INNSPUB

International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 11, No. 4, p. 46-54, 2017

RESEARCH PAPER OPEN ACCESS

Evaluation of drought tolerance in maize hybrids using stress tolerance indices

Poppy Arisandy[1], Willy Bayuardi Suwarno[*1], Muhammad Azrai[2]

[1]*Departement of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agriculture University, Meranti Dramaga Street, Bogor, Indonesian*

[2]*Research Institute for Maize and Minor Cereals, Maros, South Sulawesi, Indonesian*

Article published on October 30, 2017

Key words: Yield, Selection character, Stress susceptibility index, Stress tolerance index

Abstract

Information about tolerance indices and morphological traits related to drought stress tolerance would be useful for identifying potential maize hybrids tolerant to drought. This research aimed to determine tolerance indices and selection traits for drought tolerance, and to identify the tolerant and adaptive maize hybrids to normal and drought conditions. This research was conducted at the IPB Experimental Fields Leuwikopo and Cikabayan, Dramaga, Bogor as normal environments in April to October 2016 and Experimental Field Bajeng, Gowa, South of Sulawesi as drought environments in June to September 2016. Screening with PEG was conducted at Laboratory of Seed Testing and Seed Storage, Bogor Agricultural University in January to February 2017. Results showed that harmonic mean (HM) and modified stress tolerance index (k2STI) can be used for selection adaptive maize hybrids to drought stress; stress tolerance index (STI) used for selection adaptive maize hybrids to normal environment and drought stress; and stress susceptibility index (SSI) and modified stress tolerance index (k1STI) used for selection tolerant maize hybrids to drought stress. Best selection character for hybrid maize tolerant to drought were ear diameter, weight of ear, number of seed row, ear length, days to tasseling, stem diameter, ear height, root fresh weight, root dry weight, number of ears and branch tassel number. Adaptive maize hybrids on normal environment and drought stress based on stress tolerance index (STI) were H32, H13, and H21. Drought tolerant maize hybrids based on stress susceptibility index (SSI) were T11, H17, and H15.

* **Corresponding Author:** Willy Bayuardi Suwarno ✉ bayuardi@gmail.com

Introduction

Increased production of maize to reduce import is facing various obstacles. The main obstacle is most of maize cultivation was conducted at dry land (69%) than irrigation field (21%) (Efendi, 2009). The problem encountered on dry land is limited availability of water in the soil that is not sufficient for maize (Faesal and Syuryawati, 2009; Sutoro, 2012). Drought stress on every growth stage of maize plant affecting plant productivity (Baneti and Wesgate, 1992). Development of hybrid maize through dialel crosses is an effective way to obtain drought tolerant maize hybrids, as it demonstrated combining ability and information about the genetic effect of characters that being evaluated (Yustiana *et al.*, 2013).

Drought tolerance in maize is defined as the ability of plants to grow and maintain yield under insufficient water content (Passioura, 1983). Tolerance level of a maize genotype in stress condition can be determined by using the value of stress tolerance index measured based on yield loss in drought conditions compared to normal conditions (Mitra, 2001). Evaluation of drought tolerance on plant can be predicted with two approaches; direct prediction based on the relative reduction of seed produced in drought condition compared to normal condition and indirect prediction based on an observation of various morphology and physiology variables related to drought tolerance (Banziger *et al.*, 2000). Direct selection of drought tolerant hybrids by yields only has a low selection effectivity because of environmental influences sometimes are greater than genetic influence (Shiri *et al.*, 2010). Plant characters that have a correlation with yield under drought conditions can be used as selection characters of drought tolerant maize hybrids (Banziger *et al.*, 2000; Betran *et al.*, 2003).

Fernandez, (1992) divide the maize hybrid reactions under normal and drought conditions in four groups consisting of group A: hybrids with high yield under normal and drought conditions; group B; hybrids with high yield under normal conditions; group; hybrids with high yield in drought conditions and group ; hybrids with low yield under normal and drought conditions.

This study is expected to provide an information about stress tolerance indices and selection characters of drought tolerance and obtain maize hybrids that tolerant and adaptive under normal and drought conditions.

