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Selection of Maize Hybrids Resulting from Line × Tester Crossing Tolerant to Drought Stress

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Efforts to enhance maize productivity in regions like Madura Island, Indonesia, plagued by low yields due to drought stress, necessitate the development of resilient and high-yielding maize hybrids. Employing the line x tester method represents a promising approach to breed varieties tolerant to drought stress. This study aims to identify drought-tolerant maize hybrids derived from line x tester crosses. The research utilized a Randomized Complete Block Design (RCBD) with 40 genotypes replicated three times, totaling 120 experimental units. Drought stress was imposed following the CIMMYT method, wherein irrigation was provided at field capacity from 0 to 40 days after planting (DAP) at 10-day intervals, while drought stress commenced from 50 DAP until harvest. Under optimal conditions, irrigation occurred every 10 days until 80 DAP. Key observation parameters included plant height, days to 50% tasselling, harvest age, ear height, ear length, ear diameter, kernel weight per plant, 1000-kernel weight, and production per hectare. Results indicated several adaptive hybrid maize genotypes for both normal and drought conditions, as discerned by the Stress Tolerance Index (STI), including G2, G12, G13, G14, and G15. Moreover, hybrids G2, G18, G19, G21, and G24 exhibited notable drought tolerance based on the Stress Susceptibility Index (SSI). These findings underscore the potential of employing the line x tester method in breeding resilient maize hybrids tailored to mitigate the adverse impacts of drought stress, thereby fostering agricultural sustainability in resource-constrained environments like Madura Island.

Keywords: Drought stress, line x tester crossing, maize hybrid, selection, stress tolerance index, Maize hybrids, drought tolerance, Line x tester method, CIMMYT method, Madura Island, crop productivity, breeding strategies.

INTRODUCTION

Developing maize varieties with high production and tolerance to drought stress characteristics is one solution to solve the problem of low maize production in Indonesia, especially on Madura Island. Maize productivity in Indonesia (5.72 tons ha^{-1}) is below the world average productivity (5.88 tons ha^{-1}) (FAO, 2021). One of the areas causing low maize productivity in Indonesia is Madura Island. Madura Island has a maize productivity of 2.7 tons ha^{-1} (BPS-Statis,tics Indonesia, 2019), where this productivity is below the national average productivity (5.86 tons ha^{-1}) (Astuti *et al*., 2020). The cause of low maize productivity in Madura is the use of local varieties with low production potential and the dominance of dry land in Madura Island. Research results (Amzeri *et al*., 2022) show that the average productivity of local Madura maize ranges from 1212 – 3468 tons ha^{-1}. Furthermore, research results (Suhartono *et al*., 2020) show that the average annual rainfall in the Madura area was 1346.89 mm/year. Dry land is characterized by an average annual rainfall of less than 2000 mm/year and a short rainy period (3-5 months) (Mulyani and Sarwani, 2013). The development of superior maize varieties with high production and tolerance to drought stress characteristics through the hybridization method is a strategic step to solve the problem of low maize production on Madura Island.

The line x tester hybridization method is often used to determine the combining ability of inbred lines, hybrid, and synthetic varieties being tested because this method is simpler to implement (Aldulaimy and Hammadi, 2021; Subba *et al*., 2022; Abdel-Aty *et al*., 2023). The results of hybridization between the parents need to be tested for their tolerance to drought stress to determine their ability to combine with drought stress. In drought conditions, genes that control quantitative characters react to water shortage conditions due to environmental influences (Lanceras *et al*., 2004; Bhandari

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et al., 2023). Selection in the target environment can maximize the expression of genes that control the adaptability and yield of plants under environmental stress conditions (Ahanger et al., 2017; Zhang et al., 2020). Plants that have a tolerance to drought stress will be able to produce well under drought-stress conditions. Estimation of drought tolerance traits was carried out based on yield losses under normal conditions and drought stress (Nandhini et al., 2022; Li et al., 2023). Genotype selection in drought-stress environments aims to increase plant productivity and protect against loss of yield due to drought stress (Guizani et al., 2023).

Determining the level of tolerance of maize plants to environmental stress can be determined by calculating the tolerance index value. The drought stress tolerance index value is calculated based on crop yield loss under drought conditions compared to normal conditions (Selamawit et al., 2021). The tolerance index value for drought stress can be used to select drought-tolerant genotypes. The tolerance index value of plants to environmental stress has several criteria so all the tolerance value calculation criteria need to be studied to determine the appropriate tolerance value criteria to use. Several criteria proposed by several researchers to determine the tolerance index value are stress tolerance (TOL) (Shahrokhi et al., 2020), Mean Productivity (MP) (Shahrokhi et al., 2020), harmonic mean (HM) (Bidinger et al., 1987), Stress Susceptibility Index (SSI) (Shahrokhi et al., 2020), Geometric Mean Productivity (GMP) (Fernandez et al., 1992), stress tolerance index (STI) (Fernandez et al., 1992), Yield Indeks (YI) (Gavuzzi et al., 1997), Yield Stability Index (YSI) (Khayatnezhad et al., 2010), modified stress tolerance index (MSTI) (Farshadfar and Sutka, 2002). The response shown by hybrid maize genotypes to drought conditions is divided into two categories, namely adaptive genotypes and tolerant genotypes. Selection of adaptive genotypes is carried out using the STI index while tolerant genotypes use the SSI index. The research aimed to select maize hybrids resulting from line x tester crosses against drought stress.

