

Original Research Article

Genetic variances, heritability and traits association of early maturing maize hybrids under induced drought ~~imposed~~ at seedling and flowering stages

ABSTRACT

Aims: Information on traits association and inheritance are crucial to designing appropriate breeding strategies for improving maize production and productivity in drought-prone ecologies. The objectives of this study were to investigate inter-trait relationships among maize hybrids and estimate genetic variances and heritability of drought tolerance parameters under seedling and flowering drought conditions.

Methodology: Sixty-six single cross hybrids generated using diallel mating design plus nine hybrid checks were evaluated using a 5 x 15 alpha lattice and randomized incomplete block designs in three replicates on the field and in the screenhouse respectively, during 2015 cropping season. Data were collected on grain yield, ears per plant, anthesis-silking interval, seedling aspect, chlorophyll content and leaf area and these data were subjected to analysis of variance as well as correlation and path coefficient analyses.

Results: Significant mean squares ($P = .05$) were observed for all measured traits except leaf area and shoot fresh weight. Narrow-sense heritability estimate for grain yield was moderate (33.4%) on the field and low (0 – 25%) for all the seedling traits. The low narrow-sense heritability estimates observed for most seedling traits implied that the scope for improvement of these traits in the genotypes is limited. Seedling traits under drought stress were not directly correlated with grain yield on the field except number of dead leaves relative to the total number of leaves. Results of the path analysis revealed that number of leaves, number of dead leaves and chlorophyll content under the screenhouse conditions had significant direct effects on grain yield on the field.

Conclusion: Number of leaves, and chlorophyll content under drought at seedling stage could therefore be used as indicator traits for grain yield improvement in maize exposed to drought stress at flowering stage.

Keywords: Drought, heritability, genetic variance, path analysis, maize hybrids, screenhouse conditions.

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37 **Introduction**

38 Maize is an important staple food, animal feed and industrial crop in sub-Saharan Africa
39 (SSA). The savannas of the sub region offer ideal environments for maize production because
40 they are characterized by high solar radiation, low night temperatures, low incidence of pests,
41 and diseases. Over 85% of the population of people in the rural areas in Africa grows maize
42 due to its suitability in diverse farming systems and its ability for increased yield under
43 improved management practices as compared to other cereal crops [1]. [Auta et al.](#) [2]
44 recommended that the development and accelerated deployment of maize hybrids would
45 increase maize yields in the major maize producing countries of West and Central Africa
46 (WCA). Studies have demonstrated that hybrids can increase farmers' maize yields by more
47 than 40% in favourable growing environments and by more than 30% even under stressful
48 conditions [3].

49 Drought is a major constraint in boosting maize production in Africa especially in the SSA,
50 coupled with other abiotic stresses it has resulted in maize displacement by high value crops
51 to marginal areas [4]. Drought exerts its effects on yield through its effects on physiological
52 processes, and through losses in plant stand when such stress occurs during emergence and at
53 the seedling stage. The extent of grain yield reduction in maize due to drought stress depends
54 on the stage of crop development at the time of the stress and its severity. However, the
55 flowering period in maize is the most sensitive to drought. The most economically feasible
56 and sustainable way to boost maize production and productivity in SSA is to develop drought
57 tolerant varieties for the farmers. Earlier studies conducted in the rainforest agro-climatic
58 zone showed that maize planted early significantly out-yielded those planted later in the
59 season primarily because grain filling coincided with the period of relatively high incident
60 solar radiation [5]. Maize plants with excellent adaptive response to drought at seedling stage
61 will help in combating the effect of early season drought in the rainforest agro-ecology of
62 southwestern Nigeria. Therefore, the evaluation of maize crop at the seedling stage is an
63 important aspect of crop breeding program with the objective to evolve drought tolerant
64 varieties. Developing specific maize genotypes which can tolerate drought at seedling stage,
65 especially in southwestern Nigeria where the rainfall pattern is bimodal, will offer the farmers
66 in this region the opportunity of planting maize earlier in the year (that is, late February to
67 early April), immediately after the first few rains and by extension West Africa. Therefore,
68 development of high yielding cultivars that combine tolerance to drought at both seedling and

69 flowering stages could be a coping strategy to combat detrimental effects of climate change
70 on maize production and productivity in the sub-region.

