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Full Length Research Paper

Combining ability analysis for drought tolerance among single-cross tropical maize (*Zea mays* L.) hybrids in semi-arid Kenya

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Abstract

Drought stress is a major challenge in maize (*Zea mays* L.) production negatively impacting on production in semi-arid areas of eastern Africa. Breeding hybrid cultivars for semi-arid areas is essential to reduce yield losses experienced under rain-fed maize production. The objective of this study was to estimate combining ability for drought tolerance among single-cross maize hybrids in semi-arid environments. Eleven parents with known drought resistance were crossed in a half diallel mating design to generate 55 crosses, the Griffing's diallel method IV, model II was used in analysis. The F1s, alongside two local checks, were evaluated in α-lattice design with two replications during 2020/2021 cropping season. Combined analysis of variance over environments revealed significant ($p<0.05$) main effects for genotypes, locations, and genotype-by-location interactions in most traits studied. Significant ($p< 0.05$) general combining ability (GCA) and specific combining ability (SCA) for grain yield, ear height and plant height demonstrated the role of additive and non-additive genetic variance in inheritance of these traits. Hybrids KAT-DT-EE-07×KAT-DT-EE-14 and KAT-DT-EE-07×KAT-DT-EE-04 had superior grain yield of 6.18 t ha^{-1} and 6.16 t ha^{-1}, respectively. KAT-DT-M-31×KAT-DT-EE-07 showed significant SCA for grain yield which demonstrated the potential of obtaining drought tolerant hybrids for possible deployment to farmers.

Key words: drought stress, general combining ability, heritability, hybrid cultivars, specific combining ability.

INTRODUCTION

Maize (*Zea mays* L.) is an important food crop in sub-Saharan Africa (SSA) due to its high yielding capacity and adaptability to a wide range of agro-ecological zones (Akaogu et al., 2017; Sheikh et al., 2017). Drought has been reported to cause major yield reduction in maize of up to 34% (FAO, 2021). In the ASALs, frequent droughts cause crop failures once in every three seasons (Quandt, 2021; GoK, 2010). Drought induced losses are common in subsistence agriculture, impacting negatively on maize production (FAO, 2022). In addition, climate change has intensified drought by altering weather patterns causing irregular and unpredictable rainfall quantities (Quandt, 2021).

Maize production in the semi-arid areas of eastern Africa is mainly carried out by small-scale farmers under rain-fed conditions (GoK, 2010). Maize being a low value crop, has not attracted investment in irrigation facilities. In addition, the use of hybrid seeds in arid and semi-arid areas is low due to high prices and poor access to input

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stores (Marenya et al., 2022; Schroeder et al., 2013). Furthermore, socio-economic reasons have compelled farmers to produce maize with low input application, thus further plummeting yield (Mang'eni, 2022). Currently, the average production under semi-arid conditions stands at 1,400 kg ha^{-1} against a potential of 5,600 kg ha^{-1} (FAO, 2019).

Previous breeding efforts towards maize improvement for semi-arid areas of Kenya mainly focused on developing open pollinated varieties (OPVs) (Njoroge, 1982). Such maize varieties are known to have adequate inherent genetic variability that allow them to survive under adverse conditions. However, OPVs are innately low yielding compared to hybrid varieties (Muinga et al., 2019). Thus, continuous cultivation of OPVs of maize in dry areas is partly the cause of perennial low yields (Muinga et al., 2019; Schroeder et al., 2013). The need for increased productivity in semi-arid areas has directed the focus towards developing hybrid varieties (Issa et al., 2018). This is because hybrid varieties have the genetic potential for high productivity compared to OPVs (Kutka, 2011).

Development and deployment of hybrid cultivars that mature within a cropping season with the available moisture can improve productivity under semi-arid conditions, hence improve food security (Rezende et al., 2020). Knowledge of gene action modulating drought tolerance and genes present in the germplasm are key in the attainment of desirable breeding objectives. An effective maize genetic improvement programme for drought stress lays emphasis on exploiting drought tolerant genes (Badu-Apraku et al., 2013). Grain yield is a key trait in breeding maize under drought stress (Bänziger et al., 2000). It is controlled by many genes acting additively to express the trait. Under drought stress, selection for grain yield is slowed down by low heritability, low yields and poor adaptability (Blum, 2011). To avert this challenge, secondary traits that are positively correlated to grain yield, easy to measure and highly heritable are used (Araus et al., 2008).

A diallel mating design is used to estimate combining ability of lines and characterize the nature and extent of additive and dominance effects (Griffing, 1956). The significance of specific combining ability (SCA) as well as general combining ability (GCA) in control of drought tolerance has been reported (Aswin et al., 2020; Ilyas et al., 2019; Murthadha et al., 2018; Makanda et al., 2010). Studies of diallel mating design on single-cross maize hybrids showed that inheritance of grain rows per ear and ear length were governed by non-additive gene action (Aslam et al., 2017). In addition, specific combining ability for grain yield, plant height and ear height were due to non-additive gene action. Raihani et al. (2019) reported significant general combining ability variances for ear height, number of kernels per row as controlled by additive gene action. Nevertheless, additional knowledge on combining ability is necessary to facilitate germplasm improvement for drought tolerance. The objective of this study was to estimate combining ability effects for drought tolerance among maize germplasm in semi-arid environments.

MATERIALS AND METHODS

Site description

The experiment was carried out at Kenya Agricultural and Livestock Research Organization (KALRO), Agricultural Mechanization Research Institute (AMRI) Katumani in Machakos County and at Kiboko in Makueni County. The distribution of monthly rainfall and the average temperature during the experimental period are presented in Figure 1 and Figure 2. The mean annual rainfall was 830 and 675 mm for Katumani and Kiboko, respectively. Kiboko is hotter with a maximum temperature of 30.6^{o}C and a minimum of 16.6^{o}C compared to Katumani, with a maximum temperature of 24.7^{o}C and a minimum of 16.5^{o}C. The highest amount of rainfall during the performance evaluation was received in November 2020, with very little rainfall being received between December and March, indicating poor distribution (Figure 1 and Figure 2).

Germplasm for study

Eleven single-cross maize hybrids were used in this study as both male and female parents. The parental materials were selected based on high grain yield and adaptability to drought prone conditions following the results of preliminary evaluation conducted under drought conditions during the 2018/2019 October/November cropping season. Two commercial checks; DUMA 43 and PAN 4M-19 were included to benchmark the performance with the test material (Table 1).

Field operations

Land preparation was carried out using a mould board plough followed by harrowing. Two seeds per hill were sown and later thinned to one seed per hill. During planting, di- ammonium phosphate fertilizer (DAP) with an N:P: K ratio of 18:46:0 was applied at a recommended rate of 150 kg ha^{-1} to supply 6.45 kg of P for the total area of 0.15 ha. At 21 days after emergence, top-dressing with 150 kg ha^{-1} of calcium ammonium nitrate (CAN) with nitrogen (N) composition of 26% was applied to supply a total of 5.85 kg of N. Weed management practices were carried out to keep plots free of weeds. Fall armyworms were controlled using emamectin benzoate 19 g L^{-1}.