MATERIALS AND METHODS

***Plant Materials and Research Implementation*:** The research was carried out in May-August 2023 in Pamekasan Regency, Madura (altitude: 7 m asl, temperature: 25-33 ^{O}C, soil type: alluvial). The genetic material used was 40 hybrids resulting from crossing 20 lines with the UTM08.5 and UTM09.6 testers (Table 1). Each genotype was planted in a 1 x 5m plot with a spacing of 70 x 20 cm. Drought stress research follows the CIMMYT method (Weber et al., 2012), namely, drought stress takes place when the plants are 50 days after planting (DAP) until harvest but provides irrigation with field capacity from 0 to 40 DAP with intervals of every 10 days. Under optimum conditions, irrigation is carried out at intervals of once every 10 days by providing water up to field capacity from plants aged 0 DAP to plants aged 80 DAP. Fertilization is carried out in three stages, namely when the plants are 7 DAP (200 kg ha^{-1} SP-36, 100 kg ha^{-1} Urea and 50 kg ha^{-1} KCl), 25 HST (100 kg ha^{-1} Urea and 50 kg ha^{-1} KCl, and 40 HST (100 kg ha^{-1} Urea and 50 kg ha^{-1} KCl).

***Data collection and analysis*:** Observations were made on 20 sample plants in each experimental unit. The characteristics observed were plant height, days to 50% tasselling, harvest age, ear height, ear length, ear diameter, kernel weight per plant, 1000-kernel weight, and production per hectare. Harvesting of maize plants is carried out when the maize cobs are physiologically mature, which is characterized by the husks being dry or brownish in color, the seeds have hardened

Table 1. 40 maize hybrids used in the research.

No.	Genotype	Crossing	No.	Genotype	Crossing
1	G1	TS-5-20 x UTM08.5	21	G21	TS-5-20 x UTM09.6
2	G2	T2S-5-11 x UTM08.5	22	G22	T2S-5-11 x UTM09.6
3	G3	DuS-5-24 x UTM08.5	23	G23	DuS-5-24 x UTM09.6
4	G4	ES-5-24 x UTM08.5	24	G24	ES-5-24 x UTM09.6
5	G5	MS-5-06 x UTM08.5	25	G25	MS-5-06 x UTM09.6
6	G6	CS-5-43 x UTM08.5	26	G26	CS-5-43 x UTM09.6
7	G7	DS-5-3-1 x UTM08.5	27	G27	DS-5-3-1 x UTM09.6
8	G8	GS-4-2-1 x UTM08.5	28	G28	GS-4-2-1 x UTM09.6
9	G9	An-S-4-1-5 x UTM08.5	29	G29	An-S-4-1-5 x UTM09.6
10	G10	La-S-4-2-4 x UTM08.5	30	G30	La-S-4-2-4 x UTM089.6
11	G11	Bi-S-4-1-10 x UTM08.5	31	G31	Bi-S-4-1-10 x UTM09.6
12	G12	Su-S-4-2-4 x UTM 08.5	32	G32	Su-S-4-2-4 x UTM 09.6
13	G13	Su-S-4-1-12 x UTM08.5	33	G33	Su-S-4-1-12 x UTM09.6
14	G14	Su-S-4-1-15 x UTM08.5	34	G34	Su-S-4-1-15 x UTM09.6
15	G15	Su-S-4-3-16 x UTM08.5	35	G35	Su-S-4-3-16 x UTM09.6
16	G16	Lm-S-4-2-12 X UTM08.5	36	G36	Lm-S-4-2-12 x UTM09.6
17	G17	Lm-S-4-2-2 x UTM08.5	37	G37	Lm-S-4-2-2 x UTM09.6
18	G18	Ba-S-4-3-1 x UTM08.5	38	G38	Ba-S-4-3-1 x UTM09.6
19	G19	Ba-S-4-2-2 x UTM08.5	39	G39	Ba-S-4-2-2 x UTM09.6
20	G20	Pl-S-5-2 x UTM08.5	40	G40	Pl-S-5-2 x UTM09.6

and formed a black layer of at least 50% in each row of seeds. At that time, the moisture content of the seeds usually reaches less than 30%. Observations of maize grain yield were carried out on all plant samples for each experimental unit and converted into maize grain yield per hectare at a water content of 15% using the following formula:

$$Y = \frac{10.000}{HA} \times \frac{100 - MC}{100 - 15} \times GW$$

Where Y is grain yield (kg ha^{-1}), HA is harvested area per plot (m^2), MC is moisture content at harvest time (%) and GW is harvested grain weight per plot (kg).

The calculation of the stress selection index follows the following equation:

1. Tolerance index (TOL) (Shahrokhi *et al.*, 2020): TOL = Yp – Ys
2. Mean Productivity (MP) (Shahrokhi *et al.*, 2020): $MP = \frac{Yp+Ys}{2}$
3. Harmonic Mean (HM) (Bidinger *et al.*, 1987): $HM = \frac{2(Yp+Ys)}{(Yp+Ys)}$
4. Stress Susceptibility Index (SSI) (Shahrokhi *et al.*, 2020): $SSI = \frac{1-(\frac{Ys}{Yp})}{1-(\frac{\bar{Y}s}{\bar{Y}p})}$
5. Geometric Mean Productivity (GMP) (Fernandez *et al.*, 1992): GMP = $(Yp \times Ys)^{1/2}$
6. Stress Tolerance Index (STI) (Fernandez *et al.*, 1992) $STI = \frac{Yp \times Ys}{(\bar{Y}p)^2}$
7. Yield Index (YI) (Gavuzzi *et al.*, 1997): $YI = \frac{Ys}{\bar{Y}s}$
8. Yield Stability Index (YSI) (Khayatnezhad *et al.*, 2010): $YI = \frac{Ys}{Ys}$
9. Modified Stress Tolerance Index (MSTI) (Farshadfar and Sutka, 2002):
10. MSTI = KiSTI, dimana K1 = $Yp^2/\bar{Y}p^2$, dan K2 = $Ys^2/\bar{Y}s^2$,

