**RESEARCH ARTICLE**

# DROUGHT RESISTANCE PARAMETERS AS SELECTION PARAMETERS TO IDENTIFY DROUGHT TOLERANT RICE GENOTYPES

**A.K. Mall and Varucha Misra***

*ICAR-Indian Institute of Sugarcane Research, Lucknow-226 002, U.P.*
*Email: Ashutosh.Mall@icar.gov.in*

*Received-07.11.2018, Revised-27.11.2018*

**Abstract:** Multidimensional effect of drought on rice cultivation in Asia is a recurring climatic event. about 4.62 and 6 million ha area of rice in India in year 2002 and 2009, respectively had been reduced alone due to drought. The development of high yielding drought tolerant rice varieties for diverse nature of drought prone upland ecology is still in its infancy and germplasm still needs to be improved in rainfed eastern India. Considering this, this study has been done to evaluate early maturing genotypes over the season for upland areas of sufficient and deficit moisture regimes. Twenty seven genotypes in advanced yield trial less than 100 days (AYTLT 100 days) were tested for drought tolerance and yield performance. Results showed that Genotype x environment interaction accounted for 32 per cent of the total sum of squares, with environment and genotype responsible for 25 per cent and 43 per cent. There was also significant variation in the delay in flowering among drought stressed genotypes in which flowering time was similar under irrigated condition. Similarly, significant genotypic differences in Drought susceptibility index (DSI) based on grain yield (t $ha^{-1}$) in each year was also observed. Yield reduction was above 50 per cent except Lalsar in all the environments, while, yield reduction varied from 83.33 per cent in Brown Gora up to 99.28 per cent in RR 366-5 under severe drought stress. In case of desirable stability factor, among the genotypes, only Lalsar followed by CR 143-2-2 showed desirable stability factor for grain yield (t $ha^{-1}$). Results also revealed that 66 out 78 estimates of correlations assumed significant in all the years and out of 66 estimates of significant correlations, forty two had positive sign and fourteen were negative, mostly estimates were common in nature and led to similar inferences in all the years. Furthermore, the biplot analysis for indices showed that drought resistance parameters and their interaction with drought tolerance parameters were highly significant ($P<0.001$) and accounted for 94.6 and 3.6 per cent of the treatment combination sum of squares, respectively.

**Keywords:** Drought, DSI, DTE, G X E interaction, rice, biplot analysis

**Abbreviations:** AYTLT 100 days- Advanced Yield Trial Less Than 100 days, $RY_{WW}$ - Relative yield under well water, $RY_{SS}$ -Relative yield under stress condition, GMP - Geometric Mean, STI- Stress Tolerance Index, TOL- Stress Tolerance, MP- Mean Productivity, GMP- Geometric Mean Productivity, YRR- Yield Reduction Ratio, TOL- Stress Tolerance, DTI- Drought Tolerance Index; DSI- Drought Susceptibility Index, DTE- Drought Tolerant Efficiency, GY- Grain Yield; DFF- Days To Fifty Per Cent Flowering, HI- Harvest Index

## INTRODUCTION

Multidimensional effect of drought on rice cultivation in Asia is a recurring climatic event and climatically induced phenomenon. India accounts for the largest share (13.57 m ha) of the total drought prone rice area in Asia where yield losses due to drought are reported to cost an average of US $259 million annually (Bernier *et al.*, 2008). Drought alone reduced the area of rice about 4.62 and 6 million ha in year 2002 and 2009, respectively. In the eastern Indian states of Jarkhand, Orissa, and Chhattisgarh alone, rice production losses during severe droughts (about 1 year in 5) average about 40 per cent of total production, with an estimated value of $650 million (Pandey *et al.*, 2005). These losses affect the poorest farmers and their communities disproportionately. Drought risk reduces productivity, even in favorable years, because farmers avoid investing in inputs when they fear crop loss. Therefore, droughts have long-term destabilizing effects. Grain yield may be drastically reduced when water deficit coincides with vegetative stage or intermittent and screening for drought resistance at the vegetative stage in the dry season had long been used (Chang *et al.*, 1974; De Datta *et al.*, 1988 and Pantuwan *et al.*, 2004). The development of high yielding drought tolerant rice varieties for diverse nature of drought prone upland ecology is still in its infancy and germplasm still needs to be improved in rainfed eastern India. In the view of above, at CRRI, Cuttack considerable work has been done to evaluate early maturing genotypes over the season for upland areas of sufficient and deficit moisture regimes.

## MATERIALS AND METHODS

### Experimental site, design and tested genotypes

Field experiments conducted under well-watered ($E_1$) and managed stress ($E_2$) conditions by direct-sown, non-puddled and non-flooded in leveled fields. Drought stress was artificial imposed during the vegetative stage as managed stress environment under aerobic condition and experiments under well water condition where no stress was imposed are referred to as non-stress trials and conducted under an anaerobic soil environment with pounded water. Twenty seven genotypes in advanced yield trial less than 100 days (AYTLT 100 days) were tested for

*Corresponding Author

drought tolerance and yield performance. Performance under vegetative stage drought stress twelve genotypes were selected and evaluated over three years during dry season to study the magnitude and consistency of yield response of diverse, rainfed upland rice genotypes and to identify genotypes that confer drought tolerance at CRRI, Cuttack. The experiments were established by dry seeding in late January and exposing 30 days old seedlings to drought stress for more than 30 days in Alpha Lattice Design with three replications.

### Crop management

Rice varieties were directly sown at 2-3 cm soil depth in dry and pulverized soil by hand plough with the seed rate of 60 Kg ha$^{-1}$ to maintain 3-4 seeds per hill. This method gave uniform seedling emergence for all the plots in 6-8 days. Each plot was 4.5 m long and 5.0 m wide, row to row distance was 15 cm and plant to plant distance was 10 cm each plot. Fertilizer was applied at the rate of 80, 40, and 40 kg ha$^{-1}$ of N, $P_2O_5$, and $K_2O$, respectively. One third of nitrogen and entire dose of $P_2O_5$ and $K_2O$ were given as basal dressing and remaining N was split into two doses applied at maximum tillering and flowering stages. Recommended package of practices was followed to raise good crop. Weeds were controlled by treating plot by pre-emergence herbicide (Petrilachlore) after three days of sowing followed by two hand weeding. Need based pest control measures were taken as and when required.