Experimental design

Eleven parents (single-cross maize hybrids) were crossed

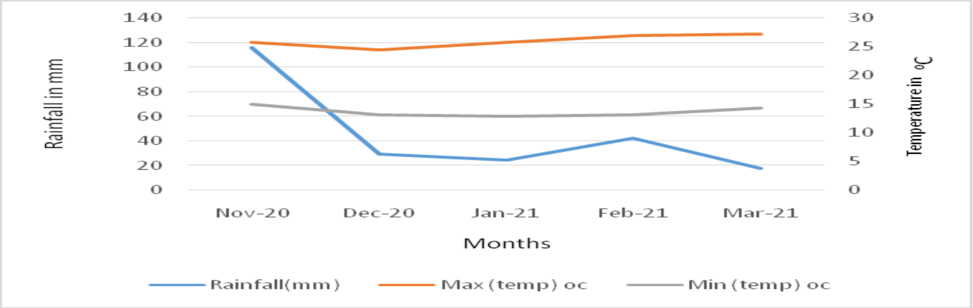

Figure 1. Total monthly rainfall, average minimum and maximum temperatures for 2020/2021 growing season in Katumani-random drought site; data obtained from Machakos meteorological station

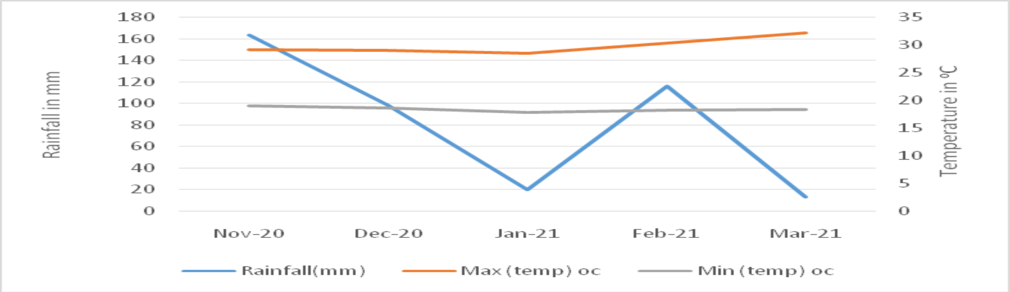

Figure 2. Total monthly rainfall, average minimum and maximum temperatures for 2020/2021 growing season in Kiboko-managed drought site; data obtained from Makindu meteorological station.

Table 1. Classification of genotypes used in the study by maturity duration

No.	Genotype	Maturity duration
1	KAT-DT-EE-02	Extra-early
2	KAT-DT-EE-04	Extra-early
3	KAT-DT-EE-05	Extra-early
4	KAT-DT-EE-07	Extra-early
5	KAT-DT-EE-14	Extra-early
6	KAT-DT-EE-15	Extra-early
7	KAT-DT-E-06	Early
8	KAT-DT-EE-18	Extra-early
9	KAT-DT-M-31	Medium early
10	KAT-DT-M-38	Medium early
11	KAT-DT-M-39	Medium early
	Checks	
12	DUMA 43	Extra-early
13	PAN 4M-19	Medium early

in half-diallel mating scheme to generate 55 F_1 progenies (double crosses). The 55 F_1's alongside two checks were screened for drought tolerance in α-lattice design with two replications at two locations for one cropping season. Each genotype was sown in two-row plots measuring 5 m each. Spacing of 0.75 m between the rows and 0.25 m within the rows was used. To evaluate hybrids for drought tolerance, the experiment was conducted in two environments *viz*; random drought at Katumani Research Centre and managed drought environments at the Kiboko sub-Centre. In the random drought environment, the trial relied on natural rainfall, while in the managed drought environment, supplemental irrigation was applied using drip irrigation. Water stress was achieved by withholding irrigation for two weeks before 50% male flowering to the end of the flowering period (Bänziger *et al*., 2000).

Data collection

Data were collected on grain yield (GY), plant height (PH), ear height (EH), number of plants (NP) and number of ears per plant (EPP) as described by Bänziger et al. (2000). Grain yield was measured in tonnes per hectare adjusted to grain moisture content of 13% and assuming a shelling percentage of 80%. All ears harvested from

Table 2. REML table of variance components of all entries, including hybrids and checks for grain yield and yield contributing traits of maize hybrids in managed drought environment during the 2020/2021 growing season.

ASI			**PH**			**EH**			**EPP**		
Fixed	Wald (df)	P	Fixed	Wald (df)	P	Fixed	Wald (df)	P	Fixed	Wald (df)	P
Rep	1.67 (1)	0.404	Rep	1.04 (1)	0.309	Rep	1.86 (1)	0.172	Rep	0.29 (1)	0.642
Geno	83.46 (56)	0.118	Geno	232.78 (56)	<0.001	Geno	196.53 (56)	<0.001	Geno	63.67 (56)	0.327
Random	Estimate	SE	Random	Estimate	SE	Random	Estimate	SE	Random	Estimate	SE
Rep.bloc	0.0013	0.002	Rep.bloc	-6.3	11.2	Rep.bloc	-0.08	7.76	Rep.bloc	0.002	0.0004
Residual	0.23	0.456	Residual	195.2	38.4	Residual	92.23	18.53	Residual	0.002	0.005
GY											
Fixed	Wald (df)	P									
Rep	9.41 (1)	0.129									
Genotype	117.7 (56)	0.010									
Random	Estimate	SE									
Rep.bloc	0.048	0.142									
Residual	1.388	0.272									

Rep = replication, P= Probability, SE=standard error, EPP=Ears per plant, Geno = Genotype, Rep.bloc = Replication*bloc

Table 3. REML table of variance components for all entries including hybrids and checks for grain yield and yield contributing traits in random drought environment during the 2020/2021 growing season.

ASI			**PH**			**EH**			**EPP**		
Fixed	Wald (df)	P	Fixed	Wald (df)	P	Fixed	Wald (df)	P	Fixed	Wald (df)	P
Rep	2.10 (1)	0.34	Rep	0.03 (1)	0.8	Rep	0.7 (1)	0.4	Rep	0.00 (1)	*
Geno	45.78 (56)	0.74	Geno	130.5 (56)	<0.001	Geno	134.03 (56)	<0.001	Geno	20.92 (56)	0.4
Random	Estimate	SE	Random	Estimate	SE	Random	Estimate	SE	Random	Estimate	SE
Rep.bloc	0.19	0.912	Rep.bloc	-23	25.7	Rep.bloc	0.17	0.10	Rep.bloc	0.002	0.0004
Residual	9.97	1.95	Residual	501.3	102.1	Residual	0.08	0.01	Residual	0.002	0.005
GY											
Fixed	Wald (df)	P									
Rep	0.01 (1)	0.9									
Geno	6.25 (56)	0.9									
Random	Estimate	SE									
Rep.bloc	0.004	0.01									
Residual	0.309	0.05									

Rep = replication, P= Probability, SE=standard error, EPP=Ears per plant, Geno = Genotype, Rep.bloc = Replication*bloc each plot were weighed, and a representative sample of ears were shelled to determine the percentage moisture of the grain using a Dickey John™ moisture meter. Moisture content correction was carried out using the equation (Badu-Apraku et al., 2012). Anthesis-silking interval (ASI) was the difference between the date of tasseling and the date at which 50% of plant produced silk from six randomly selected plants. Ear height in cm (EH) was determined by measuring from ground level to the node bearing the uppermost ear. Number of plants (NP) at harvest was determined by counting the number of plants that survived to physiological maturity. At physiological maturity, heights of 6 randomly selected plants in a plot were measured using a metre scale from the soil surface to the base of the tassel. Ears per plant (EPP) was determined by counting the number of ears with at least fully developed grains and divided by the number of plants per plot at harvest.

