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Selection in Recombinant Inbred Lines of rice (*Oryza sativa* L.) by Drought Tolerant Indices

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The development of drought tolerant cultivars is paramount to attain stability of production in the rainfed lowlands. Inefficiencies of screening techniques for drought flagged the use drought index, which is a mathematical association between yield under stress and non-stress conditions. This study aimed to determine the effectiveness of indices in classifying and identifying drought tolerant rice genotypes. An experiment was conducted in the Philippine Rice Research Institute Central Experiment Station on ten recombinant inbred lines developed through single cross of popular local varieties in replicated RCBD. Each population was subjected to two cycles of seasonal selection, under non-stress ($E_{ns-1,}$) and reproductive stage drought (E_{s-1}) on the 1st cycle at severe stress intensity (SI) of 0.94 and during the 2nd cycle (SI = 0.27, moderate stress) under non-stress (E_{ns-2}) and favorable rainfed (E_{s-2}) conditions. Eleven drought tolerance indices *viz.*, relative drought index (RDI), stress tolerance (TOL), mean productivity (MP), yield stability index (YSI), geometric mean productivity (GMP), stress tolerance index (STI), harmonic mean (HAM), drought resistance index (DI), sensitivity drought index (SDI), stress susceptibility index (SSI) and yield index (YI) were calculated. High heritability (h^2) were computed for yield in E_{ns-1} ($h^2 = 0.91$), E_{s-1} ($h^2 = 0.63$) and E_{ns-2}, E_{s-2} ($h^2 = 0.93$). Significantly positive correlation of GMP, STI and HAM to yield under E_{s-1}, E_{s-2}, and E_{ns-2} showed that these indices were effective in identifying stable and high yielding genotypes across three environments. Screening genotypes through drought indices, correlation, principal component and genotype x environment analyses delineated, PR39269-B-3-B-1-3 derived from cross combination of PSB Rc10 and NSIC Rc138 as high yielding and stable under reproductive stage drought, favorable rainfed and non-stress environment.

Keywords: selection, drought tolerant index, correlation, genotype x environment analysis, rice

Introduction

Drought stress occurs frequently in rice ecosystems that are either rainfed or rely on impounded surface water, affecting about 20 - 25 million hectares (ha)

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worldwide (Atlin *et al*., 2008). In Asia, about 50% of all rice land is rainfed and although rice yields in irrigated systems have doubled and tripled over the past 30 years, only modest gains have occurred in the rainfed systems (Fischer *et al*., 2003). The main share of total rice production will continue to come from irrigated systems but there are indications that irrigated systems alone will not be able to supply the additional amount needed in the near future (Pingali *et al*., 1997). In the Philippines, 1.48 million ha or about 46% of the 4.73 million ha of areas designated for rice are rainfed, but only 32% of rice produced is sourced through this ecosystem. These areas are geographically distributed in the archipelago‘s three major islands, 340,000 ha in Luzon, 730, 000 ha in Visayas and 420,000 ha in Mindanao (BAS, 2015), wherein more distinct areas are located in the Cagayan Valley, Ilocos, IloIlo and on the coastal plains of Visayas (Maclean, 2002). Since these areas fully rely on rainfall as its only source of irrigation, yield continually remains low and inconsistent due to intermittent rainfall patterns, occurrence of drought and/or submergence with varied intensity across seasons and years. In addition, most irrigated areas rely on surface irrigation from run-off river systems and reservoirs can suffer from conditions similar to rainfed conditions during drought years.

In the context of current and predicted water scarcity scenarios, irrigation is generally not a viable option to alleviate drought problems in rainfed rice-growing systems (Serraj *et al*., 2008), therefore there is an imperative need for a different strategy such as varietal development for drought-prone environments. Although, varietal development for drought tolerance is complicated by the lack of fast, reproducible screening techniques and the ability to routinely create defined repeatable water stress conditions where large populations can be efficiently evaluated (Ramirez and Kelly, 1998). The development of rice cultivars that combine improved yield under stress with high yield potential can be obtained by screening breeding lines for both yield potential in favorable environments and yield under managed stress (Atlin *et al*., 2008).