Note: Yp = productivity resulting from normal conditions; Ys = productivity resulting from drought conditions; $\hat{Y}p$ = average productivity of all genotypes under normal conditions; $\hat{Y}s$ = average productivity of all genotypes under drought conditions; ki = correction coefficient.

Multiple regression model testing is carried out stepwise, which means that model testing is carried out in stages. Stepwise testing is carried out to obtain the best model to explain the dependent variable based on a series of independent variables. Stepwise regression analysis was performed using STAR software version 2.0.1 (IRRI, 2013). Creation of 3D plot 40 for grouping maize hybrids based on drought tolerance using RStudio version 3.0.1 software (Wickham, 2016)

RESULTS AND DISCUSSION

Selection of Tolerance Index and Modeling of Drought Stress Tolerance Index**:** The tolerance index aims to select genotypes based on plant productivity levels under normal and stress conditions. Several tolerance index calculations proposed by several researchers need to be selected to obtain a genotype that meets the desired criteria. Determining the correct drought tolerance index can be done by calculating the close relationship between the tolerance indices (Selamawit *et al.*, 2021). The significant and high correlation coefficient values for productivity under drought stress conditions (Ys) and the percentage of yield reduction (Yr) indicate that the tolerance index can be used as a reference to determine the ability of genotypes to maintain productivity under drought stress conditions. The results of the correlation analysis between the stress tolerance indices show that the correlation coefficient values are real and high for HM and MP, GMP and MP, HM and GMP, HM and STI, HM and YI, and STI and

Table 2. Correlation between yield productivity under normal conditions (Yp), yield productivity under drought conditions (Ys), percentage reduction in yield productivity (Yr), and stress tolerance index in hybrid maize genotypes.

	Yp	Ys	Yr	TOL	MP	HM	SSI	GMP	STI	YI	YSI	K1STI	K2STI
Yp	1.00												
Ys	0.83**	1.00											
Yr	-0.46**	-0.87**	1.00										
TOL	0.12	-0.45**	0.82**	1.00									
MP	0.95**	0.96**	-0.70**	-0.19	1.00								
HM	0.90**	0.99**	-0.80**	-0.33	0.99**	1.00							
SSI	-0.46	-0.87**	0.99**	0.81**	-0.70**	-0.80**	1.00						
GMP	0.92**	0.98**	-0.76**	-0.27	0.99**	0.99**	-0.76**	1.00					
STI	0.89**	0.98**	-0.76**	-0.31	0.98**	0.99**	-0.76**	0.99**	1.00				
YI	0.83**	0.99**	-0.87**	-0.46**	0.96**	0.99**	-0.87**	0.98**	0.98**	1.00			
YSI	0.46**	0.87**	-1.00**	-0.82**	0.70**	0.80**	0.99**	0.76**	0.76**	0.87**	1.00		
K1STI	0.99**	0.84**	-0.47**	0.08	0.95**	0.90**	-0.47**	0.93**	0.92**	0.84**	0.47**	1.00	
K2STI	0.81**	0.99**	-0.85**	-0.47	0.94**	0.98**	-0.85**	0.97**	0.98**	0.99**	0.85**	0.83**	1.00

Note: * = significantly correlated at α 5%, ** = significantly correlated at α 1%, TOL = tolerance index, MP = mean productivity, HM = harmonic mean, SSI = stress susceptibility index, GMP = geometric mean productivity, STI = stress tolerance index, YI = yield index, YSI = yield stability index, k1STI dan k2STI = modified stress tolerance index

GMP each at 0.99 (Table 2). This value shows that these indices have the same function and purpose in determining the level of tolerance of genotypes to drought, so they need to be selected.

Determining the criteria for genotypic tolerance to drought stress can be determined based on the correlation coefficient value between productivity under normal conditions (Yp), yield productivity under drought conditions (Ys), the percentage reduction in yield productivity (Yr), and the stress tolerance index. The correlation coefficient value between Yp and Ys shows a strong and real relationship (0.83). These results indicate that hybrid maize genotypes show differences in productivity under normal conditions and drought stress, so that selection carried out only under drought stress conditions is very effective in producing drought stress tolerant hybrid maize genotype (Fadhli *et al*., 2020; Naidu *et al*., 2023). For this reason, hybrid maize genotype selection is not effective when carried out under normal conditions.

Stepwise regression analysis on the TOL, MP, HM, SSI, GMP, STI, YSI, and K2STI indices shows real results with yield productivity under drought conditions (Ys), while the YI and K1STI indices show unreal results with yield productivity under dry conditions. drought (Ys) (Table 3).

Table 3. Results of stepwise regression analysis of yield productivity under drought conditions (Ys) with the stress tolerance index in hybrid maize genotypes.

