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Diallel Analysis and Evaluation of Parents and F_1 Progenies of Maize (*Zea mays* L.) for Tolerance to Drought and *Striga hermonthica* (Del.) Benth in the Guinea Savanna Agro-Ecological Zone of Ghana

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Abstract: Field studies were conducted to evaluate 6 parents and 30 F_1 hybrids of maize for tolerance to drought and *Striga hermonthica* in Nyankpala, Ghana during the 2014 and 2015 cropping seasons. These genotypes were evaluated for two years on single-row plots of three replicates, in a randomized complete block design. The control plants were planted in July each year which is the normal and usual time of planting of maize in the study area, whilst the water-stressed plants were planted six weeks later to ensure that their growth period coincides with the drought period. The *Striga hermonthica* infested plants were also planted at the normal time of planting maize in the study area. Results showed that highly negative significant GCA effect for the parent populations was observed in TAIS03, KOBN03-OB, DT-STR-W-C2 and IWD-C3-SYN-F2 for majority of the traits. The four parents were good general combiners for majority of the traits observed. For the F_1 hybrids, KOBN03 × DT, DT × TAIS03, TAIS03 × KOBN03, IWD × GUMA03, GUMA03 × DT, GUMA03 × SISF03 and SISF03 × TAIS03 gave the highest negative significant SCA effect for most of the traits studied and are good specific combiners for the traits observed. The highly significant negative GCA and SCA effects of parents and F_1 hybrids for majority of observed traits showed that those genotypes were highly tolerant to drought and/or *Striga hermonthica*. Drought rating, leaf-rolling rating, striga rating, striga count and Anthesis-Silking Interval (ASI) had been reduced significantly when plants were watered throughout the experimental period (control) as compared to the water-stressed and striga-infested plants. However, grain yield, hundred-grain weight, number of ears harvested, plant height, ear height, days to 50% anthesis, days to 50% pollen shed and days to 50% silking were significantly higher ($p<0.05$) for the normal (control) plants as compared to the water-stress and striga-infested plants. In drought-prevalent or striga-infested geographical areas like Northern Ghana, parent and F_1 hybrid populations such as (TAIS03, KOBN03-OB, DT-STR-W-C2 and IWD-C3-SYN-F2) and (KOBN03 × DT, DT × TAIS03, TAIS03 × KOBN03, IWD × GUMA03, GUMA03 × DT, GUMA03 × SISF03 and SISF03 × TAIS03) respectively, can be used for increased grain yield.

Keywords: Maize, Drought and Striga Tolerance, Combining Ability, Diallel Analysis, Ghana

Introduction

Maize (*Zea mays* L.) belongs to the tribe *Maydeae* and the family *Poaceae.* The crop is a native of Southern Mexico. Globally, maize is the third most important cereal after wheat and rice in area and total production (FAO, 2011). The world maize production area is about 176 million ha (FAOSTAT, 2012), whilst Africa maize production area is about 21 million ha. About 70% of maize is mostly used for animal feed and only 5% is consumed by humans in developed countries. However, maize contributes to about 70% of the food consumed in sub-Saharan Africa (FAO, 2007). Word maize production for 2012 was 875 million tons (FAOSTAT, 2012). The share of Africa's maize production for the same period (2012) was 69 million metric tons or about 8% of the world production (FAOSTAT, 2012).

In Ghana, maize is the largest and most widely cultivated crop and contributes to 50-60% of total cereal production. It is the second largest commodity crop after cocoa (IITA, 2013) and contributes to more than 45% of the agricultural income among smallholder farmers in the country. The maize production area in Ghana is about 1 million ha (IITA, 2013). Ghana's total maize production for 2012 was 1.65 million tons (IITA, 2013).

The most important limiting factors to maize production in Ghana are drought, striga infestation and low soil fertility (MoFA-SRID, 2011). Maize productivity can be increased in Ghana by reducing yield losses caused by various stress factors such as parasitic weeds and drought (Wegary *et al*., 2004). The development of drought and striga tolerant varieties in maize might improve the performance of the crop even under water stressed and/or striga infested conditions and hence increase yield to meet the food requirements of the people of Ghana in particular and the sub-Saharan Africa in general.

Population improvement and hybridization are major factors in successful maize breeding programs, especially, in developing countries where both population and hybrid seeds are in similar demand (Naspolini *et al*., 1981). The yield traits of exotic introductions can be improved by introgression of high yielding traits of local cultivars into the germplasm of the exotic introductions or by the direct use of well-identified introduced potentialities. The development of resistant or tolerant maize varieties might be the most feasible method for striga and drought control (Ejeta *et al*., 1992).

Six superior parents were crossed in a complete diallel manner to produce 30 F_1 hybrids. These hybrids and their parents were evaluated for combining abilities and heritability in two years. The objective of the study was to evaluate parents and their F_1 hybrids for tolerance to drought and/or *Striga hermonthica*.

Materials and Methods

Location

The experiment was conducted in two years; at the experimental field of the Savanna Agricultural Research Institute (SARI) at Nyankpala in the Northern Region of Ghana. Nyankpala is located on latitude 9°25^1 N and longitude 0°58^1 W in the Guinea Savanna Agro-ecological Zone of Ghana (SARI, 2012). The Guinea Savanna Zone covers over one-third of the entire land area of Ghana and is characterized by high temperature and low humidity during most parts of the year. The rain fall pattern is monomodal and erratic with an annual mean of 1100 mm which mostly begins in period between April and May and end October. The area is also characterized by long dry season (4-6 months) which normally takes place from November to April. Intermittent dry spells often lasting up to two weeks also occur during the growing season.

Experimental Design

The experimental design used for this study was Randomized Complete Block Design (RCBD) with three replications. The replications were separated from one another by a 2 m alley. Six parent populations of maize obtained from the Savannah Agricultural Research Institute (SARI), Nyankpala and their 30 F_1 hybrid populations, developed through a 6×6 diallel mating design, were evaluated for drought and striga tolerance under field conditions. The study was conducted during the 2014 and 2015 cropping seasons at SARI experimental field. For each year, the experiment consisted of three different trials (normal, water-stressed and striga-infested trials). The normal trial was the controlled trial in which the maize plants were planted in July which is the normal time of planting maize in the study area. The early planting of the normal trial was to make sure that the trial did not coincide with drought. Again, the normal trial was not infested with seeds of *Striga hermonthica.* The genotypes that were drought-stress were planted six weeks late to ensure that their growth and development stage coincided with the drought period. According to SARI (2012), Nyankpala (the study area) experiences a monomodal rain fall pattern and that the rainy season usually occurs between the months of May to October, with the optimum rainfall in terms amount and distribution occurring within the months of July to September.