The preliminary point in the selection of desirable genotypes is distinguishing genotypes expressing comparative superiority in both stress and non-stress environments due to unpredictable rainfed conditions (Mohammadi *et al*., 2010). Although some researchers believe in selection under favorable condition (Betran *et al.*, 2003), in target stress condition (Mohammadi *et al.*, 2011) and selection under both favorable and stress conditions (Nouri *et al*., 2011). Selection of suitable genotypes based on relative yield performance has been considered a reliable technique for evaluating a large number of genotypes in drought stressed conditions (Panthuwan *et al.*, 2002).

Several selection criteria have been proposed for selecting genotypes based on their performance in stress and non-stress environments (Fischer and

Maurer, 1978, Rosielle and Hamblin, 1981, Fernandez, 1992). Drought indices, which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions, have been used for screening genotypes for drought tolerance (Mitra, 2001).

Although there are several studies on the use of drought indices for selection in barley (Amini *et al*., 2012; Eizavi *et al*., 2013), bread wheat (Abdi *et al*., 2012; Dehbalaei *et al*., 2013; Drikvand *et al*., 2012; Nouraein *et al*., 2013), corn (Kiani, 2013; Moradi *et al*., 2012; Naghavi *et al*., 2013), oat (Akcura and Ceri, 2011; Rabiei *et al*., 2012), rapeseed (Rad and Abassian, 2011; Zebarjadi *et al*., 2011), soybean (Bahari and Nasirifard, 2014), sorghum (Menezes *et al*., 2013) and sunflower (Safavi *et al*., 2005), studies in rice are uncommon. Selection of drought tolerant genotypes among advanced breeding lines through drought tolerant indices may prove to be a good selection criterion in hastening and improving selection process for cultivar development programs.

Materials and Methods

Plant Genetic Materials and Field Experiment

The study was conducted in an experimental field in the Philippine Rice Research Institute Central Experiment Station, Maligaya, Science City of Muñoz, Nueva Ecija, Philippines, which is, located at latitude 15° 40’ N, longitude 120° 53’ E and an elevation of 60.4 m above sea level during the 2014 dry and wet cropping seasons. Selection program was initiated by screening ten F_7 to F_8 generation recombinant inbred lines (RIL) from cross combination of popular high yielding local varieties (Table 1). Rice seedlings were planted (21 days old) in 20 cm x 20 cm spacing. Fertilizers were applied prior to sowing and side dressing preceding panicle initiation following local fertilizer recommendations at the rate of 120-60-60 on the dry season and 90-60-60 of N-P-K during the wet season.

Table 1. List of recombinant inbred lines (RIL), its corresponding pedigree and cross combinations during the 2014 dry and wet season divergent trials

Genotype	Genotype	Parentage
G1	PR39955-B-2-1-3-2	PSB Rc14/PSB Rc82
G2	PR39269-B-3-B-1-3	PSB Rc10/NSIC Rc138
G3	PR39172-B-19-B-B-2	PSB Rc62/NSIC Rc138
G4	PR39949-B-5-2-2-2	PR25769-B-9-1/PSB Rc14
G5	PR39955-B-4-2-4-2	PSB Rc14/PSB Rc82
G6	PR39954-B-15-2-4-1-3	PSB Rc14/PSB Rc68
G7	PR40029-B-20-1-7-2-1	PSB Rc14/NSIC Rc152
G8	PR40029-B-14-B-2-2-2	PSB Rc14/NSIC Rc152
G9	PR40029-B-16-1-1-1-1	PSB Rc14/NSIC Rc152
G10	PR40028-B-6-B-5-1-3	PSB Rc14/NSIC Rc158

Divergent Field Trials

The 1st cycle of screening was in a 5.6 m^2 plot under non-stress and managed reproductive stage drought conditions. Second cycle screening was in an 8m^2 plot under non-stress and rainfed conditions. During the 1st cycle reproductive drought, two series of drought were imposed in the trial until crop maturity. Initiation of differential irrigation started at panicle initiation or at 36 days after transplanting (DAT) by withholding water for 27 days, and then the field was surface flooded water for 3 days. The 2nd series of drought followed and continued for 32 days. Water below soil surface reached 104 - 114 cm and 15-20% soil moisture at 30 cm soil depth prior re-irrigation. Moreover, the 1st cycle screening received 26 mm of rainfall. The 2nd cycle of rainfed plots were not provided with any supplemental irrigation after transplanting other than precipitation amounting to 635 mm in the course of the season. The non-stress experiment maintained 2 - 3 cm standing water from transplanting to 10 days before maturity by providing water by supplementary irrigation through a water pump as required.