Index	Regression equation	Adj R^2	Nilai P
TOL	Ys = 2.46 – 0.26TOL	0.20	0.00**
MP	Ys = 1.23 + 0.87MP	0.92	0.00**
HM	Ys = 0.71 + 0.96HM	0.98	0.00**
SSI	Ys = 1.90 – 0.28SSI	0.75	0.00**
GMP	Ys = 0.96 + 0.92GMP	0.96	0.00**
STI	Ys = -0.31 + 0.34STI	0.96	0.00**
YI	Ys = 0.00 + 0.33YI	0.99	0.69
YSI	Ys = 0.31 + 0.10YSI	0.75	0.00**
K1STI	Ys = 0.10 + 0.33K1STI	0.70	0.13
K2STI	Ys = -1.06 + 0.77	0.97	0.00**

Note: * = significant at α 5%, ** = significant at α 1%, TOL = tolerance index, MP = mean productivity, HM = harmonic mean, SSI = stress susceptibility index, GMP = geometric mean productivity, STI = stress tolerance index, YI = yield index, YSI = yield stability index, k1STI dan k2STI = modified stress tolerance index

Stepwise regression analysis on the TOL, MP, HM, SSI, GMP, STI, YSI, and K2STI indices shows real results with yield productivity under drought conditions (Ys), while the YI and K1STI indices show nonsignificant results with yield productivity under drought conditions (Ys) (Table 3). For this reason, the selection of maize hybrid genotypes for the character of tolerance to drought stress was carried out using the TOL, MP, HM, SSI, GMP, STI, YSI, and K2STI indices because they have significant regression values on productivity under drought stress conditions (Ys). The coefficient of determination describes the value of diversity in yield productivity under drought conditions (Ys) which can be explained by the tolerance index which has a significant regression value (Sun *et al*., 2021). High regression values are shown by the MP, HM, GMP, STI, and K2STI indices of 0.92 – 0.99. The higher the value of the coefficient of determination, the greater the stress tolerance index will describe the diversity of yield productivity under drought conditions so that the index is better used to predict the level of tolerance of maize hybrid genotypes to drought (Khatibi *et al*., 2022). For this reason, the MP, HM, GMP, STI, and K2STI indices are the best stress tolerance indices for selecting hybrid maize genotypes under drought stress conditions.

***Drought Tolerance Criteria using the Ranking Method*:** Determining genotype tolerance to drought can be done using the ranking method. The ranking method is carried out by calculating all the average tolerance indices for all observed characters and the standard deviation of the ranking (Singh *et al*., 2015). The selection of genotypes that are tolerant to drought stress is determined based on low RS values. G12, G13, G14, and G15 have low RS values of 8.68, 11.90, 10.03, and 10.38 respectively so these four maize hybrids are the genotypes most tolerant to drought stress (Tables 4, 5, and 6). G3, G25, G26, and G27 have high RS values of 39.96, 42.16, 39.64, and 40.73 respectively so the four hybrid maize are categorized as maize that is sensitive to drought stress. The ranking method can be used as a reference to determine the level of tolerance and potential productivity of maize yields under normal and stress conditions in general based on the values of several tolerance indices (Mubushar *et al*., 2022). Maize hybrid genotypes G12, G13, G14, and G15 based on the SSI index are classified as drought stress tolerant, so the ranking method can be used to estimate the level of tolerance of a maize hybrid genotype to drought stress.

***Selection of Hybrid Maize Genotypes tolerant to drought stress*:** Selection of genotypes that are resistant to stress using the STI and SSI indices. The STI index is used to determine genotypes that are adaptive to drought stress, while the SSI index is used to determine genotypes that are tolerant to drought stress. The STI index is a measure of the high and low characteristics of a genotype under normal and drought conditions (Agili *et al*., 2012). The SSI index is a measure of the ability of a genotype to suppress yield reduction under drought stress conditions so that it can be used to select drought-tolerant hybrid genotypes (Xin *et al*., 2022). The selection of hybrid maize that is adaptive and tolerant to drought stress aims to obtain maize varieties that are capable of high production under normal and drought conditions. The reaction of maize genotypes under normal and drought conditions is divided into four groups, namely (1) Group A is the genotype with high yield productivity under normal and

Table 4. Average yield productivity under normal conditions (Yp), yield productivity under conditions of drought (Ys), percentage of yield reduction (Yr), genotype ranking, and tolerance index stress on hybrid maize genotypes.