### Observations and evaluation

Ten plants from each plot were randomly chosen for recording observations on their days to fifty per cent flowering (DFF) and harvest index (HI). Observations on grain yield (GY) were recorded on the plot basis. The plot yield was recorded in grams in each line and then data was converted in tons to hectare basis. The effect of drought was assessed as percentage reduction in mean performance of characteristics under managed drought stress condition relatively to the performance of the same trait under well water condition. The levels of stress were monitored through tensiometers. The trials were re-irrigated only when the tensiometers reading reached to 80 kPa at 20 cm depth. Genotypes were visually scored for drought reaction at 10-12 per cent soil moisture content at 30-cm soil depth and below 90 cm water table depth. Grain yield and yield attributes were recorded at maturity after recovering the crop on re-irrigation. The data were analyzed by appropriate statistical analysis (Gomez and Gomez, 1984) using CropStat 7.2 (2009) programme.

To assess the selection criteria for identifying drought tolerant genotypes and high yielding genotypes under both the water regimes, ten drought tolerance indices *viz*., drought susceptibility index (DSI) by Fischer and Maurer (1978) and drought tolerant efficiency (DTE): yield stability parameters which are based on reduction under stress by Fischer and Wood (1981); drought tolerance index (DTI): yield reduction in per cent by Fernandez (1992); stress tolerance (TOL): differences in yield under stress ($Y_S$) and well water conditions ($Y_I$) by Rosielle and Hamblin (1981); geometric mean productivity (GMP): relative performance by Fernandez (1992); mean productivity (MP): average of $Y_s$ and $Y_{WW}$ by Rosielle and Hamblin (1981); stress tolerance index (STI): identify genotypes producing high $Y_S$ and $Y_{WW}$ by Fernandez (1992); rate of productivity (RP): ratio of $Y_S$ and $Y_I$; yield reduction ratio (YRR): 1-($Y_S/Y_I$) by Golestani and Assad (1998) and relative yield ($RY_S$ and $RY_{WW}$): yield under drought divided by that of the highest yielding genotypes in population by Ahmad *et al*. (2003) were used.

## RESULTS

### Analysis of variance

The nature of genotype by environment (G x E) interaction in rainfed upland rice genotypes was examined using data for 12 genotypes under irrigated and vegetative stage stress during 2007, 2008 and 2009. Varieties were significantly varied from each other, indicating presence of genetic variability in the experimental materials while, all the characters were influenced by environments and recorded significant genotype x environment interactions (G x E).

Genotype x environment interaction accounted for 32 per cent of the total sum of squares, with environment and genotype responsible for 25 per cent and 43 per cent. Significant differences environments (E) and genotype x environment interactions (G x E) for all the characters indicating the differential response of genotypes in different environmental conditions. This is in agreement with earlier reports (Wade *et al*., 1999 and Panwar *et al*., 2008).

### Drought susceptibility index for days to 50 per cent flowering (days) and harvest index

In rice, drought stressed plants delay flowering relative to well-watered plants. Drought in the vegetative development stage can delay flowering up to 3 to 4 weeks in photoperiod-insensitive varieties. The delay in flowering is largest with drought early in the vegetative stage and is smaller when drought occurs later. In present study, results revealed significant variation in the delay in flowering among drought stressed genotypes in which flowering time was similar under irrigated condition. The delay was negatively associated with grain yield (r = -0.41** in $E_1$, r = -0.51** in $E_2$ & r = -0.44** in $E_3$) and harvest index (r = -0.38** in $E_1$, r = -0.45** in $E_2$ & r = -0.52** in $E_3$) and positively associated with yield reduction percentage (r = -0.50** in $E_1$, r = -0.58** in $E_2$ & r = -0.54** in $E_3$). There was a negative (r = -0.35** in $E_1$, r = -0.41** in $E_2$ & r = -0.40** in $E_3$) relationship between delay in flowering time and grain yield under drought stress. Genotypes that had a shorter delay produced higher grain yield.

The drought stress in all the years, generally delayed flowering time in all the tested genotypes (Table 1). The estimate of DSI for genotype ranged from 0.49 (CR 143-2-2) to 3.70 (RR 440-167-2-13) in $E_1$, 0.21 (CR 143-2-2) to 2.18 (IR 76569-259-1-1-3) $E_2$ and 0.38 (Thara) to 2.72 (RR 440-167-2-13) in $E_3$. Kalinga III showed high DSI values (>1) over the years while, Vandana recorded low DSI (<1) value almost the years. The genotypes *viz*., CR 143-2-2, Lalsar, CBT 3-06 and Brown Gora were consistent performer and recorded low DSI and little delay in flowering.

The genotypes with drought resistance can be identified by measuring delay in flowering indicated by several studies (Pantuwan *et al*., 2002, Jongdee *et al*., 2006, Zou *et al*., 2007 & Bernier *et al*., 2008). The varieties for drought prone rainfed upland, less than 100 days duration is desirable. However, if flowering is delayed by more than a few days, severe yield losses usually occur. So, upland genotypes cannot have luxury of larger delay in flowering due to short maturing nature. It has been reported that the greater the delay in flowering, the greater the yield and harvest index reduction due to drought (Bernier *et al*., 2008 & Pantuwan *et al*., 2002). Early maturing cultivars may be affected severely by early season drought, whereas late maturing cultivars may have sufficient time to recover from it (Maurya and O'Toole, 1986). Furthermore, selection for drought tolerance did not alter days to flowering and non-significant differences were observed under severe stress and as well as under well water condition reported by Kumar *et al*. (2008). The variation in DSI among and within twelve rice genotypes was measured when plants were exposed to vegetative stage severe stress condition. Variation in the delay in flowering among genotypes that have been exposed to the same drought conditions can be used as an index of drought tolerance (Pantuwan *et al*., 2002).

A short delay in flowering was associated with lower yield under early season drought conditions, in contrast to the case of terminal drought. In which a short delay was advantageous. In formal case, early flowering varieties flowered before full recovery and hence yield decreased, whereas late flowering varieties had more time to recover before flowering took place. The result indicated that genotypes with drought resistance can be identified by using DSI or delay in flowering. Genotypes with a longer delay in flowering time were consistently associated with a larger yield reduction under severe stress condition. The consistent estimates of DSI or flowering delay were obtained among almost all the genotypes during across the years. However, Pantuwan *et al*. (2002) observed large genotype by environment interactions for grain yield and delay flowering and reported inconsistent estimates of DSI and flowering delay under various types of drought.

Rice genotypes with drought tolerance traits are known to produce the highest seed yield under severe stress conditions (Kamoshita *et al*., 2008). Because of the long time from the time of stress to harvest, drought-resistance traits during vegetative stage drought may not be related to grain yield (Lafitte *et al*., 2002). Plant growth resumes after vegetative stage drought and this recovery growth then affects the development of sink size as well as source supply to meet the demand of the grain. Field studies (Lilley and Fukai, 1994 and Mitchell *et al*., 1998) and pot studies (Wade *et al*., 2000; Kamoshita *et al*., 2004) both show genotypic variation in short term recovery growth (e.g., 1 week to a few weeks) after vegetative stage drought, and these authors have reported the relationships between this genotypic variation and the amount of leaf remaining at the end of drought and the ability to tiller after drought.