Drought Tolerant Indices Computation

After physiological maturity stage, non-stress yield (Y_{ns1-2}) and stress yield (Y_{s1-2}) were harvested, threshed, sundried and measured for weight and moisture content. The yield was adjusted based on 14% moisture content and computed as tons per hectare ($t.ha^{-1}$). Narrow sense heritability (h^2) was computed based on the ratio of genotypic to phenotypic variance. In order to ascertain the best drought tolerance indices as well as the drought tolerant lines computations were done with 11 different indices: TOL, MP, HAM, SSI, GMP, STI, YI, YSI, DI, RDI and SDI using yield under non-stress and stress conditions.

Table 2. Drought tolerant indices and correponding formula and references

Drought Tolerant Index (DTI)	Equation	References
Stress susceptibility index (SSI)	$1 - Y_s / Y_{ns}$ / SI, where; stress intensity SI= $1 - (\bar{Y}_s / \bar{Y}_{ns})$	Fischer and Maurer, 1978
Relative drought index (RDI)	$Y_s / Y_{ns} / \bar{Y}_s / \bar{Y}_{ns}$	
Tolerance Index (TOL)	$Y_{ns} - Y_s$	Rosielle and Hamblin, 1981
Mean productivity (MP)	$Y_{ns} + Y_s / 2$	
Yield stability index (YSI)	Y_s / Y_{ns}	Bouslama and Schapaugh, 1984
Geometric mean productivity (GMP)	$\sqrt{(Y_s * Y_{ns})}$	Fernandez, 1992
Stress tolerance index (STI)	$Y_s * Y_{ns} / \bar{Y}_{ns}^2$	
Harmonic mean (HAM)	$2 (Y_s*Y_{ns}) / Y_s + Y_{ns}$	Kristin *et al.*, 1997
Yield index (YI)	$Y_s/\bar{Y}_s$	Gavuzzi *et al.*, 1997
Drought resistance index (DI)	$Y_s * (Y_s / Y_{ns}) / \bar{Y}_s$	Lan, 1998
Sensitivity drought index (SDI)	$Y_{ns}-Y_s / Y_{ns}$	Farshadfar and Javadinia, 2011

Y_s (stress yield), Y_{ns} (non-stress yield), $\bar{Y}_s$ (stress mean yield) and $\bar{Y}_{ns}$ (non-stress mean yield)

Statistical Analysis

Experiments were planted in Randomized Complete Block Design (RCBD) in three replicates under two divergent trials. Analysis of variance (ANOVA), Pearson's correlation, genotype x environment and principal component analyses (PCA) were generated using CRAN packages: agricolae, GGEBiplotGUI, FactoMineR and factoextra of R: A language and environment for statistical computing.

Results and Discussion

Stress Intensity and Heritability

Association of drought tolerant indices through yield in contrasting target population environments (TPE) were used to assess drought tolerance in RILs. During the 1st Cycle, results showed that water stress reduced the grain yield of all genotypes during the 1st cycle. The mean yield in non-stressed and stressed conditions were 6.93 $t.ha^{-1}$ and 0.16 $t.ha^{-1,}$ which indicated that the stress intensity, (SI) was extremely severe (0.94). In the 2nd cycle of selection, mean yield under non-stress resulted to 4.73 $t.ha^{-1}$ and 3.46 $t.ha^{-1}$ under rainfed condition and stress intensity was (0.27) or moderately stress. At the reproductive stage, yield reduction in rice is significant even with moderate stress (Verulkar *et al.*, 2010). High heritability (h^2) were computed for yield

Y_{ns-1} (h^2 = 0.91), Y_{s-1} (h^2 = 0.63) and Y_{ns-2}, Y_{s-2} (h^2 = 0.93). Thus, seletion for yield across two cycles of selection is appropriate since it is highly heritable.

Correlation Analysis

Correlation is useful in finding out the overall linear association between two variables or traits. Significant associations present in yield under stress to non-stress conditions and drought indices present a suitable criterion for selecting drought tolerant genotypes. Correlation analysis didn't reveal any significant association between stress and non-stress yield in the 1st cycle of selection (Table 3), comparable results were obtained by (Amini *et al*., 2012, Drikvand *et al*., 2012, Farshadfar *et al*., 2013 and Kiani, 2013). The lack of correlation between an optimum and stress environment ascertains that selection for high yield under stress does not fully guarantee high yield in non - stress environment. The absence of correlation deduced only selection for either stress or non-stress environment since selection for both environments will not surely create directly proportional yield gains.