71 Grain yield is a complex trait and it is collectively influenced by various component traits,
72 besides being polygenically inherited and highly influenced by environmental variation. The
73 appropriate knowledge of interrelationships between grain yield and its contributing
74 components can significantly improve the efficiency of breeding programs using appropriate
75 selection indices [6]. In making selection for improved genotypes in maize, yield is the
76 primary trait but selection under drought based on grain yield alone is inefficient due to low
77 heritability of grain yield and the complexity of genotype-environment interactions [7].
78 Genetic variance and heritability of maize grain yield are reduced under drought whereas
79 secondary traits have relatively high genetic variance and heritability [8,9]. However, the
80 relative usefulness of secondary traits as indirect selection criteria for grain yield is often
81 inconclusive for all experiments because of the nature of the genetic materials and different
82 conditions of experiments [10]. In the past years, the use of secondary traits with grain yield
83 in making selection has increased selection breeding efficiency in maize grown under stress
84 conditions by 20 to 50% [11,12]. [Badu-Apraku et al.](#) [13] reported that the most reliable traits
85 for selection for improved grain yield under drought stress in the early maturing germplasm
86 were ear aspect, ears per plant, anthesis-silking interval, and plant aspect. There is dearth of
87 information on reliable seedling drought traits for predicting improved grain yield under
88 flowering drought conditions.

89 The determination of correlation coefficients helps to measure the level of relationships
90 among traits and to establish the level at which these traits are mutually different [14]. Path
91 coefficient analysis helps to know the nature, extent and direction of selection; it is the most
92 valuable tool commonly used to establish the exact relationships in terms of cause and effect,
93 identifying the direct, indirect and total (direct plus indirect) causal effects, as well as to
94 remove any spurious effect that may be present [15]. Studies had reported that tolerance to
95 drought stress at seedling stage and at flowering stage has no relationship, using correlation
96 analysis [16]. However, correlation analysis, being a bivariate analysis only detect linear
97 relationships between two variables while it assumes no significant influence of
98 interrelationship of other variables. Therefore, the use of multivariate techniques such as path
99 coefficient analysis, which considers the effect of several independent traits on a target
100 (dependent) trait by partitioning the total correlation into direct and indirect effects (effects
101 exerted through other independent variables) is necessary. In such analysis, traits with

102 significant direct effect on a target trait are identified while those with indirect effect through
103 other traits are also detected. Information obtained from such analysis is more important than
104 mere correlation and would not only help in identifying important secondary traits that could
105 be used as indirect selection criteria for improving maize genotypes for a desired trait, but
106 will provide adequate information useful to formulate base index which will in turn improve
107 the efficiency of selection for the target trait.

108 The primary objectives of this present study were to (i) estimate genetic variance and
109 heritability of [traits for](#) drought tolerance ~~traits~~ at seedling and flowering stages of maize
110 hybrids; and (ii) investigate the inter-trait relationships under seedling and flowering drought
111 stress conditions, using simple correlations and path co-efficient analyses.

112

113 **Materials and Methods**

114 **Generation of crosses**

115 Twelve inbred lines were planted in breeding nursery in a single-row plot, 5 m long at a
116 spacing of 0.75_m x 0.25_m. Standard agronomic practices were employed to ensure good
117 crop stand. At flowering, the twelve inbred parents were crossed in a diallel fashion to
118 generate 66 single-cross hybrids. The different crosses were harvested separately, processed
119 and packaged into trials for evaluation.