Material and methods

Screening test for drought stress on hybrid maize on two different locations

This research was conducted on April until October 2016 in two different locations with different altitudes and seasons. Location used for evaluation in normal conditions was IPB Fieldstation, Bogor, West Java with 203 m Above Sea Level (ASL) of altitude, location used for drought conditions was Bajeng Fieldstation, Gowa, South Sulawesi with 50m ASL of altitude. Genetic materials used in this study were 28 maize hybrids from dialelle cross and 12 check variety (Bima 19, Lamuru, NK33, Bima 7, Bima 20, Sukmaraga, NK6326, P27, DK979, Bisi 222, Bisi 816, and Bisi 2). Ten hybrids were the result of half-dialelle cross namely T2, T4, T6, T7, T8, T9, T11, T12, T14, T15 and 18 hybrids were the resutl from full-dialelle cross namely H13, H14, H15, H16, H17, H21 , H22, H23, H24, H30, H31, H32, H33, H34, H36, H37, H40, H41. On each location, experiment was designed using α-Lattice with two replications and seven blocks on each replication, therefore each experimental unit size was 1 × 4m. Experimental units on normal conditions watered every 2 weeks, while in drought conditions watering is stopped 2 weeks before flowering following CIMMYT procedure (Banziger *et al.*, 2000). Observations were conducted on agronomy and yield traits of plant height, ear height, ratio of ear height and plant height, stem diameter, plant aspect, days to tasseling, days to silking, anthesis silking interval, husk cover, ear aspect, weight of ear, seed moisture content, ear length, ear diameter, number of seeds row, number of seeds per row, weight of 1000 grain, and shelling percentage (IBPGR, 1991). In addition, there were some important observation variables observed only in drought conditions based on Banziger *et al.* (2000) such as leaf chlorophyll, leaf temperature (^{o}C), leaf aging score, leaf roll score, number of ear, lenght of tassel (cm) and branch tassel number.

Screening test for drought stress on hybrid maize using PEG

Test for drought stress on hybrid maize using 10% PEG solution conducted on January until February 2017 at Laboratory of Seed Testing and Seed Storage, Bogor Agricultural University. Experiment was designed using Factorial Completely Randomized Design with three replications. The first factors was drought stress with two levels: without PEG and PEG 6000 10% concentration (equal to -0.19 Mpa) (Effendi, 2009). The second factors were hybrid maize genotypes, with 40 maize hybrid genotypes. Seeds were germinated using paper method. Observations were conducted on seed germination, rate of growth, vigor index, root length, shoot length, fresh root weight, fresh shoot weight, dry root weight, dry shoot weight, and ratio of dry weight root/shoot.

Data analysis

Data were analyzed using the software STAR software version 2.0.1 for analysis of correlation and stepwise regression for selection of stress tolerance indices and character related to drought stress. Calculation of stress tolerance indices follow these equations:

1. Tolerance Index (TOL) (Rosielle dan Hamblin, 1981):
   TOL = $(Yp - Ys)$
2. dan Mean Productivity (MP) (Rosielle dan Hamblin, 1981):
   MP = $\frac{(Yp + Ys)}{2}$
3. Harmonic Mean (HM) (Kristin *et al*., 1997):
   HM = $\frac{2\,(Yp\ x\ Ys)}{(Yp + Ys)}$
4. Stress Susceptibility Index (SSI) (Fisher dan Maurer, 1978):
   SSI = $\frac{1 - (\frac{Ys}{Yp})}{1 - (\frac{\hat{Y}s}{\hat{Y}p})}$
5. Geometric Mean Productivity (GMP) (Fernandez 1992; Kristin *et al.,*1997):
   GMP = $(Yp\ x\ Ys)^{0.5}$
6. Stress Tolerance Index (STI) (Fernandez 1992; Kristin *et al.,*1997):
   STI = $\frac{(Yp\ x\ Ys)}{(\hat{Y}p)^2}$
7. Yield Index (YI) (Gavuzzi *et al.,*1997):
   YI = $\frac{Ys}{\hat{Y}s}$
8. Yield Stability Index (YSI) (Bouslama dan Schapaugh, 1984):
   YSI = $\frac{Ys}{Yp}$
9. Modified Stress Tolerance Index (MSTI) (Farshadfar dan Sutka, 2002):
   MSTI = kiSTI where as k1 = $\frac{Yp^2}{\hat{Y}p^2}$ and k2 = = $\frac{Ys^2}{\hat{Y}s^2}$

Note: Ys = yields in drought conditions; Yp = yields in normal conditions; $\hat{Y}p$ = average yield of all hybrids in normal conditions; $\hat{Y}s$ = average yield of all hybrids in drought conditions; ki = correction coefficient.