Although the benefits of short term drought recovery traits on yield are difficult to demonstrate, a number of studies have shown that later maturing and longer growth duration cultivars show less growth stagnation and drought damage and have a higher yield when they encounter mild water shortages during the vegetative to panicle initiation stages (e.g., Fukai and Cooper, 1995; Hayashi *et al*., 2006 and Ikeda *et al*., 2008).

## Drought resistance parameters

### Drought susceptibility index (DSI) and drought tolerance efficiency (DTE)

Drought susceptibility index (DSI) is represents drought tolerance at whole plant level regardless of drought tolerance mechanism in operation (Chauhan *et al*., 2007). The selected genotypes for lower drought susceptibility index may have diverse tolerance mechanisms rather than based on single drought tolerant traits because drought tolerance is a complex phenomenon and does not always solely depend on single plant trait. Therefore, such type of genotypes may successfully cope with drought under range of environments.

The DSI for the various characteristics is presented in Table 3. There were significant genotypic differences in DSI based on grain yield (t $ha^{-1}$) in each year (Table 4). Drought susceptibility index which was one of the drought resistance parameters were ranged from 0.53 (Lalsar) to 0.91 (Kalinga III) in $E_1$; 0.53 (Lalsar) to 0.90 (CBT 3-06) in $E_2$ and 0.53 (Lalsar) to 0.96 (Thara) in $E_3$. The mean values of DSI for grain yield in all the years were below 1 (0.79 in $E_1$ & $E_2$, 0.80 in $E_3$), indicating the relative tolerance for grain yield in tested genotypes which recorded low DSI consistently over the years. Genotype with low DSI values (less than 1) can be considered to be drought resistant (Chauhan *et al*., 2007) because they exhibited smaller yield reductions under severe stress compared with well water conditions than the mean of all genotypes. Differences in DSI between genotypes were observed for all characteristics under investigation. A genotype with low DSI must have some characteristics that prevent the loss of yield under drought, but will not be desirable if those yields are below average.

Another drought tolerant parameter, DTE and values of this parameter were ranged from 18 (Kalinga III) to 52 (Lalsar) in $E_1$; 16 (CBT 3-06 & Thara) to 50 (Lalsar) in $E_2$ and 20 (Kalinga III & Thara) to 62 (Lalsar) in $E_3$. While, Lalsar had the highest DTE and lowest DSI values followed by CR 143-2-2 in all the years. Interestingly, above mentioned genotypes recorded high yields (>1 t $ha^{-1}$) under drought but showed low yield potential (<3 t $ha^{-1}$) under irrigated condition, might be because of high inherent tolerance to drought stress.

Drought tolerant genotypes in general have high DTE, low DSI and minimum reduction in grain yield under severe stress. The reduction in most of the characteristics under drought condition could be attributed to decreased translocation of assimilates and growth substances, impairing nitrogen metabolism, loss of turgidity and consequently reduced sink size. In view of this, Lalsar and CR 143-2-2 were identified as the most drought tolerant genotypes among the tested genotypes. On the other hand, Thara, Vandana and Kalinga III were the drought sensitive genotypes with maximum yield loss in comparison to above said genotypes.

The reduction in seed yield under stress condition among the different genotypes across the years, which ranged between 38 per cent and 84 per cent, while, earlier findings where large yield reductions in rice under drought stress conditions were reported (Ouk *et al*., 2006 and Pantuwan *et al*., 2002). Genotypes differed in DSI, but the estimate of the DSI was almost consistent across drought stress years. Pantuwan *et al* (2002) used this method to estimate the magnitude of the response of genotypes to a particular drought stress environment and reported inconsistent estimate of DSI among most of the experiments due to differences in timing and intensity of water stress. Although large variation persist between stress condition, genotypes with low DSI and high yield potential performed consistently across the stress conditions for most of the genotypes. Thus DSI was shown to be associated with drought tolerance. Ouk *et al*. (2006) reported that this techniques can be used to identify genotypes that confer drought tolerance. These findings differ from that of Pantuwan *et al*. (2002) who suggested that there was no consistency of DSI across varying drought environments. Considering the assimilate partitioning in component traits, Lalsar increased the grain yield. Further, it had the highest DTE, least DSI and highest percentage increase in the grain yield due to stress. So, the preliminary findings showed *Lalsar* was the most drought tolerant genotype among the tested ones. In present study, significant correlations were observed between $GY_{WW}$ and $GY_{SS}$, and drought stress parameters (DTE and DSI). Similar findings were reported by Bahar and Yildirim (2010) and found positive correlation (r=0.416*) between $GY_{SS}$ and DTE, and a negative correlation (r=-0.620**) between $GY_{WW}$ and DTE. While, significant negative correlation was found between DTE and DSI. In addition to this, they suggested that these indices can be easily used to find drought tolerant genotypes in wheat breeding programme.

**Drought tolerance index (DTI), Stress tolerance (TOL), mean productivity (MP), geometric mean (GMP), stress tolerance index (STI) and yield reduction ratio (YRR):**

Drought tolerance index indicated the percentage reduction in grain yield caused by drought stress. In present study, yield reduction was above 50 per cent except Lalsar in all the environments and CR 143-2-2 in $E_3$ only, while, yield reduction varied from 83.33 per cent in Brown Gora up to 99.28 per cent in RR 366-5 under severe drought stress.

Genotypes with high TOL values are sensitive to stress and selection must be done based on low rates of this index in order to selecting drought tolerant genotypes. Lalsar, RR 440-167-2-13 and CR 143-2-2 genotypes in all the year, from this view had the yield stability among the other genotypes. Using MP and TOL indices, it can be separated genotypes producing high yields solely under well water condition. Furthermore, Kalinga in $E_1$ and $E_2$ and CBT 3-06 in $E_3$ had the highest MP value and hence, had the highest genotypic yield under irrigated condition. Based on GMP, genotypes, Kalinga, CBT 3-06 and CR 143-2-2 in $E_1$, $E_2$ and $E_3$, so could be classified as genotypes with high yields under both conditions. According to Fernandez (1993), more stable genotypes have higher rates of STI. Using this index, genotypes having remarkable yields under stress and non stress conditions could be recognized. Based on this index, Kalinga and CBT 3-06 were classified as moderate tolerant genotypes. In respect of YRR, low value is desirable and Lalsar and CR 143-2-2 recoded low value for this index in all the environments.