120

121 **Field performance evaluation**

122 Drought stress at flowering stage was achieved in the field. The experiment was conducted at
123 the Crop Science Unit of the Teaching and Research Farm, Obafemi Awolowo University, Ile
124 Ife ($7^{\circ}28'N$ $4^{\circ}33'E$, 244_m, 1200 mm rainfall) during the 2015 cropping season. The planting
125 was done on the 21st September, such that flowering could coincide with a period of no
126 rainfall (drought). A trial composed of the sixty-six (66) single cross hybrids plus nine checks
127 was laid out using a 5 x 15 alpha lattice design with three replications. Each entry was
128 planted into a single-row plot, 5 m long with 0.75 m spacing between rows and 0.50 m
129 spacing between plants within a row. Three seeds were sown per hole and later thinned to
130 two plants per hill to attain a population density of 53,333 plants ha⁻¹. A compound fertilizer
131 of NPK 15:15:15 was applied at the rates of 60 kgN, 60 kgP and 60 kg K₂O ha⁻¹ at two weeks
132 after planting. An additional 60 kgN ha⁻¹ was also applied as side dressing at four weeks after
133 planting (WAP) using urea (46% N). On each plot on the field, data were collected on days to

134 anthesis, days to silking, number of ears per plant (EPP), plant and ear heights. Plant aspect
135 was rated on a scale of 1 to 9, where 1 = excellent overall phenotypic appeal and 9 = poor
136 overall phenotypic appeal. Ear aspect was scored on a scale of 1 to 9, where 1 = clean,
137 uniform and large ears and 9 = rotten, variable and small ears. Stay-green characteristic (leaf
138 death score) was scored per plot at 70 days after planting, on a scale of 1 to 9, where 1 =
139 almost all leaves green and 9 = virtually all leaves dead. Harvested ears from each plot were
140 shelled to determine the percentage grain moisture. Grain yield in kg ha^{-1} was adjusted to
141 15% moisture content and computed from the shelled grain weight.

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143 **Screenhouse evaluation**

144 Drought stress at seedling stage was imposed in the screenhouse. The sixty-six single-cross
145 hybrids plus nine hybrid checks were planted under drought stress imposed at the seedling
146 stage at the screen house, Department of Crop Production and Protection, Obafemi Awolowo
147 University, Ile Ife in 2015. The trial was laid out in a randomized incomplete block design
148 with three replications. Six seeds of each inbred were sown per pot. The methodology
149 proposed by Akinwale [17] for screening maize genotypes for tolerance to drought at
150 seedling stage was adopted, water was applied to each pot at the rate of 0.6 litres daily for 7
151 days, after which watering stopped. Data were collected at two-day intervals from 3 days
152 after watering had stopped (DAWS) till 9 DAWS on the following: plant height, number of
153 leaves, number of dead leaves, leaf length and breadth, leaf area, and number of dead leaves
154 relative to the total number of leaves (RDL) in percentage. In addition, seedling aspect was
155 scored on a scale of 1 to 9, where 1 = absence of visible symptoms of stress: vigorous plants,
156 no wilting, no dead leaves, no chlorosis, no height reduction and unrolled turgid leaves and 9
157 = total collapse or 100% death of seedlings, dried leaves and stem, as described by Akinwale
158 [17].

159

160 **Data analysis**

161 Data collected were subjected to analysis of variance using PROC general linear model
162 (GLM) procedure of Statistical Analysis Software (SAS), version 9.2 [18]. In the analysis,
163 genotype was considered as a random factor and to achieve that, random statement option in
164 GLM was used. Genetic variances were estimated using Proc Varcomp procedure of SAS.
165 Estimate of narrow-sense heritability was performed as the proportion of additive variance
166 over phenotypic variance expressed in percentage and this was done on plot mean basis for

167 all traits under the two study conditions. In addition, path coefficient analysis was carried out
168 to partition total correlation among traits into direct and indirect effects considering grain
169 yield as the dependent variable. Pearson correlation (phenotypic correlation) was first
170 calculated and then the correlation coefficients were partitioned into direct and indirect
171 effects through path coefficient analysis using PATHSAS program developed by [Cramer et](#)
172 [al.](#) [19].
173