Phenotypic data analysis

Data collected was subjected to residual/restricted maximum likelihood (REML) where replication, genotypes, location and interaction between genotype and location was considered fixed while the random term was block nested within replication using GenStat (VSN, 2014; Patterson & Thompson 1971). Data analysis was conducted for single environments and combined environments to show the influence of the environment on genotypic expression. The model below was used;

$$Y_{ijk} = \mu + G_i + R_l + B_{l(k)} + L_j + GL_{ij} + \varepsilon_{ijk}$$

Where Y_{ijk} is the observed trait for the i^{th} genotype in the k^{th} block within the l^{th} replicate, μ = overall mean, G_i is the effect of the i^{th} genotype, R_l is the effect of the l^{th} replicate, Bl(k) is the effect of the k^{th} block in the l^{th} replicate, L_j is the effect of the j^{th} location GL_{ij} is the interaction effect between the i^{th} genotype and j^{th} location and ε_{ijk} is the random error term. Mean separation was carried out using LSD at 5% significance level using suitable error terms.

Genetic data analysis

Combining ability was estimated based on Griffing's (1956) method IV, model II, analysis using the Diallel-SAS programme as described by Zhang and Kang (1997). The genetic model for the combining ability analysis is given by;

$$y_{ij} = \mu + g_i + g_j + s_{ij}$$

where μ is the overall mean of all hybrids in the diallel design, g_i is the general combining ability of the i^{th} parent, g_j is the general combining ability of the j^{th} parent while s_{ij} is the specific combining ability between the i^{th} and the j^{th} parents (Singh & Chaudhary, 1985).

Heritability in narrow sense (h^2) was estimated on a plot basis,

$$h^2 = \frac{\sigma_A^2}{\sigma_A^2 + \sigma_D^2 + \sigma_e^2}$$

Where h^2 is heritability in narrow sense, σ_A^2 is the additive variance, σ_D^2 is the dominance variance and σ_e^2 is the environmental (Singh & Chaudhary, 1985).

Baker's ratio (BR) was calculated using the following formula;

$$BR = \frac{2\sigma_{GCA}^2}{2\sigma_{GCA}^2 + \sigma_{SCA}^2}$$

where σ_{GCA}^2 refers to general combining ability variance and σ_{SCA}^2 refers to specific combining ability variance (Baker, 1979).

RESULTS

Variance components for grain yield and yield contributing traits

Residual maximum likelihood (REML) analyses for managed drought environment revealed ($p< 0.05$) main effects of genotypes for all measured traits except ASI. In the random drought environment, significant ($p< 0.05$) main effects for genotype were observed for PH and EH traits only (Table 2 and Table 3). Combined analysis of variance over environments revealed significant ($p< 0.01$) main effects for genotypes for all traits except ASI and EPP. In addition, significant ($p< 0.01$) location main effects were observed for all traits studied. Genotype by location interactions were significant ($p < 0.01$) for all traits except ASI (Table 2).

Mean performance of grain yield and yield contributing traits

In the managed drought environment, the best performing hybrid in terms of GY was KAT-DT-EE-14×KAT-DT-EE-05 which yielded 9.82 t ha^{-1}, compared to the best performing check variety PAN 5M-19 which yielded 8.73 t ha^{-1}. KAT-DT-E-06×KAT-DT-EE-04, KAT-DT-EE-15×KAT-DT-EE-04 and KAT-DT-M-38×KAT-DT-M-31 recorded ASI of 1, 2 and 3, respectively. In addition to this, the lowest plant heights of 128.2, 147 and 156.8were observed on KAT-

DT-M-38×KAT-DT-EE-15,KAT-DT-EE-18×KAT-DT-M-31 and KAT-DT-M-31×KAT-DT-EE-02, respectively. Longest ear heights were observed on KAT-DT-EE-14×KAT-DT-E-06, KAT-DT-EE-18×KAT-DT-M-39 and KAT-DT-EE-07×KAT-DT-E-06, ear heights of 118.75 cm, 117.75 cm and 115.25 cm. With regards to ears per plant, KAT-DT-EE-18×KAT-DT-EE-14 recorded

Table 4. REML table of variance components of all entries, including hybrids and checks for grain yield and yield contributing traits combined across environments during the 2020/2021 growing season

ASI			**PH**			**EH**			**EPP**		
Fixed	Wald (df)	P	Fixed	Wald (df)	P	Fixed	Wald (df)	P	Fixed	Wald (df)	P
Rep	1.45 (1)	0.23	Rep	3.25 (1)	0.07	Rep	23.92 (1)	<0.001	Rep	0.25 (1)	0.62
Geno	0.79 (56)	0.87	Geno	4.09 (56)	<0.001	Geno	12.80 (56)	<0.001	Geno	1.30 (56)	0.06
Loc	24.37 (1)	<0.001	Loc	3613.9 (1)	<0.001	Loc	4460.5 (1)	<0.001	Loc	657.61 (1)	<0.001
Loc.geno	50.39(56)	0.68	Loc.geno	82.25 (56)	0.0013	Loc.geno	148.3 (56)	<0.001	Loc.geno	75.54 (56)	0.042
Random	Estimate	SE	Random	Estimate	SE	Random	Estimate	SE	Random	Estimate	SE
L.R.B	0.127	0.217	L.R.B	-11.5	0.01	L.R.B	127.5	18	L.R.B	-0.001	0.001
Residual	3.53	0.498	Residual	7.7	46.5	Residual	-5.7	2.1	Error term	0.05	0.007
GY											
Fixed	Wald (df)	P									
Rep	6.02 (1)	<0.001									
Geno	1.97 (56)	<0.001									
Loc	945.4 (1)	<0.001									
Loc.geno	93.28(56)	0.001									
Random	Estimate	SE									
L.R.B	0.09	0.084									
Residual	0.948	0.135									

Rep = replication, P= Probability, SE=standard error, EPP=Ears per plant, Geno = Genotype, Rep.bloc = Replication*bloc

Table 5. Mean performance of hybrids for measured traits in managed and random drought experiments, the cut-off point was the best performing check for GY during the 2020/2021 growing season.

Managed drought experiment						**Random drought experiment**					
Hybrid	**ASI**	**PH**	**EH**	**EPP**	**GY**	**Hybrid**	**ASI**	**PH**	**EH**	**EPP**	**GY**
KAT-DT-EE-14×KAT-DT-EE-05	1.5	210.4	113	1.0	9.82	KAT-DT-M-38×KAT-DT-EE-15	3.5	101.5	10.6	0.67	2.03
KAT-DT-EE-04×KAT-DT-EE-02	1	203.5	91	1.1	9.67	KAT-DT-EE-18×KAT-DT-EE-02	4.5	143.2	67	0.84	1.75
KAT-DT-EE-18×KAT-DT-EE-14	2.5	217	90.8	1.4	9.35	KAT-DT-EE-15×KAT-DT-EE-02	3.5	109.5	51	0.62	1.67
KAT-DT-EE-15×KAT-DT-E-06	1	196.8	82	1.0	9.13	KAT-DT-M-31×KAT-DT-EE-02	-0.5	112.8	46.3	0.92	1.59
KAT-DT-E-06×KAT-DT-EE-04	1	203.1	86.8	1.0	9.04	KAT-DT-E-06×KAT-DT-EE-04	1	125.2	56.5	0.73	1.54
KAT-DT-EE-07×KAT-DT-EE-04	1	193	97	1.1	8.99	KAT-DT-M-38×KAT-DT-M-31	3	94.2	9.43	0.56	1.42
KAT-DT-M-39×KAT-DT-EE-02	1	197.5	83.8	1.1	8.98	KAT-DT-EE-15×KAT-DT-EE-04	2	118.2	58.5	0.67	1.39
KAT-DT-E-06×KAT-DT-EE-05	1	205.8	84.8	1.0	8.92	KAT-DT-EE-18×KAT-DT-EE-15	3.5	71.8	7.17	0.64	1.38
KAT-DT-EE-15×KAT-DT-EE-02	1	175.8	85.8	1.0	8.91	KAT-DT-EE-04×KAT-DT-EE-02	1.5	117.5	51	0.54	1.34
KAT-DT-EE-07×KAT-DT-EE-14	1	196.2	111.8	1.0	8.88	KAT-DT-M-38×KAT-DT-EE-14	1.5	88.5	36.5	0.44	1.30
KAT-DT-EE-18×KAT-DT-EE-05	1.5	210.1	102.3	0.9	8.78	KAT-DT-M-38×KAT-DT-EE-02	1.5	86.2	43.2	0.71	1.30
KAT-DT-EE-18×KAT-DT-EE-02	1	209.2	97.5	1.0	8.76	KAT-DT-M-31×KAT-DT-EE-07	3.5	102	49.3	0.84	1.29
PAN 5M-19	1	197.2	101.8	1.1	8.73	KAT-DT-EE-07×KAT-DT-E-06	-2	142	74.3	0.57	1.25
DUMA 43	0.5	172	105.8	1.1	7.42	KAT-DT-EE-05×KAT-DT-EE-02	2.5	122.5	57.5	0.80	1.22
						DUMA 43	5	87	8.7	0.53	1.19
						PAN 5M-19	4.5	81	8.1	0.58	0.90
Trial mean	1.1	195.3	93.32	1.1	7.63		2.6	103.9	44.6	0.4	0.8
LSD (0.05)	1.0	28.94	21.47	0.4	2.5		6.5	54	33.2	0.53	1.3
CV %	15.4	7.13	11.21	16.5	15.4		19.1	25.9	37.1	13.2	26

