most of the traits except ear height (Table 2).

Table 2: Analysis of variance for grain yield and other agronomic traits in twenty-five maize genotypes tested at Gezira Research Farm during the rainy season in 2008 and 2009.

Source	d.f.	Grain yield (t ha^{-1})	Days to anthesis (day)	Days to silking (day)	Plant height (cm)	Ear height (cm)	Ear length (cm)
Year (Y)	1	1352.55**	96.81***	85.53**	8165.15***	1174.82***	137.53***
Reps. x Year	4	413.76***	73.22**	76.17**	670.26***	196.76***	5.63*
Genotypes (G)	24	182.49***	75.96**	41.72*	719.25***	213.21***	7.79**
G x Y	24	127.41**	56.92*	59.47**	354.19**	94.73ns	5.14*
Pooled error	96	54.29	33.72	21.15	92.41	49.22	2.08

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.
ns – not significantly different at P = 0.05.

Analysis of variance of combining ability showed that mean squares for lines (parental local OPVs) and testers (inbred lines) were highly significant (P < 0.001) for grain yield, ear length, days to anthesis and silking, plant and ear heights. Line x tester interaction also revealed significant mean squares for grain yield, days to anthesis and silking, plant and ear height. The mean squares for interactions of lines x year and testers x year were significant for most of the traits measured in this study (Table 3). Line x tester interactions with year was significant only for grain yield, days to silking and plant height. The ratio of variances due to general combining ability (GCA) and specific combining ability (SCA) revealed the predominance of non-additive gene action for most of the traits except ear length (Table 3).

Table 3: Analysis of combining ability for grain yield and other agronomic traits in twenty top-cross maize hybrids tested at Gezira Research Farm during rainy season in 2008 and 2009.

Source	d.f.	Grain yield (t ha^{-1})	Days to anthesis (day)	Days to silking (day)	Plant height (cm)	Ear height (cm)	Ear length (cm)
Year (Y)	1	23.70***	61.30***	58.69***	936.53***	579.52***	13.55***
Reps. x Year	4	0.53*	13.41**	12.76**	156.41*	142.96**	5.41*
Lines (L)	4	2.57***	12.17**	14.82**	426.31**	370.84***	6.99**
Testers (T)	3	3.82***	18.23**	21.94**	795.33***	591.56***	6.32**
Line x Tester	12	1.13***	16.18**	15.86**	171.42**	152.98**	1.78ns
L (Y)	4	2.26***	11.75**	17.23**	130.13ns	128.30**	0.98ns
T(Y)	3	2.61***	28.62***	32.14***	53.92ns	40.59ns	8.94***
L x T (Y)	12	0.73**	7.36ns	13.82**	67.83ns	59.37*	1.94ns
Error	76	0.23	5.37	4.96	72.81	53.82	2.41
GCA		0.02	-0.06	-0.09	4.95	3.91	0.09
SCA		0.56	3.92	3.27	37.79	34.81	0.07
CGA: SCA		0.04	-0.02	-0.03	0.13	0.11	1.29

*, **, *** significant at 0.05, 0.01 and 0.001 probability levels, respectively.
ns – not significantly different at P = 0.05., GCA – general combining ability estimate., SCA – specific combining ability estimate.

Estimates of GCA for parental OPV lines showed that Hudeiba-2, Mugtama-45 and Giza-2 were good general combiners for grain yield, while Hudeiba-1 and VAR113 were poor combiners for this trait. Both Hudeiba-2 and Mugtama-45 were also good combiners for ear length (Table 4). In addition, Hudeiba-2 was a good combiner for earliness and low ear placement, while Mugtama-45 was a good combiner for tall plants. Estimate of GCA for parental inbred lines revealed that Pop10 was the best tester for grain yield and ear length with late flowering and tall plants. Tester 9006 and 1824 were good combiners for earliness and short plants with sacrifice to grain yield (Table 4). As shown in Table 5, estimates of SCA effects for grain yield among the twenty (20) hybrids showed that (Mugtama-45 x Pop10), (Hudeiba-1 x Pop10), and (Giza-2 x 1824) had positive and significant SCA effects, indicating that these hybrids could be exploited for yield improvement of the local OPVs.

Table 4: Estimates of general combining ability effects of lines and testers for grain yield and other agronomic traits averaged over two years.