174 Results and Discussion

175 Results of analysis of variance (ANOVA) showed significant ($P = .05$) differences among the
176 genotypes for all seedling traits evaluated in the screenhouse except leaf area and fresh shoot
177 weight (Table 1). Similarly, significant ($P = .05$) effects were observed for genotype for all
178 measured traits under stress conditions on the field (Table 2). The significant mean squares
179 observed among the genotypes under the different stress conditions indicated presence of
180 ~~wide~~ genetic variability within the genetic materials, which implies that ~~a good genetic~~
181 progress ~~could be achieved~~ from selection for improvement for drought tolerance at both
182 growth stages. ~~could be achieved.~~

183 The additive variance measures the variation due to the average effects of alleles (additive
184 effects, ~~same locus~~) and the variation in the effects that are transmitted from one generation
185 to another while the dominance variance is the variance due to interaction of average effects
186 of alleles (dominance effects, ~~same locus~~) [20]. The dominance variance is a function of
187 allele frequencies and the level of dominance. In our present study, the additive variance was
188 greater than non-additive (dominance) variance for all traits except number of ears per plant
189 under the flowering drought conditions (Table 3). In contrast, the dominance variance was
190 greater than the additive variance for all traits under the seedling drought conditions, which
191 implied ~~that the dominance component is more important than the additive components for~~
192 ~~these traits~~ tolerance to drought involves different genes or combinations of genes depending
193 of the stage at which happens in the crop cycle. Estimates of additive genetic variance were
194 significantly different from zero for all traits under field drought conditions and for all traits
195 under the screenhouse conditions except seedling aspect, dry shoot weight and fresh shoot
196 weight. Dominance variances were significantly different from zero for all measured traits
197 except seedling fresh shoot weight. Due to negative estimates, additive variance of dry shoot
198 weight and dominance variance of fresh shoot weight were equated to zero. Thus, their
199 dominance to additive genetic variance ratio could not be estimated. The dominance to

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200 additive genetic variance ratios were greater than 0.5 for four out of the eight traits under
201 drought at the flowering stage and for seven out of the nine traits under seedling drought
202 conditions.
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204 Table 1: Mean squares of seedling aspects and other seedling traits of 66 hybrids plus 9 checks evaluated under induced drought at seedling stage at the
 205 screen house, 2015-

SV	Df	Seedling aspect score	Chlorophyll content ($\mu\text{mol L}^{-1}$)	Plant height _r (cm)	Leaf area, (cm^2)	Number of dead leaves	Number of leaves	RDL	Fresh shoot weight _r (g)	Dry shoot weight _r (g)
Rep	2	12.20**	25.39	102.09**	90.15	5.32	39.66	854.30	9.07**	0.16*
Entry	74	1.83*	55.62**	29.04*	94.20	10.00**	55.56**	717.58**	0.26	0.05**
Error	148	1.27	16.39	19.34	79.73	3.17	35.91	416.36	0.26	0.03
R^2		0.46	0.63	0.45	0.37	0.62	0.44	0.47	0.49	0.53
C-V		20.65	11.95	18.61	40.84	37.11	30.95	41.90	50.95	41.68

206 *, ** Significant at 0.05 probability level, ** significant at 0.01 probability levels respectively.

207 RDL = number of dead leaves relative to the total number of leaves.

208 Table 2: Mean squares for grain yield and other agronomic traits of 66 hybrids plus 9 hybrid checks evaluated under drought at flowering stage, at the
 209 Teaching and Research Farm Obafemi Awolowo University, Ile Ife, 2015-

Source of variation	Df	Grain yield	Ears per plant	Plant aspect	Ear Aspect	Anthesis - silking interval	Plant height	Ear height	Stay green characteristics
Block (Replicate)	12	652613.3**	0.16**	6.91**	5.64**	9.55**	1223.52**	388.68**	3.99**
Replicate	2	977096.1**	0.47**	9.76**	21.63**	9.75**	2628.29**	882.79**	13.26**
Genotype	74	318140.3**	0.112**	2.24**	2.73**	4.69**	455.57**	162.38**	2.17**

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Comment [O2]: What was interpretation made of R^2 ? To be taken out if it is not informative.