The striga-infested trial was planted at the same time as the control (normal) trial. However, the maize plants were planted together with seeds of *Striga hermonthica* in each hole. The artificial infestation with striga was to ensure that the *Striga hermonthica* parasitizes with the maize plants. All agronomic practices observed in the three trials were the same, with the introduction of drought or striga infestation as the only difference. In all cases, treatments were replicated three times in randomized complete block design. Blocks were separated from one another by a 2 m alley whilst the inter-row and intra-row spacings were 0.75 and 0.40 m, respectively. The following model was used for statistical analysis:

$$Y_{ijk} = \mu + G_i + G_j + S_{ij} + R_k + E_{ijk}$$

Where:

Y_{ijk} = The observed value for a hybrid between the i^{th} and j^{th} parents in the k^{th} replication

μ = Population mean

G_i and G_j = GCA effect of the i^{th} and j^{th} parents
S_{ij} = SCA effect for the hybrid between the i^{th} and j^{th} parents
R_k = Effect of the k^{th} replication
E_{ijk} = The error associated with the ijk^{th} hybrid (the residual) (Johnson and King, 1998)

Estimation of the additive and dominance genetic variance was done after estimating the GCA variance (σ^2_{GCA}) and SCA variance (σ^2_{SCA}) (Zhang *et al*., 2005).

When inbreeding coefficient (F) of parents = 0; $\sigma^2 A = 4\sigma^2_{GCA}$; $\sigma^2 D = 4\sigma^2_{SCA}$.

Broad sense heritability values were obtained using GCA and SCA values:

$$H_b^2 = \sigma_g^2 / \sigma_p^2 = 4\ \sigma_{GCA}^2 + 4\sigma_{SCA}^2 / 2\sigma_{GCA}^2 + \sigma_{SCA}^2 + \sigma_E^2$$

Where:
H^2_b = Heritability in the broad sense
σ^2_g = Total genetic variance = $4\sigma^2_{GCA} + 4\sigma^2_{SCA}$
σ^2_p = Phenotypic variance = $2\sigma^2_{GCA} + \sigma^2_{SCA} + \sigma^2_E$

Narrow sense heritability was computed from the variance components in the ANOVA for the analysis of combining ability:

$$H_n^2 = \sigma^2 A / \sigma_P^2 = 4\sigma_{GCA}^2 / 2\sigma_{GCA}^2 + \sigma_{SCA}^2 + \sigma_E^2$$

Where:
H^2_n = Narrow sense heritability
$4\sigma^2_{GCA}$ = Variance due to *GCA*
σ^2_{SCA} = Variance due to *SCA*
σ^2_E = Variance due to residual error

Cultural Practices

For the two years of the field study, chemical weed control was carried out. A combination of Pendimethalin [N- (1- ethylpropyl)-3, 4-dimethyl -2, 6-dinitrobenzenamine] and Gesaprim [2-chloro-4-(ethylamino)-6-(isopropylamino)-5-triazine] at 1.5 l and 1.0 l ha^{-1}, were applied at planting. Paraquat (1, 1-dimethyl4, 4-bipyridinium ion) was also applied at 1.0 l ha^{-1} in addition to Pendimethalin and Gesaprim. Hand weeding was also carried out to keep the plots free of weeds at 4 weeks after planting in the field experiment. Basal fertilizer was applied at 2 weeks after planting at the rate of 30 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1}. Plants were also top-dressed with additional N at 30 kg N ha^{-1} at 4 weeks after planting.

Data Collection and Analysis

Plant height, days to 50% anthesis, days to 50% pollen shed, days to 50% silking, anthesis-silking interval, ear height, plant stand, drought rating at 10 Weeks After Plant Establishment (WAPE), leaf-rolling rating at 10 WAPE, striga rating at 10 WAPE, striga count at 10 WAPE, number of ears harvested per plot, grain yield and hundred-grain weight were recorded.

Data for the 6×6 complete diallel crosses obtained from the normal (control), water-stressed and striga-infested trials for the two years were combined and analyzed using SAS version 9.1. Analysis of variance was carried out to determine significance of variability among the parents and F_1 hybrids. Mean, standard error and co-efficient of variation for each characteristic was determined. Diallel analysis was performed and general and specific combining ability effects estimated following Griffing (1956) diallel analysis (Zhang *et al*., 2005).

Results and Discussion

Analysis of Variance for Yield and Yield Components

The combined analysis of variance for plant height, days to 50% anthesis, days to 50% silking, anthesis-silking interval, grain yield and hundred-grain weight is presented in Table 1. The study established highly significant differences ($p<0.001$) among genotypes for all the six traits. The significant variation among genotypes for the traits, especially plant height, anthesis-silking interval and grain yield, could have been caused by different factors including striga infestation, the water-stressed condition, variation in soil fertility level or inherent genetic factors. Both the general and specific combining ability effects across the two years were highly significant ($p<0.001$) for all the six traits. In the present study, genotype x environment interaction was not significant ($p>0.05$) for the traits and could be attributed mostly to the non-significant general and specific combining ability x environment interaction. The maternal and reciprocal effects were not significant. Hence, there were no maternal and reciprocal effects for the five traits. The maternal and environment interaction was also not significant ($p>0.05$).

A combined analysis of variance for mean striga count, striga rating, leaf-rolling rating and drought rating is presented in Table 2. There was highly significant difference ($p<0.001$) among genotypes for striga count, striga rating, leaf-rolling rating and drought rating. The highly significant variations ($p<0.001$) among genotypes for the traits especially, striga and drought rating could have been attributed to the inherent genetic factors. The General Combining Ability (GCA) effect was highly significant ($p<0.001$) for striga count, striga rating and leaf-rolling rating. However, GCA effect was not significant ($p>0.05$) for drought rating. The Specific Combining Ability (SCA) effect was also highly significant ($p<0.01$) for drought rating, leaf-rolling rating and striga count. Genotype x environment interaction was not significant ($p>0.05$) for all the traits and could be attributed mostly to the non significant general combining ability x environment interaction. Maternal effect was not significant (p>0.05) for all the 4 traits. Both the maternal x environment and reciprocal x environment interactions were also not significant (p>0.05).

