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Identification of Drought Tolerant Rice (*Oryza sativa* L.) Genotypes Using Drought Tolerance Indices under Normal and Water Stress Condition

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A B S T R A C T

Sixteen medium maturity duration rice genotypes carrying QTLs for drought tolerance were evaluated under reproductive stage drought stress and controlled conditions during *kharif*, 2015 to identify drought tolerant genotypes. Drought tolerance indices like stress susceptibility index (SSI), drought tolerance efficiency (DTE), stress tolerance index (STI) and stress tolerance level (TOL) were employed in screening of the genotypes. Significant yield reduction was observed under drought stress in majority of the rice genotypes studied. The variation in SSI values ranged from 0.74 – 1.12, DTE from 43.38 -62.61%, STI ranged from 0.37-0.65 and TOL varied from 2.50 -5.13. The genotypes with high DTE and STI and low SSI and TOL were identified as drought tolerant genotypes. Based on drought tolerance indices screening, rice genotypes IR96321-315-294-1-1-1, IR96321-558-563-B-2-1-1 and IR96321-558-563-B-2-1-1 showed low SSI and TOL and high DTE and STI values were identified as drought tolerant genotypes. Drought tolerant genotypes viz., the genotype IR 96321-558-563-B-2-1-3 (4791 kg/ha) and IR 96321-558-209-B-6-1-1 (4538 kg/ha) had lesser leaf rolling, leaf drying and better stress recovery as well as delayed leaf rolling and drying. These drought tolerant genotypes also showed superior performance with respect to grain. The present study indicate that selection based on stress tolerance indices likes drought tolerance efficiency, stress susceptibility index, stress tolerance index and stress tolerance level will results in identification of drought tolerant genotypes for rainfed ecosystem.

Keywords

Rice, drought stress, drought tolerance indices, grain yield

Introduction

Rice (*Oryza sativa* L.) is the major food for more than 60% of the population in India. Rainfed rice accounts for around 45% of the world's rice area and around 40 million ha of rain-fed area is concentrated in South and South East Asia alone. Rice occupies around 44 million hectares of cultivable land and it plays a vital role in the nation's food security. India's rice production nearly tripled between 1960 and 2010, with a compound growth rate of 2.53%. India is expected to surpass its demand by 2030 if rice production grows at 1.34% per annum. But, it will have a deficit of around 2.5 million tons if the present growth rate of 1.14% continues up to 2030. Rain-fed ricegrowing areas are highly prone to abiotic stresses such as drought, high temperature and submergence depending upon the distribution of rainfall and topography. Current speculations about increase in the frequency of droughts along with a 1.1-6.4^{o}C increase in global average surface temperature by the end of this century poses serious threat to rice production and thus, food security of Asia. Among the different stresses, drought is the single largest yield reducing factor in rain-fed areas of South and Southeast Asia, affecting more than 23 million ha area (Huke *et al.,* 1997). Out of the total 20.7 million ha located in India, approximately 16.2 million ha is in eastern India (Singh and Singh, 2000), of which 6.3 million ha of upland and 7.3 million ha of lowland area are highly drought prone (Pandey *et al.,* 2008). Rice crop is highly sensitive to soil moisture deficit and high/low temperature stresses at reproductive stage. Losses due to reproductive-stage drought stress are most severe in eastern India. Most of the traditional as well as high yielding varieties cultivated in the eastern region are highly susceptible to drought, particularly reproductive stage drought. The higher frequency and intensity of drought spells necessitates development of rice cultivars, which are able to survive under water deficit stress at reproductive stage and quickly recover after the drought spells, by rapid growth upon improved availability of soil moisture (Kamoshita *et al.,* 2008). Mean yield and relative yield performance under stressed and controlled environments are the most widely used criteria for selecting genotypes for stress prone environments. Pinter *et al.,* (1990), and Kumar *et al.,* (2014) found relative grain yield to be a useful criterion for assessing drought response of wheat genotypes. The ability of crop cultivars to perform reasonably well in drought stressed environments is paramount for stability of production. The combination of high yield stability and high relative yield under drought has been proposed as useful selection criteria for characterizing genotypic performance under varying degrees of water stress (Pinter *et al.,* 1990). There are some indices to determine drought tolerance i.e. stress tolerance level (TOL), stress tolerance index (STI), stress susceptibility index (SSI) and drought tolerance efficiency (DTE), which may be useful as an indicator to identify drought tolerant genotypes that perform well in stress environments. These indices are yield stability parameters which are based on how much reduction are realized under drought stress condition. Raman *et al.,* (2012) reported minimum yield reduction in rice genotypes, which had the lowest SSI and TOL values.