Comment [O3]: What is the information provided by the coefficient of variation? To be taken out if it is not informative.

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Error	136	120633.0	0.06	0.77	1.59	1.65	124.48	50.26	0.93	210
R ²		0.68	0.62	0.75	0.63	0.71	0.79	0.75	0.68	
CV		27.26	33.22	15.35	16.7	31.69	11.35	16.35	16.3	

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Comment [O4]: What interpretations were made of R² and CV values? Should be taken out if they are not necessary.

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*, ** Significant at 0.05 probability level, ** significant at 0.01 probability levels respectively; NS= not significant

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221 Table 3: Additive ($\hat{\sigma}_A^2$) and non-additive ($\hat{\sigma}_{NA}^2$) variances, narrow-sense heritability estimates (h^2),
 222 for grain yield and other agronomic traits of hybrids generated from diallel crosses evaluated under
 223 terminal drought in the field and under imposed drought in the screen house-

Traits	$\hat{\sigma}_A^2 \pm SE$	$\hat{\sigma}_{NA}^2 \pm SE$	$\hat{\sigma}_{NA}^2 / \hat{\sigma}_A^2$	h^2 (%)
Flowering drought environment				
Grain yield, <u>kg/ha</u>	40465.76±3512.730	36639.40±2026.930	0.91	33.4
Ears per plant	0.02±0.001	0.02±0.001	1.00	7.3
Plant aspect	0.35±0.030	0.22±0.020	0.63	35.7
Ear aspect	0.53±0.040	0.06±0.020	0.11	46.0
Anthesis-silking interval	0.90±0.070	0.37±0.030	0.41	45.0
Plant height, <u>cm</u>	99.55±7.380	30.60±2.590	0.31	49.9
Ear height, <u>cm</u>	17.70±1.590	13.58±1.010	0.77	31.1
Stay green characteristic	0.436±0.030	0.20±0.020	0.45	44.0
Seedling drought environment				
Seedling aspect	0.002±0.010	0.140±0.015	61.670	0.390
Chlorophyll content, <u>µmol L⁻¹</u>	3.154±0.390	15.270±0.360	4.840	17.000
Plant height	2.000±0.240	2.080±0.230	1.040	18.700
Leaf area	1.520±0.540	4.970±0.910	3.270	4.300
Number of dead leaves	0.412±0.070	2.080±0.060	5.060	11.600
Number of leaves	6.870±0.690	12.200±0.500	1.770	25.000
RDL	5.320±1.190	30.060±1.630	5.650	7.600
Fresh weight, <u>kg</u>	0.001±0.001	0±0.003	0	0.380
Dry weight, <u>kg</u>	0±0.0002	0.011±0.001	0	0.0

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235 Narrow-sense heritability estimate for grain yield was moderate (33.4%). The values of
236 narrow-sense heritability for the traits ranged from 7.3% for ears per plant to 50% for plant
237 height under drought at flowering and 0.38% for fresh weight to 25% for number of leaves
238 under seedling drought conditions. Heritability estimates provide information on how
239 ~~efficient~~ ~~probable~~ a trait could be transmitted from parents to their offspring [20]. Low
240 narrow-sense heritability estimate observed for most measured traits, especially under
241 drought at seedling stage is an indication that the scope for improvement of these traits in the
242 parents is limited. However, introgression of genes for tolerance to seedling drought stress
243 into the genotypes under study could guarantee continued progress from selection for
244 improved grain yield and seedling traits under drought stress conditions. In addition, it might
245 be desirable to increase the number of replications and locations to increase the accuracy of
246 estimated entry means, and thus the heritability.

Comment [O5]: The section does not make sense in Genetics. How do you expect to introgress the genes of tolerance to drought. It is not the purpose of the study. Suggested to be taken out.

