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Full Length Article

Phenotypic Response of Rice (*Oryza sativa*) Genotypes to Variable Moisture Stress Regimes

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Abstract

Water stress in a climate change scenario is one of the major threats for sustainable rice productivity. A certain level of drought can cause considerable yield losses. Combining drought resistance with yield potential is the most promising challenge for the rice breeders. The present study was conducted using eight rice genotypes of diverse origin to explore their response against variable drought stress. Two water stress treatments for one week and two weeks were given sixty days after seeding. Significant differences for genotypes and water stress levels were observed from phenotypic performance. Correlation studies indicated a positive and significant association of paddy yield with spikelet fertility and 1000 grain weight. Rice genotype IR55419-04 showed least effect of water stress treatments for 1000 grain weight i.e., 6.28% and 10.44% reduction, spikelet fertility percentage with 19.99% and 40.01% reduction and the paddy yield per plant of 24.97% and 51.35% under one week and two weeks water stress, respectively. On contrary, Basmati 2000 and Super Basmati were found to be the most sensitive to drought for paddy yield with 92.8% and 91.5% reduction under severe water stress given for two weeks, respectively. The existence of enough amount of genetic variability might be a result of diverse source of the present stock. Rice strain 'IR55419-04' showed the potential for drought stress tolerance amongst all the tested genotypes and needs attention of the breeders to explore the genetic tolerance through modern mapping techniques and then incorporating it through advance biotechnological approaches like marker assisted backcrossing into elite varieties. © 2014 Friends Science Publishers

Keywords: Evaluation; Genetic variation; Water stress; Correlation; Rice genotypes

Introduction

Climate change is anticipated to explain for about 20 percent of the global increase in water scarcity this century. Intergovernmental Panel on Climate Change (IPCC, USA) has predicted that fluctuations in precipitation patterns around the world due to global warming resulting in extremes of droughts and floods. Irrigated agriculture accounts for 20% of cultivated land but contributes about 40% of the global harvest. In this sector, there is an alarming situation for the future of water availability and food security worldwide (Davis, 2007).

Rice is of semi aquatic phylogenetic origins and the choice of rice ecosystems and growing conditions is diverse (O'Toole, 2004; Bibi *et al.,* 2013). The sustainability of rice production is endangered by increasing irrigation water scarcity. Approximately 500 L of water is needed to produce 1 kg of biomass in the case of irrigated rice (Jodo, 1995; Cho and Oki, 2012). However, actual water requirements for irrigation are far more for paddy rice i.e., about 3000 to 5000 L to harvest one kilogram of rice under irrigated ecosystem (Hossain and Fischer, 1995; IRRI, 2001; Hoekstra, 2008).

On other hand, rice is more prone to water deficit at particular growth stages like other cereals. A certain level of drought at the vegetative stage can cause a moderate reduction in yield, but the same stress can purge yield entirely if it coincides with pollen meiosis or fertilization (O'Toole, 1982). In few cases, superior response to vegetative stage stress is linked with better performance under reproductive stage stress, but in many cases apparently successful strategies at the reproductive stage may be unproductive when stress prevails at flowering stage (Pantuwan *et al.,* 2002b). Progress in direct selection for improved yield under drought and the use of managed environments testing has made to facilitate progress in breeding drought tolerant rice (Chang *et al.,* 1982; Fischer *et al.,* 2003; Pinheiro and de Almeida, 2003).

The ability to tolerate the water stress differs greatly among rice genotypes. Japonica varieties like Azucena and Morobereken have shown their greatest ability to produce some grains with prolonged moderate water shortage (Mackill *et al.,* 1996). Reasonable drought tolerant levels have also been observed in early maturing *aus* and *indica* rice varieties namely N22 and Dehula grown traditionally in India (Lafitte and Courtois, 2002). Limited deep rooting and weaker ability to extract water from soil layer are associated with most of the rice varieties well adapted to anaerobic

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ecosystems (Lilley and Fukai, 1994). Certain rice varieties of *indica* group including Nam Sagui 19 from Thailand have ability to tolerate tissue moisture stress with good yielding ability and thus have served as parental lines in many genetic improvement programs.

Reports on variable drought tolerance have indicated its complex genetic nature. Considering the tolerance as the ability to maintain leaf area and growth under extended water stress at vegetative stage, then the main basis of variation seems to be constitutive roots architecture that permits maintenance of favorable plant water status (Nguyen *et al.,* 1997). In adaptive response of roots distribution in dried soil, differences have also been reported (Azhiri-Sigari *et al.,* 2000; Liu *et al.,* 2004). In both constitutive and adaptive root systems, the mechanisms underlying genetic differences may be the involvement of signals sensitivity that affects root elongation and branching (Bao *et al.,* 2004; Ge *et al.*, 2004). Stress between panicle initiation and pollen meiosis results in delayed flowering due to an apparent delay in floral parts development (Kathiresan *et al.,* 2006). It has been documented that only part of genetic variation in delayed flowering under drought is dependent on plant water status (Pantuwan *et al.,* 2002b). Drought also has adverse effect on starch deposition process in pollen grain which normally starts three days prior to anthesis resulting in reduced anther dehiscence. Genetic variation for anther dehiscence to deficit water has been reported (Liu *et al.*, 2006). Drought at heading results in panicle desiccation. Genotype specific mechanisms may be important to check panicle failure due to its ability to refill cavitated xylem vessels in shoots (Stiller *et al.,* 2003). Genotypes capable of maintaining shoot water potential have an advantage under water stress.

The objective of this study was to explore the genetic differences among the local and exotic rice varieties for tolerance under variable moisture stress regimes. The information obtained will be utilized in the future breeding programs for rice crop improvement to address the food security and poverty alleviation issues in climate change scenario.

Materials and Methods

Crop Husbandry

The experiment was conducted in the green house at National Institute for Biotechnology and Genetic Engineering, Faisalabad, Pakistan (11° 26' N 73°16' E, 184.4 m above sea level) during summer, 2007. In addition to local rice varieties Super Basmati, Basmati 2000 and KS282 developed at Rice Research Institute, Kala Shah Kaku, five exotic rice genotypes developed by International Rice Research Institute, Philippines were included in the study. The seed of 8 rice genotypes were sown on the raised wet beds. Proper management practices were done for healthy seedlings. Earthen pots (25 cm diameter – 45 cm depth) were filled with homogenized NIBGE field soil mixed with canal silt (1:2). It was ensured that each pot had no hole in the bottom. In order to settle down the soil, the pots were saturated with water for few days before transplanting of the rice seedlings. The soil level was set aside about 5 cm below the edge of the pots. The experiment was laid out in factorial design under randomized completely block design with three repeats. The pots were divided into 3 groups for different levels of water treatments i.e., well watered-control, one-week water stress and two weeks water stress imposed 60 days after seeding. The total pots in each group were 24. Thirty days old seedlings were transplanted into the pots. Half dose of nitrogen (N), full doses of phosphorus and potassium fertilizers were applied @120-60-50 kg ha^{-1} as a basal before transplanting of the rice seedlings. Remaining half dose of N was applied at 15 days after transplanting (DAT) of seedlings. The pots were watered thrice a week to maintain the soil near field capacity for the whole duration of the experiment in control treatment and for the first 30 DAT in stress treatments. Water stress treatments were protected from rain during the stress periods. The pots were re-irrigated at 67 and 74 days after seeding (DAS) in stress treatments, respectively.