Result and discussion

Selection of an appropriate stress tolerance indices can be used to obtain hybrids according to desired criterias (Efendi and Azrai, 2015). The results of correlation analysis between stress tolerance indices showed significant and high correlation coefficient between YI and HM index (0.974), YSI and SSI – (0.998), and STI and GMP were (0.993) (Table 1). These results showed that indexes have the same function in determining tolerance level of maize hybrid related to drought conditions needs to be selected. The significant correlation between HM index with yield on drought condition (Ys) and percentage of yield decrease (Yr) showed that HM index can be used for maize hybrid selection with high yield under drought conditions. Significant correlation coefficient between SSI index and Yr indicates that SSI index has a relationship with percentage of yield decrease (Yr) so SSI index can be used for selection of drought tolerant maize hybrid. Significant correlation between STI and GMP index with yield under normal (Yp) and drought (Ys) conditions showed that index of STI and GMP can provide information aboutmaize yield under normal and drought condition. Results of correlation analysis indicates that TOL, MP, HM, SSI, STI, k1STI and k2STI indices are predictors of drought tolerance level and yield which is suitable for selection of maize hybrids under normal and drought conditions. The results of stepwise regression analysis on TOL, MP, HM, SSI, STI, k1STI and k2STI indices showed that HM, SSI, STI, k1STI and k2STI indices have significant results with yield under drought conditions (Ys).

While TOL and MP indices showed no significant results on yield under drought conditions (Ys). Based on these results, selection of maize hybrid related to drought tolerance can be done by using HM, SSI, STI, k1STI and k2STI indices.

Relationship of the Stress Tolerance Indices with Decrease in Yields

Tolerance criterias for drought stress based on SSI and k1STI indices were related to the ability of maize hybrids to reduce yield loss. SSI and k1STI indices which showed a significant and high correlation with percentage of yield decrease (Yr). The correlation coefficient value of SSI indices with Yr is 1, indicates that smaller percentage of yield decrease in maize hybrid was more tolerant in drought conditions (Table 1). Selection of drought tolerant maize hybrids based on SSI indices is more accurate because it has very close relationship with the percentage of yield decrease (Yr) compared with k1 STI indices.

Relationship of the Stress Tolerance Indices with Yields

Tolerance criterias for a maize hybrid based on the level of yield under normal and drought conditions can be predicted using STI, HM and k2STI indices. HM and k2STI indices show a significant and high correlation coefficient with yield under drought conditions (Ys).

While STI indices showed a significant and high correlation coefficient with yield under normal conditions (Yp) and drought conditions (Ys) (Table 1). The result of correlation analysis showed that HM and k2STI indices were associated with the ability of a maize hybrid that have a high yield or adaptive under drought condition.

While STI indices is associated with maize hybrids that have high yield or adaptive under normal and drought conditions.

Table 1. Correlation between yield under normal conditions (Yp), drought conditions (Ys), percentage yield decrease (Yr) and stress tolerance indices.