Table 1. Combined analysis of variance of agronomic and yield data recorded of the 6% populations of maize and their 30 F1 hybrid populations

		Mean square					
Source	df	Plant height	Days to 50% anthesis	Days to 50% silking	Anthesis-silking interval	Grain yield (ton/ha)	Hundred-grain weight (g)
Replication	2	4171.31^{ns}	76.74^{***}	97.64^{ns}	27.26^{*}	0.19500^{ns}	1.17425^{*}
Environment	1	0.48^{ns}	31.56^{ns}	21.49^{ns}	0.96^{ns}	0.00220^{ns}	0.01211^{ns}
Genotype	35	1434.58^{***}	58.50^{***}	136.07^{***}	46.03^{***}	0.27250^{***}	0.43526^{***}
Genotype *ENV	36	0.02^{ns}	0.88^{ns}	0.33^{ns}	0.32^{ns}	0.00006^{ns}	0.00035^{ns}
GCA	5	2293.34^{***}	55.10^{***}	293.59^{***}	162.93^{***}	0.37040^{**}	0.68540^{***}
SCA	15	1501.40^{***}	73.95^{***}	126.31^{***}	22.05^{**}	0.26600^{**}	0.33430^{**}
GCA*ENV	5	0.02^{ns}	0.012^{ns}	0.35^{ns}	0.32^{ns}	0.00006^{ns}	0.00005^{ns}
SCA*ENV	15	0.010^{ns}	0.013^{ns}	0.23^{ns}	0.21^{ns}	0.00001^{ns}	0.00000^{ns}
REC	15	1081.50^{ns}	44.19^{ns}	93.34^{ns}	31.04^{ns}	0.24640^{ns}	0.45270^{ns}
REC*ENV	15	0.01^{ns}	0.02^{ns}	0.42^{ns}	0.38^{ns}	0.000002^{ns}	0.00002^{ns}
MAT	5	578.10^{ns}	22.94^{ns}	26.41^{ns}	23.26^{ns}	0.11500^{ns}	0.47530^{ns}
NONM	10	13332.07^{*}	54.82^{***}	126.80^{***}	34.93^{***}	0.31210^{**}	0.44145^{***}
MAT*ENV	5	0.01^{ns}	0.02^{ns}	0.61^{ns}	0.55^{ns}	0.00004^{ns}	0.00006^{ns}
NONM*ENV	10	0.01^{ns}	0.02^{ns}	0.32^{ns}	0.29^{ns}	0.00001^{ns}	0.00000^{ns}
Model	75	9023.39^{***}	65.22^{***}	135.0^{1***}	27.74^{***}	0.49620^{***}	0.44550^{***}
Error	572	1560.77	9.95	12.07	8.77	0.06030	0.13300

***, **,* and ns indicate significant at 0.001, 0.01, 0.05 and non-significant levels respectively; GCA, general combining ability; MAT, maternal effects; SCA, Specific Combining Ability; REC, Reciprocal Effects; NONM, Non-Maternal effects; DF, Degrees of Freedom

Table 2. Combined analysis of variance of mean drought rating, leaf-rolling rating, Striga count and Striga rating of the 6 parent populations of maize and their 30 F_1 hybrid populations

		Mean square			
Source	df	Striga count at 10 WAPE	Striga rating at 10 WAPE	Leaf-rolling rating at 10 WAPE	Drought rating at 10 WAPE
Replication	2	42.80^{ns}	2.02^{ns}	1.31^{ns}	3.85^{ns}
Environment	1	34.24^{ns}	0.00^{ns}	0.67^{ns}	12.52^{ns}
Genotype	35	18.71^{***}	1.72^{***}	1.75^{***}	0.82^{***}
ENV*Genotype	35	0.10^{ns}	0.00^{ns}	0.05^{ns}	0.16^{ns}
GCA	5	39.47^{***}	5.24^{***}	2.11^{***}	0.41^{ns}
SCA	15	21.64^{**}	0.69^{ns}	1.95^{***}	0.71^{**}
GCA*ENV	5	0.04^{ns}	0.00^{ns}	0.16^{ns}	0.22^{ns}
SCA*ENV	15	0.10^{ns}	0.00^{ns}	0.04^{ns}	0.17^{ns}
REC	15	8.85^{ns}	1.58^{ns}	1.44^{ns}	1.06^{ns}
REC*ENV	15	0.12^{ns}	0.00^{ns}	0.02^{ns}	0.12^{ns}
MAT	5	3.03^{ns}	3.42^{ns}	2.17^{ns}	1.92^{ns}
NONM	10	11.76^{*}	0.66^{*}	1.07^{*}	0.63^{*}
MAT*ENV	5	0.22^{ns}	0.00^{ns}	0.02^{ns}	0.11^{ns}
NONM*ENV	10	0.06^{ns}	0.00^{ns}	0.02^{ns}	0.13^{ns}
Model	75	10.38^{ns}	0.86^{ns}	0.89^{***}	0.73^{***}
Error	140	8.43	0.71	0.36	0.34

***, **,* and ns indicate significant at 0.001, 0.01, 0.05 and non significant levels respectively; GCA, General Combining Ability; SCA, Specific Combining Ability; MAT, Maternal Effects; REC, Reciprocal Effects; NONM, Non-Maternal effects; DF, Degrees of Freedom

Genetic Variability of Agronomic and Yield Components among Parents and their Hybrid Populations

Diallel analysis of self- and cross-pollinating populations is used to study the genetic control of quantitative traits and to assess general and specific combining abilities (Griffing, 1956). Diallel analysis helps in the selection of superior pure lines for hybridization and, in cross-pollinating species, to screen populations for use in intra- and inter-population breeding programmes.