Therefore present study was undertaken to identify rice genotypes having high yield potential and stability under drought stress conditions by analyzing drought tolerance indices at reproductive stage under rainfed condition of eastern India particularly in Bihar.

Materials and Methods

Experimental site and plant materials

The field experiments were carried out at Rice research farm, Bihar Agricultural University, Sabour (Bhagalpur) India (latitude 25^{0}15'40'' N, longitude 87^{o}2'42'' E) during *Kharif* 2015-16. The total rainfall was 1024 mm during crop growth periods in 2015, respectively. Sixteen rice genotypes comprising of advanced breeding lines of 100-120 days of maturity duration and check varieties Swarna and Swarna Sub-1 were used for testing under irrigated and reproductive stage drought stress condition. The rice genotypes used in the present study were obtained from International Rice Research Institute (IRRI), Philippines under STRASA (Stress-Tolerant Rice for Africa and South Asia) (STRASA) project.

Field experiments

The field experiments were conducted under stress (reproductive stage drought) and non-stress control (irrigated) condition with of sixteen medium maturity duration rice genotypes carrying QTLs for drought tolerance including two checks namely Swarna and Swarna Sub-1 under normal and reproductive stage drought condition at rice research farm of Bihar Agricultural University, Sabour, (Bihar), India during Kharif, 2015. Experiments were laid out in an alpha lattice design with two replications. Twenty-one days old seedlings were transplanted at 20 x 15 cm spacing. In each plot a uniform plant stand was maintained and standard agronomic practices were followed for raising and maintenance of plants. Both stress and control fields were fertilized at the rate of 100, 60 and 40 kg N/ha, P_2O_5 and K_2O, respectively. Nitrogen was applied on 3 occasions (1/3each at basal, maximum tillering and panicle initiation stage), while the $P_2O_5$and K_2O were applied as a basal application In non-stress experiments, standing water was maintained from transplanting to 20 days before maturity by providing water by rain or by supplementary irrigation as and when required. The reproductive stage drought stress experiment was irrigated like the non-stress (control) experiments by keeping standing water up to 28 days after transplanting. Thereafter, the field was drained to allow them dry and for stress to develop. The drought stress experiments were not provided any supplemental irrigation after drainage. During the reproductive stage stress period soil moisture content was monitored through periodical soil sampling at 15 and 30 cm soil depth after suspension of irrigation. Water table depth was also monitored during the stress period. The drought scores, leaf rolling, leaf drying and stress recovery observations were taken as per SES method, 1 to 9 scales (IRRI, 1996). Observations of yield and yield contributing traits were recorded on five randomly selected plants per genotype per replication. The relative yield (yield potential) under drought stress was calculated as the yield of specific genotypes under drought divided by that of the highest yielding genotype in the sample.