247 Adequate knowledge on the inter-relationship among traits is important in designing effective
248 selection programs for crop improvement. Results showed that seedling traits were not
249 directly correlated with grain yield except number of dead leaves relative to the total number
250 of leaves which displayed significant negative relationship (Table 4). Ears per plant showed
251 significant negative relationship with number of dead leaves and number of dead leaves
252 relative to the total number of leaves. This implied that a hybrid with high number of dead
253 leaves under drought at seedling stage will possibly give lower number of ears harvested per
254 plot under drought conditions at flowering. Plant aspect had significant negative relationship
255 with leaf area, number of leaves, shoot fresh weight and shoot dry weight. This suggests that
256 maize hybrids under drought stress at seedling stage with high number of leaves, leaf area,
257 shoot fresh weight and shoot dry weight would give rise to plants with excellent physical
258 appearance under the same condition at flowering stage. In addition, stay green characteristic
259 showed significant positive relationship with number of dead leaves and number of dead
260 leaves relative to the total number of leaves. Though some of the seedling drought traits were
261 found to be significantly correlated with traits taken on the field under flowering drought
262 conditions, the strength of the relationships was generally low. The highest value of r (0.30)
263 was obtained between number of dead leaves at seedling and stay-green characteristics at
264 flowering. Therefore, the results of this study showed that seedling drought tolerance traits
265 cannot be used as the main criteria for predicting grain yield in the hybrids under flowering
266 drought conditions. This corroborates the findings from the study of Meeks et al. [16] who
267 reported that the seedling drought conditions were independent of drought responses at

Comment [O6]: It should be noted that the existence of a correlation obtained by an analysis doesn't always translate to a reality. Having some dead leaves doesn't predict that the crop would not recover fast, produce more leaves later for increased grain yield. Cassava adapts to drought by losing its leaves.

Comment [O7]: This correlation coefficient is too weak to be considered as physiologically binding.

268 flowering on the field, possibly due to the type of screening environments used and the high
269 genetic diversity that segregated for traits conditioning drought tolerance. Even though low
270 values of correlation coefficients (r) were obtained, r measures only linear relationship, which
271 path analysis helps to decompose among the studied characters, thereby enhancing better
272 interpretation of relationships as well as pattern of the effects of one trait on the other.

273 An important objective of this study was to identify seedling drought traits with greatest
274 influence on grain yield for use in future breeding programs. Thus, the correlation
275 coefficients of the seedling drought traits with grain yield were further partitioned into direct
276 and indirect effects through path analysis (Table 5). The low residual effect (0.25) indicates
277 that the seedling traits altogether contributed substantially to grain yield. Among the seedling
278 traits, path analysis identified number of leaves (0.2949), and number of dead leaves (-0.242),
279 chlorophyll content (0.0524) as traits with significant direct contributions to grain yield,
280 whereas number of leaves had the highest direct effect. This result was not surprising since
281 leaf synthesizes the photosynthates, which are stored in plant tissues and culminate in yield
282 for the crop. Number of leaves was related to the number of photosynthetic components such
283 as chloroplasts and therefore an increase in the number of leaves improves photosynthetic
284 capacity. Path coefficient analysis showed that number of seedling leaves was the most
285 important trait for grain yield improvement through its direct and indirect effects on grain
286 yield. Number of leaves, relative number of dead leaves to the total number of leaves are
287 contributing indirectly to the number of dead leaves. For number of leaves, number of dead
288 leaves recorded the highest indirect effect. Under seedling drought conditions, in our study,
289 number of leaves, chlorophyll content and leaf area were identified as the most important
290 traits contributing to the variation in grain yield, suggesting that they are reliable secondary
291 traits under drought stress conditions. In addition, these traits can be used as criteria for
292 selecting for drought-tolerant genotypes under seedling stress conditions in early maturing
293 maize hybrids. Under the field conditions, the path analysis identified ear aspect (-0.48), ears
294 per plant (0.331), ear height (0.283), plant height (-0.255) and plant aspect (-0.219) as traits
295 with the highest direct effect on grain yield on grain yield (Table not shown). These results
296 are similar with those of [9], who identified plant and ear aspects and plant and ear heights as
297 the most reliable traits for the simultaneous selection in the extra-early inbreds for improved
298 yield under low-N and drought stress environments.