The study revealed that General Combining Ability (GCA) effects significantly varied ($p<0.001$) for plant height and days to anthesis among the parent populations. The parent SISF03-OB exhibited the highest significant positive GCA effect of 4.2208* for plant height, while DT-STR-W-C2 also recorded a positive significant GCA value of 0.9182*** for days to 50% anthesis (Table 3). The study established that the parents SISF03-OB, DT-STR-W-C2 and IWD-C3-SYN-F2 were good general combiners for traits such as plant height and days to anthesis as compared to parents such as TAIS03, KOBN03-OB and GUMA03-OB and it is possible that additive gene action might be important in the expression and inheritance of these traits.

Table 3. Means of plant height, days to 50% anthesis and days to 50% silking and estimates of GCA effects for each trait tested in two years

	Plant height (cm)		Days to 50% anthesis		Days to 50% silking	
Parent population	Mean	GCA	Mean	GCA	Mean	GCA
IWD-C3-SYN-F2	131.21	-0.9667^{ns}	65	-0.3549^{ns}	73	-0.5957*
DT-STR-W-C2	163.22	-2.7986^{ns}	63	0.9182***	72	0.9969***
TAIS03	151.43	-3.6167^{ns}	63	-0.2577^{ns}	76	-1.2901***
SISF03-OB	161.81	4.2208*	61	-0.2623^{ns}	71	-0.8735**
GUMA03-OB	154.16	3.6333^{ns}	63	-0.3133^{ns}	71	0.0247^{ns}
KOBN03-OB	154.52	-0.4722^{ns}	64	0.2701^{ns}	71	1.7377***
Mean	152.73		63		72	
SEM	21.90		2.30		3.47	

***, **,* and ns indicate significant at 0.001, 0.01, 0.05 and non significant levels respectively; GCA, General Combining Ability; SEM, Standard Error of Means

Table 4. Estimates of SCA for mean plant height, days to 50% anthesis and days to 50% silking of each of the 30 F_1 hybrid populations tested in two years

	Plant height (cm)		Days to 50% anthesis		Days to 50% silking	
F_1 hybrid population	Mean	SCA	Mean	SCA	Mean	SCA
IWD × DT	151.64	-2.3491^{ns}	62	-0.1728^{ns}	69	0.2346^{ns}
IWD × TAIS03	146.73	-1.9727^{ns}	58	-0.6636^{ns}	65	-0.9784^{ns}
IWD × SISF03	173.73	4.7315^{ns}	60	-1.6867***	66	-1.3673*
IWD × GUMA03	138.66	-12.3644*	65	0.0031***	72	-0.4321^{ns}
IWD × KOBN03	163.30	2.3356^{ns}	60	-0.0802^{ns}	66	-1.1728^{ns}
DT × IWD	146.32	8.1500^{ns}	58	-0.3889^{ns}	65	-0.3333^{ns}
DT × TAIS03	156.77	1.6704^{ns}	63	0.4521^{ns}	71	0.0401^{ns}
DT × SISF03	149.31	-3.3616^{ns}	61	-1.0432*	69	-0.1821^{ns}
DT × GUMA03	157.57	4.7759^{ns}	61	-0.1034^{ns}	70	-0.7191^{ns}
DT × KOBN03	161.53	-4.9519^{ns}	59	1.0355*	68	1.0957^{ns}
TAIS03 × IWD	165.36	-2.6639^{ns}	60	-1.7222***	69	-1.6111*
TAIS03 × DT	156.10	12.1306*	60	-2.6667***	69	-2.6667*
TAIS03 × SISF03	159.63	4.2231^{ns}	61	-0.5895^{ns}	71	-0.7006ns
TAIS03 × GUMA03	148.82	8.5773^{ns}	64	-0.8164*	77	-1.2654*
TAIS03 × KOBN03	164.28	4.5995^{ns}	62	-2.6774***	70	-3.0895***
SISF03 × IWD	154.53	-1.9889^{ns}	60	0.0278**	69	0.9722^{ns}
SISF03 × DT	142.37	0.0417^{ns}	60	-0.9444^{ns}	68	-0.4167^{ns}
SISF03 × TAIS03	155.09	2.9361^{ns}	63	-0.3333^{ns}	75	-1.0556^{ns}
SISF03 × GUMA03	164.71	1.3426^{ns}	61	0.1327^{ns}	68	-0.3210^{ns}
SISF03 × KOBN03	164.41	2.5204^{ns}	60	0.5499^{ns}	67	-0.3673^{ns}
GUMA03 × IWD	162.92	3.4722^{ns}	60	0.4444^{ns}	67	0.3611^{ns}
GUMA03 × DT	141.27	-3.5639^{ns}	62	1.1667*	71	2.2222**
GUMA03 × TAIS03	145.81	9.5972^{ns}	63	-0.1667^{ns}	71	-1.2778^{ns}
GUMA03 × SISF03	157.58	0.3278^{ns}	63	0.8889^{ns}	72	1.3056^{ns}
GUMA03 × KOBN03	153.64	-1.3394^{ns}	60	0.4892^{ns}	69	1.2623*
KOBN03 × IWD	157.43	0.3333^{ns}	61	1.2778*	68	1.0000^{ns}
KOBN03 × DT	165.51	-1.5028^{ns}	59	-0.4444^{ns}	66	-3.1389***
KOBN03 × TAIS03	159.33	-9.3139^{ns}	62	-1.0000^{ns}	70	-1.9444*
KOBN03 × SISF03	165.06	-2.4778^{ns}	62	-0.4444^{ns}	70	-0.1389^{ns}
KOBN03 × GUMA03	153.56	-2.2694^{ns}	62	1.3333*	70	1.9444*
Mean	156.50		61		69	
SEM	21.90		2.30		3.47	

***, **,* and ns indicate significant at 0.001, 0.01, 0.05 and non significant levels respectively; SCA, Specific Combining Ability; SEM, Standard Error of Means; IWD = IWD-C3-SYN-F2; and DT = DT-STR-W-C2

The good combining parents could be selected for development into composites and synthetic varieties in breeding programme. The poor combining parents for the desirable traits as stated above, such as KOBN03-OB probably did not produce the best hybrids because of negative heterosis. Desai and Singh (2001) conducted 7×7 half diallel crosses of maize inbred lines and reported significant differences in general combining ability for plant height.