Significantly positive correlation were observed for Y_{ns-1} to TOL (r=0.96) and MP (r = 0.95). Selection from high values of these indices would provide high yield if selected TPE is under non-stress condition. Whereas, perfect correlation was recorded for YI (r=1.00) to Y_{s-1}. Moreover, highly significant and positive correlation of Y_{s-1} were identified for RDI, YSI, HAM (r=0.99); STI (r=0.98); GMP, DI (r=0.97), while negative correlation were observed for SDI, SSI (r=-0.99). Thus, genotypes with high values of YI, RDI, YSI, HAM, STI, GMP and DI and low values of SDI and SSI will yield higher under stress conditions.

In the 2nd cycle of selection, correlation was observed for Y_{ns-2} to Y_{s-2} (r=0.717), similar connections were detailed by Akcura and Ceri, 2011, Eizavi *et al*., 2013 and Menezes *et al*., 2014. Positive correlation of Y_{ns-2} were noted for MP (r=0.93), STI (r=0.92), GMP (r=0.91), HAM (r=0.88) and YI (r=0.72). Yield under rainfed condition (Y_{s-2}) was seamlessly correlated to YI (r=1.00), and positively interrelated with HAM (r=0.96), GMP (r=0.94); STI, DI, MP (r=0.92); RDI, YSI (r=0.67) while negative relationship were observed for SDI and SSI (r=-0.67) (Table 3). MP, GMP, STI, HM and YI are simultaneously related to Y_{ns-2} and Y_{s-2}. Highly correlated indices to both Y_s and Y_{ns}, are most appropriate in identifying stress tolerant cultivars (Farshadfar and Javadinia, 2011).

Table 3. Correlation matrix Y_s, Y_{ns} and 11 DTI in the 1st cycle (above diagonal) and 2nd cycle (below diagonal) selection

Indices	Y_{ns-1}	Y_{s-1}	RDI	TOL	MP	YSI	GMP	STI	HM	DI	SDI	SSI	YI
Y_{ns-2}	**1**	-0.17	-0.32	**0.96**	**0.95**	-0.32	0.07	0.01	-0.15	-0.3	0.32	0.32	-0.17
Y_{s-2}	**0.72**	**1**	**0.99**	-0.45	0.16	**0.99**	**0.97**	**0.98**	**1**	**0.97**	**-0.99**	**-0.99**	**1**
RDI	-0.03	**0.67**	**1**	-0.59	0	**1**	**0.92**	**0.94**	**0.98**	**0.98**	**-1**	**-1**	**0.99**
TOL	0.42	-0.33	**-0.92**	**1**	**0.81**	-0.59	-0.23	-0.28	-0.43	-0.56	0.59	0.59	-0.45
MP	**0.93**	**0.92**	0.34	0.06	**1**	0	0.39	0.34	0.18	0.02	0	0	0.16
YSI	-0.03	**0.67**	**1**	**-0.92**	0.34	**1**	**0.92**	**0.94**	**0.98**	**0.98**	**-1**	**-1**	**0.99**
GMP	**0.91**	**0.94**	0.39	0	**1**	0.39	**1**	**0.99**	**0.97**	**0.89**	**-0.92**	**-0.92**	**0.97**
STI	**0.92**	**0.92**	0.34	0.05	**1**	0.34	**1**	**1**	**0.99**	**0.93**	**-0.94**	**-0.94**	**0.98**
HM	**0.88**	**0.96**	0.44	-0.06	**0.99**	0.44	**1**	**0.99**	**1**	**0.97**	**-0.98**	**-0.98**	**1**
DI	0.39	**0.92**	**0.9**	**-0.67**	**0.7**	**0.9**	**0.74**	**0.71**	**0.78**	**1**	**-0.98**	**-0.98**	**0.97**
SDI	0.03	**-0.67**	**-1**	**0.92**	-0.34	**-1**	-0.39	-0.34	-0.44	**-0.9**	**1**	**1**	**-0.99**
SSI	0.03	**-0.67**	**-1**	**0.92**	-0.34	**-1**	-0.39	-0.34	-0.44	**-0.9**	**1**	**1**	**-0.99**
YI	**0.72**	**1**	**0.67**	-0.33	**0.92**	**0.67**	**0.94**	**0.92**	**0.96**	**0.92**	**-0.67**	**-0.67**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Many studies indicated that MP, GMP and STI were the most appropriate indices in identifying drought tolerant genotypes (Abdi *et al*., 2012; Bahari and Nasirifard. 2014; Drikvand *et al.*, 2012), there also studies which include HAM along with STI, MP and GMP (Farshadfar and Elyasi, 2012; Menezes *et al*., 2014). Ultimately considering the two cycles of divergent selection, indices GMP, STI and HAM, which were similarly present as positively significant correlation for the 1st cycle (E_{s-1}) and 2nd cycle (E_{s-2} and E_{ns-2}), were categorized as the most suitable indices for selecting drought tolerant genotypes.