Data Collection

The Standard Evaluation System for Rice prepared by International Rice Research Institute, Philippines was used for the description of the recorded plant traits for this study (Anonymous, 2002). Plant height was measured from the ground level to the tip of the panicle by using a measuring rod. For number of fertile tillers per plant, actual counts of the total number of tillers bearing panicles per plant were recorded in both the treatments at harvest. Days to 50% flowering were recorded as the number of days taken from seeding to the appearance of 50% panicles from sheath. Similarly, maturity days are the actual count of the days from seeding to grain ripening of 85% florets on the panicles. Five panicles from each entry were harvested separately for calculating the spikelet fertility percentage. The fertile florets were identified by pressing the spikelets with finger. Fully filled grains and unfilled grains were counted and spikelet fertility was calculated by the formula:

$$\text{Spikelet fertility (\%)} = \frac{\text{(fully filled grains/total number of spikelets)} \times 100}{\text{No. of panicles}}$$

Fertile and fully filled 1000 grains from a bulk of five panicles were counted manually and grain weight was measured. At maturity, the plants of each variety from three moisture regimes were manually harvested and threshed separately. The paddy weight of the harvested plants was taken in grams by using the electric balance. The paddy yield per plant was adjusted at 14% moisture by the following formula:

$$\text{Paddy yield (14\% WC)} = \text{Weight of paddy} \times [(100\text{-observed WC})/86]$$

Where, WC is moisture content

The observed moisture was measured at the time of weighing by using moisture meter. Relative performance of each plant trait was estimated using following formula:

Relative performance (%) = 100 × [1-(performance under stress/performance under control condition)]

Statistical analysis

Analysis of variance (ANOVA) and mean comparison within and between genotypes using Least Square Differences (LSD) test were performed using Statistix v8.1 package (USA). Pearson product-moment correlation coefficient analysis (Pearson, 1896) was performed for assessment of associations among studied plant characters. Components of variance were calculated by the equation proposed by Burton (1952). Phenotypic variance (VP or σp^2) represents the total variance present in a population for a specific character and is calculated by the formula (σp^2) = $\sigma g^2 + \sigma e^2$ where, σg^2 and σe^2 are genotypic and error variances, respectively. The genotypic variance (VG or σg^2) is the variance due to the genotypes existing in the population and was calculated by the following formula:

$$6g^2 = \frac{\text{MSSt} - \text{EMS}}{\text{r}}$$

Where, MSSt, EMS and r represent the mean sum of squares due to treatment, error mean sum of squares and number of replications, respectively. Similarly, the environmental variance (Ve or σe^2) denotes for the variance due to environmental influences i.e., Ve = EMS.

Broad sense heritability (h^2_{bs}) is the ratio of genotypic variance to the total variance. It is the portion of total variability or phenotypic variability, which is heritable and is due to the genotype. It was calculated by the following formula (Simmonds and Smartt, 1999).

$$h^2_{bs} = \frac{\text{Vg}}{\text{Vp+Ve}} \times 100$$

Where, Vg = genotypic variance and Vp = phenotypic variance.

Results

Performance of Rice Genotypes under Different Water Treatment Levels

Significant differences (P<0.01) were present among the genotypes for plant height, number of fertile tillers per plant, days to 50% flowering and maturity, 1000 grain weight and paddy yield per plant (Table 1). The effect of water treatment levels and interaction between water treatment levels and genotypes was also significant for all the traits.

Under well watered control conditions the plant parameters viz. plant height (cm), number of fertile tillers per plant, days to 50% flowering, maturity days, paddy yield per plant (g), spikelet fertility (%) and 1000 grain weight (g) varied from 94.3 to 124.3, 9.0 to 22.7, 75.0 to 105.7, 105.0 to 138.7, 8.38 to 17.83, 80.10 to 91.47 and 20.86 to 23.65, respectively (Table 2). The water stress levels affected adversely and resulted in significant relative percent reduction of all the plant traits. The highest relative reduction (42.2%) due to one week stress was observed for paddy yield per plant followed by 34.4% for spikelet fertility, 32.4% for plant height, 18.9% for number of tillers per plant and 10.5% for 1000 grain weight, whereas opposite response for delay in days to 50% flowering (4.2%) and maturity (3.1%) was recorded (Table 3). Under severe water stress conditions, again maximum relative reduction was recorded for paddy yield per plant i.e., 78.1% followed by 70.6% for spikelet fertility, 44.3% for plant height, 31.8% for number of tillers per plant and 14.0% for 1000 grain weight. On exposure to severe water stress, days to 50% flowering and maturity were extended by 11.5% and 8.5%, respectively.

Among genotypes, maximum plant height was attained by Basmati 2000 followed by IR55419-04 and Super Basmati whereas minimum plant height was recorded for IR74371-3-1-1 under well watered control (Table 2). Under stress conditions, plant height substantially reduced with increasing water stress level. Basmati 2000 and IR55419-04 produced plants with maximum height under both stress levels and this increase was statistically similar to IR71525-19-1-1 for one week stress and followed by Super Basmati for two weeks stress. IR71525-19-1-1 exhibited the least relative plant height reduction (%) followed by IR64683-87-2-2-3-3 when exposed for one week stress, whereas the maximum relative reduction (%) effect was noticed in Super Basmati (Table 3). KS282 showed maximum sensitivity in terms of reduction (%) in plant stature followed by IR78875-131-B-1-4 and Basmati 2000, while IR71525-19-1-1 displayed the minimum adverse effect under two weeks stress.

Maximum number of fertile tillers per plant were exhibited by IR78875-131-B-1-4 and followed by IR74371-3-1-1 and KS282, whereas IR71525-19-1-1 exhibited the minimum fertile tillers per plant under fully irrigated control conditions (Table 2). The water stress conditions reduced number of fertile tillers per plant with the depleting water levels except for Basmati 2000 with no reduction under one week stress. Rice genotype IR78875-131-B-1-4 produced maximum fertile tillers under both water stress levels followed by IR74371-3-1-1 and was statistically different from KS282 under one week stress and IR64683-87-2-2-3-3 under both stresses. Minimum number of fertile tillers per plant was observed on IR71525-19-1-1 followed by Basmati 2000 and IR 64683-87-2-2-3-3 when grown under severe water stress (Table 2).