	Ys	Yp	Yr	TOL	MP	HM	SSI	GMP	STI	YI	YSI	k1STI	k2STI
Ys	1												
Yp	0.08	1											
Yr	-0.61 **	0.70 **	1										
TOL	-0.12	0.98 **	0.82 **	1									
MP	0.28	0.98 **	0.55 **	0.92 **	1								
HM	0.97 **	0.28	-0.42 **	0.08	0.47 **	1							
SSI	-0.61 **	0.69 **	1.00 **	0.82 **	0.55 **	-0.42 **	1						
GMP	0.75 **	0.71 **	0.05	0.55 **	0.84 **	0.88 **	0.05	1					
STI	0.74 **	0.71 **	0.05	0.56 **	0.83 **	0.87 **	0.05	0.99 **	1				
YI	1.00 **	0.08	-0.61 **	-0.12	0.28	0.97 **	-0.61 **	0.75 **	0.74 **	1			
YSI	0.61 **	-0.70 **	-0.99 **	-0.82 **	-0.55 **	0.42 **	-0.99 **	-0.05	-0.05	0.61 **	1		
k1STI	0.46 **	0.85 **	0.32 *	0.76 **	0.91 **	0.62 **	0.32 *	0.88 **	0.91 **	0.46 **	-0.32 *	1	
k2STI	0.86 **	0.46 **	-0.22	0.28	0.62 **	0.92 **	-0.22	0.91 **	0.93 **	0.86 **	0.22	0.78 **	1

Information: * significant difference at P <0.05, ** significant difference at P <0.01. 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.

Selection of Characters Related to Drought Tolerance

Selection of drought tolerant maize hybrids is not only based on yields, but also need to be followed by characterization of secondary characters related to the tolerance effectiveness of hybrids in drought condition (Banziger *et al.*, 2000). Results of correlation between vegetative and generative characters with stress tolerance indices showed that ear height can be used as a selection characters to choose maize hybrids with high yield or adaptive on drought condition through HM and k2STI indices and stem diameter and days to tasseling can be used as selection characters to select drought tolerant hybrids through the SSI indices (Table 2). Stem diameter character indicates the highest correlation coefficient

compared to other characters in vegetative and generative phase. Large stem diameter are characteristic of drought tolerance maize hybrid (Betran *et al*., 2003). Results of correlation analysis of yield component character such as number of seeds row with SSI indices and weight of ear and ear diameter with HM, STI, k1STI and k2STI indices showed significant result with high correlation coefficient (Table 3). Correlation results show that characters is effectively used in determining drought tolerance level and yields of maize hybrid under normal and drought conditions. The decrease of yield in drought conditions also caused by decrease in ear diameter and ear length which impact the decrease of weight of ear (Earl and Davis, 2003). Correlation results of drought characters show that the number of the branch tasselcan be used as a selection character to select maize hybrids with high yield or adaptive under normal and drought conditions through the STI and k1 STI indices, as well as the number of ear as a selection character to select a maize hybrid with high yield under drought conditions through HM and k2STI indices (Table 4). Efendi, (2009) mentioned that PEG concentration of 10% (-0.19 Mpa) in germination media is effective for selecting and classifying drought tolerance maize hybrids. Results of correlation analysis showed that the character of fresh root weight and dry root weight correlated significantly with k2STI indices (Table 5).

These results indicate that fresh root weight and dry root weight can be used as an early selection characters to determine which maize hybrids have high yield or adaptive under drought conditions. Selection of tolerance maize hybrids based on root characters in the germination phase showed that maize hybrids with longer roots, large number of root branches, and large dry root weight were able to grow and has higher yield than hybrids with smaller root weight (Bruce *et al*., 2002).

Table 2. Correlation of stress tolerance indices with vegetative and generative phase of maize hybrid in drought conditions.

Character	Correlation coefficient				
	HM	SSI	STI	k1STI	k2STI
Anthesis silking interval	0.024	-0.144	-0.062	-0.138	-0.049
Husk cover	0.129	-0.122	0.047	-0.046	0.090
Days to silking	0.150	-0.063	0.137	0.087	0.098
Plant height	0.189	-0.057	0.179	0.140	0.227
Days to tasseling	-0.227	0.319 *	-0.024	0.152	-0.073
Stem diameter	-0.047	0.474 **	0.163	0.226	0.064
Ratio of ear and plant height	0.239	0.003	0.215	0.131	0.231
Ear height	0.324 *	-0.059	0.291	0.195	0.343 *

Information: * significant difference at P <0.05, ** significant difference at P <0.01.

Table 3. Correlation stress tolerance indices with yield component character of maize hybrid in drought conditions.