Code	Genotype	Yp	R	Ys	R	Yr	R	TOL	R
G1	TS-5-20 x UTM08.5	5.63	9	4.71	8	16.35	35	0.92	35
G2	T2S-5-11 x UTM08.5	6.14	5	5.15	5	16.11	36	0.99	34
G3	DuS-5-24 x UTM08.5	2.75	38	1.32	39	51.71	11	1.42	23
G4	ES-5-24 x UTM08.5	4.24	25	3.00	16	29.13	27	1.23	28
G5	MS-5-06 x UTM08.5	3.42	33	1.86	32	45.77	17	1.57	22
G6	CS-5-43 x UTM08.5	2.36	40	1.19	40	49.65	13	1.17	29
G7	DS-5-3-1 x UTM08.5	4.77	23	3.42	13	28.28	28	1.35	25
G8	GS-4-2-1 x UTM08.5	2.83	36	1.48	36	47.76	14	1.35	24
G9	An-S-4-1-5 x UTM08.5	4.18	26	2.19	25	47.49	15	1.98	12
G10	La-S-4-2-4 x UTM08.5	4.05	28	2.21	24	45.36	18	1.84	14
G11	Bi-S-4-1-10 x UTM08.5	4.11	27	2.26	22	44.93	19	1.85	13
G12	Su-S-4-2-4 x UTM 08.5	6.83	3	5.20	3	23.85	29	1.63	19
G13	Su-S-4-1-12 x UTM08.5	7.44	1	5.77	1	22.38	31	1.68	18
G14	Su-S-4-1-15 x UTM08.5	6.95	2	5.36	2	22.82	30	1.59	21
G15	Su-S-4-3-16 x UTM08.5	6.33	4	5.18	4	18.17	33	1.15	32
G16	Lm-S-4-2-12 X UTM08.5	4.29	24	2.59	17	39.91	22	1.71	16
G17	Lm-S-4-2-2 x UTM08.5	3.89	30	1.49	35	61.65	2	2.40	9
G18	Ba-S-4-3-1 x UTM08.5	5.46	10	4.84	6	11.42	38	0.63	38
G19	Ba-S-4-2-2 x UTM08.5	5.33	12	4.74	7	11.16	40	0.60	39
G20	Pl-S-5-2 x UTM08.5	3.87	31	1.83	33	52.60	10	2.04	10
G21	TS-5-20 x UTM09.6	5.37	11	4.63	10	13.77	37	0.74	37
G22	T2S-5-11 x UTM09.6	5.74	8	4.59	11	20.04	32	1.15	31
G23	DuS-5-24 x UTM09.6	3.30	34	2.06	29	37.06	24	1.24	27
G24	ES-5-24 x UTM09.6	5.22	13	4.64	9	11.22	39	0.59	40
G25	MS-5-06 x UTM09.6	2.48	39	1.44	38	42.16	21	1.04	33
G26	CS-5-43 x UTM09.6	2.80	37	1.48	37	47.25	16	1.32	26
G27	DS-5-3-1 x UTM09.6	3.60	32	1.58	34	56.05	7	2.01	11
G28	GS-4-2-1 x UTM09.6	3.03	35	1.87	30	38.20	23	1.16	30
G29	An-S-4-1-5 x UTM09.6	4.96	18	2.41	18	51.32	12	2.54	8
G30	La-S-4-2-4 x UTM089.6	5.00	15	2.10	28	57.97	5	2.90	5
G31	Bi-S-4-1-10 x UTM09.6	4.98	17	2.26	23	54.63	8	2.72	6
G32	Su-S-4-2-4 x UTM 09.6	5.81	7	2.38	19	59.03	4	3.43	2
G33	Su-S-4-1-12 x UTM09.6	5.08	14	2.14	27	57.90	6	2.94	4
G34	Su-S-4-1-15 x UTM09.6	5.00	15	3.24	15	35.22	25	1.76	15
G35	Su-S-4-3-16 x UTM09.6	5.86	6	2.33	20	60.26	3	3.53	1
G36	Lm-S-4-2-12 x UTM09.6	4.79	22	2.18	26	54.47	9	2.61	7
G37	Lm-S-4-2-2 x UTM09.6	4.94	19	1.87	30	62.15	1	3.07	3
G38	Ba-S-4-3-1 x UTM09.6	4.89	20	4.00	12	18.05	34	0.88	36
G39	Ba-S-4-2-2 x UTM09.6	4.86	21	3.26	14	32.87	26	1.60	20
G40	Pl-S-5-2 x UTM09.6	4.03	29	2.32	21	42.31	20	1.71	17

drought conditions, (2) Group B is the genotype with high yield productivity under normal conditions, (3) Group C is a genotype with high yield productivity under drought conditions, and (4) Group D is a genotype with low yield productivity under normal and drought conditions.

The results of grouping based on 3D plots on 40 maize hybrid genotypes show that the genotypes included in group A are G2, G12, G13, G13, G14, and G15 with yield productivity under normal conditions of 6.14, 6.83, 7.44, 6.95 and 6.33 tons ha^{-1} and in drought conditions, it was 5.15, 5.20, 5.77, 5.36 and 5.18 tons ha^{-1} (Table 7) with STI values of 1.45, 1.63, 1.97, 1.71 and 1.50. The hybrid maize genotypes that comply with group B criteria are G32 and G35 with productivity under normal conditions of 5.81 and 5.86 tons ha^{-1} with STI values of 0.63 and 0.62. Genotypes that comply with group C criteria are G21, G22, G24, and G38 with productivity under drought stress of 4.63, 4.56, 4.64, and 4.40 tons ha-1 with STI values of 1.14, 1.22, 1.11, and 0.90. Genotypes that comply with group D criteria are G3, G6, G25, and G26 with STI values of 0.17, 0.13, 0.19, and 0.16 (Figure 2). The hybrid maize genotypes in group A, namely G2, G12, G13, G14, and G15, are genotypes that are adaptive to normal conditions and drought stress.

Table 5. Average yield productivity under normal conditions (Yp), yield productivity under conditions of drought (Ys), percentage of yield reduction (Yr), genotype ranking, and tolerance index stress on hybrid maize genotypes (continue).