Maximum days for 50% flowering were recorded for Basmati 2000 followed by IR74371-3-1-1 and Super Basmati, whereas IR78875-131-B-1-4 took minimum days for 50% flowering under full irrigation (Table 2). Exposure to water stress delayed heading. Basmati 2000 was the most late flowering under water stress conditions followed by IR 74371-3-1-1, which was statistically similar to Super

Table 1: Analysis of variance (ANOVA) of different agronomic parameters of rice genotypes

SOV	Df	Plant height (cm)	Number of fertile tillers per plant	Days to 50% Flowering	Maturity days	Paddy yield per plant (g)	Spikelet Fertility (%)	1000 grain weight (g)
Variety (V)	7	454.27**	129.32**	940.39**	1058.25**	48.83**	419.09**	11.00**
Stress (S)	2	13965.2**	118.43**	666.17**	666.16**	725.72**	22264.2**	62.92**
V × S	14	36.88**	6.56**	44.96**	44.93**	8.42**	146.27**	0.365*
Error	46	4.520	2.401	0.841	0.841	0.285	10.042	0.218
Total	71							
CV%		2.71	13.44	0.96	0.72	6.34	5.65	2.29

*and ** are significance levels at P<0.05 and P<0.01, respectively

Table 2: Performance of rice genotypes under different water treatment levels for agronomic and yield traits

Treatment	Plant height (cm)	Number of fertile tillers per plant	Days to 50% flowering	Maturity days	Paddy yield per plant (g)	Spikelet fertility (%)	1000 grain weight (g)
Control							
Super Basmati	112.0±1.65^{b}	10.0±0.71^{cd}	99.3±0.33^{b}	132.3±0.33^{b}	11.5±0.93^{d}	86.2±1.51^{abc}	21.4±0.87^{c}
Basmati 2000	124.3±3.63^{a}	9.0±0.47^{cd}	105.7±0.47^{a}	138.7±0.47^{a}	11.0±0.18^{d}	85.2±2.96^{abc}	22.5±0.98^{b}
KS282	98.0±1.83^{cd}	17.0±0.85^{b}	99.7±0.83^{b}	132.7±0.83^{b}	16.6±0.31^{ab}	82.8±1.88^{bc}	23.7±1.04^{a}
IR55419-04	114.3±1.04^{b}	11.3±0.65^{c}	85.3±0.67^{c}	115.3±0.70^{d}	14.8±0.73^{c}	88.2±1.85^{ab}	23.6±1.27^{a}
IR 71525-19-1-1	102.7±1.12^{c}	7.7±0.58^{d}	79.0±0.99^{d}	112.0±1.00^{e}	8.3±0.52^{e}	80.1±3.65^{c}	20.9±0.98^{c}
IR 74371-3-1-1	94.3±3.05^{d}	17.7±0.71^{b}	100.7±1.30^{b}	130.7±1.30^{c}	17.8±0.21^{a}	85.2±2.81^{abc}	22.5±0.97^{b}
IR 64683-87-2-2-3-3	101.0±0.50^{c}	15.7±0.62^{b}	86.7±0.67^{c}	116.7±0.70^{d}	16.3±0.16^{b}	91.5±1.54^{a}	21.2±0.95^{c}
IR 78875-131-B-1-4	95.3±1.84^{d}	22.7±1.76^{a}	75.0±2.00^{e}	105.0±2.00^{f}	16.2±0.54^{b}	90.8±0.94^{ab}	22.5±0.88^{b}
$LSD_{0.05}$	*4.81*	*2.66*	*1.50*	*1.49*	*1.34*	*8.02*	*0.87*
One week water stress							
Super Basmati	70.5±1.34^{bcd}	8.0±0.50^{d}	105.3±1.08^{b}	138.3±1.08^{b}	5.4±0.28^{d}	51.7±1.99^{c}	19.0±0.88^{de}
Basmati 2000	78.7±1.26^{a}	9.0±0.62^{cd}	109.0±2.59^{a}	142.0±2.60^{a}	5.5±0.18^{d}	55.4±0.63^{bc}	19.9±0.68^{c}
KS282	64.7±1.45^{e}	12.3±1.56^{b}	97.3±2.15^{c}	130.3±2.15^{d}	7.5±0.19^{c}	58.0±4.55^{b}	20.8±0.49^{b}
IR55419-04	77.3±1.36^{a}	8.3±0.82^{d}	92.3±1.86^{d}	122.3±1.86^{e}	11.1±0.42^{a}	70.6±1.16^{a}	22.1±0.55^{a}
IR 71525-19-1-1	73.7±2.46^{ab}	7.3±0.53^{d}	78.3±4.07^{e}	112.3±4.07^{f}	5.4±0.77^{d}	52.1±0.70^{c}	18.4±0.53^{e}
IR 74371-3-1-1	66.2±0.26^{de}	14.3±1.77^{b}	104.7±1.31^{b}	134.7±1.32^{c}	9.8±0.16^{b}	58.8±2.75^{b}	19.7±0.35^{cd}
IR 64683-87-2-2-3-3	71.7±0.46^{bc}	11.7±0.88^{bc}	91.0±3.44^{d}	121.0±3.45^{e}	9.4±0.69^{b}	60.4±1.85^{b}	18.8±0.53^{e}
IR 78875-131-B-1-4	66.5±2.73^{cde}	18.0±1.31^{a}	78.3±2.33^{e}	108.3±2.34^{g}	10.8±0.31^{a}	45.4±1.02^{d}	20.8±0.45^{b}
$LSD_{0.05}$	*3.29*	*3.05*	*1.68*	*1.68*	*0.75*	*5.31*	*0.79*
Two weeks water stress							
Super Basmati	62.5±0.55^{bc}	6.7±0.47^{e}	104.3±0.71^{c}	137.3±0.72^{b}	1.0±0.03^{f}	9.0±0.76^{g}	18.6±0.33^{d}
Basmati 2000	68.7±0.80^{a}	8.3±0.58^{de}	112.3±1.72^{a}	145.3±1.72^{a}	0.8±0.03^{f}	17.0±1.05^{f}	19.2±0.64^{cd}
KS282	52.7±1.18^{e}	9.7±0.41^{cd}	94.0±0.55^{f}	127.0±0.56^{d}	1.7±0.09^{e}	20.7±1.32^{e}	19.5±0.66^{bc}
IR55419-04	63.3±0.82^{b}	6.7±0.33^{e}	100.0±0.62^{d}	130.0±0.62^{e}	7.2±0.18^{a}	52.9±0.98^{a}	21.1±0.76^{a}
IR 71525-19-1-1	59.7±1.13^{cd}	7.3±0.50^{e}	98.0±0.41^{e}	131.0±0.42^{e}	2.7±0.08^{d}	26.1±0.76^{c}	18.0±0.79^{ef}
IR 74371-3-1-1	52.2±0.91^{e}	11.7±0.60^{b}	107.7±0.53^{b}	137.7±0.53^{b}	3.0±0.11^{d}	24.1±1.86^{cd}	19.4±0.56^{bc}
IR 64683-87-2-2-3-3	57.7±0.71^{d}	10.7±0.50^{bc}	105.3±0.29^{c}	135.3±0.30^{c}	4.5±0.15^{b}	31.2±0.82^{b}	17.5±0.63^{f}
IR 78875-131-B-1-4	52.5±1.12^{e}	14.7±0.69^{a}	81.7±0.24^{g}	111.7±0.25^{f}	3.7±0.13^{c}	21.8±0.39^{de}	19.9±1.51^{b}
$LSD_{0.05}$	*3.29*	*1.83*	*1.42*	*1.43*	*0.61*	*2.86*	*0.61*