Parents	Grain yield (t ha^{-1})	Days to anthesis (day)	Days to silking (day)	Plant height (cm)	Ear height (cm)	Ear length (cm)
LINES (Females)						
Hudeiba-1	-0.24*	0.34	-0.29	-2.46**	0.41	-0.30
Hudeiba-2	0.20	-0.76*	-0.65*	0.31	-0.18	0.38
Giza-2	0.04	-0.06	-0.19	2.48**	0.71*	-0.22
Mugtama-45	0.08	0.10	0.21	0.72*	0.15	0.08
VAR 113	-0.10	0.38	0.19	0.30	0.52*	0.06

SE±	0.04	0.13	0.09	0.50	0.11	0.06
TESTERS (Males)						
9006	-0.12	-0.54*	-0.38*	-0.87	0.43	-0.24
Pop10	0.29*	0.56*	0.32*	2.18*	-0.09	0.36
1824	-0.04	-0.28	0.16	-1.89*	0.14	-0.20
KU1409	-0.10	0.26	0.13	0.30	-0.23	0.08
SE±	0.05	0.08	0.06	0.44	0.07	0.06

*, ** significant at 0.05and 0.01 probability levels, respectively.

Table 5: Estimates of specific combining ability effects for grain yield in 20 top-cross hybrids.

Hybrid	2008	2009	Combined
Giza-2 x 9006	0.08	0.11	0.11
Giza-2 x Pop10	-0.12	-0.19	-0.20
Giza-2 x 1824	0.32*	0.17	0.24*
Giza-2 x KU1409	-0.34*	-0.21	-0.27*
Hudeiba-1 x 9006	0.01	0.04	0.03
Hudeiba-1 x Pop10	0.53*	0.38*	0.43*
Hudeiba-1 x 1824	-0.03	0.07	0.01
Hudeiba-1 x KU1409	-0.33*	-0.12	-0.18
Hudeiba-2 x 9006	0.34*	0.22	0.31
Hudeiba-2 x Pop10	0.14	0.49*	0.25
Hudeiba-2 x 1824	0.02	0.05	0.03
Hudeiba-2 x KU1409	-0.49*	-0.24	-0.27
Mugtama-45 x 9006	-0.23	-0.20	-0.19
Mugtama-45 x Pop10	0.27	0.59**	0.35*
Mugtama-45 x 1824	-0.15	-0.36*	-0.21
Mugtama-45 x KU1409	0.13	0.35*	0.28
VAR 113 x 9006	-0.17	-0.09	-0.13
VAR 113 x Pop10	-0.05	-0.08	-0.04
VAR 113 x 1824	0.28	0.06	0.18
VAR 113 x KU1409	0.10	0.13	0.11
SE±	0.03	0.03	0.02

*, ** significant at 0.05and 0.01 probability levels, respectively.

Generally, the hybrids had higher grain yields and relatively longer ears than their OPV parents. The mean grain yield of hybrids averaged across two years was 3.90 t ha^{-1} and that of the local OPVs 2.44 t ha^{-1}. Most of the hybrids and local OPVs had similar days to flowering (Table 6). However, the hybrids were taller and had higher ear placement than the local OPV parental lines. As shown in Figure 1, majority of hybrids had grain yield above 3.5 t ha^{-1} and ear length of 13.5 cm. Regression of grain yield of both hybrids and the local OPVs on their ear length showed that grain yield accounted for 62% of the total variability. A unit increase in ear length would contribute to increase in grain yield.

Table 6: Mean grain yield and other agronomic traits of twenty top-cross maize hybrids and five local open-pollinated varieties tested at Gezira Research Farm in 2008 and 2009.