Character	Correlation coefficient				
	HM	SSI	STI	k1STI	k2STI
Rendemen	0.239	-0.295	0.125	0.064	0.169
Number of plant	0.176	-0.222	0.107	0.038	0.231
Seed moisture content	-0.050	0.085	-0.061	-0.070	-0.147
Weight of 1000 grain	0.096	0.070	0.138	0.091	0.069
Ear diameter	0.598 **	-0.386 *	0.503 **	0.357 *	0.579 **
Weight of ear	0.663 **	-0.269	0.616 **	0.472 **	0.614 **
Number of seeds row	0.338 *	-0.446 **	0.168	0.059	0.336 *
Number of seeds per row	0.281	-0.215	0.215	0.188	0.235
Ear length	0.357 **	-0.065	0.372 **	0.280	0.293
Ear aspect	-0.127	0.092	-0.036	0.002	-0.102

Information: * significant difference at P <0.05, ** significant difference at P <0.01.

Table 4. Correlation stress tolerance indices with drought character of maize hybrid in drought conditions.

Character	Correlation coefficient				
	HM	SSI	STI	k1STI	k2STI
Leaf roll score	-0.075	0.085	-0.044	-0.053	-0.082
Leaf chlorophyll	-0.273	0.251	-0.148	-0.022	-0.168
Leaf aging score	-0.294	0.016	-0.274	-0.165	-0.219
Number of ear	0.346 *	-0.280	0.222	0.130	0.359 *
Lenght of tassel	-0.090	0.146	-0.085	-0.122	-0.147
Leaf temperature	-0.116	0.079	-0.121	-0.133	-0.084
Branch tassel number	-0.208	-0.156	-0.339 *	-0.355 *	-0.308

Information: * significant difference at P <0.05, ** significant difference at P <0.01.

Table 5. Correlation stress tolerance indices with seed germination character of maize hybrid in drought conditions.

Character	Correlation coefficient				
	HM	SSI	STI	k1STI	k2STI
Shoot length	0.094	-0.021	0.062	-0.019	0.099
Root length	0.164	0.141	0.230	0.148	0.283
Daya Berkecambah	0.031	-0.173	-0.055	-0.137	0.067
Vigor index	0.001	-0.109	-0.053	-0.133	0.076
Rate of growth	0.055	-0.157	-0.018	-0.105	0.109
Fresh root weight	0.170	0.143	0.289	0.273	0.364 *
Fresh shoot weight	0.087	0.012	0.093	0.022	0.155
Dry root weight	0.168	0.108	0.254	0.203	0.329 *
Dry shoot weight	0.089	0.058	0.141	0.090	0.204
Ratio of dry weight root : shoot	0.155	0.018	0.160	0.098	0.210

Information: * significant difference at P <0.05, ** significant difference at P <0.01.

Modeling Maize Hybrid Character Selection to Stress Tolerance Indices

Selection character used in the stepwise regression analysis is the selected character based on the correlation analysis related to the hybrid maize response under drought conditions. Selected characters were ear diameter, weight of ear, number of seed row, ear length, days to tasseling, stem diameter, ear height, root fresh weight, root dry weight, number of ears and branch tassel number. The results of the stepwise regression analysis with the selected characters showed significant result with HM, SSI, STI, k1STI and k2STI indices (Table 6). Based on these results, selection of maize hybrids related to drought tolerance can be done using the selected characters.

Table 6. Stepwise regression analysis between stress tolerance indices and maize hybrids character in germination phase, vegetative and generative as well as specific characteristic of drought condition.