*Means having different letters differ significantly

Basmati under one week stress. The least delay in 50% flowering due to one week water stress was recorded for the rice genotype IR71525-19-1-1 followed by Basmati 2000 and KS282, while Super Basmati showed minimum days to flower under severe water stress (Table 3).

Basmati 2000 achieved maturity delayed followed by KS282 and Super Basmati, whereas IR78875-131-B-1-4 took minimum days to mature under well watered treatment (Table 2). Maturity was delayed in all the genotypes under water stress conditions. Maximum maturity days were recorded for Basmati 2000 followed by Super Basmati that was statistically similar to IR74371-3-1-1 under severe water stress conditions. Moreover, IR78875-131-B-1-4 was the earliest maturing rice variety under water stress levels (Table 3).

Maximum paddy yield per plant was produced by rice genotype IR74371-3-1-1 and KS282 statistically while minimum for IR71525-19-1-1 under fully irrigated control conditions (Table 2). Data revealed substantial yield reduction due to water stress levels. Genotype IR55419-04 produced maximum paddy yield per plant under both stress levels and was statistically not similar for IR78875-131-B-1-4 under one week stress. Minimum paddy yield was recorded for Super Basmati and IR71525-19-1-1 statistically similar with Basmati 2000. Nonetheless, Basmati 2000 and Super Basmati suffered the most under severe water stress.

Maximum spikelet fertility percentage was exhibited by IR64683-87-2-2-3-3 and was not significantly different from IR78875-131-B-1-4, IR55419-04, Super Basmati, Basmati 2000 and IR 74371-3-1-1 under well watered conditions (Table 2). Exposure to one week water stress, the highest spikelet fertility percentage was observed for IR55419-04 followed by IR64683-87-2-2-3-3 and was statistically similar to IR74371-3-1-1, KS282 and Basmati

Table 3: Relative percent reduction in different plant traits of rice genotypes under water stress conditions

Genotype	Treatment	Plant height (cm)	Number of fertile tillers per plant	Days to 50% flowering	Maturity days	Paddy yield per plant (g)	Spikelet fertility (%)	1000 grain weight (g)
Super Basmati	One week water stress	37.1	20.0	-6.0	-4.5	53.3	40.2	11.2
	Two weeks water stress	44.2	33.3	-5.0	-3.8	91.5	89.6	13.0
Basmati 2000	One week water stress	36.7	0.0	-3.2	-2.4	50.0	35.0	11.7
	Two weeks water stress	44.8	7.4	-6.3	-4.8	92.8	80.0	14.9
KS282	One week water stress	34.0	27.5	-3.5	-2.6	55.1	30.3	12.0
	Two weeks water stress	46.3	43.1	-6.0	-4.5	89.7	75.0	17.5
IR55419-04	One week water stress	32.4	26.5	-8.2	-6.1	25.0	20.1	6.3
	Two weeks water stress	44.6	41.1	-17.2	-12.7	51.4	40.1	10.4
IR 71525-19-1-1	One week water stress	28.3	4.4	-0.9	-0.6	35.1	35.0	11.9
	Two weeks water stress	41.9	4.4	-24.1	-17.0	67.9	67.5	13.6
IR 74371-3-1-1	One week water stress	29.9	18.9	-4.0	-3.1	45.0	31.2	12.2
	Two weeks water stress	44.7	34.0	-7.0	-5.4	83.0	71.7	13.9
IR 64683-87-2-2-3-3	One week water stress	29.0	25.5	-5.0	-3.7	41.8	34.1	11.5
	Two weeks water stress	42.9	31.9	-21.5	-16.0	72.3	65.9	17.4
IR 78875-131-B-1-4	One week water stress	30.2	20.6	-4.4	-3.2	32.9	50.3	7.6
	Two weeks water stress	44.9	35.3	-8.9	-6.4	77.0	76.0	11.3

*negative sign shows delay in trait expression

Table 4: Genetic parameters for various quantitative traits of rice varieties

Character	Variances			Broad Sense Heritability (h^2_{bs})
	Genotypic (σg^2)	Phenotypic (σp^2)	Environmental (σe^2)	
Plant height (cm)	149.92	154.44	4.52	94.3
Number of fertile tillers per plant	42.31	44.71	2.40	89.8
Days to 50% flowering	313.18	314.02	0.84	99.5
Maturity days	352.47	353.31	0.84	99.5
Paddy yield per plant (g)	16.18	16.47	0.29	96.6
Spikelet fertility (%)	136.35	146.39	10.04	87.2
1000 grain weight (g)	3.59	3.81	0.22	89.2

2000, whereas IR78875-131-B-1-4 had minimum for spikelet fertility percentage. Under severe water stress, IR55419-04 had maximum spikelet fertility percentage followed by IR64683-87-2-2-3-3 while Super Basmati was categorized as the most sensitive (Table 3). The most adverse effect of water stress treatments was observed on IR78875-131-B-1-4 and Super Basmati.

Maximum 1000-grain weight was recorded for KS282 and significantly similar to IR55419-04 followed by Basmati 2000, IR64683-87-2-2-3-3 and IR 78875-131-B-1-4 under well watered conditions (Table 2). Under water stress conditions, the highest 1000 grain weight was recorded for IR55419-04 followed by IR 78875-131-B-1-4 and KS282. Minimum 1000 grain weight was recorded for IR64683-87-2-2-3-3 and was statistically similar with IR 71525-19-1-1 under both stress levels. The relatively maximum 1000 grain weight was for IR55419-04 with minimum reduction.

Estimates of Components of Variance

A wide range of phenotypic variance (Vp) and genotypic variance (Vg) were estimated for various traits (Table 4). The highest value of Vp (353.31) and Vg (352.47) were recorded for maturity days. The estimates of phenotypic and genotypic variances were 314.02 and 313.18 for days to 50% flowering, plant height (154.44 and 149.92), number of fertile tillers per plant (44.71 and 42.31), paddy yield per plant (16.47 and 16.18) and 1000 grain weight (3.81 and 3.59) (Table 4).