**Relative yield under well water ($RY_{WW}$) and stress condition ($RY_{SS}$) and Rate of productivity**

A stress tolerant genotype as defined by DSI need necessarily not have a high yield potential. The mean relative grain yields values under imposed water stress and well water conditions were 0.70 in $E_1$, 0.66 in $E_2$ and 0.59 in $E_3$ and 0.73 in $E_1$, 0.67 in $E_2$ and 0.72 in $E_3$, respectively. Mean relative yield in case of water stress was less than that of irrigated conditions. The genotypes CR 143-2-2 (0.93), Lalsar (0.85) and IR 76569-259-1-1-3 (0.70) in $E_1$; CR 143-2-2 (1.01), Kalinga III (0.78), RR 440-167-2 (0.78), Lalsar (0.74) and CB 0-13-1 (0.67) in $E_2$ and CBT 3-06 (0.96), Vandana (0.96), CR 143-2-2 (0.78) and Lalsar (0.65) in $E_3$ were relatively high yielding under severe stress condition (RY> mean RY), while rest of the genotypes in all the environments were relatively low yielding (RY< mean RY) in this treatment.

In the present study, among the genotypes, only Lalsar followed by CR 143-2-2 showed desirable stability factor for grain yield (t $ha^{-1}$). Contrary to this rest of the genotypes were showed unfavorable stability factor (SF<1) except two above said genotypes (Table 3). None of the genotypes recorded relatively greater value of stability factor ratio (>1.00) for grain yield (t $ha^{-1}$). Cursory view of stability factors for grain yield *vis-à-vis* that stability of grain yield in respect of promising hybrids was imparted by component traits. This superior performance of such genotypes for stability could possible is attributed to the pre dominance of non-fixable effects.

**Correlation Coefficient**

In the present study, 66 out 78 estimates of correlations assumed significant in all the years and out of 66 estimates of significant correlations, forty two had positive sign and fourteen were negative, mostly estimates were common in nature and led to similar inferences in all the years. It appears that the adverse nature of severe drought condition brought increase in degree of character associations (Table 5).

In this study, statistically significant correlations between grain yields under well water condition ($GY_{WW}$), grain yield under severe stress ($GY_{SS}$), and drought stress parameters (DTE and DSI) were obtained. Thus, negative correlation (r= -0.890** in $E_1$, -0.801** in $E_2$ and -0.604** in $E_3$, $p < 0.01$) was shown between $GY_{WW}$ and DTE while positive correlation (r= 0.607** in $E_1$, 0.687** in $E_2$ and 0.664** in $E_3$, $p < 0.01$) between $GY_{SS}$ and DTE. Also, there was a positive correlation (r= 0.891** in $E_1$, 0.803** in $E_2$ and 0.604** in $E_3$, $p < 0.01$) between $GY_{WW}$ and DSI; and negative correlation (r= -0.605** in $E_1$, -0.683** in $E_2$ and -0.664** in $E_3$, $p < 0.01$) between $GY_{SS}$ and DSI. In addition, a great negative correlation (r = - 0.999***) over the years, $P < 0.001$) was found between DTE and DSI.

To determine the most desirable drought tolerance criteria, the correlation coefficient between $Y_{WW}$, $Y_{SS}$ and other quantitative indices of drought tolerance were calculated (Table 5). The correlation matrix, indicated strong and significant ($p< 0.01$) correlation of $GY_{WW}$ with DSI, DTI and YRR simultaneously, above said indices showed strong negative association with $GY_{SS}$. Also, grain yield was positively and significantly correlated with DTE, TOL and RP under stress environment, while this relationship stronger in irrigated conditions. There were positive significant correlations among $GY_{WW}$ and (MP, GMP and STI) and $GY_{SS}$ and (MP, GMP and STI). The correlation coefficient for $RY_{WW}$ *vs*. grain yield under well water condition ($GY_{WW}$) and $RY_{SS}$ *vs*. grain yield under severe stress ($GY_{SS}$) were positive and strong in all the years. Non significant and negative associations were found between $GY_{WW}$ and $GY_{SS}$ over the years.

In the present study, a very strong negative association of DSI was observed with DTE, TOL, RP and $RY_{SS}$. On the other hand, DTI followed by YRR, $RY_{WW}$ GMP and STI were found to be most important associates of DSI. The two indices *viz*., $RY_{WW}$ and $RY_{SS}$ were exhibited strong positive correlations with GMP and STI.

All the parameters studied above helped to select the lines, which may be promising for dry land conditions, but it is difficult to conclude that which parameters(s) is more effective than the other for screening the drought resistant genotypes. To solve this problem, correlation studies were made between the drought parameters in each variety and presented in Table 5.

Grain yield under well water condition was not correlated with severe stress condition suggesting that a high potential yield under optimum condition does not necessarily result in improved yield under stress condition like above, $GY_{SS}$ *vs* $RY_{WW}$ and $GY_{WW}$ *vs* $RY_{SS}$ were adversely correlated. Almost all the indices were highly correlated with each other as well as with $GY_{SS}$ and $GY_{WW}$. Thus, through these indices it is possible to distinguish high yielding genotypes in either condition. $GY_{WW}$ and $GY_{SS}$ had significant and positive correlation with GMP and results of Ramirez *et al*. (1998) confirmed this matter. $GY_{SS}$ with STI, GMP and STI had negative and significant correlation which is in agreement with Golabadi *et al*. (2006). Pleiotropy and/or linkage may also be the genetic reason for this type of negative association. Moreover, the correlations among STI, MP and GMP exhibited same trend, thus they can be introduced as the most desirable indices for screening drought tolerance genotypes. Nazari and Pakniyat (2010) stated the importance of stress intensity and reported that STI is most desirable index for drought tolerance.

The correlation coefficient of DSI with $GY_{WW}$ was high and positive while, that of TOL with $GY_{SS}$ was high and negative. Thus, selection for tolerance should decrease yield in the well water condition and increase grain yield under severe stress. The correlation coefficients of TOL with $GY_{SS}$ and that of SSI with $GY_{WW}$ were negligible by Saba *et al*. (2001). The greater the TOL value, the larger the yield reduction under severe stress condition and the higher the drought sensitivity. The lack of a correlation between TOL and GMP and between TOL and STI would indicate that the combination of high GMP and STI with low TOL can accessible in rice (Nazari and Pakniyat, 2010). Mean productivity was not correlated with $RY_{SS}$ and yield under severe stress (Table 5). While, above said index negatively correlated with stability factor. Correlation coefficient values for MP index indicated that increase in yield potential would not beneficial for developing high yielding genotypes for water limiting or drought prone areas. $GY_{SS}$ and $GY_{WW}$ had significant and positive correlation with MP which was completely in accordance with Ferrandez (1993). In present study, TOL and DSI associated with all the indices except MP with TOL. However, TOL and SSI were not strongly correlated with the above mentioned indices reported by Saba *et al* (2001).