The study established highly significant variations ($p<0.001$) in Specific Combining Ability (SCA) effects for plant height. The best cross combination, which exhibited maximum positive SCA effect for the trait was TAIS03 × DT (12.1306^{*}), while the cross that exhibited maximum negative SCA effect of -12.3644^{*} was IWD×GUMA03 (Table 4). The F_1 hybrid TAIS03 x DT was a better specific combiner for plant height and days to anthesis than F_1 hybrids such as IWD × DT, IWD × TAIS03, IWD × KOBN03, TAIS03 × SISF03, SISF03 × DT, SISF03 × KOBN03, GUMA03 × IWD, GUMA03 × TAIS03, GUMA03 × SISF03, GUMA03 × KOBN03 and KOBN03 × SISF03, probable as a result of genotype × environment interaction, since the phenotypic expression of one genotype might be superior to another genotype in one environment but inferior in a different environment. Hybrids IWD × SISF03, DT × SISF03, TAIS03 × KOBN03 and KOBN03 × GUMA03 were better specific combiners for days to anthesis and days to silking than other hybrids such as IWD × DT and this might be due to the presence of divergent and superior frequencies of the desirable genes as compared to the mean frequencies in the hybrid IWD x DT. It is likely that non-additive gene effect might have played a role in inheritance of plant height, days to anthesis and days silking in F_1 hybrids with good specific combining ability such as TAIS03 × DT, IWD × SISF03, DT × SISF03, TAIS03 × KOBN03, KOBN03 × GUMA03 and IWD × GUMA03. Machikowa *et al*. (2011) reported that SCA were highly significant for plant height in sunflower and revealed that non-additive effects were important for plant height. The parental populations of the crosses such as, TAIS03 × DT, IWD × SISF03, DT × SISF03, TAIS03 × KOBN03, KOBN03 × GUMA03 and IWD × GUMA03, that exhibited highest SCA effects as already stated above, were composites obtained from Taha, Gurumanchagyili, Sibgungyili, Kokpeng and Savanna Agricultural Research Institute (SARI), all of which are different communities in the Northern region of Ghana. Singh *et al*. (1977) observed that the best inter-population cross involved parents of different origin and that high specific combining ability effects could be obtained by crossing materials of greater genetic diversity.

Genetic Variability and its Implications for Grain Yield and Hundred-Grain Weight among Parents and their Hybrid Populations

The results showed significant variations ($p<0.001$) of GCA among the parent genotypes for yield and yield components such as anthesis-silking interval. The highest significant positive GCA effect for anthesis-silking interval was found for parent KOBN03-OB (1.4676^{***}), whilst the maximum significant negative GCA effect was shown in TAIS03 (-1.0324^{***}) (Table 5). The parent SISF03-OB obtained the highest positive significant GCA effect of 0.0492^{*} for grain yield, while the highly significant negative GCA effect for this trait was observed in KOBN03-OB (-0.0595^{**}) (Table 5). Also, the highest significant positive GCA effect for hundred-grain weight was found for parent DT-STR-W-C2 (0.0018^{*}), whilst the maximum significant negative GCA effect was shown in IWD-C3-SYN-F2 (-0.0029^{***}) (Table 5). The parents DT-STR-W-C2, TAIS03, SISF03-OB and KOBN03-OB were the best general combiners for grain yield and yield components like days to silking, anthesis-silking interval and grain weight as compared to parents like GUMA03-OB and IWD-C3-SYN-F2, probably as a result of presence of superior frequency of favorable genes. The parent DT-STR-W-C2 and SISF03-OB which are good general combiners for grain yield and other yield component traits, were also found to be good combiners for traits such as days to anthesis and plant height and may be appropriate for selection in breeding programmes. Sprague and Tatum (1942) reported that good general or specific combining ability is an important criterion for the evaluation and selection of parents and crosses.

Table 5. Means of anthesis-silking interval, grain yield and hundred-grain weight and estimates of GCA for the parent populations tested in two years

	Anthesis-silking interval		Grain yield (ton/ha)		Hundred-grain weight (g)	
Parent population	Mean	GCA	Mean	GCA	Mean	GCA
IWD-C3-SYN-F2	8	-0.2407^{ns}	2.53	-0.0130^{ns}	23.5	-0.0029^{***}
DT-STR-W-C2	9	0.0787^{ns}	2.78	-0.0206^{ns}	21.8	0.0018^{*}
TAIS03	13	-1.0324^{***}	2.57	0.0449^{*}	30.7	-0.0009^{ns}
SISF03-OB	10	-0.6111^{***}	3.03	0.0492^{*}	32.3	-0.0005^{ns}
GUMA03-OB	8	0.3380^{ns}	2.55	-0.0010^{ns}	30.7	0.0012^{ns}
KOBN03-OB	7	1.4676^{***}	3.17	-0.0595^{**}	27.4	0.0012^{ns}
Mean	9		2.77		27.7	
SEM	2.85		0.25		10.30	

***, **,* and ns indicate significant at 0.001, 0.01, 0.05 and non significant levels respectively. GCA, general combining ability; SEM, standard error of means

Table 6. Estimates of SCA and mean anthesis-silking interval, grain yield and hundred-grain weight of each of the 30 F1 hybrid populations tested in two years