Principal Component Analysis

PCA is one way to compress data sets of high dimensional vectors into lower dimensions (Abdi *et al*., 2013). PCA revealed that the 1st component explained 77.5 % and 68.9 % of the variation with Y_s, Y_{ns} and the selected indices in the 1st and 2nd cycle, respectively. Thus, the first PCA can be named as the yield potential and drought tolerance dimension (Ali and El-Sadek, 2016). High and positive values of PC_1 will be equivalent to high yielding genotypes under a stress environment. The second PCA amounted to 22.1 % and 31.0 % of the total variability, thus it is the non-stress dimension. The correlation coefficient among any two indices is approximately the cosine of the angle between their vectors. Thus, r= cos180 ≒ -1, cos 0 ≒ 1 and cos 90 ≒ 0 (Yan and Rajcan, 2002).

In the 1st cycle, the most prominent relations present in the biplot are: (1) Strong positive correlation between Yn_{s-1} to TOL and MP. Y_{S-1} is positively associated to GMP, STI, HM, YI, YSI, RDI and DI as indicated by acute angles formed between their segment vectors; (2) Near zero association between Y_{ns-1} to GMP, STI as shown by the near perpendicular vectors and (3) Negative association between Y_{s-1} to SDI and SSI as indicated by the obtuse angles formed through their vectors (Figure 1A). First cycle selection was able to delineate two groups, wherein the 1st group contains G3, G5, G7 and G9, with high values of TOL and MP with negative PC_1 and positive PC_2 values. Additionally, the 2nd group have positive PC_1 scores which contains G2 and G4, which will perform best in stress environment. G2 and G4 have high values of GMP, STI, HAM, YI, DI, YSI and RDI. During the 2nd cycle, both Y_{s-2} and Y_{ns-2} are positively correlated with STI, GMP, MP, HAM and YI, while Y_{ns-2} has almost no observed correlation with RDI, YSI, SDI and SSI while Y_{s-2} also has no correlation to TOL.

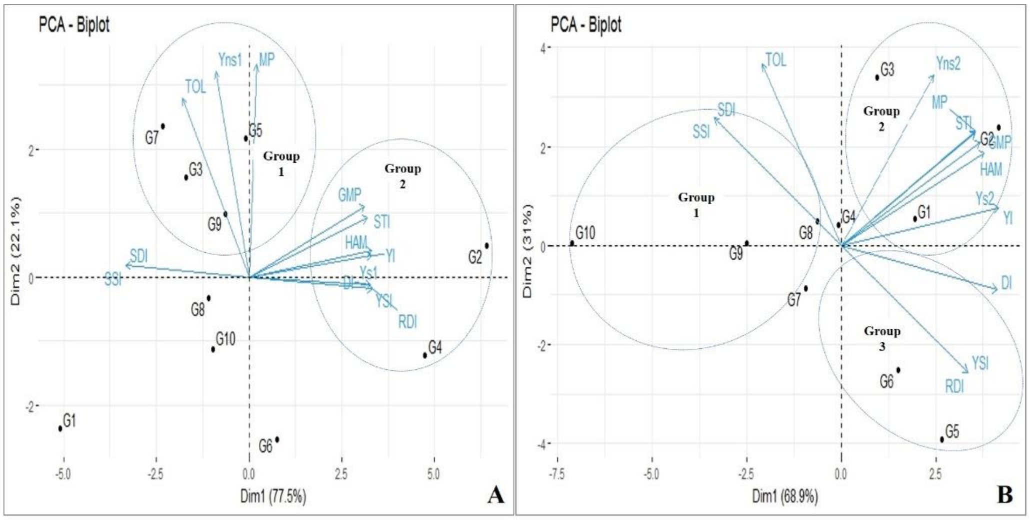

Figure 1. PCA biplot of (A) 1st cycle (B) 2nd cycle of selection among 10 genotypes, Y_{ns}, Y_s and 11 drought tolerant indices