Several drought tolerance indices have been calculated on the basis of a mathematical relationship between yield under drought stress and non-stressed conditions. Hossain *et al.,* (1999) defined mean productivity index (MPI) as the average of (Yi)NS and (Yi)S. Based on the mean grain yield across trials under stress and non-stress conditions, drought tolerance indices including stress tolerance level (TOL), stress tolerance index (STI), stress susceptibility index (SSI), drought tolerance efficiency (DTE) were calculated. Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the stress and non-stress environments, i.e., TOL= (Yi)NS - (Yi)S. Let (Yi)S and (Yi)NS denote the yield of the ith genotype under stress and non-stress (irrigated) condition, respectively. Higher value of TOL indicates susceptibility of a given genotype. Fernandez (1992) defined a stress tolerance index (STI) as STI = [(Yi)NS x (Yi)S] /(YNS)2, which can be used to identify genotype that produce high yield under both stress and non-stress conditions. A high value of STI implies higher tolerance to drought stress. Fisher and Maurer (1978) proposed stress susceptibility index (SSI), which assesses the reduction in yield caused by unfavourable (stress) compared to favourable irrigated environments SSI is expressed as SSI =[1- ((Yi)S / (Yi) NS] / SI. SI, the stress intensity is estimated as SI = 1- (YS/YNS). YS and YNS denote the mean yield of all genotypes evaluated under stress and non-stress environments, respectively. Lower SSI values indicate lower difference in yield across stress level, in other words, more tolerance to drought. SSI has often been used for identifying genotypes with yield stability in moisture limited environment (Puri *et al.*, 2010; Raman *et al.*, 2012). Drought tolerance efficiency (DTE) is estimated by the equation of Fischer and Wood (1981). According to this equation: DTE (%) = (Yield under stress /Yield under non-stress) x 100. Higher values of DTE indicates higher drought tolerance ability of genotypes as successfully demonstrated by many groups (Raman *et al.*, 2012, Ouk *et al.*, 2006; Talebi *et al.*, 2009; Singh *et al.*, 2011).

Results and Discussion

Effect of reproductive stage drought stress on yield attributes

The results related to yield attributes of rice genotypes under drought stress at reproductive stage and control (irrigated) condition have been presented in Table- 1. The analysis of variance revealed significant differences among the genotypes for yield and yield attributing characters. Rice genotypes grown under water stress condition produced significantly lower grain yields than flooded rice. Yield decline was observed almost in all the rice genotypes grown under drought stress condition. The range of yield decline was 3.08 to 5.13 t /ha under water stress condition in comparison with non-stress (irrigated) condition. Genotype mean yields ranged from 6696 kg/ ha (IR 96321-315-294-B-1-1-1) to 9464 kg/ ha (IR 96321-558-563-B-2-1-3) under non-stress (control) irrigated condition and from 3590 (IR 96321-558-257-B-4-1-2) kg/ha to 4791 kg/ha (IR 96321-558-563-B-2-1-3) under stress condition. The reduction in yield varies between drought stressed and control treatment ranged between 37.39 to 56.62%. Ouk *et al.,* (2006) reported 12 to 46% reduction in grain yield under drought stress. Basnayake *et al.,* (2004) observed 9 to 51% yield reduction due to drought in rice genotypes in multi-location trial conducted for 3 year in target environment. Out of 50 rice genotypes evaluated, 12 were identified as promising genotypes which performed better than check and existing high yielding varieties of eastern region. The difference in grain yield between drought stress and non-stress treatment was 49.54 % in IR 96321-558-563-B-2-1-3, 52.17% in IR 96322-34-260-B-5-1-1and 51.25 % in IR 96321-315-323-B-3-1-1whereas it was 56.42 % in Swarna Sub-1 and 56.62% in Swarna.