Genotype	Grain yield ($t\ ha^{-1}$)	Days to anthesis (day)	Days to silking (day)	Plant height (cm)	Ear height (cm)	Ear length (cm)
HYBRID						
Giza-2 x 9006	4.1	52	56	166	75	14.0
Giza-2 x Pop10	4.6	54	59	154	67	13.5
Giza-2 x 1824	5.1	51	54	167	80	15.4
Giza-2 x KU1409	3.8	53	56	149	71	13.8
Hudeiba-1 x 9006	3.6	52	56	161	65	14.7
Hudeiba-1 x Pop10	4.5	53	55	163	76	14.2
Hudeiba-1 x 1824	2.8	52	55	170	70	13.3
Hudeiba-1 x KU1409	3.9	53	55	152	71	14.3
Hudeiba-2 x 9006	4.8	51	54	162	72	15.0
Hudeiba-2 x Pop10	3.4	54	58	159	74	13.2
Hudeiba-2 x 1824	3.6	51	54	174	86	13.4
Hudeiba-2 x KU1409	4.1	53	57	147	68	14.2
Mugtama-45 x 9006	3.9	53	55	169	72	13.7
Mugtama-45 x Pop10	5.7	52	55	175	95	16.0
Mugtama-45 x 1824	4.3	51	53	180	101	14.9
Mugtama-45 x KU1409	4.2	53	58	165	58	13.8
VAR 113 x 9006	2.4	51	55	172	84	12.9
VAR 113 x Pop10	3.2	51	54	155	77	13.1
VAR 113 x 1824	3.1	52	55	148	67	13.6
VAR 113 x KU1409	2.9	52	54	165	76	13.4
OPV†						
Giza-2	3.0	51	55	150	63	14.6
Hudeiba-1	2.8	51	56	143	59	14.0
Hudeiba-2	1.9	52	56	149	61	11.9
Mugtama-45	2.4	50	53	145	67	13.7
VAR 113	2.1	51	54	136	58	13.0
Mean	3.6	51.9	55.3	159.0	72.5	13.9
SE±	0.19	0.22	0.31	2.25	2.10	0.17

†OPV – open pollinated variety.