Significant negative associations of Y_{S-2} were recorded for SDI and SSI. Second cycle selection was able to identify three groups: (1) Indices such as SDI, SSI was correlated to G8, G9 and G10 and are also negatively associated with Y_{ns-2} and with positive PC_1 and negative PC_2; (2) Both Y_{ns-2} and Y_{s-2} have positive association to STI, MP, GMP, HM and YI containing G1, G2 and G3; (3) Negative association of DI, YSI and RDI for Y_{s-2} were detailed for G5 and G6 which will perform best only in stress environment.

Genotype x environment (GGE) biplot analysis.

The combined ANOVA for Y_{ns} and Y_s during two divergent trials indicated highly significant variation ($P < 0.001$) (Table 4). The environment (E) effect was a predominant source of variation and accounted for 95.66 % of the total sum of squares, while G and GE interaction sources of variation accounted for 1.48 % and 2.33 % of the total variation. The first two principal components explained 84.4 % of the total GGE variation. First principal component accounted for 62.99 % whereas the second principal component is equal to 24.99 %.

Table 4. Combined analysis of variance of yield data in two divergent trials, 2014 dry and wet seasons

Source	Df	Sum of Squares	Mean Square	Pr(>F)
Genotype(G)	9	10.24	1.14	< 2.2e-16 ***
Environment (E)	3	663	220.99	6.081e-12 ***
G x E	27	16.14	0.6	< 2.2e-16 ***
Residuals	72	3.71	0.05	

Significance codes: 0.0001 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

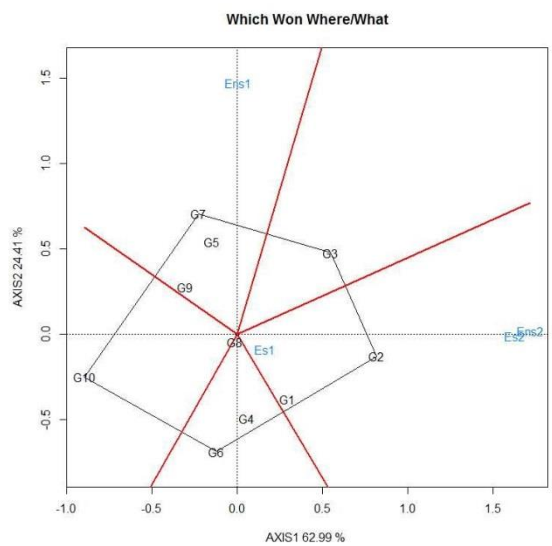

Figure 2. Biplot showing which won where among 10 genotypes in two divergent trials, 2014 dry and wet seasons.

Visualization of the “which-won-where” pattern of multi-environment data is important for studying the possible existence of different environments in a region (Yan *et al*., 2001). The polygon view of a biplot is the best way to visualize the interaction pattern between genotypes and environments and to effecti vely interpret a biplot (Yan and Kang, 2003). The polygon view showing “which-won-where” of the GGE biplot revealed that there were two mega environmnets (Figure 2). The 1st environment contains E_{ns-1} (1st cycle non-stress environment), indicating G7 as the best genotype in the environment along with G5 and G9. The 2nd mega-environment consisted of E_{S-1} (1st cycle stress environment), E_{ns-2} (2nd cycle non-stress environment) and E_{S-2} (2nd cycle stress environment) which was succeeded by G2 and followed by G1.

Conclusion

Several studies have reported that selection of drought tolerant genotypes can be based on the relative performance of a combination of drought indices in contrasting environments. The use of drought indices with apposite interpretations of statistical tools including correlation, principal component and genotype x environment analyses can be predictors of drought tolerant genotypes. Selection for reproductive stage drought, rainfed and irrigated environments based on the combination of HAM, GMP and STI resulted in the identification of probable drought tolerant genotype, PR39269-B-3-B-1-3 with high yield and stability across three environments.