Broad Sense Heritability

Heritability estimated for seven quantitative characters of rice genotypes, ranged from 87.2% (spikelet fertility %) to 99.5% (maturity days and days to 50% flowering). The broad sense heritability estimates for other traits viz.; paddy yield per plant, plant height, number of fertile tillers per plant and 1000 grain weight were 96.6%, 94.3%, 89.8% and 89.2%, respectively.

Correlation Studies

The correlation analysis revealed the association of different plant traits with each other under various moisture treatment levels (Table 5). Plant height showed highly significant ($P<0.01$) and negative association with number of fertile tillers per plant under all moisture treatment levels while a positive association with days to 50% flowering and maturity days (under control and two weeks stress) and spikelet fertility percentage (under one week stress) was found. The impact of number of fertile tillers per plant on 50% flowering days and maturity days (under all water treatment levels) and spikelet fertility percentage (one week stress) was significant but depressing in nature, whereas it showed positive and significant association with paddy yield (under control and one week stress), spikelet fertility percentage (control) and 1000 grain weight (control). The results indicated that days to 50% flowering were strongly associated with maturity days under all water treatments but its correlation with paddy yield (under stress conditions) and 1000 grain weight (two weeks stress) was significantly negative. The influence of maturity days on paddy yield (water stress levels) and 1000 grain weight (severe water stress) was significantly negative. Both spikelet fertility % and 1000 grain weight showed positive and significant influence on paddy yield. Similarly, a significantly positive association of spikelet fertility percentage with 1000 grain weight was found under water stress levels (Table 5).

Discussion

Significant differences for all traits due to genotypes and water stress levels proposed that the genotypes were genetically different and the impact of different water levels was considerably important for their performance. It indicates that there is sufficient scope to select the promising genotypes from the present study for yield and some other economic plant traits. The existence of enough amount of genetic variability (Table 4) might be a result of diverse source of the present stock studied as well as environmental factors that influence the phenotypic performances. There is significant variation in yield and yield components in rice germplasm worldwide (Cheema *et al.*, 2004; Ishwar *et al.*, 2007; Ouk *et al.*, 2006; Singh *et al.*, 2006).

The interaction between genotypes and moisture regimes was significant confirming that testing across a range of water levels is essential to identify superior genotypes. Selection under severe stress can lead to better improvement in drought tolerance but the identification of target stress level /environment for which the selection is being done is very important (Bernier *et al.*, 2008; Serraj *et al.*, 2011; Venuprasad *et al.*, 2011). Rice genotypes show significant interactions with environment (Atlin, 2003; Atlin *et al.*, 2006; Lafitte *et al.*, 2007). Selection for yield under reproductive stage stress is much better for improved yield of rice under drought especially for terminal drought environments (Atlin, 2003; Kumar *et al.*, 2008). Guan *et al.* (2010) suggested that severe stress at vegetative and reproductive stage are needed to screen segregating populations because variable types of stress imposition expose genetic variation due to underlying different drought tolerance mechanisms. The stress imposed in the present study coincided more or less at the onset of reproductive stage as observed from a very low level of spikelet fertility especially under severe stress (Table 2). It has been documented that biomass production (plant height and number of tillers per plant) is more affected under vegetative stage stress whereas severe effects on sink size (spikelet fertility, 1000 grain weight and seed yield) under reproductive stage stress would be resulted (Guan *et al.*, 2010).

Under well watered conditions, the absorption and transport of water and nutrient are higher due to high soil water potential. Soil moisture stress decreases nutrient transport to the root surfaces and roots are unable to absorb nutrients from the soil. Water stress affects nutrient uptake by changing nutrient capability of mycorrhizal or non-

Table 5: Pearson-Correlation coefficients comparisons for various plant traits under various moisture treatment levels

Variable	Treatment[1]	PLHT[2]	Till#	DTF	MYDY	YLD	SF
Till#	C	-0.71**					
	S1	-0.62**					
	S2	-0.67**					
DTF	C	0.44*	-0.29*				
	S1	0.12	-0.28*				
	S2	0.49*	-0.48*				
MYDY	C	0.47*	-0.35*	0.99**			
	S1	0.13	-0.33*	0.99**			
	S2	0.52**	-0.54**	0.99**			
YLD	C	-0.56**	0.80**	-0.01	-0.10		
	S1	-0.24	0.53**	-0.31*	-0.42*		
	S2	-0.09	0.06	-0.29*	-0.40*		
SF	C	-0.03	0.38*	-0.14	-0.20	0.34*	
	S1	0.38*	-0.32*	0.26*	0.21	0.34*	
	S2	0.07	-0.15	-0.10	-0.19	0.92**	
GWT	C	0.07	0.30*	0.16	0.13	0.48*	0.04
	S1	-0.02	0.08	0.01	-0.03	0.56**	0.40*
	S2	-0.01	0.04	-0.29*	-0.32*	0.42**	0.45**

[1]C=Control (Well watered); S1=One week water stress and S2=Two weeks water stress

[2]PLHT=Plant height; Till#=Number of tillers per plant; DTF= Days to 50% flowering; YLD=Paddy yield per plant; SF=Spikelet fertility % and GWT=1000 grain weight

*and ** show the significance at P<0.05 and P<0.01 respectively mycorrhizal roots (Rennenberg *et al.,* 2006) and finally results in decreased plant growth (Table 2).

It is a well-established that drought tolerant cultivars have the ability to produce more stable yields under water stress conditions than sensitive ones (Mackill *et al.,* 1996; Lafitte *et al.,* 2006; Guan *et al.,* 2010). Rice lines used in this study exhibited tremendous yield variation as a result of water stress imposed. Varieties developed for irrigated ecosystems are more prone to drought stress (Lafitte *et al.,* 2007; Serraj *et al.,* 2009). Local varieties bred for irrigated conditions showed more sensitivity to water stress than the exotic rice genotypes developed for rainfed upland conditions (Table 2). The possible explanation might be that the sensitive cultivars of irrigated environment has not shown the adaptability to water stress due to poor response of the root system to grow deeper with depleting soil water status thus unable to extract water from the deeper soil layers (Kondo *et al.,* 2003; Gowda *et al.,* 2011). The cultivars with poor root penetration ability have been reported as drought sensitive (Ikeda *et al.,* 2007).