	Anthesis-silking interval		Grain yield (ton/ha)		Hundred-grain weight (g)	
F_1 hybrid population	Mean	SCA	Mean	SCA	Mean	SCA
IWD × DT	7	0.4074^{ns}	4.36	0.002^{ns}	25.6	-0.0057^{***}
IWD × TAIS03	7	-0.3148^{ns}	4.40	0.050^{ns}	30.1	0.0021^{ns}
IWD × SISF03	6	0.3194^{ns}	4.59	-0.001^{ns}	30.1	-0.0012^{ns}
IWD × GUMA03	7	-0.4352^{ns}	3.68	-0.019^{ns}	24.8	0.0010^{ns}
IWD × KOBN03	6	-1.0926^{**}	4.76	0.0314^{ns}	21.7	0.0031^{*}
DT × IWD	7	0.0556^{ns}	4.11	0.024^{ns}	26.7	0.0023^{ns}
DT × TAIS03	8	-0.4120^{ns}	4.00	-0.042^{ns}	29.5	-0.0003^{ns}
DT × SISF03	8	0.8611^{*}	4.08	0.023^{ns}	30.6	0.0035^{*}
DT × GUMA03	9	-0.6157^{ns}	4.00	0.111^{*}	23.4	-0.0024^{ns}
DT × KOBN03	9	0.0602^{ns}	4.99	0.039^{ns}	27.8	0.0049^{**}
TAIS03 × IWD	9	0.1111^{ns}	4.20	-0.047^{ns}	25.0	0.0006^{ns}
TAIS03 × DT	9	0.0000^{ns}	4.82	0.111^{*}	29.1	0.0037^{*}
TAIS03 × SISF03	10	-0.1111^{ns}	3.77	0.110^{*}	23.3	-0.0004^{ns}
TAIS03 × GUMA03	13	-0.4491^{ns}	3.53	0.035^{ns}	37.8	0.0010^{ns}
TAIS03 × KOBN03	8	-0.4120^{ns}	3.96	0.120^{*}	23.9	-0.0007^{ns}
SISF03 × IWD	8	0.9444^{*}	3.87	-0.046^{ns}	28.3	0.0044^{*}
SISF03 × DT	8	0.5278^{ns}	3.79	0.048^{ns}	23.9	0.0050^{*}
SISF03 × TAIS03	12	-0.7222^{ns}	3.45	0.074^{ns}	29.7	-0.0044^{*}
SISF03 × GUMA03	7	-0.4537^{ns}	4.67	-0.042^{ns}	25.0	0.0014^{ns}
SISF03 × KOBN03	7	-0.9167^{*}	4.22	-0.048^{ns}	37.8	-0.0047^{**}
GUMA03 × IWD	7	-0.0833^{ns}	4.27	0.055^{ns}	32.2	0.0034^{ns}
GUMA03 × DT	9	1.0556^{*}	3.87	-0.155^{**}	18.9	0.0036^{ns}
GUMA03 × TAIS03	7	-1.1111^{*}	4.29	0.134^{*}	33.9	0.0009^{ns}
GUMA03 × SISF03	9	0.4167^{ns}	3.84	-0.070^{ns}	32.2	-0.0078^{***}
GUMA03 × KOBN03	9	0.7731^{ns}	4.28	-0.093^{*}	37.8	-0.0039^{*}
KOBN03 × IWD	7	-0.2778^{ns}	4.37	0.035^{ns}	30.6	0.0002^{ns}
KOBN03 × DT	7	-2.6944^{***}	4.23	0.142^{**}	18.9	-0.0019^{ns}
KOBN03 × TAIS03	9	$-.0.9444^{*}$	3.76	0.038^{ns}	23.9	0.0025^{ns}
KOBN03 × SISF03	8	0.3056^{ns}	3.85	-0.038^{ns}	22.3	0.0003^{ns}
KOBN03 × GUMA03	8	0.6111^{ns}	4.03	-0.060^{ns}	27.8	0.0032^{ns}
Mean	8		2.90		4.13	
SEM	0.30		27.8		10.30	

***, **,* and ns indicate significant at 0.001, 0.01, 0.05 and non significant levels respectively; SCA, Specific Combining Ability; SEM, Standard Error of Means; IWD = IWD-C3-SYN-F2; and DT = DT-STR-W-C2

Table 7. Means of striga count, striga rates, leaf-rolling rates and drought rates and estimates of GCA for the parent populations tested in two years

	Striga count at 10 WAPE		*Striga* rating at 10 WAPErating at		Leaf rolling 10 WAPE		Drought rating at 10 WAPE	
Parent population	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA
IWD-C3-SYN-F2	1	-0.310^{ns}	4	-0.093^{ns}	2	0.190^{**}	4	0.037^{ns}
DT-STR-W-C2	6	0.857^{**}	3	0.185^{*}	2	-0.296^{***}	3	0.120^{*}
TAIS03	5	-1.005^{**}	4	-0.315^{***}	1	0.051^{ns}	3	-0.102^{ns}
SISF03-OB	3	0.843^{**}	4	-0.287^{**}	1	0.009^{ns}	3	-0.046^{ns}
GUMA03-OB	4	0.051^{ns}	4	0.185^{*}	1	0.120^{ns}	3	-0.005^{ns}
KOBN03-OB	3	-0.435^{ns}	3	0.324^{***}	2	-0.074^{ns}	3	-0.005^{ns}
Mean	4		4		2		3	
SEM	2.90		0.84		0.60		0.58	

***, **,* and ns indicate significant at 0.001, 0.01, 0.05 and non significant levels respectively; GCA, General Combining Ability; SEM, Standard Error of Means; WAPE, Weeks After Plant Establishment

The study revealed significant SCA effects for grain yield and yield components. Hybrid SISF03 × IWD gave the highest significant positive SCA effect of 0.9444^{*} for anthesis-silking interval, with KOBN03 × DT showing the highest significant negative SCA effect of -2.6944^{***} for the trait (Table 6). The F_1 hybrid KOBN03 × DT gave the highest positive significant SCA effect of 0.142^{**} for grain yield, whilst GUMA03 × DT showed the highest negative significant SCA effect of -0.155** for the trait (Table 6). Hybrid SISF03 × DT gave the highest significant positive SCA effects of 0.0050** for hundred-grain weight, with GUMA03 × SISF03 showing the highest negative significant SCA effect of -0.0078*** for the trait (Table 6). The F_1 hybrids, for instance GUMA03 × DT, GUMA03 × SISF03 and KOBN03 × DT which recorded negative significant SCA, were tolerant to the striga and/or the drought condition than F_1 hybrids such as SISF03 × IWD and SISF03 x DT which exhibited positive significant SCA effects as reported by Sprague and Tatum (1942). The identification and selection of drought and striga tolerant genotypes will enable plant breeders advice and guide farmers on which varieties to use in drought prone and/or striga infested agricultural lands.

The hybrid GUMA03 × DT, KOBN03 × DT and KOBN03 × TAIS03 were found to be better specific combiners for days to silking and anthesis-silking interval as compared to the other hybrids and might possibly be derived from parent populations with the greatest differences in gene frequencies. Hybrids TAIS03 × DT, GUMA03 × TAIS03 and GUMA03 × KOBN03 were also found to be better specific combiners for grain yield and grain weight relative to the other hybrid populations and the superiority in grain yield and grain weight might be due to high heterosis. Ali *et al*. (2011) used 6×6 diallel crossing and found that SCA mean squares were highly significant in some yield components, there by manifesting non-additive gene action.