ASI=anthesis-silking interval, GY= grain yield, PH=plant height, EH=ear height, EPP=ears per plant, LSD = Least significant difference, CV% = coefficient of variation.

Table 6. Mean performance of hybrids for measured traits combined over study environments, cut-off point is the best performing check for GY during the 2020/2021 growing season.

Genotype	**ASI**	**PH**	**EH**	**EPP**	**GY**
KAT-DT-EE-07×KAT-DT-EE-14	0.5	128.5	73.25	0.64	6.18
KAT-DT-EE-07×KAT-DT-EE-04	1.5	138.6	60.25	0.63	6.16
KAT-DT-E-06×KAT-DT-EE-05	2.25	162.1	71.5	0.62	6.10
KAT-DT-EE-15×KAT-DT-EE-14	1.5	138.5	65	0.56	5.74
KAT-DT-EE-04×KAT-DT-EE-02	1.25	160.5	71	0.83	5.51
KAT-DT-M-39×KAT-DT-EE-04	2.25	120.9	46.62	0.53	5.50
KAT-DT-EE-14×KAT-DT-E-06	3	176.9	72.38	0.60	5.35
KAT-DT-EE-14×KAT-DT-EE-05	1.75	156.2	85.12	0.70	5.32
KAT-DT-E-06×KAT-DT-EE-04	1	164.2	71.62	0.88	5.29
KAT-DT-EE-15×KAT-DT-EE-02	2.25	142.6	68.38	0.81	5.29
KAT-DT-EE-18×KAT-DT-EE-02	2.75	176.2	82.25	0.94	5.26
KAT-DT-EE-15×KAT-DT-E-06	3.25	148.5	67	0.70	4.92
KAT-DT-M-38×KAT-DT-EE-14	1.25	146.6	65	0.76	4.89
KAT-DT-EE-15×KAT-DT-EE-04	1.5	161.6	73	0.78	4.83
PAN 5M-19	2.75	139.1	54.92	0.82	4.82
DUMA 43	2.75	129.5	57.23	0.83	4.31
Trial mean	1.86	149.7	68.98	0.47	4.24
LSD (0.05)	3.19	30.21	19.42	0.32	30.21
CV %	27.1	0.6	1.5	1.9	0.6

ASI=anthesis-silking interval, GY= grain yield, PH=plant height, EH=ear height, EPP=ears per plant, LSD = Least significant difference, CV% = coefficient of variation.

Table 7. Mean squares due to GCA and SCA for measured traits in a half diallel mating design of 11 parents during the 2020/2021 growing season

Double cross hybrids						
Source of variation	**df**	**ASI**	**GY**	**PH**	**EH**	**EPP**
Hybrids	54	2.88	1.75*	944.89*	1429.3*	0.06
GCA	10	4.19	4.29*	1742.21*	3.89*	0.06
SCA	44	2.59	2.12*	784.30*	459.12*	1.31
Environment × hybrids						
ENV x GCA	10	2.97	2.00*	945.65*	304.6*	0.11*
ENV x SCA	44	3.00	0.58	365.41	157.63	0.05
Error	108	4.12	16.46	320.68	118.11	0.05
CV%		10.9	22.3	11.7	15.1	30.1
Mean		1.89	4.32	152.85	71.95	0.05

* Significant at p<0.05, df = degrees of freedom, ASI=anthesis-silking interval, GY= grain yield, PH=plant height, EH=ear height, EPP ears per plant, CV% = coefficient of variation, Env=environment.

Table 8. Specific combining ability (SCA) estimates of hybrids for yield and yield related traits according to test environment