Code	Genotype	MP	R	HM	R	SSI	R	GMP	R	STI	R
G1	TS-5-20 x UTM08.5	5.17	6	5.13	7	0.45	6	5.15	6	1.22	6
G2	T2S-5-11 x UTM08.5	5.64	5	5.60	5	0.44	5	5.62	5	1.45	5
G3	DuS-5-24 x UTM08.5	2.04	38	1.79	39	1.42	30	1.91	38	0.17	38
G4	ES-5-24 x UTM08.5	3.62	19	3.51	16	0.80	14	3.57	18	0.58	18
G5	MS-5-06 x UTM08.5	2.64	33	2.41	32	1.25	25	2.52	32	0.29	32
G6	CS-5-43 x UTM08.5	1.77	40	1.58	40	1.36	28	1.67	40	0.13	40
G7	DS-5-3-1 x UTM08.5	4.10	14	3.99	13	0.77	13	4.04	13	0.75	13
G8	GS-4-2-1 x UTM08.5	2.16	36	1.94	36	1.30	27	2.05	36	0.19	36
G9	An-S-4-1-5 x UTM08.5	3.19	27	2.88	27	1.30	26	3.03	28	0.42	28
G10	La-S-4-2-4 x UTM08.5	3.13	29	2.86	28	1.24	24	2.99	29	0.41	29
G11	Bi-S-4-1-10 x UTM08.5	3.19	26	2.92	26	1.23	23	3.05	26	0.43	26
G12	Su-S-4-2-4 x UTM 08.5	6.02	3	5.91	3	0.65	12	5.96	3	1.63	3
G13	Su-S-4-1-12 x UTM08.5	6.61	1	6.50	1	0.62	10	6.55	1	1.97	1
G14	Su-S-4-1-15 x UTM08.5	6.15	2	6.05	2	0.62	11	6.10	2	1.71	2
G15	Su-S-4-3-16 x UTM08.5	5.76	4	5.70	4	0.50	8	5.73	4	1.50	4
G16	Lm-S-4-2-12 X UTM08.5	3.44	24	3.23	20	1.09	19	3.33	21	0.51	21
G17	Lm-S-4-2-2 x UTM08.5	2.69	31	2.16	35	1.68	39	2.41	33	0.27	33
G18	Ba-S-4-3-1 x UTM08.5	5.15	8	5.13	6	0.31	3	5.14	7	1.21	7
G19	Ba-S-4-2-2 x UTM08.5	5.04	9	5.02	9	0.31	1	5.03	9	1.16	9
G20	Pl-S-5-2 x UTM08.5	2.85	30	2.49	31	1.44	31	2.66	30	0.33	30
G21	TS-5-20 x UTM09.6	5.00	10	4.98	10	0.38	4	4.99	10	1.14	10
G22	T2S-5-11 x UTM09.6	5.17	7	5.10	8	0.55	9	5.13	8	1.21	8
G23	DuS-5-24 x UTM09.6	2.68	32	2.54	30	1.02	17	2.61	31	0.31	31
G24	ES-5-24 x UTM09.6	4.93	11	4.91	11	0.31	2	4.92	11	1.11	11
G25	MS-5-06 x UTM09.6	1.96	39	1.82	38	1.15	20	1.89	39	0.16	39
G26	CS-5-43 x UTM09.6	2.14	37	1.94	37	1.29	25	2.04	37	0.19	37
G27	DS-5-3-1 x UTM09.6	2.59	34	2.20	34	1.53	34	2.39	34	0.26	34
G28	GS-4-2-1 x UTM09.6	2.45	35	2.31	33	1.05	18	2.38	35	0.26	35
G29	An-S-4-1-5 x UTM09.6	3.69	18	3.25	19	1.40	29	3.46	19	0.55	19
G30	La-S-4-2-4 x UTM089.6	3.55	22	2.96	24	1.58	36	3.24	23	0.48	23
G31	Bi-S-4-1-10 x UTM09.6	3.62	19	3.11	21	1.49	33	3.35	20	0.52	20
G32	Su-S-4-2-4 x UTM 09.6	4.09	15	3.37	17	1.61	37	3.72	16	0.63	16
G33	Su-S-4-1-12 x UTM09.6	3.61	21	3.01	22	1.58	35	3.29	22	0.50	22
G34	Su-S-4-1-15 x UTM09.6	4.12	13	3.93	14	0.96	16	4.02	14	0.74	14
G35	Su-S-4-3-16 x UTM09.6	4.09	16	3.33	18	1.65	38	3.69	17	0.62	17
G36	Lm-S-4-2-12 x UTM09.6	3.49	23	3.00	23	1.49	32	3.24	24	0.48	24
G37	Lm-S-4-2-2 x UTM09.6	3.41	25	2.71	29	1.70	40	3.04	27	0.42	27
G38	Ba-S-4-3-1 x UTM09.6	4.45	12	4.40	12	0.49	7	4.42	12	0.90	12
G39	Ba-S-4-2-2 x UTM09.6	4.06	17	3.90	15	0.90	15	3.98	15	0.73	15
G40	Pl-S-5-2 x UTM09.6	3.18	28	2.95	25	1.16	21	3.06	25	0.43	25

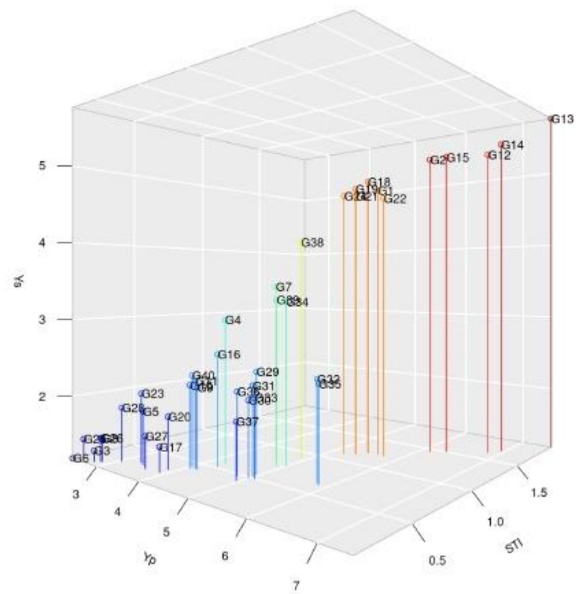
Table 6. Average yield productivity under normal conditions (Yp), yield productivity under conditions of drought (Ys), percentage of yield reduction (Yr), genotype ranking, and tolerance index stress on hybrid maize genotypes (continue……).