Variation in Plant Rating among Parents and their Hybrid Populations and its Implications for Drought and Striga Tolerance

The study showed significant variations ($p<0.001$) of GCA among parents for traits such as striga count, striga rating, drought rating and leaf-rolling rating (Table 7). The parent KOBN03-OB obtained the highest significant positive GCA effect of 0.324*** for striga rating, while the highest significant negative GCA effect for this trait was observed in TAIS03 (-0.315***) (Table 7). However, the parent DT-STR-W-C2 recorded significant GCA effect for all the 4 traits. Namely; striga count, striga rating, leaf-rolling rating and drought rating. The parent populations DT-STR-W-C2, TAIS03-OB and SISF03-OB were the best general combiners for striga count, striga rating, drought rating and leaf-rolling rating as compared to IWD-C3-SYN-F2, GUMA03-OB and KOBN03-OB and might contained superior frequency of the genes controlling these traits as compared to the other parents. The parent DT-STR-W-C2 with the best general combining ability for striga count, striga rating, drought rating and leaf-rolling rating, was also found to be a good general combiner for grain yield and other yield component as reported earlier under section 3.3 and may be considered more tolerant to drought and striga infestation.

Analysis of Specific Combining Ability (SCA) in this study showed that the hybrid KOBN03 × GUMA03 gave the highest positive significant SCA effect of 0.667** for striga rating, whilst KOBN03 × DT showed the highest negative significant SCA effect of -0.667** for the trait (Table 8). The study further indicated that the hybrid, KOBN03 × IWD gave the highest positive significant SCA effect of 0.667*** for drought rating, while DT × TAIS03 showed the highest negative significant SCA effect of -0.454** for the trait.

Trait Heritability, GCA and SCA Effects among Traits of Maize Populations

The high broad sense heritability values for grain yield and grain weight (Table 9) is probably due to high values of additive variance and these traits could be associated with higher selective precision. Rao *et al.* (2008) also showed high broad sense heritability (88%) for plant height in 34 month old Jatropha plants and concluded that the high value of heritability were associated with higher selective precision, revealing the possibility of high accuracy in the selection. The high GCA: SCA ratio for the yield and yield component traits might be due to the fact that the GCA variance was relatively greater than SCA variance and so additive gene action might have played a major role than dominance gene action in the control of inheritance of grain yield, grain weight, ears harvested and ear height. This will therefore guide breeders in the selection of genotypes during plant breeding programmes. Hakizimana (2001) observed that GCA: SCA ratio with a value greater than one indicated additive gene action, whereas a GCA: SCA ratio with a value lower than one indicated dominant gene action.

The relative high broad sense heritability compared to narrow sense heritability for traits such as striga rating and drought rating (Table 9) was probably due to high values of additive variance and selection of parent genotypes that are good combiners for these traits will be relatively easy. Fisher (1918) reported that if heritability of a character is low, say less than 40%, selection may be considerably or virtually impractical due to the masking effect of the environment on genotypic effects. The relative low GCA: SCA ratio for drought rating might be as a result of high SCA variance than GCA variance and so dominance gene effect played a major role than additive gene effect in the control of inheritance of drought rating. Dubey *et al*. (2001) reported significant mean squares for hundred-grain weight and that specific combining ability variance was greater than general combining ability variance indicating preponderance of non-additive gene action in the expression of this trait.

Table 8. Estimates of SCA and mean striga count, striga rates, leaf rolling rates and drought rates of each of the 30 F_1 hybrid populations tested in two years

	Striga count at 10 WAPE		*Striga* rating at 10 WAPE		Leaf-rolling rating at 10 WAPE		Drought rating at 10 WAPE	
F_1 hybrid population	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA
IWD × DT	3	-0.093^{ns}	2	0.120^{ns}	2	-0.023^{ns}	2	0.157^{ns}
IWD × TAIS03	1	0.019^{ns}	2	-0.213^{ns}	1	0.296^{ns}	2	-0.120^{ns}
IWD × SISF03	2	-1.162^{ns}	2	0.093^{ns}	3	-0.662^{***}	2	-0.259^{ns}
IWD × GUMA03	4	-1.287^{ns}	2	0.287ns	1	0.227^{ns}	2	0.199^{ns}
IWD × KOBN03	1	-0.968^{ns}	2	-0.185^{ns}	2	0.338^{*}	2	-0.051^{ns}
DT × IWD	0	2.250^{**}	2	-0.166^{ns}	3	0.000^{ns}	2	-0.333^{*}
DT × TAIS03	1	0.435^{ns}	2	0.009^{ns}	3	-0.384^{**}	3	-0.454^{**}
DT × SISF03	0	2.005^{**}	3	-0.185^{ns}	2	-0.009^{ns}	2	0.157^{ns}
DT × GUMA03	5	-0.370^{ns}	3	-0.157^{ns}	2	0.046^{ns}	2	-0.134^{ns}
DT × KOBN03	2	-1.468^{*}	2	-0.130^{ns}	2	0.574^{***}	2	0.199^{ns}
TAIS03 × IWD	2	-1.167^{ns}	3	0.000^{ns}	1	0.167^{ns}	2	-0.167^{ns}
TAIS03 × DT	1	-0.917^{ns}	3	0.167^{ns}	2	0.167^{ns}	1	-0.083^{ns}
TAIS03 × SISF03	2	-0.801^{ns}	3	-0.352^{ns}	2	0.477^{**}	2	0.296^{*}
TAIS03 × GUMA03	2	0.074^{ns}	4	0.009^{ns}	2	0.282^{*}	2	-0.162^{ns}
TAIS03 × KOBN03	4	-0.107^{ns}	3	-0.130^{ns}	1	-0.606^{***}	2	-0.245^{ns}
SISF03 × IWD	2	-0.167^{ns}	3	0.000^{ns}	2	0.333^{*}	2	-0.250^{ns}
SISF03 × DT	2	-0.333^{ns}	3	0.000^{ns}	3	-0.167^{ns}	2	-0.083^{ns}
SISF03 × TAIS03	3	-0.667^{ns}	4	0.000^{ns}	3	-0.833^{***}	2	-0.167^{ns}
SISF03 × GUMA03	2	1.894^{**}	3	-0.019^{ns}	2	-0.093^{ns}	2	0.032^{ns}
SISF03 × KOBN03	5	-0.454^{ns}	3	0.176^{ns}	2	-0.231^{ns}	2	0.032^{ns}
GUMA03 × IWD	2	-0.750^{ns}	3	-0.333^{ns}	1	-0.167^{ns}	2	-0.083^{ns}
GUMA03 × DT	1	1.000^{ns}	3	-0.500^{*}	2	0.000^{ns}	3	0.500^{**}
GUMA03 × TAIS03	2	-0.083^{ns}	2	-0.500^{*}	2	0.250^{ns}	3	-0.250^{ns}
GUMA03 × SISF03	4	0.417^{ns}	2	-0.167^{ns}	2	-0.167^{ns}	3	0.000^{ns}
GUMA03 × KOBN03	6	-0.079^{ns}	2	0.204^{ns}	1	0.241^{ns}	2	0.074^{ns}
KOBN03 × IWD	2	-0.083^{ns}	2	-0.333^{ns}	3	0.583^{**}	2	0.667^{***}
KOBN03 × DT	2	0.083^{ns}	2	-0.667^{**}	1	0.000^{ns}	2	0.333^{*}
KOBN03 × TAIS03	2	-0.417^{ns}	3	-0.500^{*}	2	0.167^{ns}	2	0.167^{ns}
KOBN03 × SISF03	6	-0.917^{ns}	2	-0.167^{ns}	2	0.500^{**}	2	0.333^{*}
KOBN03 × GUMA03	7	0.667^{ns}	2	0.667^{**}	2	0.417^{*}	2	0.250^{ns}
Mean	3		3		1.80		2	
SEM	2.90		0.84		0.60		0.58	