Double cross hybrid /Trait	**ASI**		**PH**		**EH**		**GY**		**EPP**	
Environment	**MD**	**RD**	**MD**	**RD**	**MD**	**RD**	**MD**	**RD**	**MD**	**RD**
KAT-DT-EE-04×KAT-DT-EE-02	-0.27	-0.50	8.20	9.20	6.88	-0.75	1.25	0.26	0.00	0.01
KAT-DT-EE-05×KAT-DT-EE-02	-0.04	0.50	5.56	-2.66	6.55	-4.92	-0.75	0.30	0.00	-0.01
KAT-DT-E-06×KAT-DT-EE-02	0.96	-0.39	7.09	-2.69	7.99	0.53	0.13	-0.72	0.21*	0.29*
KAT-DT-M-39×KAT-DT-EE-02	0.07	-1.11	7.38	-4.61	-3.09	-9.11	1.40	-0.45	0.00	-0.01
KAT-DT-EE-14×KAT-DT-EE-02	-0.26	1.44	-21.21*	-0.66	-10.40	-3.39	-0.71	-0.32	0.03	-0.12
KAT-DT-EE-07×KAT-DT-EE-02	-0.04	1.11	-11.66	-18.24	-18.20	-16.72	-1.85	-0.45	0.00	0.00
KAT-DT-M-31×KAT-DT-EE-02	-0.10	-2.94	-16.91	2.28	-10.42	3.27	-1.32	0.40	0.00	-0.04
KAT-DT-EE-15×KAT-DT-EE-02	0.01	1.28	1.79	1.51	9.71	4.14	0.71	0.25	0.01	-0.05
KAT-DT-M-38×KAT-DT-EE-02	-0.04	-0.50	2.91	-15.11	2.66	5.26	0.56	-0.02	0.00	-0.01
KAT-DT-EE-18×KAT-DT-EE-02	0.44	-0.2	25.40	2.679	14.47	-4.19	0.86	0.13	-0.02	0.1
KAT-DT-EE-05×KAT-DT-EE-04	-0.27	-0.11	-3.07	9.56	-2.05	-2.25	-1.68	0.11	0.28	-1.06*
KAT-DT-E-06×KAT-DT-EE-04	-0.27	-2.50	-12.50	13.28	-9.10	-0.81	0.55	0.85	0.05	0.30
KAT-DT-M-39×KAT-DT-EE-04	0.34	1.28	-11.75	-57.63*	-11.44	-35.95	0.50	-0.55	0.00	1.08
KAT-DT-EE-14×KAT-DT-EE-04	-0.49	3.83	-19.94*	24.06	-11.90	2.03	-2.09	0.27	0.01	-1.44
KAT-DT-EE-07×KAT-DT-EE-04	-0.27	0.50	-16.29	-15.27	-2.30	-26.56	0.90	-0.19	0.01	1.35
KAT-DT-M-31×KAT-DT-EE-04	1.18*	-0.56	27.45	3.01	23.73*	8.69	0.83	-0.46	0.01	-0.03
KAT-DT-EE-15×KAT-DT-EE-04	-0.21	-0.33	15.40	20.73	2.62	15.80	-0.09	0.32	0.03	-0.24
KAT-DT-M-38×KAT-DT-EE-04	-0.27	-1.11	-0.22	11.37	-2.69	19.92*	-0.38	-0.12	0.00	-0.37
KAT-DT-EE-18×KAT-DT-EE-04	0.02	-0.03	-1.29	-0.09	17.69	0.17	-0.24	0.34	0.11	-0.02
KAT-DT-E-06×KAT-DT-EE-05	-0.04	0.00	-13.69	-10.33	-17.19	-9.72	0.44	-0.07	0.03	-0.10
KAT-DT-M-39×KAT-DT-EE-05	0.07	-1.22	-2.14	14.01	3.73	5.89	-0.45	0.11	0.01	-0.06
KAT-DT-EE-14×KAT-DT-EE-05	0.23	-0.67	-2.13	-18.05	8.52	-8.64	1.50	0.23	0.00	0.00
KAT-DT-EE-07×KAT-DT-EE-05	-0.04	-1.50	2.57	15.12	-0.38	6.03	-0.40	0.11	0.01	-0.05
KAT-DT-M-31×KAT-DT-EE-05	-0.10	0.94	0.06	-25.61	1.15	-1.73	0.89	0.01	0.01	-0.06
KAT-DT-EE-15×KAT-DT-EE-05	0.01	1.67	3.01	1.87	5.79	8.89	-0.27	-0.11	0.00	0.04
KAT-DT-M-38×KAT-DT-EE-05	-0.04	0.89	11.64	17.26	-4.27	17.26	0.26	-0.39	0.00	0.01
KAT-DT-EE-18×KAT-DT-EE-05	-0.09	-0.16	0.00	10.27	-6.86	6.51	0.13	0.1	-0.14	-0.04
KAT-DT-M-39×KAT-DT-E-06	-0.43	-0.61	3.64	-6.77	14.18*	14.47	-1.30	-0.07	0.00	0.00
KAT-DT-EE-14×KAT-DT-E-06	-0.27	0.94	19.95	3.17	17.46*	-1.29	-0.56	-0.04	0.02	-0.08
KAT-DT-EE-07×KAT-DT-E-06	-0.04	-1.89	8.60	28.34	13.06	-0.42	0.04	0.60	0.30*	0.35*
KAT-DT-M-31×KAT-DT-E-06	-0.10	-0.44	5.34	-15.13	-5.16	2.45	0.99	0.05	0.00	-0.02
KAT-DT-EE-15×KAT-DT-E-06	0.01	1.78	2.54	-11.41	-5.77	-0.33	0.85	-0.33	0.01	-0.07
KAT-DT-M-38×KAT-DT-E-06	-0.04	2.00	-14.59	-7.27	-11.07	-0.43	-0.57	-0.43	0.00	-0.01
KAT-DT-EE-18×KAT-DT-E-06	0.69	0.54	2.7	9.27	0.84	5.68	-0.29	0.26	-0.17	0.001
KAT-DT-EE-14×KAT-DT-M-39	-0.16	1.22	-12.51	2.01	-14.87	-12.34	-0.70	0.57	0.01	-0.07
KAT-DT-EE-07×KAT-DT-M-39	0.07	2.39	-20.61	1.67	-15.02	2.58	-1.69	0.17	0.01	0.05
KAT-DT-M-31×KAT-DT-M-39	0.01	2.33	8.14	21.70	-3.99	15.58	1.31	0.46	0.10	0.20
KAT-DT-EE-15×KAT-DT-M-39	0.12	-3.44	-0.91	-1.33	-3.60	2.19	-0.48	-0.47	0.00*	0.04
KAT-DT-M-38×KAT-DT-M-39	0.07	0.28	15.11	19.81	17.09*	20.06*	0.68	0.20	0.04	-0.13
KAT-DT-EE-18×KAT-DT-M-39	-0.61	-0.39	13.88	1.08	13.24	3.91	0.43	-0.31	-0.08	-0.04
KAT-DT-EE-07×KAT-DT-EE-14	-0.27	-2.06	-10.80	6.62	7.02	5.80	0.07	0.07	0.00	-0.04
KAT-DT-M-31×KAT-DT-EE-14	0.68*	-2.61	15.00	5.64	10.80	8.55	-0.57	-0.57	0.00	-0.04
KAT-DT-EE-15×KAT-DT-EE-14	-0.21	-0.89	3.90	-17.13	7.69	13.66	-0.13	-0.13	0.00	-0.04
KAT-DT-M-38×KAT-DT-EE-14	-0.27	-1.17	16.52	-7.74	-1.62	-4.97	0.32	0.32	0.02	0.09
KAT-DT-EE-18×KAT-DT-EE-14	0.27	0.21	4.88	4.71	-4.37	8.28	0.2	0.33	-0.02	-0.03
KAT-DT-M-31×KAT-DT-EE-07	-0.10	1.56	-11.40	0.31	-8.10	7.96	1.72*	0.48	0.01	-0.05
KAT-DT-EE-15×KAT-DT-EE-07	0.01	0.28	18.80	12.78	7.54	8.58	0.27	-0.15	0.03	-0.11
KAT-DT-M-38×KAT-DT-EE-07	0.96*	0.00	20.92	-31.58*	7.73	-7.80	-0.78	-0.67	0.02	-0.09
KAT-DT-EE-18×KAT-DT-EE-07	-0.32	-0.43	7.22	4.25	4.32	-2.92	0.28	0.07	-0.09	0.03
KAT-DT-EE-15×KAT-DT-M-31	-0.04	-1.28	20.79*	11.81	4.56	-15.63	-0.48	-0.48	0.00	-0.04
KAT-DT-M-38×KAT-DT-M-31	-0.60	0.44	-9.09	1.20	7.26	0.35	0.35	0.35	0.01	0.05
KAT-DT-EE-18×KAT-DT-M-31	0.88	0.1	-23.92	-6.71	-22.53	-9.61	-1.13	0.07	0.06	0.00
KAT-DT-M-38×KAT-DT-EE-15	0.86	-0.06	-17.67	3.7	-21.70	-21.70	0.32	0.33	0.1	0.00
KAT-DT-EE-18×KAT-DT-EE-15	-0.19	-0.18	-27.03	8.64	-8.98	-8.98	-0.22	0.34	0.19	0.01
KAT-DT-EE-18×KAT-DT-M-38	-1.93	0.13	-4.34	8.86	-14.77	4.48	0.36	-0.5	0	0.02

* Significant at p<0.05, df = degrees of freedom, ASI=anthesis-silking interval, GY= grain yield, PH=plant height, EH=ear height, EPP ears per plant, CV% = coefficient of variation, Env=environment, MD=managed drought, RD=Random drought.

1.4, while the commercial checks had 1.1 ears per plant, as shown in Table 5.