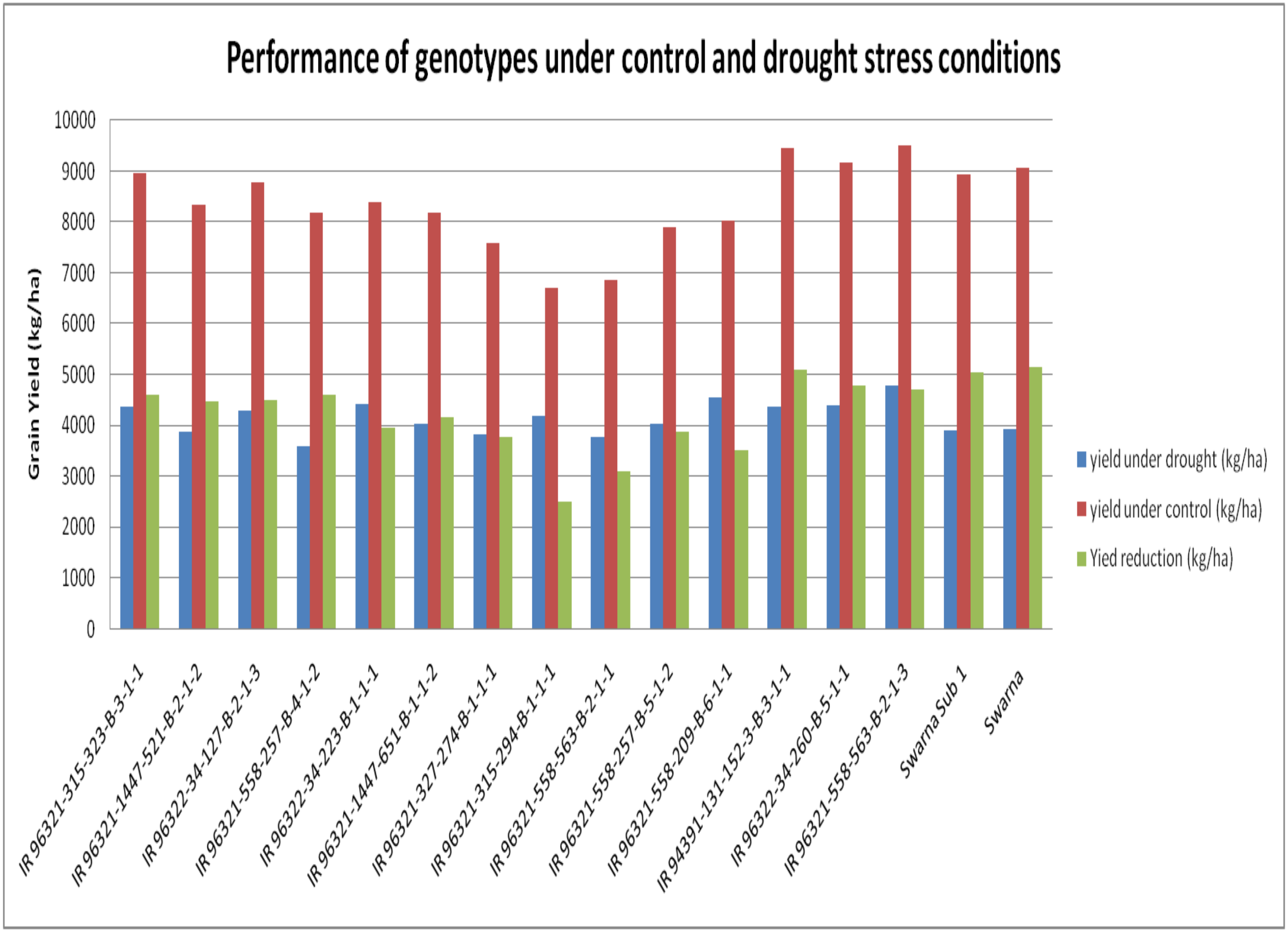
Under non-stress condition, maximum grain yield was observed in IR 96321-558-563-B-2-1-3 (9464 kg/ ha) followed by IR 96322-34-260-B-5-1-1(9167 kg/ha). However, under reproductive stress conditions, the genotype IR 96321-558-563-B-2-1-3 (4791 kg/ha) and IR 96321-558-209-B-6-1-1 (4538 kg/ha) were found to be significantly superior to the best check Swarna and Swarna Sub-1 for grain yield. The significant delay in fifty percent flowering was observed under water stress condition as compared to non-stress irrigated situation; however, the responses varied among genotypes. Similar finding was also reported by Kumar *et al.,* (2009). Significant decrease in plant height was also observed in rice genotypes grown under drought stress condition. Rice grown in drought stress condition produced significantly less total biomass than irrigated rice. These findings are in accordance with the results of Kumar *et al.,* (2014) and Singh *et al.,* (2016).