Fernandez (1993) compared effectiveness of several stress tolerance criteria (GMP, MP, DSI, STI, TOL) and concluded that MP, DSI and TOL failed to identify genotypes with both high yield and stress tolerance potentials, whereas through STI, genotypes with these attributes could be identified. Clark *et al* (1992) observed year-to-year variation in DSI within genotypes as well as changes in genotype ranking within years. Limitations of using the DSI and TOL indices have already been described in wheat (Clarke *et al*., 1992). Therefore, on the basis of the results and earlier studies, DSI, DTE, STI and TOL seem to be useful yield-based drought tolerance indices to be employed in plant breeding programs for rice.

The conventional method of partitioning total variation in to components, convey little information on the individual pattern of response (Zobel *et al*., 1988). To increase accuracy, additive main effects and multiplicative interaction is the first model of choice when main effects and interaction are both important. Many researchers has been used the biplot analysis for comparison of different genotypes for different criteria and in different crops. Kaya *et al*. (2002) were reported that wheat genotypes with larger IPCA 1 and lower IPCA 2 scores gave high yields (stable genotypes) and genotypes with lower IPCA 1 and larger IPCA 2 scores had low yields (unstable genotypes). In present study, drought tolerance indices which accounted for 94.6 per cent of the total sum square and the genotype by drought tolerance indices interaction effects which captured 3.6 per cent which accounted for principal component analysis (PCA) were significant indicating that two out of three sources are important in the analysis. The results showed that indices main effect was the most important source of variation, due to its large contribution to the total sum of squares. Variation due to drought tolerance indices was larger than that due to interaction, but interaction was significant meaning that differences among genotypes vary across indices. The IPCA1 explained 72.4 per cent of the interaction sum of square with yield potential and drought tolerance. Similarly, the second principal component axis named as stress tolerant dimension explained 26.6 per cent of interaction sum of square. Genotypes or indices with large negative or positive IPCA1 scores have high interactions, while those with IPCA1 scores near zero (close to the horizontal line) have little interaction across indices and *vice versa* for indices (Crossa *et al*., 1991) and are considered more stable than those further away from the line. Thus, selection of genotypes that have high PCA 1 and low PCA 2 are suitable for favorable and stress conditions. Therefore, genotypes Lalsar, RR 440-167-2-13 and CR 143-2-2 are desirable for both water regimes. Similarly, Nazari and Pankniyat (2010) reported 69.27 per cent for IPCA 1 with five drought tolerance indices.

### Biplot analysis

The biplot analysis for indices showed that drought resistance parameters and their interaction with drought tolerance parameters were highly significant ($P<0.001$) and accounted for 94.6 and 3.6 per cent of the treatment combination sum of squares, respectively. Biplot analysis confirmed correlation analysis between studied criteria. As indicated by the F-test, the first two interaction PCA axes were highly significant. The IPCA1 and IPCA2 declared 72.4 and 26.6 per cent of the observed drought resistance parameters by genotypes variation sum of squares, respectively.

**Table 1.** Drought Susceptibility Index (DSI) for days to 50 per cent flowering (DFF) and harvest index (HI) in Upland rice genotypes

| Genotypes | Drought Susceptibility Index (DSI) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Days to 50 per cent flowering (Days) | | | | Plant Height (cm) | | | | Harvest index | | | |
| | 2007 | 2008 | 2009 | Pooled | 2007 | 2008 | 2009 | Pooled | 2007 | 2008 | 2009 | Pooled |
| **Brown Gora** | 0.68 | 1.01 | 0.54 | 0.74 | 1.07 | 1.03 | 1.15 | 1.09 | 1.06 | 1.10 | 1.94 | 1.37 |
| **CB 0-13-1** | 1.21 | 1.22 | 1.79 | 1.41 | 1.50 | 1.75 | 1.69 | 1.67 | 1.05 | 0.99 | 1.71 | 1.25 |
| **CBT 3-06** | 0.75 | 1.94 | 1.64 | 1.44 | 1.60 | 1.56 | 1.44 | 1.56 | 0.84 | 0.94 | 1.65 | 1.14 |
| **CR 143-2-2** | 0.49 | 0.21 | 0.90 | 0.53 | 0.85 | 1.16 | -0.14 | 0.65 | 0.84 | 1.04 | 1.79 | 1.22 |
| **IR 76569-259-1-1-3** | 0.82 | 2.18 | 1.37 | 1.46 | 0.78 | 0.58 | 0.83 | 0.74 | 0.89 | 0.94 | 1.71 | 1.18 |
| **Kakro** | 0.76 | 1.79 | 1.21 | 1.25 | 1.72 | 1.44 | 1.74 | 1.66 | 1.04 | 0.99 | 1.76 | 1.26 |
| **Kalinga** | 1.13 | 2.02 | 1.80 | 1.65 | 0.72 | 0.84 | 0.84 | 0.80 | 1.03 | 1.02 | 1.77 | 1.27 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lalsar** | 0.70 | 0.89 | 0.91 | 0.83 | 0.58 | 0.70 | -0.28 | 0.34 | 0.89 | 0.80 | 1.59 | 1.09 |
| **RR 383-2** | 1.20 | 0.83 | 1.17 | 1.07 | 0.93 | 1.00 | 0.99 | 0.98 | 1.06 | 1.07 | 1.89 | 1.34 |
| **RR 440-167-2-13** | 3.70 | 0.31 | 2.72 | 2.24 | 0.31 | 0.10 | 0.24 | 0.19 | 0.78 | 0.71 | 1.49 | 0.99 |
| **Thara** | 0.99 | 1.03 | 0.38 | 0.80 | 0.68 | 0.88 | 0.86 | 0.82 | 1.06 | 1.07 | 1.87 | 1.33 |
| **Vandana** | 0.79 | 0.93 | 1.09 | 0.94 | 0.93 | 0.68 | 1.62 | 1.10 | 0.96 | 0.88 | 1.65 | 1.16 |
| **Mean** | 1.10 | 1.19 | 1.29 | 1.19 | 0.97 | 0.97 | 0.91 | 0.97 | 0.96 | 0.96 | 1.73 | 1.22 |