In the random drought environment, KAT-DT-M-38×KAT-DT-EE-15 was the highest yielding hybrid with 2.03 t ha^{-1}, while the best performing check DUMA 43 yielded 1.19 t ha^{-1}.The least anthesis-silking interval of 0.5 was observed in KAT-DT-M-39×KAT-DT-E-06, KAT-DT-M-38×KAT-DT-M-31, KAT-DT-EE-18×KAT-DT-M-31 and DUMA 43.Hybrids KAT-DT-M-38×KAT-DT-EE-07, KAT-DT-M-39×KAT-DT-EE-04 andKAT-DT-M-31×KAT-DT-EE-14 had significantly lower plant heights of 41.2, 47.8 and 55.5, respectively. The longest ear height values were recorded in KAT-DT-EE-07×KAT-DT-E-06, KAT-DT-M-39×KAT-DT-EE-05 and KAT-DT-EE-18×KAT-DT-EE-02 with values of 74.25 cm, 70.5 cm and 67 cm, respectively possibly contributing to lower GY. On ears per plant trait, hybrids showed more EPP as KAT-DT-M-31×KAT-DT-EE-02 had 0.92, in comparison with the best performing commercial check registered 0.58.

Mean performance of measured traits in combined environments is shown in Table 6. Mean GY of hybrids outperformed commercial checks for example, cross KAT-DT-EE-07×KAT-DT-EE-14, KAT-DT-EE-07×KAT-DT-EE-04, and KAT-DT-E-06×KAT-DT-EE-05 yielded 6.18 t ha^{-1}, 6.16 t ha^{-1} and 6.10 t ha^{-1}, respectively while commercial checks PAN 5M-19 and DUMA 43 yielded 4.82 t ha^{-1} and 4.31 t ha^{-1}, respectively. Mean ASI values of experimental hybrids was lower than commercial checks. In addition, commercial checks recorded lower plant height values as compared to hybrids. In regards to ear heights, hybrids showed higher ear heights than commercial checks. Higher ears per plant were observed in commercial checks however, the checks had lower GY as compared to hybrids. EPP of 0.82 and 0.83 against a GY of 4.82 and 4.31t ha^{-1} respectively was observed for commercial check PAN 5M-19 and DUMA 43 while an EPP of 0.81 KAT-DT-EE-15×KAT-DT-EE-02 and 0.83 yielded GY of 5.29 and 5.51 t ha^{-1}, respectively by hybrids.

Mean squares due to GCA and SCA for measured traits across test environments

Mean square of double cross hybrids was significant ($p< 0.05$) for all measured traits except ASI and EPP. Combining ability analysis showed significant ($p<0.05$) mean squares due to GCA and SCA for GY, EH and PH. Significant GCA-by-environment ($p<0.05$) mean squares were observed for all measured traits except ASI. In contrast, SCA by environment interaction mean squares were not significant for all studied traits (Table 7).

Specific combining ability of hybrids across locations for grain yield and yield contributing traits

Results of specific combining ability (SCA) for grain yield and yield related traits are presented in Table 8. Significant negative SCA estimates for reduced plant heights was observed on hybrid KAT-DT-M-39×KAT-DT-EE-04 and KAT-DT-M-38×KAT-DT-EE-07 in random drought and KAT-DT-EE-14×KAT-DT-EE-02 and KAT-DT-EE-14×KAT-DT-EE-04 under managed drought conditions. Significant positive SCA for ear height was recorded in hybrids KAT-DT-M-31×KAT-DT-EE-04, KAT-DT-M-39×KAT-DT-E-06, KAT-DT-EE-14×KAT-DT-E-06 and KAT-DT-M-38×KAT-DT-M-39 in managed drought environment and KAT-DT-M-38×KAT-DT-EE-04, KAT-DT-M-38×KAT-DT-M-39 in random drought environment. Notably, KAT-DT-M-38×KAT-DT-M-39 showed good specific combining ability for increased ear height in both study environments. In regards to GY, KAT-DT-M-31×KAT-DT-EE-07 showed a significant and positive SCA for GY under managed drought conditions. In ears per plant, significant positive SCA was recorded for hybrids KAT-DT-E-06×KAT-DT-EE-02, KAT-DT-EE-07×KAT-DT-E-06 and KAT-DT-EE-15×KAT-DT-M-39 in managed drought conditions and KAT-DT-E-06×KAT-DT-EE-02, KAT-DT-EE-07×KAT-DT-E-06 under random drought conditions. Evidently, KAT-DT-E-06×KAT-DT-EE-02 and KAT-DT-EE-07×KAT-DT-E-06 showed significant and positive SCA for EPP in both study environments.

Heritability and Baker's ratio

Bakers' ratios of 0.2 for anthesis-silking interval, 0.2 for plant height, 0.5 for ear height, 0.8 for ears per plant and 0.2 for grain yield were obtained as shown in Table 9. Low heritability in narrow sense estimates of 0.28%, 3.81%, 31.68% and 4.07% were recorded for anthesis-silking interval, plant height, ear height and grain yield, respectively.

Table 9. Baker's ratios of addictive and non-additive gene effects on yield and yield contributing traits

Variances	ASI	PH	EH	EPP	GY
σ^2_{gca}	0.00	10.49	337.82	0.02	0.00
σ^2_{sca}	0.04	104.72	6691.1	0.01	0.00
Baker's Ratio	0.2	0.2	0.5	0.8	0.2

ASI=anthesis-silking interval, PH=plant height, EH=ear height, EPP =ears per plant, GY= grain yield, σ^2_{gca}= variance due to GCA and σ^2_{sca} = variance due to SCA

Baker's Ratio: $\mathrm{BR} = \frac{2\sigma^2_{GCA}}{2\sigma^2_{GCA} + \sigma^2_{SCA}}$, GCA =general combining ability, SCA = specific combining ability.

Table 10. Estimates of genetic parameters and heritability in grain yield and yield contributing traits

Trait	σ^2_A	σ^2_D	σ^2_G	σ^2_e	σ^2_P	h^2
ASI	0.00	0.04	0.04	3.21	1.65	0.28
PH	10.49	104.72	115.21	320.68	275.55	3.81
EPP	337.82	669.42	1007.24	118.11	1066.29	31.68
GY	0.02	0.00	0.02	0.94	0.49	4.07

ASI= antheisis-silking interval, PH= plant height, EH= ear height, EPP = ears per plant, GY = grain yield, σ^2_A additive variance, σ^2_D = dominance variance, σ^2_E = error variance, σ^2_P = phenotypic variance, h^2 = narrow sense heritability.

DISCUSSION

-The magnitude of genetic variance for drought tolerance can be quantified using yield and correlated traits (Bänziger et al., 2000; Araus et al., 2008).Significant genotype differences observed for most traits studied suggest the presence of high genetic variability within the germplasm (Islam et al., 2020). Furthermore, significant ($p<0.05$) location effects and genotype-by-location interactions show that the environment contributed significantly to the total variation in hybrid performance. Similar findings of significant main effects for genotypes, location and genotype-by-environment interactions were reported (Rezende et al., 2020).

Superior performance of the F_1 hybrids over the commercial checks for grain yield, anthesis-silking interval and ear height across environments was observed in this study. Grain yield is a key trait in selection for drought tolerance while ASI is important for drought escape (Bänziger et al., 2000; Murtadha et al., 2018). Similar results were reported by Dhakal et al. (2022) and Rezende et al. (2020) where experimental materials outperformed commercial checks on plant height and anthesis-silking-interval traits. Improved performance of these traits could be explained by the heterosis phenomenon. The relevance of heterosis in increasing performance in hybrids for agronomic traits under drought was drawn by Mogesse et al. (2020), Ilyas et al. (2019), Kenga et al. (2004) and Li & Li (1998) in maize and sorghum (*Sorghum bicolor* L.). Presence of heterosis presents an opportunity to exploit hybrid cultivars for semi-arid Kenya.