Table . Yield and yield attributes of rice genotypes and check varieties in response to drought stress and control condition.

Sl. No.	Genotype	Days to flowering		Plant height (cm)		H.I		Biomass (Kg)		Grain yield (Kg)/plot		Grain yield (Kg/ha)		% reduction in yield under stress
		Control	Stress	Control	Stress	Control	Stress	Control	Stress	Control	Stress	Control	Stress	
1	IR 96321-315-323-B-3-1-1	108	105	103	97	0.53	0.52	16862	8436	3.01	3.41	8958	4368	51.25
2	IR 96321-1447-521-B-2-1-2	101	103	100	91	0.51	0.51	16266	7560	2.80	3.01	8333	3863	53.64
3	IR 96322-34-127-B-2-1-3	101	102	96	90	0.52	0.48	16869	8927	2.95	3.34	8780	4286	51.18
4	IR 96321-558-257-B-4-1-2	101	102	93	87	0.51	0.48	16012	7470	2.75	2.80	8185	3590	56.14
5	IR 96322-34-223-B-1-1-1	108	116	96	92	0.47	0.53	17560	8291	2.82	3.45	8378	4423	47.21
6	IR 96321-1447-651-B-1-1-2	104	105	99	90	0.51	0.49	15967	8218	2.75	3.13	8185	4017	50.92
7	IR 96321-327-274-B-1-1-1	121	124	93	86	0.49	0.43	15744	8859	2.55	2.98	7589	3825	49.60
8	IR 96321-315-294-B-1-1-1	119	125	100	94	0.46	0.50	14583	8419	2.25	3.27	6696	4192	37.39
9	IR 96321-558-563-B-2-1-1	115	125	97	85	0.48	0.49	14315	7654	2.30	2.93	6845	3761	45.06
10	IR 96321-558-257-B-5-1-2	121	124	90	87	0.48	0.51	16518	7876	2.65	3.13	7887	4017	49.07
11	IR 96321-558-209-B-6-1-1	119	121	98	94	0.49	0.54	16518	8359	2.70	3.54	8036	4538	43.52
12	IR 94391-131-152-3-B-3-1-1	106	116	98	98	0.50	0.51	18827	8538	3.18	3.40	9464	4363	53.90
13	IR 96322-34-260-B-5-1-1	105	105	101	93	0.52	0.51	17634	8671	3.08	3.42	9167	4385	52.17
14	IR 96321-558-563-B-2-1-3	114	124	100	93	0.51	0.53	18604	8962	3.19	3.74	9494	4791	49.54
15	Swarna Sub- 1 (C)	116	125	100	91	0.50	0.51	17753	7603	3.01	3.04	8943	3897	56.42
16	Swarna ©	114	122	102	96	0.52	0.52	17560	7577	3.05	3.07	9063	3932	56.62
Mean		111	115	98	92	0.50	0.50	16724	8214	2.81	3.23	8375	4140	50.23
CD at 5%		1.78	1.34	11.04	8.7	0.43	0.54	852.9	4485.26	0.77	0.44	566.87	566.87	
CD at 1%		2.46	1.81	15.26	11.72	0.58	0.74	1148.49	6199.66	1.07	0.59	763.33	763.33	
SE (+_)		0.59	0.46	3.66	3.01	0.15	0.17	295.3	1488.09	0.257	0.15	196.27	196.27	

Table.2 Drought tolerances indices of rice genotypes and check varieties in response to drought stress and irrigated condition.