Local variety Super Basmati was extremely sensitive to both stress levels (Table 2) and a critical analysis on the yield related parameters of this genotype revealed that reduction was partly contributed by loss of spikelet fertility percentage, reduced 1000 grain weight (shrinked grain size) and decreased number of fertile tillers per plant resulting in poor yield under water stress conditions (Table 2). The increase in spikelet sterility is supposed to be associated with diminishing rate of translocation of assimilates from other plant parts to the panicles and with induced pollen or ovule abortion under drought (Davatgar *et al.,* 2009; Maqsood *et al.,* 2012). The decrease in grain size results in reduced 1000 grain weight (Majeed *et al.,* 2011). The grain size is usually conservative (Sadras, 2007) but is mainly reduced by fall in assimilate and nitrogen availability to floral parts under water stress. In addition, decreased photosynthetic activity under water stress ultimately affects the crop growth (Cornic, 2002) and grain-filling process becomes increasingly reliant on stem reserve mobilization/utilization (Blum, 2005), which is related to yield under water stress in rice (Yang *et al.,* 2002). Reduced grain size, reduced spikelet fertility percentage and decrease in yield under moisture stress environment has been reported in rice (Lafitte *et al.,* 2004; Atlin *et al.,* 2006; Kumar *et al.,* 2006; Centritto *et al.,* 2009; Davatgar *et al.,* 2009; Fukai *et al.,* 2009; Henry *et al.,* 2009; Serraj *et al.,* 2009; Luo, 2010; Gowda *et al.,* 2011; Boopathi *et al.,* 2013) confirms present study findings.

Delayed heading due to water stress is a common strategy in most of the rice cultivars (Lilley and Fukai, 1994; Lafitte *et al.,* 2006) as observed in all the genotypes of present study (Table 2). This might allow the cultivars to confer a little benefit under temporary drought spell (Lafitte *et al.,* 2006). But the timing and intensity of water stress are of high consideration. Delay in flowering followed by prolonged maturity of rice genotypes has been reported earlier (Lafitte *et al.,* 2007; Guan *et al.,* 2010). In the present study, the decrease in plant height 29.04-46.26% (Table 2) was observed in all the genotypes under drought conditions which might be due to either inhibition of cell elongation or expansion on exposure to water stress as earlier reported (Pantuwan *et al.,* 2002b; Davatgar *et al.,* 2009; Farooq *et al.,* 2009; Majeed *et al.,* 2011).

IR71525-19-1-1 has shown the least adverse effect on number of tillers per plant. The possible reason might be that the variety completed its tillering phase with least adverse effect on the trait. Rice genotype IR55419-04 exhibited a better level of tolerance for paddy yield under both water stress levels than the rest of the genotypes (Table 2). This least adverse effect on yield of IR55419-04 was partly contributed by relatively improved 1000 grain weight and high spikelet fertility. The possible mechanism for drought tolerance of IR55419-04 may be the drought avoidance (either through deep rooting or stomatal conductance) due to the fact that drought avoider genotypes at reproductive stage have the ability to maintain better plant water status around flowering and seed setting (Fukai *et al.,* 2009; Serraj *et al.,* 2011). Atlin *et al.* (2006) has also reported the genetic variation among rice varieties and IR55423-01 was marked as the superior one that gave high spikelet fertility percentage under water stress environment. Use of highly tolerant and agronomic superior donor genotypes can result in better improvements (Atlin, 2003). Drought tolerant rice varieties Azucena and Bala have been used for the development of new drought tolerant varieties (Price *et al.,* 2002). IR55419-04 has shown the potential for drought stress tolerance amongst all the tested genotypes. On the contrary, Super Basmati and Basmati 2000 appeared to be the most sensitive genotypes to water stress.

Correlation studies revealed that a negative association between grain yield and flowering days exist (Pantuwan *et al.,* 2002a; Kumar *et al.,* 2006). A strong association of spikelet fertility percentage with paddy yield indicated exploitation of this interaction, while selecting a genotype for moisture stress conditions and a strong association between spikelet fertility and paddy yield (Ramakrishnan *et al.,* 2006; Tripathi *et al.,* 2011). Similarly, a positive correlation of 1000 grain weight with paddy yield indicates that the decrease in paddy yield was contributed due to the shrinkage of grain size and loss of spikelet fertility under water stress conditions (Table 5). Kumar *et al.* (2011) studied 40 rice genotypes under different environments and found a positive strong association between grain yield per plant and 1000 grain weight.

The genotypic variance estimates (Vg) help in the measurement of the genotypic contribution to the expression of a particular trait and gave evidence to associate the genetic variability for different plant characters. Higher phenotypic variance than the genotypic variance for all the characters shows the impact of environmental influences on these traits. Low values of differences in the estimates of genotypic and phenotypic variances and higher values of genotypic variances compared to environmental variances for all the parameters (Table 6) proposed that the variation among the genotypes were predominantly contributed by the genetic architecture of the genotypes with minimum environmental effect and hence were heritable.

Heritability is referred as a measure of the level of phenotypic variation resulted by the genes action. It reflects the inherited genetic variability from the parents to the offspring. High values (87.2-99.5%) of broad sense heritability estimates indicate that the inheritance of these characters is believed to be governed predominantly by additive gene action (Panse, 1958) and these traits are suitable for selection of suitable genotype. High heritability for various plant traits in rice has been well established (Kuldeep *et al.*, 2004; Pandey *et al.*, 2009; Sabesan *et al.*, 2009).

In conclusion, water stress affects the growth and maturity period and influences the yield and yield related traits but the tolerance of rice genotypes varied remarkably. Significant genotype × environment interaction was observed. The strong association of paddy yield with spikelet fertility and 1000 grain weight suggested that these plant traits should be considered as the secondary traits for selection of genotypes under water stress environment. Super Basmati, was the most sensitive to water stress amongst the tested genotypes and IR55419-04 as tolerant to water stress and invites the attention of the breeders to explore the genetic tolerance through modern mapping approaches and then incorporating it through advance biotechnological approaches like marker assisted backcrossing into the well adapted varieties.

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References

Anonymous, 2002. *Standard Evaluation System for Rice.* International Rice Research Institute, Philippines

Atlin, G., 2003. *Improving Drought Tolerance by Selecting for Yield*, pp: 14–22. Breeding rice for drought-prone environments

Atlin, G., H. Lafitte, D. Tao, M. Laza, M. Amante and B. Courtois. 2006. Developing rice cultivars for high-fertility upland systems in the Asian tropics. *Field Crops Res.*, 97: 43–52

Azhiri-Sigari, T., A. Yamauchi, A. Kamoshita and L. Wade, 2000. Genotypic variation in response of rainfed lowland rice to drought and rewatering. *Plant Prod. Sci.*,3: 180–188

Bao, J., M. Sun, L. Zhu and H. Corke, 2004. Analysis of quantitative trait loci for some starch properties of rice (*Oryza sativa* L.): thermal properties, gel texture and swelling volume. *J. Cereal Sci*., 39: 379–385

Bernier, J., G.N. Atlin, R. Serraj, A. Kumar and D. Spaner, 2008. Breeding upland rice for drought resistance. *J. Sci. Food Agric.*, 88: 927–939