***, **,* and ns indicate significant at 0.001, 0.01, 0.05 and non significant levels respectively; SCA, Specific Combining Ability; SEM, Standard Error of Means; WAPE, Weeks After Plant Establishment; IWD = IWD-C3-SYN-F2; and DT = DT-STR-W-C2

Table 9. Quadratic components of GCA, SCA, narrow and broad sense heritability and ratio of GCA: SCA

	Trait							
Parameter	Plant height	Days to 50% anthesis	Days to 50% silking	Anthesis-silking interval	Grain yield	Hundred-grain weight	Drought rating at 10 WAPE	Striga rating at 10 WAPE
σ^2_{SCA}	1501.40	73.95	126.31	22.05	0.2660	0.0003	0.7142	0.6901
σ^2_{GCA}	2293.34	55.10	293.59	162.93	0.3704	0.0007	0.4093	5.2370
σ^2_D	6005.59	295.79	505.48	88.19	1.064	0.0013	2.8568	2.7604
σ^2_A	9173.36	220.39	1174.36	651.72	1.4816	0.0027	1.6370	20.948
σ^2_E	1560.77	9.95	21.03	8.77	0.0600	0.0001	0.3392	0.7045
H^2b	90.68	98.11	98.76	98.83	97.70	97.56	92.98	97.11
H^2n	54.80	41.89	69.04	87.95	56.86	65.85	33.87	85.81
GCA:SCA	1.5275	0.7451	2.3244	7.3891	1.3925	2.0909	0.5731	7.5888

Note: SCA variance (σ^2_{SCA}); GCA variance (σ^2_{GCA}); dominance variance (σ^2_D); additive variance (σ^2_A); broad sense heritability (H^2b); narrow sense heritability (H^2n); WAPE, Weeks After Plant Establishment

Conclusion

The study was conducted to evaluate parent and F_1 hybrid populations of maize for drought and/or striga tolerance. From the foregoing results and discussion of the experiments, the following conclusions can be deduced:

The study demonstrated that the parent populations, DT-STR-W-C2, KOBN03-OB, SISF03-OB and IWD-C3-SYN-F2 gave the highest positive significant GCA effects for majority of the traits. Therefore, the four parents are good combiners for the observed traits. The highly negative significant GCA effect for the parent populations was observed in TAIS03, KOBN03-OB, DT-STR-W-C2 and IWD-C3-SYN-F2 for majority of the traits. Therefore, the four parents are good combiners for most of the traits observed.

The highly positive significant SCA effect for the hybrids was observed in KOBN03 × GUMA03, KOBN03 × IWD, KOBN03 × DT, TAIS03 × DT, GUMA03 × TAIS03, SISF03 × IWD and SISF03 × DT. The seven F_1 hybrid populations are therefore, good combiners for the observed traits. For the F_1 hybrids, KOBN03 × DT, DT × TAIS03, TAIS03 × KOBN03, IWD × GUMA03, GUMA03 × DT, GUMA03 × SISF03 and SISF03 × TAIS03 gave the highest negative significant SCA effect for majority of the traits. Therefore the seven hybrid populations are good combiners for the traits observed.

Sprague and Tatum (1942) reported that negative values for GCA and SCA effects reveal a contribution to drought and/or striga tolerant traits, while positive values for GCA and SCA effects indicate tendency towards drought and/or striga sensitive.

The cultivation of the parent populations that gave highly significant negative GCA effect such as TAIS03, KOBN03-OB, DT-STR-W-C2 and IWD-C3-SYN-F2 on striga infested and/or drought prone areas will result in increased yield.

The cultivation of the hybrid populations that showed highly negative significant SCA effect such as KOBN03 × DT, DT × TAIS03, TAIS03 × KOBN03, IWD × GUMA03, GUMA03 × DT, GUMA03 × SISF03 and SISF03 × TAIS03 on striga infested and/or drought prone areas will result in increased yield.

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Author's Contributions

Alhassan Bawa and Isaac Kwahene Addai: Developed the concept of the experiment, designed the research, participated in data collection, interpretation of analysed data and the entire process of the article preparation.

Mashark Seidu Abdulai: Participated in the research design, field preparation and data analysis.

Al-Hassan Issahaku: Participated in data organization and data analysis.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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