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References

Abdi, H., Azizov, E., Bihamta, M.R., Chogan, R. and Nemati, A.K. (2012). Assessment and determination of the most suitable drought resistance index for figures and advanced lines of bread wheat. International Journal of AgriScience 2(1):78-87.

Akçura, M., Ceri, S. (2011). Evaluation of drought tolerance indices for selection of Turkish oat (*Avena sativa* L.) landraces under various environmental conditions. Zemdirbyste = Agriculture 98(2):157-166.

Ali, M. B. and El-Sadek, A. N. (2016). Evaluation of drought tolerance indices for wheat (*Triticum aestivum* L.) under irrigated and rainfed conditions. *Communications in Biometry and* Crop Science *11*, 77-89.

Amini, A.R., Soleymani, A. and Shahrajabian, M.H. (2012). Assess the usefulness of various indices and yield potential in identifying cultivars of barley adapted to water stress. International Journal of Agriculture and Crop Sciences 4(7):364-367.

Atlin, G., Venuprasad, R., Bernier, J., Zhao, D., Virk, P. and Kumar, A. (2008). Rice germplasm development for drought-prone environments: progress made in breeding and genetic analysis at the. In: Serraj J, Bennett J, Hardy B, editors. Drought frontiers in rice: crop improvement for increased rainfed production. International Rice Research Institute.

Bahari, N. and Nasirifard, E. (2014). A study of drought-tolerance of soybeans using tolerance indices. Journal of Biodiversity and Environmental Sciences 4(5):349-353.

Betran, F.J., Beck, D., Banziger, M. and Edmeades, G.O. (2003). Genetic analysis of inbred and hybrid grain yield under stress and non-stress environments in tropical maize. Crop Sci 43:807- 817.

Bouslama, M. and Schapaugh, W.T. (1984). Stress tolerance in soybeans. I. Evaluation of three screening techniques for heat and drought tolerance. Crop Science *24*(5): 933-937.

Dehbalaei, S., Farshadfar, E. and Farshadfar, M. (2013). Assessment of drought tolerance in bread wheat genotypes based on resistance/tolerance indices. International Journal of Agriculture and Crop Sciences 5(20):2352-2358.

Drikvand, R., Doosty, B. and Hosseinpour, T. (2012). Response of rainfed wheat genotypes to drought stress using drought tolerance indices. Journal of Agricultural Science 4(7):126.

Farshadfar, E. and Elyasi, P. (2012). Screening quantitative indicators of drought tolerance in bread wheat (*Triticum aestivum* L.) landraces. Eur J of Exper Biol 2(3):577-584.

Farshadfar, E. and Javadinia, J. (2011). Evaluation of chickpea (*Cicer arietinum* L.) genotypes for drought tolerance. Seed and Plant Improvement Journal 27(1): 517-537.

Farshadfar, E., Mohammadi, R., Farshadfar, M. and Dabiri, S. (2013). Relationships and repeatability of drought tolerance indices in wheat-rye disomic addition lines. Australian Journal of Crop Science 7(1):130.

Fernandez, G.C.J. (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 water stress. Taiwan pp.257-270.

Fischer, K.S., Lafitte, R., Fukai, S., Atlin, G. and Hardy, B. editors. (2003). Breeding Rice for drought prone environments. Los Baños (Philippines): International Rice Research Institute p. 98.

Fischer, R.A. and Maurer, R. (1978). Drought resistance in spring wheat cultivars: I. Grain yield responses. Australian Journal of Agricultural Science 29:897-912.

Gavuzzi, P., Rizza, F., Palumbo, M., Campaline, R.G., Ricciardi, G.L. and Borghi, B. (1997). Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. Canadian Journal of Plant Science 77:523-531.

Kiani, M. (2013). Screening Drought Tolerance Criteria in Maize. Asian Journal of Agriculture and Rural Development 3(5):290-295.

Kristin, A.S., Senra, R.R., Perez, F.I., Enriquez, B.C., Gallegos, A.A., Vallego, P.R., Wassimi, N. and Kelley, J.D. (1997). Improving common bean performance under drought stress. Crop Science 37:43-50.

Lan, J. (1998). Comparison of evaluating methods for agronomic drought resistance in crops. Acta Agricult Bor-occid Sinic 7:85-87.

Maclean, J.L. (2002). Rice Almanac: Source Book for the Most Important Economic Activity on Earth. International Rice Research Institute.