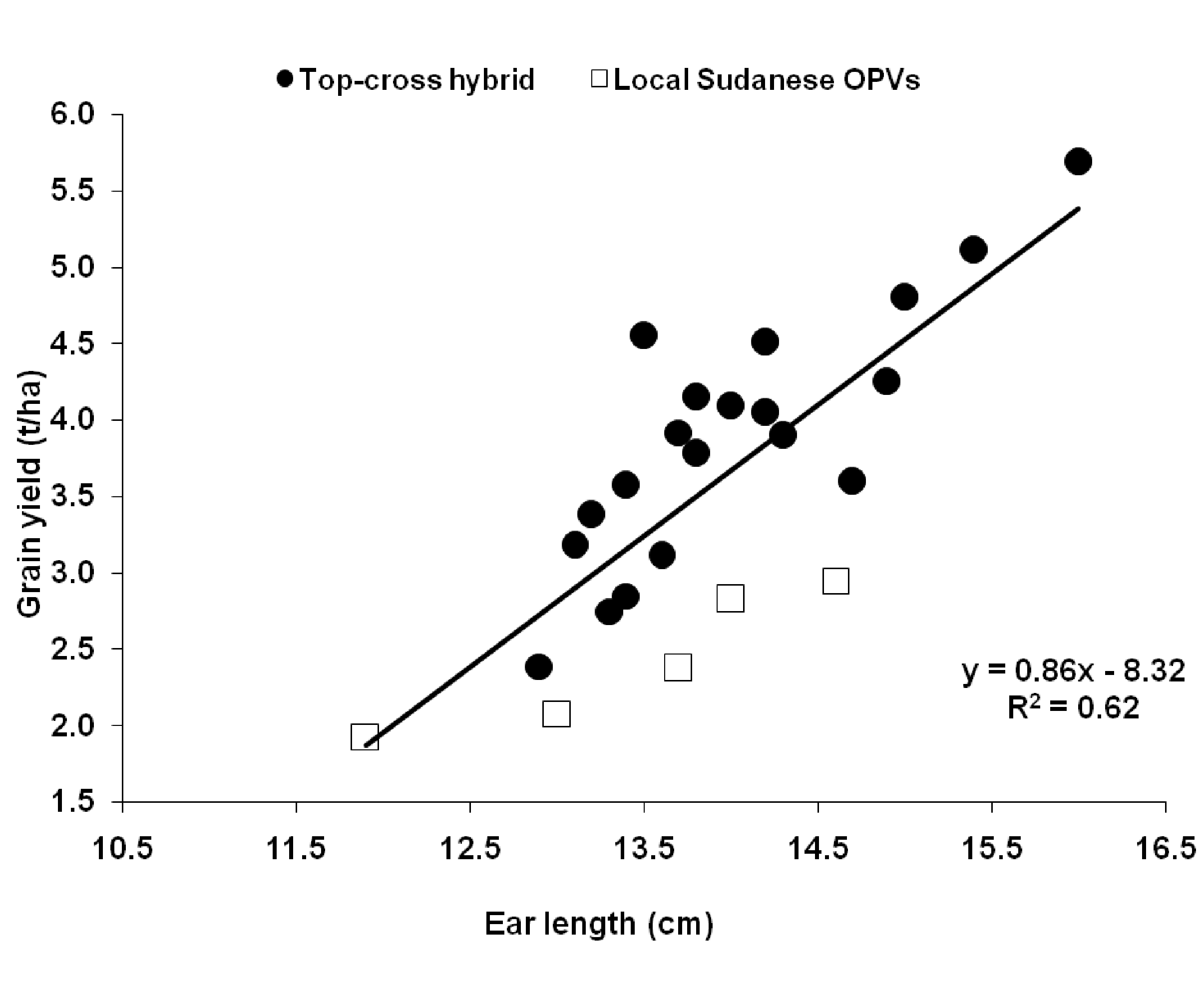

Figure 1: Regression of grain yield of twenty-five maize genotypes on their ear length.

DISCUSSION

The significance of mean squares of lines and testers reported in this investigation suggested the prevalence of additive variance for these traits. The significant line x tester detected in this study suggested that dominance or non-additive variance was important for these traits. The comparative variance due to GCA and SCA revealed the predominance of non-additive gene action for the majority of traits (Mohammed, 2009; Meseka *et al*., 2006; Kalaiyarasi *et al*., 2002). The usefulness of a particular cross in exploiting heterosis is judged by SCA effect. Chances are greater if outstanding parents with favorable alleles are chosen which on crossing would give heterotic hybrids. Among the 20 top-crosses, only (Mugtama-45 x Pop10), (Hudeiba-1 x Pop10) and (Giza-2 x 1824) showed significant SCA effects for grain yield. Hybrid (Mugtama-45 x Pop10) involved a cross between parental line, Mugtama-45, and a tester, Pop10, all with positive GCA effects, suggesting an additive x additive type of gene action that can be fixed in subsequent generations if no repulsion phase linkages are involved. On the other hand, (Hudeiba-1 x Pop10) involved a cross between parental line, Hudeiba-1, with negative and a tester, Pop10, with positive GCA effects; also hybrid (Giza-2 x 1824) involved a cross between parental line, Giza-2, with positive and a tester, 1824, with negative CGA effects, indicating involvement of additive x dominant gene interactions in the two hybrids. The high yield potential expressed by (Hebeiba-1 x Pop10) and (Giza-2 x 1824) could be attributed to interactions between favorable alleles from poor and good combiners. This suggests the exploitation of heterosis in F1 generation as high yield potential would not be easily fixed in the next generation. Peng and Virmani (1999) also reported the interaction between positive alleles from good combiners and negative alleles from poor combiners in rice hybrids.

Top-cross hybrids had yield advantage of 37% over the local OPVs. The yield advantage of these hybrids was associated with long ears. Correjado and Magulama (2008) reported 17% yield advantage of top-cross hybrids over their parent OPVs. The results of this study corroborate that of Paliwal (2000) who reported yield advantage of 28% of top-crosses over OPV parents. These results suggest that non-conventional hybrids can yield almost double that of OPVs; hence, the use of non-conventional hybrids would be profitable to local farmers. This approach also allows exploitation of heterosis with relatively little inbreeding depression when seeds are recycled. Since many farmers in Sudan recycle their seeds, therefore, the use of top-cross hybrids which are less sensitive to inbreeding depression could be one way of enhancing maize productivity and yield stability.

CONCLUSIONS

This study demonstrated that non-additive gene effects were more important than additive gene effects for inheritance of most traits except ear length which was controlled by additive gene effects. General combining ability had the highest contribution to total variation of plant height, ear height, and grain yield, whereas SCA had the highest contributions to days to 50% anthesis. The best combiners for grain yield and other yield components Pop10, Hudeiba-2, Mugtama-45 and Giza-2 could be utilized in breeding program to improve yield potential of local maize OPVs. Three crosses, (Mugtama-45 x Pop10), (Hudeiba-1 x Pop10) and (Giza-2 x 1824) could be used for exploiting heterosis for yield and other desirable agronomic traits. Majority of top-cross hybrids had yield potential nearly double that of their OPV parent lines. The best tester Pop10 with good combining ability for grain yield and ear length could be useful for developing hybrids and synthetics in the Sudan.

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