Index	P Value	R^2	Regression Equation
HM	0.000 **	0.535	HM = 0.634 + 0.024 BT + 0.050 JBB - 0.084 PT + 0.035 JTI
SSI	0.000 **	0.599	SSI = 0.118 -0.014 DT -0.019 JBB + 0.015 PT + 0.016 UBJ + 0.3 DB - 0.008 JM
STI	0.000 **	0.412	STI = -0.147 + 0.003 BT + 0.113 DB -0.005 JM
k1STI	0.003 **	0.334	k1STI = -2.84 -0.02 DT + 0.01 BT + 0.05 UBJ + 0.39 DB + 0.02 JTI - 0.02 JM
k2STI	0.000 **	0.554	k2STI = -0.17 + 0.01 BT + 0.02 JBB -0.05 PT + 0.324 BKA + 0.019 JTI - 0.013 JM

Information: * significant difference at P <0.05, ** significant difference at P <0.01. DT = ear diameter, BT = weight of ear, JBB = number of seeds row, PT = ear length, UBJ = days to tasseling, DB = stem diameter, TLT = ear height, BSA = fresh root weight, BKA = dry root weight, JTI = number of ear, JM = branch tassel number.

Selection of Drought Tolerance and Adaptive Maize Hybrid in Normal and Drought Condition

The classification of maize hybrids related to drought tolerance are divided into tolerance and adaptive hybrids. Selection of maize hybrids based on tolerance level to drought conditions can be done using SSI indices. Adaptive maize hybrids under normal and drought conditions can be selected based on the STI indices. Grouping results in 40 maize hybrids based on a 3D plot with the STI indices divided hybrids of group A were H32, H13 and H21. Group B were H41, H16 and H36. Group C were H15, T11, H17 and group D were H34, H24 and T9 (Fig. 1). Result of a 3D plot grouping of 40 maize hybrid based on the SSI indices show hybrids of group A were T11, H17 and H15. Group B were T8, H30 and H37. Group C were T4, H22 and H14 as well as group D were H36 and H41 (Fig. 2).

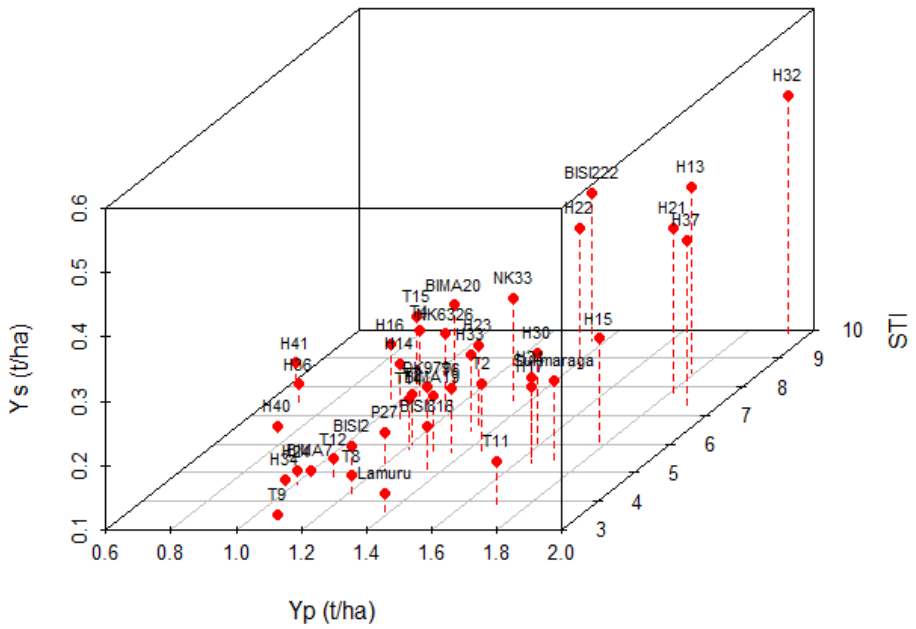

Fig. 1. 3D plot of 40 maize hybrids based on yield in normal conditions (Yp) (t/ha), yield in drought conditions (Ys) (t/ha), *stress tolerance index* (STI).