The high reduction in GY under drought stress environment could be attributed to a wider ASI under drought stress. A wide ASI is undesirable to breeding for drought tolerance because it is negatively correlated grain yield (Wang et al., 2021). Anthesis-silking interval negatively impacts grain yield due to an increase between days to pollen shed and silk emergence resulting to a low seed set (Etiro et al., 2017). Selecting genotypes according to reduced ASI under drought stress is an effective approach to improve drought tolerance (Wang et al., 2021; Murtadha et al., 2018). In addition, shorter ear heights and higher ears per plant values could be linked to the reduction observed on grain yield in random drought conditions. Results point to small and poorly filled ears contributing to reduced grain yield (Badu-Apraku et al., 2012).

In a breeding programme focused on developing hybrid cultivars, knowledge of combining ability of the parental genotypes and the inheritance of traits is key. In the present study, significant general combining ability (GCA) and specific combining ability (SCA) mean squares were observed for most measured traits but not for GY, EH and PH traits. Significant GCA and SCA show the presence of additive and non-additive gene action in governing the inheritance of the traits (Murtadha et al., 2018). The inheritance of traits during selection of maize hybrids for drought tolerance has been reported by various researchers (Ali et al., 2018; Ilyas et al., 2019; Owusu et al., 2022).GCA-by environment interactions for grain yield, plant height, ear height and number of ears indicated varied expression of additive genetic variance in different locations due to the environment's role in genotypic expression (Mogesse et al., 2020). Findings on differential expression of genes across environments for given traits show the importance of carrying out selection in target environments (Rezende et al., 2020). Therefore, hybrids may need to be subjected to advanced trials in multi-locations to test for SCA and select hybrids with potential for good performance.

Results from this study show the potential to increase grain yield trait under managed drought conditions with a significant and positive SCA. Significant combining ability for grain yield is useful in developing high yielding maize hybrids. Positive SCA for improved grain yield in maize has been documented by various researchers (Mogesse et al., 2020; Dar et al., 2017). Further, it corroborates that drought adversely affects growth and causes a reduction on maize yields (Murtadha et al., 2018). Additionally, superior hybrids with improved ASI under drought stress were identified. These results agree with other studies where drought tolerant maize was identified using ASI (Wang et al., 2021).Regarding plant height, significant negative SCA has been documented (Mbuvi et al., 2018; Hoque et al., 2016). Hybrids with good specific combining ability for short plant stature are potential candidates for selection of desirable maize genotypes for drought tolerance because shorter plants are resistant to lodging (Tulu et al., 2022; Hoque et al., 2016). Good SCA for increased ear height was observed in both study environments. Significant positive SCA for ear height is desirable because it allows more ears to develop below the nodes; however, there is a risk of breaking when the ear is too high (Amana & Hadi, 2021). The potential to increase ears per plant under random drought environment due to prolificacy where hybrids yielded a higher number of ears per plant as compared to the commercial checks. Higher ears per plant is a preferred trait since it is directly associated with improved grain yield (Mogesse et al., 2020).

Low Bakers' ratios (BRs) alongside low narrow sense heritability were recorded for most traits in this study. Narrow sense heritability is a useful statistic because it measures the proportion of variation that is fixable (Kearsey & Pooni, 1996). Low narrow sense heritability coupled with low BR demonstrates the role of dominant and or epistatic gene effects in inheritance of traits, hence difficult to be transmitted to progenies (Issa et al., 2018). ASI, PH and GY had BR of less than 0.5, implying that non-additive gene action was more important in their inheritance (Ali et al., 2018). These findings agree with reports on the preponderance of non-additive gene action in the inheritance of drought stress (Akinwale et al., 2021).Low heritability estimates in this study indicate that the inheritance of traits is largely influenced by non-genetic factors arising from environmental impact (Issa et al., 2018). However, BR for ears per plant was close to unity suggesting the predominance of additive genetic variance hence heritable (Biswas et al., 2019). Therefore, adoption of selection procedures that result in accumulation of positive genes modulating drought tolerance would be plausible.

CONCLUSION

Genotype-by-environment interaction affected grain yield and yield contributing traits significantly. Among the traits studied, non-additive gene effects predominated over the additive gene effects in the inheritance of grain yield, ear height and plant height. Specific combining ability for reduced plant heights, increased ear heights and increased ears per plant were observed. The study revealed the potential to develop hybrid cultivars with improved grain yield, reduced plant height, increased ear height, and ears per plant superior compared to those currently in the market for future deployment in semi-arid areas.

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REFERENCES

Akaogu, I. C., Badu-Apraku, B., & Adetimirin, V. O. (2017). Combining ability and performance of extra-early maturing yellow maize inbreds in hybrid combinations under drought and rain-fed conditions. *Journal of Agricultural Science*, 1,21.

Akinwale, R. O., Eze, C. E., Traore, D.,& Menkir, A. (2021). Detection of non-additive gene action within elite maize populations evaluated in contrasting environments under rainforest ecology in Nigeria. *Crop Breeding, Genetics and Genomics*, *3*(1),1-24.

Ali, S., Khan, N. U., Khalil, I. H., Samrin, M. I., Ahmed, G. S., Sajjad, M., Afridi, K., Ali, I.,& Khan, S. M. (2018). Environment effects for earliness and grain yield traits in F_1 diallel populations of maize (*Zea mays* L.). *Journal of the Science of Food and Agriculture,97*(13), 4408-4418.

Amana, A. J.,& Hadi, B.H. (2021). Genetic analysis by using partial diallel crossing of maize in high plant densities (estimation of GCA, SCA and some genetic parameters. *Earth and Environmental Science Journal*, *910*, 012135.

Araus, J. L., Slafer, G. A., Royo, C., & Serret, M. D. (2008). Breeding for yield potential and stress adaptation in cereals. *Critical Reviews in Plant Sciences*, 27(6), 377-412.

Aslam, M., Maqbool, M. A., & Cengiz, R. (2015). *Drought Stress in Maize (Zea mays L.) Effects, Resistance mechanisms, Global achievements and Biological strategies for improvement* (pp. 19-38). Springer.

Aswin, R. C., Sudha, M., Senthil, A., Sivakumar, S., & Senth, N. (2020). Identification of superior drought tolerant maize hybrids based on combining ability and heterosis with Line × Tester mating design. *Electronic Journal of Plant Breeding*, 11(2), 566-573.

Badu-Apraku, B., Fakorede, M. A. B., Menkir, A., & Sanogo, D. (2012). *Conduct and management of maize field trials*. IITA, Ibadan, Nigeria. Pp 59.

Baker, R. J. (1978). Issues in diallel analysis. *Crop Science*, *18*(4), 533- 536.

Bänziger, M., Edmeades, G. O., Beck, D., & Bellon, M. (2000). *Breeding for Drought and Nitrogen Stress Tolerance in Maize*: From Theory to Practice. Mexico, D.F. CIMMYT.

Biswas, T., Islam, M.S., &Methela, N. (2019). Heritability and genetic advance estimates from the parental lines of hybrid maize (*Zea Mays* L.).*Journal of Environmental Science and Natural Resources*, *12*, 33-36.

Blum, A. (2011). Drought resistance is it really a complex trait? *Functional Plant Biology*, *38*(10), 753-757.

Dar, Z. A., Lone, A. A., Khuroo, N. S., Ali, G., Abidi, I., &

Ahangar, M. A. (2017). Line x tester analysis in maize (*Zea mays* L.) for various morpho-agronomic traits under temperate conditions. *International Journal of Current Microbiology and Applied Sciences, 6*(7), 1430-1437.