Sl. No.	Genotypes	Grain yield (t/ha)							
		Non-stress (Control)	RSS	MPI	MRP	TOL	STI	SSI	DTE
1	IR 96321-315-323-B-3-1-1	8.96	4.37	6.66	2.12	4.59	0.56	1.01	48.75
2	IR 96321-1447-521-B-2-1-2	8.33	3.86	6.10	1.93	4.47	0.46	1.06	46.36
3	IR 96322-34-127-B-2-1-3	8.78	4.29	6.53	2.08	4.49	0.54	1.01	48.82
4	IR 96321-558-257-B-4-1-2	8.18	3.59	5.89	1.98	4.59	0.42	1.11	43.86
5	IR 96322-34-223-B-1-1-1	8.38	4.42	6.40	2.07	3.95	0.53	0.93	52.79
6	IR 96321-1447-651-B-1-1-2	8.18	4.02	6.10	1.95	4.17	0.47	1.01	49.08
7	IR 96321-327-274-B-1-1-1	7.59	3.82	5.71	1.83	3.76	0.41	0.98	50.40
8	IR 96321-315-294-B-1-1-1	6.70	4.19	5.44	1.81	2.50	0.40	0.74	62.61
9	IR 96321-558-563-B-2-1-1	6.85	3.76	5.30	1.73	3.08	0.37	0.89	54.94
10	IR 96321-558-257-B-5-1-2	7.89	4.02	5.95	1.91	3.87	0.45	0.97	50.93
11	IR 96321-558-209-B-6-1-1	8.04	4.54	6.29	2.06	3.50	0.52	0.86	56.48
12	IR 94391-131-152-3-B-3-1-1	9.46	4.36	6.91	2.18	5.10	0.59	1.07	46.10
13	IR 96322-34-260-B-5-1-1	9.17	4.38	6.78	2.15	4.78	0.57	1.03	47.83
14	IR 96321-558-563-B-2-1-3	9.49	4.79	7.14	2.29	4.70	0.65	0.98	50.46
15	Swarna Sub 1	8.94	3.90	6.42	2.01	5.05	0.50	1.12	43.58
16	Swarna	9.06	3.93	6.50	2.03	5.13	0.51	1.12	43.38
Mean		8.38	4.14						


Performance of genotypes under control and drought stress conditions
Grain Yield (kg/ha)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
yield under drought (kg/ha)
yield under control (kg/ha)
Yied reduction (kg/ha)
IR 96321-315-323-B-3-1-1
IR 96321-1447-521-B-2-1-2
IR 96322-34-127-B-2-1-3
IR 96321-558-257-B-4-1-2
IR 96322-34-223-B-1-1-1
IR 96321-1447-651-B-1-1-2
IR 96321-327-274-B-1-1-1
IR 96321-315-294-B-1-1-1
IR 96321-558-563-B-2-1-1
IR 96321-558-257-B-5-1-2
IR 96321-558-209-B-6-1-1
IR 94391-131-152-3-B-3-1-1
IR 96322-34-260-B-5-1-1
IR 96321-558-563-B-2-1-3
Swarna Sub 1
Swarna