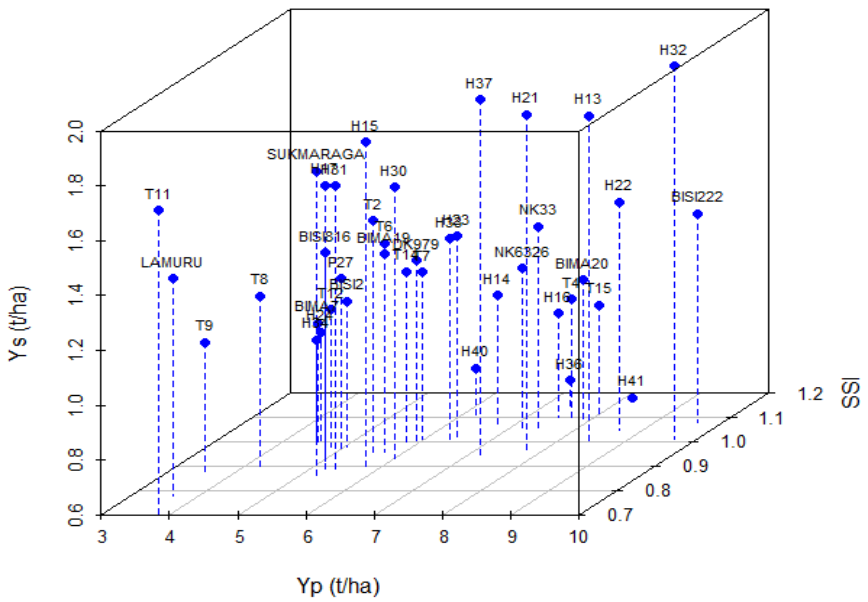

Fig. 2. 3D plot of 40 maize hybrids based on yield in normal conditions (Yp) (t/ha), yield in drought conditions (Ys) (t/ha), *stress susceptibility index* (SSI).

Characters of Drought Tolerance and Adaptive Maize Hybrid in Normal and Drought Condition

Result of observation of drought selection character showed adaptive maize hybrids under normal and drought condition were H32, H13, and H21 have a higher average of several characters such as ear diameter, weight of ear, stem diameter, fresh root weight, dry root weight and number of ear higher than adaptive maize hybrid such as Bisi 222 (Table 7). The characters showed that H32, H13 and H21 can effectively maintain yield productivity under normal and drought conditions. Tolerant maize hybrids of T11, H17, and H15 show average weight of ear, ear length, stem diameter, fresh root weight and dry root weight higher compared to tolerant maize hybrid Bisi 816 (Table 7). T11, H17, H15 are drought tolerant maize hybrids and can be use as genetic material to assemble drought tolerant maize hybrids.

Table 7. Character selection of drought tolerance and adaptive maize hybrid in normal and drought conditions.

Hybrids	Yp	Ys	Character Selection										
			DT	BT	JBB	PT	UBJ	DB	TLT	BSA	BKA	JTI	JM
STI Index													
H32	9.66	1.96	33.79	80.83	14	12.33	54	2.14	100.42	2.02	0.43	14	9
H13	8.48	1.79	33.30	74.37	12	12.11	54	2.11	93.17	1.89	0.39	12	12
H21	7.73	1.82	36.26	96.16	13	14.50	53	2.24	102.66	1.64	0.41	13	16
SSI Index													
T11	3.84	1.71	36.68	84.21	13	14.42	53	1.66	78.71	0.30	0.08	15	12
H17	5.33	1.65	30.71	64.16	13	12.03	52	2.01	96.33	0.65	0.24	9	9
H15	5.87	1.80	35.95	81.52	17	13.28	54	2.18	104.66	1.23	0.29	12	7
Bisi816	5.05	1.36	33.89	66.40	13	11.72	53	1.99	98.42	0.11	0.25	12	10
Bisi222	9.62	1.36	32.66	72.27	12	12.24	55	2.08	98.97	0.17	0.07	11	11

Information: Yp = yield in normal conditions (t/ha), Ys = yield in drought conditions (t/ha), DT = ear diameter, BT = weight of ear, JBB = number of seeds row, PT = ear length, UBJ = days to tasseling, DB = stem diameter, TLT = ear height, BSA = fresh root weight, BKA = dry root weight, JTI = number of ear, JM = branch tassel number.

Conclusion

The harmonic mean (HM) and modified stress tolerance index (k2STI) indices are used for selection adaptive maize hybrid under drought conditions; the stress tolerance index (STI) is used for selection adaptive maize hybrids under normal and drought conditions; stress susceptibilty index (SSI), and modified stress tolerance index (k1STI) are used for selection tolerance maize hybrids under drought conditions.