Dhakal, K., Keshab, R., Bandhu, R., Dipendra, K. A., & Darbin, J. D. (2022).Three-way cross white kernel hybrid maize out-yielded commercial variety tested under two contrasting environments. *Journal of Agriculture and Food Research, 7,10029.*

Ertiro, B.T., Beyene, Y., Das, B., Mugo, S., Olsen, M., Oikeh, S., Juma, C., Labuschagne, M., & Prasanna, B. M. (2017). Combining ability and testcross performance of drought-tolerant maize inbred lines under stress and non-stress environments in Kenya. *Plant Breeding, 132*(2)*, 1*97-205*.*

FAO. (2022). *Crop Prospects and Food Situation– Quarterly Global Report* No. 1, March 2022. Rome.https://doi.org/10.4060/cb8893en

FAOSTAT. (2019). *Crop production data*. Retrieved on 12thJuly, 2022 from http://www.fao.org/faostat/en/#data

G.O.K.(2010). Agricultural Sector Development Strategy 2010-2020.https://www.gafspfund.org/sites/default/files/inline-files/5.%20Kenya_strategy.pdf

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Sciences*, *9*(4), 463-493.

Hoque, M., Akhter, F., Kadir, M., Begum, H. A., & Ahmed, S. (2016). Study on combining ability and heterosis for earliness. *Bangladesh Journal of Agricultural Research*, *41*(2), 365-376.

Ilyas, M., Khan., S.A., Awan., S.I.,&Rehman., S. (2019). Assessment of heritability and genetic advance in maize (*Zea mays* L.) under natural and water stress conditions. *Sarhad Journal of Agriculture*, *35*(1), 144-154.

Islam, N. U., Ali, G., Dar, Z. A., Maqbool, S., Baghel, S., & Bhat, A. (2020). Genetic variability studies involving drought tolerance related traits in maize (Zea mays L.) inbreds. *International Journal of Chemical Studies*, 8(1), 414-419.

Issa, Z. M., Nyadanu, D., Richard A., Sangare A. R., Adejumobi, I., & Ibrahim, D. (2018). Inheritance and combining ability study on drought tolerance and grain yield among early maturing inbred lines of maize (*Zea mays* L.). *Journal of Plant Breeding and Crop Science*, *10*(6), 115-127.

Kearsey, M.J., Pooni, H.S. (1996). The genetical analysis of quantitative traits. *Genetical Research,68*(*2*),183.

Kenga, R., Alabi, S.O., &Gupta, S.C.(2004). Combining ability studies in tropical Sorghum [*Sorghum bicolor* (L.) Moench] *Field Crop Research,* 88, 251–260.

Kutka, F. (2011). Open-Pollinated vs. Hybrid Maize Cultivars. *Sustainability*, *3*,1531-1554

Li, Y., & Li, C. (1998). Genetic contribution of Chinese landraces to the development of sorghum hybrids. *Euphytica*, 102, 47-55.

Mang'eni, O. (2022). Historical analysis of declining maize production in Kenya; a case of Trans-Nzoia County.*Iconic Research and Engineering journals*, *5*(7), 2456-8880.

Marenya, P., Wanyama, R., Alemu, S., & Woyengo, V., (2022). Building resilient maize production systems with stress-adapted varieties: 'farmers' priorities in Western Kenya. *Frontiers in Sustainable Food Systems*, 6,702405.

Makanda, I., Tongoona, P., Derera, J., Sibiya, J., & Fato,P. (2010). Combining ability and cultivar superiority of sorghum germplasm for grain yield across tropical low- and mid-altitude environments. *Field Crops Research*, 116, 75-85.

Mbuvi, B., Mwimali, M., & Githiri, M. (2018).Estimation of general and specific combining ability of maize inbred lines using single-cross testers for earliness. *World Journal of Agricultural Research*, *6*(2), 37-48.

Mogesse, W., Zelleke, H., &Nigussie, M. (2020). General and specific combing ability of maize (*Zea mays* L.) inbred line for grain yield and yield related traits using 8×8 diallel crosses. *American Journal of Bio-Science*, *8*(3), 45-56.

Muinga, G., Marechera, G., Macharia, I., Mugo, S., Rotich, R., Oniang'o, R. K., Obunyali, C. O., & Oikeh, S. O. (2019). Adoption of climate-smart drought Tego® varieties in Kenya. *African Journal of Food, Agriculture and Nutrition Development,19(4),*15090-15108*.*

Murtadha, M. A., Ariyo, O. J. & Alghamdi, S. S. (2018). Analysis of combining ability over environments in diallel crosses of maize (*Zea mays* L.). *Journal of the Saudi Society of Agricultural Sciences*, *17*(1), 69-78.

Njoroge, K. (1982). Earliness and yield in maize: An evaluation of some Katumani maize varieties. *East African Agricultural and Forestry Journal*, *48*(1-4), 40-50.

Owusu, G. A., Ribeiro, P. F., & Abe, A. (2022).Genetic analysis of grain yield and agronomic traits of quality protein maize inbred lines and their single-cross hybrids under drought stress and well-watered conditions. *EcologicalGenetics and Genomics*, *22*, 2405-9854.

Patterson, H. D.,& Thompson, R. Ž. (1971). Recovery of interblock information when block sizes are unequal. *Biometrika*, 58, 545-554

Quandt, A. (2021). Coping with drought: Narratives from smallholder farmers in semi-arid Kenya. *International Journal of Disaster Risk Reduction*, *57*, 102168.

Raihani, H. Z., Sultana, S., & Hoque, M. (2019).Combining ability analysis for yield and yield contributing traits in maize (Zea mays L.). *Bangladesh Journal of Agriculture Research*, *44*(2), 253-259.

Rezende, W. S., Beyene, Y., Mugo, S., Ndou, E., Gowda, M., Sserumaga, J. P., Asea, G., Ngolinda, I., Jumbo, M., Oikeh, S. O., Olsen, M., Borém, A., Cruz, C. D., & Prasanna, B. M. (2020). Performance and yield stability of maize hybrids in stress-prone environmentsin eastern Africa. *Crop Journal*, *8*(1), 107–118.

Schroeder, C., Onyango, K., Nar Bahadur, R., Jick, N. A., Parzies, H.K., &Gemenet, D.C. (2013). Potentials of hybrid maize varieties for small-holder farmers in Kenya: A review based on SWOT analysis. *African Journal of Food, Agriculture, Nutrition and Development*, *13,*2.

Sheikh, F. A., Dar, Z. A., Sofi, P. A., &Ajaz, A. L. (2017). Recent advances in breeding for abiotic stress (drought) tolerance in maize. *International Journal of Current Microbiology and Applied Science*, *6*(4), 2226-2243.

Singh, R. K.,& Chaudhary, B. D. (1985). *Biometrical Methods in Quantitative Genetic Analyses.* Kalyani Ludhiana.

Tulu, D., Kumsa, T., Keimeso, Z., & Abakemal, D. (2022). Evaluation of promising highland maize genotypes in highland districts of western Shewa zone, Ethiopia.

East African Scholars Journal of Biotechnology and Genetics,4,2663-7286.

VSN International (2014). Genstat for Windows 21st Edition. VSN International, Hemel Hempstead, UK. Web page: Genstat.Co.UK

Wang, Y., Wang, R., LI, C., Zhang, C., Wang, Z., Kang, H., & Yang, Y.(2021). Correlation between ASI and

Yield and Drought Resistance of Maize inbred. *Agricultural Biotechnology*, *10*(1),15-18.

Zhang, Y., & Kang, M.S. (1997). DIALLEL-SAS: A SAS program for Griffing's diallel analyses. Agronomy Journal, 89,176-182.