**Table 2.** Analysis of variance for days to 50 per cent flowering, harvest index and their drought tolerance indices in upland rice genotypes

| **Source of Variation** | **Mean Sum of Squares** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Days to 50 per cent flowering** | | | | **Harvest index** | | | |
| | **DTF (I)** | **DTF (S)** | **DSI** | **DTE** | **HI (I)** | **HI (S)** | **DSI** | **DTE** |
| **Year** | 1476.12** | 3796.59** | 0.22 | 930.50** | 0.02** | 0.05** | 7.24** | 1409.76** |
| **Genotype** | 367.09** | 341.64** | 2.18 | 361.66 | 0.02** | 0.004 | 0.11** | 278.29** |
| **Year x Genotype** | 57.48 | 134.95 | 2.49 | 519.11 | 0.01 | 0.001 | 0.008 | 26.29 |

**Table 3.** Estimates of drought susceptibility index (DSI), drought tolerance efficiency (DTE), drought tolerance index (DTI) and rate of productivity (RP) of upland rice genotypes for grain yield (t ha$^{-1}$)

| **Genotypes** | **Grain yield (t ha$^{-1}$)** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2007** | | | | **2008** | | | | **2009** | | | | **Pooled** | | | |
| | **DSI** | **DTE** | **DTI** | **RP** | **DSI** | **DTE** | **DTI** | **RP** | **DSI** | **DTE** | **DTI** | **RP** | **DSI** | **DTE** | **DTI** | **RP** |
| **Brown Gora** | 0.83 | 23 | 77 | 0.23 | 0.82 | 24 | 76 | 0.24 | 0.94 | 22 | 78 | 0.22 | 0.86 | 23.08 | 77 | 0.23 |
| **CB 0-13-1** | 0.84 | 23 | 77 | 0.23 | 0.80 | 26 | 74 | 0.26 | 0.95 | 20.83 | 79 | 0.21 | 0.86 | 23.15 | 77 | 0.23 |
| **CBT 3-06** | 0.85 | 22 | 78 | 0.22 | 0.92 | 16 | 84 | 0.16 | 0.75 | 37.45 | 63 | 0.37 | 0.84 | 25.07 | 75 | 0.25 |
| **CR 143-2-2** | 0.80 | 26 | 62 | 0.38 | 0.83 | 23 | 60 | 0.40 | 0.33 | 72.29 | 50 | 0.50 | 0.68 | 39.38 | 61 | 0.39 |
| **IR 76569-259-1-1-3** | 0.77 | 30 | 70 | 0.30 | 0.89 | 18 | 82 | 0.18 | 0.90 | 25.34 | 75 | 0.25 | 0.86 | 23.83 | 76 | 0.24 |
| **Kakro** | 0.78 | 28 | 72 | 0.28 | 0.84 | 23 | 77 | 0.23 | 0.91 | 24.87 | 75 | 0.25 | 0.84 | 24.99 | 75 | 0.25 |
| **Kalinga** | 0.89 | 18 | 82 | 0.18 | 0.88 | 19 | 81 | 0.19 | 0.97 | 19.53 | 80 | 0.20 | 0.91 | 18.86 | 81 | 0.19 |
| **Lalsar** | 0.66 | 39 | 48 | 0.52 | 0.66 | 40 | 50 | 0.50 | 0.35 | 71.30 | 38 | 0.62 | 0.57 | 49.58 | 46 | 0.54 |
| **RR 383-2** | 0.82 | 25 | 75 | 0.25 | 0.85 | 22 | 78 | 0.22 | 0.93 | 22.61 | 77 | 0.23 | 0.87 | 22.93 | 77 | 0.23 |
| **RR 440-167-2-13** | 0.65 | 41 | 59 | 0.41 | 0.67 | 38 | 62 | 0.38 | 0.75 | 37.51 | 62 | 0.38 | 0.69 | 38.67 | 61 | 0.39 |
| **Thara** | 0.86 | 21 | 79 | 0.21 | 0.91 | 16 | 84 | 0.16 | 0.97 | 19.51 | 80 | 0.20 | 0.91 | 18.77 | 81 | 0.19 |
| **Vandana** | 0.87 | 20 | 80 | 0.20 | 0.90 | 17 | 83 | 0.17 | 0.67 | 44.37 | 56 | 0.44 | 0.83 | 26.51 | 73 | 0.27 |
| **Mean** | 0.80 ±0.02 | 28 ±1.23 | 72 ±1.26 | 0.28 ±0.02 | 0.83 | 26 | 74 | 0.26 | 0.79 | 34.79 | 68 | 0.32 | 0.81 ±0.008 | 27.91 ±0.71 | 72 ±0.71 | 0.28 ±0.007 |

**Table 4.** Analysis of variance for GY$_{WW}$, GY$_{SS}$ and drought tolerance indices in upland rice genotypes

| **Source of Variation** | **Mean Sum of Squares** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **GY$_{WW}$** | **GY$_{SS}$** | **DSI** | **DTE** | **DTI** | **TOL** | **MP** | **GMP** | **STI** | **YRR** | **RP** | **RY (WW)** | **RY (SS)** |
| **Year** | 1.77** | 0.36** | 0.07** | 337.55** | 337.55** | 0.36** | 0.60** | 0.44** | 6.60** | 0.03** | 0.03** | 0.04** | 0.13** |
| **Genotype** | 5.41** | 0.23** | 0.13** | 1043.93** | 1043.93** | 0.23** | 1.38** | 0.53** | 6.89** | 0.10** | 0.10** | 0.25** | 0.11** |
| **Year x Genotype** | 0.22** | 0.13** | 0.02** | 103.90** | 103.90 | 0.13** | 0.09** | 0.13** | 2.31** | 0.01** | 0.01** | 0.01** | 0.05** |

GY$_{WW}$: Grain yield under well water condition GY$_{SS}$: Grain yield under severe stress condition

**Table 5.** Correlation matrix of drought tolerance indices, grain yield under stress and well water condition in upland rice