The drought tolerance indices and relative yield for reproductive stage drought stress are presented in Table 3. Significant difference was observed between the mean grain yield of control and stress condition for all entries which implies that the performance under stress and non-stress was considerably different. With respect to MPI and STI the genotype IR96321-558-563-B-2-1-3 ranked first while, the genotype IR96322-34-223-B-1-1-1 showed for MRP. Lowest TOL value (2.50) recorded in IR96321-315-294-B-1-1-1 followed byIR96321-558-563-B-2-1-1 (3.08) and IR96321-558-209-B-6-1-1(3.50). whereas, Swarna showed its higher value (5.13). Lower value of TOL (stress tolerance) indicates the high stress tolerance ability of a given cultivar. Similar finding were reported by Raman *et al.,* (2012). Stress susceptibility index assess the reduction in yield caused by unfavorable compared to favorable environments. Lower SSI values indicate the lower differences in yield between non-stress and stress condition, in other words more tolerance to drought. SSI is a measure of yield stability. IR96321-315-294-13-1-1-1 recorded lowest SSI value of 0.74, followed by IR96321-558-209-B-6-1-1(0.86) and IR96321-558-563-B-2-1-1 (0.98) whereas, Swarna showed its higher value (1.12). Timing of drought stress in relation to the development of different genotypes or lack of adaptation to unfavorable environments could be other possible reason of variation in SSI. The results of this study are in good agreement with the earlier finding (Raman *et al.,* 2012). Genotypes with low SSI values (less than I) can be considered to be drought resistant (Chauhan *et al.,* 2007) because they exhibited smaller yield reductions under water stress compared with well watered conditions. Based upon the value and direction of desirability, ranking was done for different genotypes as highly drought tolerant (SSI < 0.50), drought tolerant (SSI: 0.51-0.75), moderately drought tolerant (SSI: 0.76-1.00) and drought susceptible (SSI > 1.00). On the basis of SSI index, one genotype out of 16 genotypes were identified as drought tolerant and two rice genotypes as moderately drought tolerant (SSI<1) while, rest of the genotypes were susceptible (SSI>1) for grain yield. An overall appraisal revealed that IR96321-315-294-13-1-1-1 possessed high level of drought tolerance (Table 3).

Drought indices TOL and SSI favor genotypes with good yield under drought stress condition. Therefore, they are more useful for identifying genotypes that perform well in stress environment. Stress tolerance index (STI) was used to identify genotypes that produce high yield under both drought stress and non-stress irrigated condition. A high value of STI implies higher tolerance to stress. The genotype 96331-558-563-B-2-1-3 showed highest value of STI (0.65). With respect to STI drought index, 94391-131-152-3-B-3-1-1 (0.59), IR96322-34-260-B-5-1-1 (0.57) and IRIR96321-315-323-B-3-1-1 (0.56) were the top performer rice genotypes under stress condition. IR 96321-558-563-B-2-1-1 showed lowest STI value (0.37) which implies that it is highly susceptible to drought stress, particularly at reproductive stage. Drought tolerance efficiency (DTE) is a measure of drought resistance mechanisms and determines the consistency of selected genotypes in response to drought stress having of different severity, timing and duration and thus may be helpful in identifying genotypes that possess drought resistance capability in rainfed lowland ecosystem of rice. Highest DTE value for grain yield was recorded in IR96321-315-294-B-1-1-1 (62.61%) followed by IR96321-558-209-B-6-1-1 (56.48%), IR96321-558-563-B-2-1-1 (54.94%) and

IR96322-34-223-B-1-1-1 (52.79%). Drought tolerant genotypes viz., the genotype IR 96321-558-563-B-2-1-3 (4791 kg/ha) and IR 96321-558-209-B-6-1-1 (4538 kg/ha) had lesser leaf rolling, leaf drying and better stress recovery as well as delayed leaf rolling and drying. Leaf rolling was induced by the loss of turgor and poor osmotic adjustment in rice and delayed leaf rolling is an indication of turgor maintenance and dehydration avoidance (Blum, 1989). Leaf rolling and drying showed negative correlation with plant biomass. Beena *et al.*, (2012) also reported similar results in rice. One of the reasons for this is the complexity of genetic control of grain yield under drought. One or more of the traits mentioned above along with traits related to yield potential such as number of tillers, panicles and fertile grains can play a role in determining the yield under drought.

Based on results related to yield attributes of rice genotypes and desired physiological traits under drought stress, rice genotypes IR 96321-558-563-B-2-1-3, IR 96321-558-209-B-6-1-1 and IR96321-558-209-B-6-1-1 showed low SSI and TOL and high DTE and STI values were identified as drought tolerant genotypes

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