Bibi, R., S.B. Hussain, A.S. Khan and I. Raza, 2013. Assessment of combining ability in bread wheat by using line x tester analysis under moisture stress conditions. *Pak. J. Agric. Sci.*, 50: 111–115

Blum, A., 2005. Drought resistance, water-use efficiency, and yield potential—are they compatible, dissonant, or mutually exclusive? *Crop Pasture Sci.*, 56: 1159–1168

Boopathi, N.M., G. Swapnashri, P. Kavitha, S. Sathish, R. Nithya, W. Ratnam and A. Kumar. 2013. Evaluation and Bulked Segregant Analysis of major yield QTL under water stress into indigenous elite line for low water. *Rice Sci.*, 20: 25–30

Burton, G.W., 1952. Quantitative inheritance in grasses. *Proc. 6th Int. Grassland Cong*, 1: 77–283

Centritto, M., M. Lauteri, M.C. Monteverdi and R. Serraj. 2009. Leaf gas exchange, carbon isotope discrimination, and grain yield in contrasting rice genotypes subjected to water deficits during the reproductive stage. *J. Exp. Bot.*, 60: 2325–2339

Chang, T., G. Loresto, J. O'Toole and J. Armenta-Soto, 1982. *Strategy and Methodology of Breeding Rice for Drought-prone Areas*, pp: 217–244. Drought resistance in crops with the emphasis on rice. The Int. Rice Research Institute, Manila

Cheema, A.A., M. Rashid, M. Ashraf and Z. Qamar, 2004. Genetic divergence in rice collection. *Pak. J. Bot.*, 36: 557–565

Cho, J. and T. Oki, 2012. Application of temperature, water stress, CO_2 in rice growth models. *Rice*, 5: 10

Cornic, G., 2002. Drought stress inhibits photosynthesis by decreasing stomatal aperture: not by affecting ATP synthesis. *Trends Plant Sci.*, 5: 187–188

Davatgar, N., M. Neishabouri, A. Sepaskhah and A. Soltani, 2009. Physiological and morphological responses of rice (*Oryza sativa* L.) to varying water stress management strategies. *Int. J. Plant Prod.*, 3: 19–32

Davis, C., 2007. The multiple dimensions of water scarcity. Earth Trends Update, USA

Farooq, M., A. Wahid, N. Kobayashi, D. Fujita and S.M.A. Basra, 2009. Plant drought stress: effects, mechanisms and management. *Agron. Sustain. Dev.*, 29: 185–212

Fischer, K.S., H. Lafitte, S. Fukai, G. Atlin and B. Hardy, 2003. *Breeding Rice for Drought-prone Environments*. International Rice Research Institute, Philippines

Fukai, S., J. Basnayake and O. Makara, 2009. Drought resistance characters and variety development for rainfed lowland rice in Southeast Asia. *In*: *Drought Frontiers in Rice: Crop Improvement for Increased Rainfed Production*, pp: 75–89. Serraj, J., J. Bennett and B. Hardy (eds.). World Scientific Publishing, Singapore

Ge, L., H. Chen, J.F. Jiang, Y. Zhao, M.L. Xu, Y.Y. Xu, K.H. Tan, Z.H. Xu and K. Chong, 2004. Overexpression of OsRAA1 causes pleiotropic phenotypes in transgenic rice plants, including altered leaf, flower and root development and root response to gravity. *Plant Physiol.*, 135: 1502–1513

Gowda, V.R., A. Henry, A. Yamauchi, H. Shashidhar and R. Serraj, 2011. Root biology and genetic improvement for drought avoidance in rice. *Field Crops Res.*, 122: 1–13

Guan, Y., R. Serraj, S. Liu, J. Xu, J. Ali, W. Wang, E. Venus, L. Zhu and Z. Li, 2010. Simultaneously improving yield under drought stress and non-stress conditions: a case study of rice (*Oryza sativa* L.). *J. Exp. Bot.*, 61: 4145–4156

Henry, A., R. Torres and R. Serraj, 2009. Dissecting the role of root architecture in drought avoidance mechanisms in rice. *Philip. J. Crop Sci.*, 34: 18–23

Hoekstra, A.Y., 2008. The water footprint of food. *In*: *Water for Food*, Förare, J. (ed.). The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas), Stockholm

Hossain, M. and K. Fischer, 1995. Rice research for food security and sustainable agricultural development in Asia: achievements and future challenges. *Geol. J.*, 35: 286–298

Ikeda, H., A. Kamoshita, and T. Manabe. 2007. Genetic analysis of rooting ability of transplanted rice (*Oryza sativa* L.) under different water conditions. *J. Exp. Bot.*, 58: 309–318

IRRI, 2001. *Annual Report 2000-2001: Rice Research: the Way Forward*, p: 71. Int. Rice Res. Institute, Philippines

Ishwar, D., B.S. Mehla and J. Singh, 2007. Multivariate analysis in rice (*Oryza sativa* L.). *National J. Plant Improv.*, 9: 115–118