| **Correlation Coefficient** | **Env.** | **GY$_S$** | **GY$_I$** | **DSI** | **DTE** | **DTI** | **TOL** | **MP** | **GMP** | **STI** | **YRR** | **RP** | **RY$_I$** | **RY$_S$** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **GY$_S$** | **E$_1$** | **1.00** | -0.261 | -0.605** | 0.607** | -0.607** | 1.00** | 0.211 | 0.445** | 0.465** | -0.605** | 0.605** | -0.262 | 0.999** |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **$E_2$** | **1.00** | -0.195 | -0.683** | 0.687** | -0.687** | 1.00** | 0.165 | 0.515** | 0.536** | -0.688** | 0.688** | -0.193 | 0.999** |
| | **$E_3$** | **1.00** | -0.136 | -0.664** | 0.664** | -0.664** | 1.00** | 0.201 | 0.831** | 0.845** | -0.664** | 0.664** | -0.199 | 0.999** |
| **$GY_I$** | **$E_1$** | | **1.00** | 0.891** | -0.890** | 0.890** | -0.261 | 0.988** | 0.867** | 0.855** | 0.891** | -0.891** | 0.999** | -0.263 |
| | **$E_2$** | | **1.00** | 0.803** | -0.801** | 0.801** | -0.195 | 0.978** | 0.735** | 0.715** | 0.799** | -0.799** | 0.999** | -0.195 |
| | **$E_3$** | | **1.00** | 0.604** | -0.604** | 0.601** | -0.135 | 0.925** | 0.659** | 0.631** | 0.603** | -0.603** | 0.999** | 0.138 |
| **DSI** | **$E_1$** | | | **1.00** | -0.999** | 0.999** | -0.605** | 0.822** | 0.605** | 0.583** | 0.999** | -.0999** | 0.891** | -0.606** |
| | **$E_2$** | | | **1.00** | -0.999** | 0.999** | -0.683** | 0.674** | 0.250** | 0.314** | 0.999** | -.0999** | 0.803** | -0.682** |
| | **$E_3$** | | | **1.00** | -0.999** | 0.999** | -0.683** | 0.474** | 0.520** | 0.378** | 0.999** | -.0999** | 0.602** | -0.661** |
| **DTE** | **$E_1$** | | | | **1.00** | -1.00** | 0.607** | -0.821** | -0.303 | -0.581** | -.0999** | 0.999** | -0.889** | 0.608** |
| | **$E_2$** | | | | **1.00** | -1.00** | 0.687** | -0.670** | -0.245 | -0.209 | -.0999** | 0.999** | -0.800** | 0.686** |
| | **$E_3$** | | | | **1.00** | -1.00** | 0.664** | -0.574** | -0.152 | 0.179 | -.0999** | 0.999** | -0.602** | 0.661** |
| **DTI** | **$E_1$** | | | | | **1.00** | -0.607** | 0.821** | 0.303 | 0.581** | 0.999** | -.0999** | 0.889** | -0.608** |
| | **$E_2$** | | | | | **1.00** | -0.687** | 0.670** | 0.245 | 0.509** | 0.999** | -.0999** | 0.800** | -0.683** |
| | **$E_3$** | | | | | **1.00** | -0.664** | 0.474** | 0.152 | 0.479** | 0.999** | -.0999** | 0.602** | -0.661** |
| **TOL** | **$E_1$** | | | | | | **1.00** | -0.111 | 0.545** | 0.565** | -0.605** | 0.605** | -0.263 | 0.999** |
| | **$E_2$** | | | | | | **1.00** | 0.015 | 0.515** | 0.536** | -0.688** | 0.688** | -0.193 | 0.999** |
| | **$E_3$** | | | | | | **1.00** | 0.501** | 0.831** | 0.845** | -0.663** | 0.664** | -0.138 | 0.999** |
| **MP** | **$E_1$** | | | | | | | **1.00** | 0.931** | 0.921** | 0.821** | -0.821** | 0.988** | 0.115 |
| | **$E_2$** | | | | | | | **1.00** | 0.859** | 0.843** | 0.669** | -0.669** | 0.978** | 0.014 |
| | **$E_3$** | | | | | | | **1.00** | 0.894** | 0.875** | 0.573** | -0.273 | 0.926** | 0.303 |
| **GMP** | **$E_1$** | | | | | | | | **1.00** | 0.996** | 0.205 | -0.205 | 0.866** | 0.442** |
| | **$E_2$** | | | | | | | | **1.00** | 0.996** | 0.243 | -0.248 | 0.736** | 0.515** |
| | **$E_3$** | | | | | | | | **1.00** | 0.996** | 0.152 | -0.152 | 0.662** | 0.833** |
| **STI** | **$E_1$** | | | | | | | | | **1.00** | 0.283 | -0.583** | 0.853** | 0.461** |
| | **$E_2$** | | | | | | | | | **1.00** | 0.208 | -0.508** | 0.716** | 0.535** |
| | **$E_3$** | | | | | | | | | **1.00** | 0.178 | -0.478** | 0.634** | 0.847** |
| **YRR** | **$E_1$** | | | | | | | | | | **1.00** | -1.00** | 0.890** | -0.606** |
| | **$E_2$** | | | | | | | | | | **1.00** | -1.00** | 0.799** | -0.687** |
| | **$E_3$** | | | | | | | | | | **1.00** | -1.00** | 0.601** | -0.660** |
| **RP** | **$E_1$** | | | | | | | | | | | **1.00** | - | 0.606** |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | 0.891** | |
| | **E$_2$** | | | | | | | | | | | **1.00** | -0.799** | 0.687** |
| | **E$_3$** | | | | | | | | | | | **1.00** | -0.601** | 0.660** |
| **RY W** | **E$_1$** | | | | | | | | | | | | **1.00** | -0.266 |
| | **E$_2$** | | | | | | | | | | | | **1.00** | -0.194 |
| | **E$_3$** | | | | | | | | | | | | **1.00** | -0.142 |
| **RY S** | **E$_1$** | | | | | | | | | | | | | **1.00** |
| | **E$_2$** | | | | | | | | | | | | | **1.00** |
| | **E$_3$** | | | | | | | | | | | | | **1.00** |

**Table 6.** Principal component loading for the grain yield (t ha$^{-1}$) of upland rice genotypes

| **Component** | **Proportion of total variation (%)** | **Variables** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **GY (I)** | **GY (S)** | **DSI** | **DTE** | **DTI** | **TOL** | **MP** | **GMP** | **STI** | **YRR** | **RP** | **RY (I)** | **RY (S)** |
| **PC1** | 72.4 | -0.26 | 0.09 | 0.01 | 4.89 | -4.78 | 0.09 | -0.09 | -0.01 | -0.11 | 0.01 | 0.10 | -0.02 | 0.08 |
| **PC2** | 26.6 | 0.53 | -0.08 | -0.28 | -0.24 | -0.31 | -0.08 | 0.23 | 0.10 | 0.88 | -0.28 | -0.28 | -0.08 | -0.11 |

## CONCLUSION

Yield is a complex character which mainly depends upon several component characters. So, direct selection of yield alone is not much effective in development of drought tolerant genotypes. Selection based on a combination of indices may provide a useful criterion for improving drought tolerant of rice. Meanwhile, if two indices show negative correlation it would be difficult to exercise simultaneous selection for these indices in the development of a variety for drought prone areas of rice. Hence, under such situations, judicious selection programme might be formulated for simultaneous improvement of such important developmental and component characters.

## ACKNOWLEDGEMENTS

We are thankful to Rockefeller Foundation and Generation Challenge Programme for funding IRRI-India Drought Breeding Network to carry out this study at Central Rice Research Institute, Cuttack, India.