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301 Table 4: Pearson correlation of traits evaluated under drought induced at the seedling at the screenhouse, Faculty of Agriculture and under drought at
 302 flowering stage at the Teaching and Research Farm, Obafemi Awolowo University, Ile Ife, 2015.

		Traits under drought at flowering stage							
		Anthesis- silking interval	Ears per plant	Plant height, cm	Ear height, cm	Plant aspect	Stay green characteristics	Ear aspect	Grain yield, kg/ha
Traits under drought at seedling	Number of dead leaves	0.15*	-0.15*	0.07	0.03	0.01	0.30**	0.17**	-0.07
	Leaf area, cm ²	0.02	0.08	0.06	0.02	-0.14*	-0.08	-0.02	-0.02
	RDL	0.14*	-0.18**	-0.03	-0.06	0.11	0.28**	0.24**	-0.14*
	Number of leaves	0.06	-0.11	0.11	0.10	-0.18**	0.09	0.05	0.12
	Seedling aspect	0.02	-0.13	-0.03	-0.05	0.12	0.13	0.07	-0.02
	Chlorophyll content	0.06	0.07	-0.09	-0.03	0.08	0.05	-0.03	0.09
	Shoot fresh weight, cm	-0.03	0.03	0.10	0.08	-0.20**	-0.12	-0.09	0.04
	Shoot dry weight, cm	-0.09	0.09	0.17**	0.16**	-0.22**	-0.10	-0.11	0.06

303 *, ** Significant at 0.05, 0.01 probability levels, respectively

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309 | Table 5: Estimates of direct (diagonal values in bold) and indirect (off-diagonal values) effects [based on path analysis](#) of yield attributing characters on grain
 310 | yield, evaluated under drought induced at the seedling stage in the screenhouse, and under drought that coincided with flowering stage.

	Seedling height	Number of dead leaves	Leaf area	RDL	Number of leaves	Seedling aspect	Chlorophyll content	Shoot fresh weight	Shoot dry weight
Seedling height	-0.051	-0.055	0.003	0.001	0.108	-0.002	-0.005	-0.006	-0.018
Number of dead leaves	-0.011	-0.242	0.001	0.149	0.169	0.003	0.001	0.006	-0.002
Leaf area	-0.021	-0.023	0.008	-0.007	0.069	-0.001	-0.009	-0.005	-0.020
RDL	0.000	-0.183	-0.003	0.196	0.035	0.003	-0.001	0.005	0.005
Number of leaves	-0.019	-0.139	0.002	0.023	0.294	0.001	-0.001	-0.001	-0.013
Seedling aspect	0.012	-0.109	-0.001	0.086	0.055	0.007	0.006	0.013	0.019
Chlorophyll content	0.005	-0.003	-0.001	0.001	-0.007	0.001	0.052	0.002	0.008
Shoot fresh weight	-0.013	0.068	0.002	-0.047	0.008	-0.004	-0.004	-0.022	-0.034
Shoot dry weight	-0.013	-0.007	0.002	-0.014	0.052	-0.002	-0.006	-0.011	0.073

311 | Residual effect = 0.2517

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312 **Conclusion**

313 There was narrow genetic base for seedling drought tolerance traits in the early-maturing
314 maize germplasm studied and this might limit the scope of improvement of the traits under
315 drought stress. In addition, low additive variances and heritability estimates were obtained
316 for most traits. Number of leaves and number of dead leaves under seedling drought stress
317 had the highest direct effects on grain yield under field conditions, indicating that these
318 seedling traits are reliable predictors of grain yield of early maize hybrids.

Comment [O8]: From the "wide genetic variability" in the section *Results and discussion*; line 180, to "narrow genetic base" in the section *Conclusion*. What went wrong?

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320 **References**

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