Menezes, C.B., Ticona-Benavente, C.A., Tardin, F.D., Cardoso, M.J., Bastos, E.A., Nogueira, D.W. and Schaffert, R.E. (2014). Selection indices to identify drought-tolerant grain sorghum cultivars. Genetics and Molecular Research 13(4):9817-9827.

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

Mohammadi, M., Karimizadeh, R. and Abdipour, M. (2011). Evaluation of drought tolerance in bread wheat genotypes under dryland and supplemental irrigation conditions. Australian Journal of Crop Science 5(4):487-493.

Mohammadi, R., Armion, M., Kahrizi, D. and Amri, A. (2010). Efficiency of screening techniques for evaluating durum wheat genotypes under mild drought conditions. International Journal of Plant Production 4(1):11-24.

Moradi, H., Akbari, G.A., Khorasani, S.K. and Ramshini, H.A. (2012). Evaluation of drought tolerance in corn (*Zea mays* L.) new hybrids with using stress tolerance indices. European Journal of Sustainable Development 1(3):543-560.

Naghavi, M.R., Aboughadareh, A.P. and Khalili, M. (2013). Evaluation of drought tolerance indices for screening some of corn (*Zea mays* L.) cultivars under environmental conditions. Notulae Scientia Biologicae 5(3):388-393.

Nouraein, M., Mohammadi, S.A., Aharizad, S., Moghaddam, M. and Sadeghzadeh, B. (2013). Evaluation of drought tolerance indices in wheat recombinant inbred line population. Annals of Biological Research 4(3):113-122.

Nouri, A., Etminan, A., Teixeira da Silva, J.A. and Mohammadi, R. (2011). Assessment of yield, yield-related traits and drought tolerance of durum wheat genotypes (*Triticum turjidum* var. *durum* Desf.). Australian Journal of Crop Science 5(1):8-16.

Panthuwan, G., Fokai, S., Cooper, M., Rajatasereekul, S.O. and Toole, J.C. (2002). Yield response of rice genotypes to different types of drought under rainfed lowlands. Part 1: grain yield and yield components. Field Crop Res 41:45-54.

Pingali, P.L. (1997). From subsistence to commercial production systems: The transformation of Asian agriculture. American Journal of Agricultural Economics 628-634.

Rabiei, E., Khodambashi, M. and Pirbalouti, A.G. (2012). The study of the drought tolerance indices of oat (*Avena sativa* L.). Journal of Food, Agriculture & Environment 10(2):646-648.

Rad, A.H.S. and Abbasian, A. (2011). Evaluation of Drought Tolerance in Rapeseed Genotypes under Non Stress and Drought Stress Conditions. Notulae Botanicae Horti Agrobotanici Cluj – Napoca 39(2):164-171.

Ramirez, P. Kelly, J.D. (1998). Traits related to drought resistance in common bean. Euphytica 99:157-166.

Rosielle, A.A. and Hamblin, J. (1981). Theoretical aspects of selection for yield in stress and non-stress environment. Crop Science 21:943-946.

Safavi, S.M., Safavi, A.S. and Safavi, S.A. (2015). Evaluation of drought tolerance in sunflower (*Helianthus annuus* L.) under non-sress and drought stress conditions. Journal of Biodiversity and Environmental Sciences 6(1):578-584.

Serraj, J., Bennett, J. and Hardy, B. editors. (2008). Drought frontiers in rice: crop improvement for increased rainfed production. Singapore: World Scientific Publishing and Los Baños (Philippines): International Rice Research Institute 400 p.

Verulkar, S. B., Mandal, N. P., Dwivedi, J. L., Singh, B. N., Sinha, P. K., Mahato, R. N. and Robin, S. (2010). Breeding resilient and productive genotypes adapted to drought-prone rainfed ecosystem of India. Field Crops Research 117(2), 197-208.

Yan, W. and Kang, M. S. (2003). GGE biplot analysis: A graphical tool for geneticists, breeders, and agronomists.

Yan, W. and Rajcan, I. (2002). Biplot analysis of test sites and trait relations of soybean in Ontario. Crop Sci 42:11-2.

Yan, W., Cornelius, P.L., Crossa, J. and Hunt, L.A. (2001). Two types of GGE biplots for analyzing multi-environment trial data. Crop Sci 41:656-663.

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