## REFERENCESS

**Ahmad, R., Qadir, S., Ahmad, N. and Shah, K.H.** (2003). Yield potential and stability of nine wheat varieties under water stress conditions. *International Journal of Agriculture and Biology,* **5 (1)**: pp 7-9.

**Bernier, J., Atlin, G.N., Rachid, S., Kumar, A. and Spaner, D.** (2008). Breeding upland rice for drought resistance. *J. Sci. Food Agric.* **88:** pp 927-939.

**Chang, T.T., Loresto, G.C. and Tagumpay, O.** (1974). Screening rice germplasm for drought resistance. *SABRAO J.* **6:** pp 9-16.

**Chauhan, J.S., Tyagi, M.K., Kumar, A., Nashaat, N.I., Singh, M., Singh, N.B., Jakhar, M.L. and Welham, S.J.** (2007). Drought effects on yield and its components in Indian mustard (*Brassica juncea* L.). *Plant Breeding,* **126**: pp 399-402.

**Clark, J.M., Depauw, R.M. and Townley-Smith, T.F.** (1992). Evaluation of Methods for Quantification of Drought Tolerance in Wheat. *Crop Sci*., **32**: pp 723-728.

**De Datta, S.K., Malabuyoc, J.A. and Aragon, E.L.** (1988). A Field Screening Technique for Evaluating Rice Germplasm for Drought Tolerance during the Vegetative Stage. *Field Crops Research,* **19:** pp 123-134.

**Feranandez, G.C.J.** (1992). Effective selection criteria for assessing plant stress tolerance. In: Adaptation of food crops to temperature and water stress, Kuo C. G. (Ed.). AVRDC Publication, Shanhua, Taiwan, ISBN: 92-9058-081-X, pp: 257-270.

**Fischer, K.S. and Wood, G.** (1981). Breeding and selection for drought tolerance in tropical maize. In: Proc. Symp. on Principles and Methods in Crop Improvement for Drought Resistance with Emphasis on Rice, IRRI, Philippines.

**Fischer, R.A. and Maurer, R.** (1978). Drought resistance in spring wheat cultivars. I. Grain yields responses. *Aust. J. Agric Res*. **29**: pp 897-912.

**Fukai, S. and Cooper, M.** (1995). Development of drought resistant cultivars using physio-morphological traits in rice. *Field Crop Research* **40**: pp 67-86.

**Gauch, H.G. and Zobel, R.W.** (1996). AMMI analysis of yield trials. In: Genotype by environment interaction, Kang, M. S. and H. G. Gauch (Eds.). Boca Raton CRC, New York, USA, pp 85-122.

**Golabadi, M.A., Arzani, S.A.M. and Mirnohammadi, Maibody** (2006). Assessment of drought tolerance in segregating population in durum wheat. *Afr. Agric J. Res*. **1**: pp 162-171.

**Golestani, S.A. and Assad, M.T.** (1998). Evaluation of four screening techniques for drought resistance and their relationship to yield reduction ratio in wheat. *Euphytica* **103**: pp 293-299.

**Gomez, K.A. and Gomez, A.A.** (1984). Statistical Procedures for Agricultural Research (2nd Edition). John Wiley & Sons. Inc. 680 p.

**International Rice Research Institute** (1996). Standard Evaluation System for Rice (4th Edition). International Rice Testing Programme, International Rice Research institute, Los Banos, Philippines.

**International Rice Research Institute** (2009). CropStat 7.2 for Windows. Crop Research Informatics Laboratory, International Rice Research Institute, Los Banos, Philippines.

**Kamoshita, A., Babu, R.C., Boopathi, N.M. and Fukai, S.** (2008). Phenotypic and genotypic analysis of drought-resistance traits for development of rice cultivars adapted to rainfed environments. *Field Crop Research* **109**: pp 1-23.

**Kaya, Y., Palta, C. and Taner, S.** (2002). Additive main effects and multiplicative interactions analysis of yield performance in bread wheat genotypes a cross environments. *Turk. J. Agric*. **26**: pp 275-279.

**Kumar, A., Bernier, J., Verulkar, S., Lafitte, H.R. and Atlin, G.N.** (2008). Breeding for drought tolerance: direct selection for yield, response to selection and use of drought tolerant donors in upland and lowland adapted populations. *Field Crop Research* **107**: pp 221-231.

**Maurya, D.M. and O'Toole, J.C.** (1986). Screening upland rice for drought tolerance. In: Progress in upland rice research; Proceedings of the 1985 Jakarta Conference. IRRI, Los Banos, Laguna, Philippines.

**Nazari, L. and Pankniyat, H.** (2010). Assessment of drought tolerance in barley genotypes. *Journal of Applied Science* **10 (2)**: pp 151-156.

**Ouk, M., Basnayake, J., Tsubo, M., Fukai, S., Fischer, K.S., Cooper, M. and Nesbitt, H.** (2006). Use of drought response index for identification of drought tolerant genotypes in rainfed lowland rice. *Field Crops Research* **99**: pp 48–58.

**Pantuwan, G., Fukai, S., Cooper, M., Rajatasereekul, S. and O'Toole, J.C.** (2002). Yield response of rice (*Oryza sativa* L.) genotypes to different types of drought under rainfed lowlands Part 1 Grain yield and yield components. *Field Crops Research* **73:** pp 153-168.

**Panwar, L.L., Joshi, V.N. and Mashit, A.** (2008). Genotype x environment interaction in scented rice. *Oryza* **45 (1):** pp 103-109.

**Ramirez, Vallejo, P. and Kelly** (1998). Traits related to drought resistance in common bean. Euphytica **99**: pp 127-136.

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

**Saba, J., Moghaddam, M., Ghassemi, K. and Nishabouri** (2001). Genetic properties of drought resistance indices. *J. Agric. Sci. Technol*. **3**: 43-49.

**Wadea, L.J., McLarena, C.G., Quintanaa, L., Harnpichitvitaya, D., Rajatasereekul, S., Sarawgi, A.K., Kumar, A., Ahmed, H.U., Sarwoto, Singh, A.K., Rodriguez, R., Siopongco, J. and Sarkarung, S.** (1999). Genotype by environment interactions across diverse rainfed lowland rice environments. *Field Crops Research* **64:** pp 35-50.

**Zou, G.H., Liu, H.Y., Mei, H.W., Liu, G.L., Yu, X.Q., Li, M.S., Wu, J.H., Chen, L. and Luo, L.J.** (2007). Screening for Drought Resistance of Rice Recombinant Inbred Populations in the Field. *Journal of Integrative Plant Biology* **49** (10): pp 1508-1516.