Code	Genotype	YI	R	YSI	R	K1STI	R	K2STI	R	RS
G1	TS-5-20 x UTM08.5	1.59	8	0.84	6	1.46	9	2.53	8	17.44
G2	T2S-5-11 x UTM08.5	1.74	5	0.84	5	1.73	5	3.02	5	12.62
G3	DuS-5-24 x UTM08.5	0.45	39	0.48	30	0.35	38	0.20	39	39.96
G4	ES-5-24 x UTM08.5	1.01	16	0.71	14	0.82	25	1.03	16	21.50
G5	MS-5-06 x UTM08.5	0.63	32	0.54	24	0.54	33	0.39	32	31.36
G6	CS-5-43 x UTM08.5	0.40	40	0.50	28	0.26	40	0.16	40	37.48
G7	DS-5-3-1 x UTM08.5	1.16	13	0.72	13	1.04	23	1.34	13	19.77
G8	GS-4-2-1 x UTM08.5	0.50	36	0.52	27	0.37	36	0.25	36	34.75
G9	An-S-4-1-5 x UTM08.5	0.74	25	0.53	26	0.80	26	0.55	25	24.98
G10	La-S-4-2-4 x UTM08.5	0.75	24	0.55	23	0.75	28	0.56	24	29.49
G11	Bi-S-4-1-10 x UTM08.5	0.76	22	0.55	22	0.77	27	0.58	22	25.18
G12	Su-S-4-2-4 x UTM 08.5	1.76	3	0.76	12	2.14	3	3.09	3	8.68
G13	Su-S-4-1-12 x UTM08.5	1.95	1	0.77	10	2.54	1	3.80	1	11.90
G14	Su-S-4-1-15 x UTM08.5	1.81	2	0.77	11	2.21	2	3.28	2	10.03
G15	Su-S-4-3-16 x UTM08.5	1.75	4	0.82	8	1.84	4	3.06	4	10.38
G16	Lm-S-4-2-12 X UTM08.5	0.87	17	0.60	19	0.85	24	0.76	17	28.87
G17	Lm-S-4-2-2 x UTM08.5	0.50	35	0.38	39	0.70	30	0.25	35	31.40
G18	Ba-S-4-3-1 x UTM08.5	1.63	6	0.89	3	1.37	10	2.67	6	16.57
G19	Ba-S-4-2-2 x UTM08.5	1.60	7	0.89	1	1.30	12	2.56	7	15.33
G20	Pl-S-5-2 x UTM08.5	0.62	33	0.47	31	0.69	31	0.38	33	33.81
G21	TS-5-20 x UTM09.6	1.57	10	0.86	4	1.32	11	2.45	10	14.62
G22	T2S-5-11 x UTM09.6	1.55	11	0.80	9	1.51	8	2.40	11	17.40
G23	DuS-5-24 x UTM09.6	0.70	29	0.63	17	0.50	34	0.49	29	36.21
G24	ES-5-24 x UTM09.6	1.57	9	0.89	2	1.25	13	2.45	9	16.23
G25	MS-5-06 x UTM09.6	0.49	38	0.58	20	0.28	39	0.24	38	42.16
G26	CS-5-43 x UTM09.6	0.50	37	0.53	25	0.36	37	0.25	37	39.64
G27	DS-5-3-1 x UTM09.6	0.53	34	0.44	34	0.59	32	0.29	34	40.73
G28	GS-4-2-1 x UTM09.6	0.63	30	0.62	18	0.42	35	0.40	30	35.37
G29	An-S-4-1-5 x UTM09.6	0.82	18	0.49	29	1.13	18	0.66	18	20.56
G30	La-S-4-2-4 x UTM089.6	0.71	28	0.42	36	1.14	15	0.50	28	25.34
G31	Bi-S-4-1-10 x UTM09.6	0.76	23	0.45	33	1.14	17	0.58	23	23.87
G32	Su-S-4-2-4 x UTM 09.6	0.80	19	0.41	37	1.55	7	0.64	19	20.45
G33	Su-S-4-1-12 x UTM09.6	0.72	27	0.42	35	1.18	14	0.52	27	23.01
G34	Su-S-4-1-15 x UTM09.6	1.09	15	0.65	16	1.14	15	1.20	15	19.74
G35	Su-S-4-3-16 x UTM09.6	0.79	20	0.40	38	1.57	6	0.62	20	20.61
G36	Lm-S-4-2-12 x UTM09.6	0.74	26	0.46	32	1.05	22	0.54	26	25.94
G37	Lm-S-4-2-2 x UTM09.6	0.63	30	0.38	40	1.12	19	0.40	30	28.21
G38	Ba-S-4-3-1 x UTM09.6	1.35	12	0.82	7	1.09	20	1.83	12	19.56
G39	Ba-S-4-2-2 x UTM09.6	1.10	14	0.67	15	1.08	21	1.21	14	18.95
G40	Pl-S-5-2 x UTM09.6	0.78	21	0.58	21	0.74	29	0.62	21	29.12