Best selection character for hybrid maize tolerant to drought were ear diameter, weight of ear, number of seed row, ear length, days to tasseling, stem diameter, ear height, root fresh weight, root dry weight, number of ears and branch tassel number. Adaptive maize hybrids under normal and drought conditions based on the STI indices were H32, H13 and H21. Drought tolerance maize hybrids based on SSI indices were T11, H17 and H15.

Reference

[IBPGR] International Board for Plant Genetic Resources. 1991. Descriptors for Maize. IBPGR, Roma IT.

Baneti P, Wesgate ME. 1992. Water deficit affects receptivity of maize silks. J Plant Breed Crop Sci **33(2),** 279-282.

Banziger M, Edmeades GO, Beck D, Bellon M. 2000. Breeding for Drought and Nitrogen Stress Tolerance in Maize: From Theory to Practice. Mexico (MX): CIMMYT.

Betran FJ, Beck, Banziger M, Edmeades GO. 2003. Secondary traits in parental inbred and hybrids under stress and non-stress environments in tropical maize. Field Crops Research **83,** 51-65.

Bouslama M, Schapaugh. 1984. Stress tolerance in soybean. Part 1: Evaluation of three screening techniques for heat and drought tolerance. J Plant Breed Crop Sci **24,** 933-937.

Bruce WB, Edmeades GO, Barker. 2002. Molecular and physiological approaches to maize improvement for drought tolerance. J. Experimental Botany **53(366),** 13-25.

Earl HJ, Davis RF. 2003. Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize. J. Agron **95,** 688-696.

Efendi R, Muhamad A. 2015. Kriteria indeks toleran jagung terhadap cekaman kekeringan dan nitrogen rendah. Di: Prosiding seminar nasional serealia. Indonesian pp. 1-12.

Efendi R. 2009. Metode dan karakter seleksi toleransi genotipe jagung terhadap cekaman kekeringan. Master Thesis, Bogor Agriculture University Indonesian.

Faesal, Syuryawati. 2009. Kendala dan prospek pengembangan jagung pada lahan sawah tadah hujan di Sulawesi Selatan. Inovasi Teknologi Serealia Menuju Kemandirian Pangan dan Agroindustri.

Farshadfar F, Sutka. 2002. Screening drought tolerance criteria in maize. Acta Agron. Hung **5(4),** 411-416.

Fernandez GCJ. 1992. Effective selection criteria for assessing plant stress tolerance. In: Proceedings of the international symposium on adaptation of vegetable and other food crops in temperature and water stress. Taiwan pp. 257-270.

Fischer RA, Maurer. 1978. Drought resistance in spring wheat cultivars: I. Grain yield responses. Aust. J. Agric. Res **29,** 897-912.

Gavuzzi P, Rizza, Palumbo, Campaline, Ricciardi GL, Borghi B. 1997. Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. Can. J. Plant Sci **77,** 523-531.

Kristin AS, Senra, Perez FI, Enriquez BC, Gallegos, Vallego, Wassimi N, Kelley. 1997. Improving common bean performance under drought stress. J. Crop Sci **37,** 43-50.

Mitra J. 2001. Genetics and genetic improvement of drought resistance in crop plants. Curr. Sci **80,** 758-762.

Passioura JB. 1983. Roots and drought resistance. Agric. Water Manage **7,** 265–280.

Rosielle AA, Hamblin J. 1981. Theoretical aspects of selection for yield in stress and non-stress environment. J. Crop Sci **21,** 943-946.

Shiri M, Aliyev, Choukan R. 2010. Water stress effects on combining ability and gene action of yield and genetic properties of drought tolerance indices in maize. Research Journal of Environmental Sciences **4(1),** 75-84.

Sutoro. 2012. Kajian penyediaan varietas jagung untuk lahan subnormal. Iptek Tanaman Pangan **7(2),** 108-112.

Yustiana, Muhamad S, Surjono HS. 2013. Analisis daya gabung galur-galur jagung tropis di dua lokasi. Jurnal Agron. Indonesia **41(2),**105-111.