Jodo, S., 1995. Water use efficiency. *Sci. Rice Plant*., 2: 447–461
Kathiresan, A., H. Lafitte, J. Chen, L. Mansueto, R. Bruskiewich and J. Bennett, 2006. Gene expression microarrays and their application in drought stress research. *Field Crops Res.,* 97: 101–110
Kondo, M., P.P. Pablico, D.V. Aragones, R. Agbisit, J. Abe, and S. Morita, 2003. Genotypic and environmental variations in root morphology in rice genotypes under upland field conditions. *Plant Soil.*, 255: 189–200
Kuldeep, T., K. Bathshwar, B. Ramesh and A. Tomer, 2004. Genetic variability and correlations for some seedlings and mature plant traits in 70 genotypes of rice. *Res., Crops*., 5: 60–65
Kumar, A., J. Bernier, S. Verulkar, H. Lafitte and G. Atlin, 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 Crops Res*., 107: 221–231
Kumar, R., A. Sarawgi, C. Ramos, S. Amarante, A. Ismail, and L. Wade, 2006. Partitioning of dry matter during drought stress in rainfed lowland rice. *Field Crops Res.,* 96: 455–465
Kumar, Y., B.N. Singh, O.P. Verma, S. Tripathi and D.K. Dwived, 2011. Correlation and Path Coefficient Analysis in Scented Rice. *Environ. Ecol.,* 29: 1550–1556
Lafitte, H. and B. Courtois, 2002. Interpreting Cultivar × Environment Interactions for Yield in Upland Rice. *Crop Sci.,* 42: 1409–1420
Lafitte, H., Z. Li, C. Vijayakumar, Y. Gao, Y. Shi, J. Xu, B. Fu, S. Yu, A. Ali and J. Domingo, 2006. Improvement of rice drought tolerance through backcross breeding: evaluation of donors and selection in drought nurseries. *Field Crops Res.,* 97: 77–86
Lafitte, H., A. Price and B. Courtois, 2004. Yield response to water deficit in an upland rice mapping population: associations among traits and genetic markers. *Theor. Appl. Genet*., 109: 1237–1246
Lafitte, H., G. Yongsheng, S. Yan and Z. Li, 2007. Whole plant responses, key processes and adaptation to drought stress: the case of rice. *J. Exp. Bot.*, 58: 169–175
Lilley, J. and S. Fukai, 1994. Effect of timing and severity of water deficit on four diverse rice cultivars I. Rooting pattern and soil water extraction. *Field Crops Res.,* 37: 205–213
Liu, J., D. Liao, R. Oane, L. Estenor, X. Yang, Z. Li and J. Bennett, 2006. Genetic variation in the sensitivity of anther dehiscence to drought stress in rice. *Field Crops Res.,* 97: 87–100
Liu, W., Y. Zhu, F.A. Smith and S.E. Smith, 2004. Do iron plaque and genotypes affect arsenate uptake and translocation by rice seedlings (*Oryza sativa* L.) grown in solution culture. *J. Exp. Bot.*, 55: 1707–1713
Luo, L., 2010. Breeding for water-saving and drought-resistance rice (WDR) in China. *J. Exp. Bot*., 61: 3509–3517
Mackill, D., Z. Zhang, E. Redona and P. Colowit, 1996. Level of polymorphism and genetic mapping of AFLP markers in rice. *Genome*, 39: 969–977
Majeed, A., M. Salim, A. Bano, M. Asim and M. Hadees, 2011. Physiology and productivity of rice crop influenced by drought stress induced at different developmental stages. *Afr. J. Biotechnol.,* 10: 5121–5136
Maqsood, M., M.A. Shehzad, M. Ahmed and W. Ahmad, 2012. Seasonal growth attributes of wheat (*Triticum aestivum* L.) genotypes in response to moisture regimes under semi arid environment. *Pak. J. Agric. Sci.,* 49: 275–280
Nguyen, H.T., R.C. Babu and A. Blum, 1997. Breeding for drought resistance in rice: physiology and molecular genetics considerations. *Crop Sci.,* 37: 1426–1434
O'Toole, J., 1982. Adaptaion of rice to drought prone environments: *In: Drought Resistance in Crops with Emphasis on Rice*, pp: 195–213. International Rice Research Institute, Los Banos, Philippines
O'Toole, J.C., 2004. Rice and Water: The Final Frontier. *1st Int. Conference on Rice for the Future*. 31 August-32 Sept. 2004, Bangkok, Thailand
Ouk, M., J. Basnayake, M. Tsubo, S. Fukai, K. Fischer, M. Cooper and H. Nesbitt. 2006. Use of drought response index for identification of drought tolerant genotypes in rainfed lowland rice. *Field Crops Res.,* 99: 48–58
Pandey, P., P.J. Anurag, D. Tiwari, S. Yadav and B. Kumar, 2009. Genetic variability, diversity and association of quantitative traits with grain yield in rice (*Oryza sativa* L.). *J. Biol. Sci.*, 17: 77–82
Panse, V., 1958. Some Comments on the Objectives and Methods of the 1960 World Census of Agriculture. *Bull. Int. Stat. Instit.*, 36: 222–227
Pantuwan, G., S. Fukai, M. Cooper, S. Rajatasereekul, and J. O'Toole, 2002a. 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 Res.,* 73: 153–168
Pantuwan, G., S. Fukai, M. Cooper, S. Rajatasereekul and J.C. O'Toole, 2002b. Yield response of rice (*Oryza sativa* L.) genotypes to drought under rainfed lowland: 3. Plant factors contributing to drought resistance. *Field Crops Res.*, 73: 181–200
Pearson, K., 1896. Mathematical Contributions to the Theory of Evolution - On a form of spurious correlation which may arise when indices are used in the measurement of organs. *Proc. Royal Society London*, 60: 489–498
Pinheiro, P.S.d.M.S. and G.A. de Almeida, 2003. *Violência Urbana*. PubliFolha
Price, A.H., J.E. Cairns, P. Horton, H.G. Jones and H. Griffiths. 2002. Linking drought resistance mechanisms to drought avoidance in upland rice using a QTL approach: progress and new opportunities to integrate stomatal and mesophyll responses. *J. Exp. Bot.,* 53: 989
Ramakrishnan, S.H., C. Anandakumar, S. Saravanan and N. Malini, 2006. Association analysis of some yield traits in rice (*Oryza sativa* L.). *J. Appl. Sci. Res.,* 2: 402–404
Rennenberg, H., F. Loreto, A. Polle, F. Brilli, S. Fares, R. Beniwal and A. Gessler, 2006. Physiological responses of forest trees to heat and drought. *Plant Biol.,* 8: 556–571
Sabesan, T., R. Suresh and K. Saravanan, 2009. Genetic variability and correlation for yield and grain quality characters of rice grown in coastal saline low land of Tamilnadu. *Electron. J. Plant Breed.,* 1: 56–59
Sadras, V.O., 2007. Evolutionary aspects of the trade-off between seed size and number in crops. *Field Crops Res.,*100: 125–138
Serraj, R., A. Kumar, K. McNally and I. Slamet-Loedin, 2009. Improvement of drought resistance in rice. *Adv. Agron.,* 103: 41–99
Serraj, R., K.L. McNally, I. Slamet-Loedin, A. Kohli, S.M. Haefele, G. Atlin and A. Kumar, 2011. Drought resistance improvement in rice: an integrated genetic and resource management strategy. *Plant Produc. Sci.,* 14: 1–14
Simmonds, N.W. and J. Smartt, 1999. *Principles of Crop Improvement*. Blackwell Science, Ltd, Oxford
Singh, S.P., G.S. Singhar, G.A. Parray and G.N. Bhat, 2006. Genetic variability and character association studies in rice (*Oryza sativa* L.). *Agric. Sci. Digest*., 26: 212–214
Stiller, V., H.R. Lafitte and J.S. Sperry, 2003. Hydraulic properties of rice and the response of gas exchange to water stress. *Plant Physiol.*, 132: 1698–1706
Tripathi, S., O.P. Verma, D.K. Dwived, Y. Kumar, P.K. Singh and G.P. Verma, 2011. Association studies in rice (*Oryza sativa* L.) hybrids under saline alkaline environment. *Environ. Ecol*., 29: 1557–1560
Venuprasad, R., S. Impa, R. Gowda, G. Atlin and R. Serraj, 2011. Rice near-isogenic-lines (NILs) contrasting for grain yield under lowland drought stress. *Field Crops Res.,* 123: 38–46
Yang, J., J. Zhang, L. Liu, Z. Wang and Q. Zhu, 2002. Carbon remobilization and grain filling in japonicalindica hybrid rice subjected to postanthesis water deficits. *Agron. J.,* 94: 102–109

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