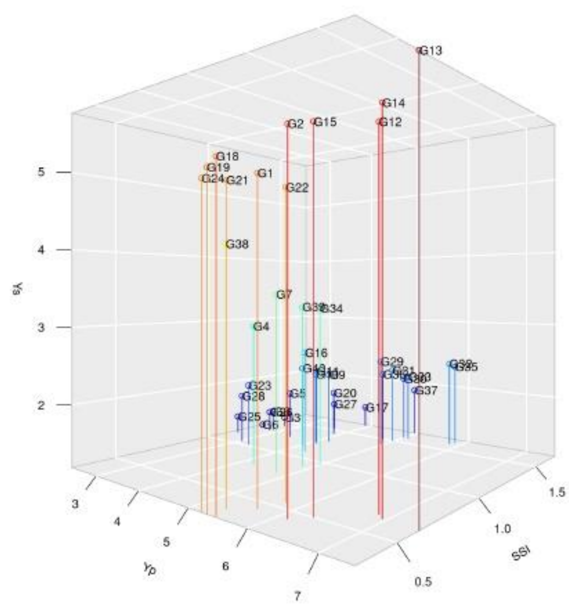
Table 7. Selection characteristics of maize hybrid genotypes that are tolerant and adaptive to drought stress.

Genotype	Yp	Ys	Characters							
			PH	DT	HA	EA	EL	ED	KWP	1000KW
					STI Index					
G2	6.14	5.15	191.43	45.11	89.22	85.26	15.21	5.19	82.50	211.33
G12	6.83	5.20	196.12	55.56	110.22	91.82	17.14	5.53	80.65	214.23
G13	7.44	5.77	199.05	54.22	106.67	92.29	16.66	5.57	84.09	217.33
G14	6.95	5.36	197.35	56.22	110.22	89.89	17.04	5.55	82.91	220.92
G15	6.33	5.18	193.66	55.56	109.33	88.39	17.64	5.54	81.79	277.66
					SSI Index					
G2	6.14	5.15	191.43	45.11	89.22	85.26	15.21	5.19	82.50	211.33
G18	5.46	4.84	194.25	49.44	98.33	90.66	14.69	5.24	79.22	219.91
G19	5.33	4.74	200.08	49.78	99.11	92.45	14.52	5.46	78.60	215.49
G21	5.37	4.63	173.78	45.67	91.11	173.78	15.14	4.95	75.49	215.66
G24	5.22	4.64	180.29	45.22	88.22	88.25	14.77	4.95	73.73	232.29
PPH	0.82**	0.93**	0.93**	0.89**	0.51**	0.90**	0.922**	0.92**	-0.13	1.00

Note: Yp = Average yield productivity under normal conditions, Ys = yield productivity under conditions of drought, PH = plant height, DT = days to 50% tasselling, H = harvest age, EH = ear height, EL = ear length, ED = ear diameter, KWP = kernel weight per plant, 1000KW = 1000-kernel weight



(a)



(b)

Figure 1. (a) 3D plot of 40 maize hybrid genotypes based on crop yield under drought conditions (Ys) (tons ha^{-1}), crop yield under normal conditions (Yp) (tons ha^{-1}), and stress tolerance index (STI); (b) 3D plot of 40 maize hybrid genotypes based on yield under drought conditions (Ys) (tons ha^{-1}), yield under normal conditions (Yp) (tons ha^{-1}) and stress susceptibility index (SSI).

The results of the 3D plot grouping of 40 maize hybrid genotypes based on the SSI index refer to the percentage of yield reduction. The level of tolerance of maize hybrid genotypes to drought based on the SSI index is divided into four groups, namely genotypes with a yield reduction percentage of less than 70% (group A); genotypes with a percentage of yield reduction between 71 to 80% (group B); genotypes with a yield reduction percentage between 81 to 90% (group C) and genotypes with a yield reduction percentage of more than 90% (group D). The results of testing hybrid maize genotypes under normal conditions and drought stress showed that all hybrid maize genotypes tested were in group A because the decrease in productivity from normal conditions to drought stress conditions was less than 70%. A low SSI index value indicates that the lower the percentage reduction in maize yield, the more tolerant the genotype is to drought stress. Determining the hybrid maize genotype that is most tolerant to drought stress is based on the lowest percentage reduction in production, namely G2, G18, G19, G21, and G24. The five hybrid maize genotypes have production under normal conditions of 6.14, 5.46, 5.33, 5.37, and 5.24 respectively with SSI values of 0.44, 0.31, 0.31, 0.38, and 0.1.

***Conclusion*:** The MP, HM, GMP, STI, and K2STI indices can be used to select maize hybrids that are tolerant of drought conditions. The ranking method can be used to estimate the level of tolerance of a hybrid maize genotype to drought stress Adaptive hybrid maize genotypes for normal and drought conditions based on the STI index are G2, G12, G13, G14, and G15. Drought-tolerant hybrid maize genotypes based on the SSI index are G2, G18, G19, G21, and G24.

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***SDG's addressed*:** Zero Hunger, Responsible Consumption and Production.

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