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Screening and identification of rice genotypes for drought tolerance at reproductive stage under rainfed lowland condition

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ABSTRACT

A field screening of twelve rice genotypes under drought stress and irrigated non-stress condition was conducted during *kharif* 2013 with the objective to study the effect of drought stress on yield and yield attributes performance of advanced breeding lines and current high yielding varieties. The effects of water deficit on various physiological traits associated with drought tolerance were also studied. Result revealed that significant yield decline was observed almost in all rice genotypes grown under water stress condition compared to irrigated situation. Out of these twelve rice genotypes, IR88964-24-2-1-4, IR88966-43-1-1-4 and IR88964-11-2-2-3 showed superior in terms of grain yield and yield attributes. Significant variation was also observed among genotypes for leaf rolling, leaf drying, stress recovery and relative water content under drought stress conditions. The tolerant lines maintained high leaf water status, membrane stability and plant biomass under reproductive stage drought condition. Based on yield and yield attributes results under drought and irrigated condition, rice genotypes IR88964-24-2-1-4, IR88966-43-1-1-4 and IR88964-11-2-2-3 were recommended for use in drought breeding programme as well as adoption in rainfed lowland ecosystem. The present study also indicates the agro-morphological and physiological traits that have direct and indirect effect on yield performance of rice genotypes under drought stress condition.

Key words: Rice, Drought, Rainfed lowland, grain yield, relative water content

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food for over half the world's population (Singh *et al.*, 2012). It provides 27 per cent of dietary energy and 20 per cent of dietary protein in the developing countries (Singh and Singh 2007). It is cultivated in at least 114 developing countries and it is the primary source of income and employment for more than 100 million house hold in Asia (Singh *et al.*, 2015). It is being cultivated under diverse ecologies ranging from irrigated to rainfed and upland to lowland to deep water system. Drought is considered one of the main constraints that limit rice yield in rainfed and poorly irrigated areas. At least 23 million hectares of rainfed rice area in Asia are estimated to be drought prone, and drought is becoming an increasing problem even in traditionally irrigated areas (Pandey *et al.*, 2005). Out of the total 20.7 million ha of rainfed rice area reported in India, approximately 16.2 million ha lie 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 and Bhandari, 2009). The eastern Indo-Gangetic Plain is one of the major, drought-prone rice-producing regions in the world (Huke and Huke, 1997). In this plain, losses due to reproductive-stage drought stress are most severe in the key rice-producing states of eastern India: Chhattisgarh, Orissa, Jharkhand, Bihar, and eastern Uttar Pradesh. Adverse agroclimatic conditions also invite the pest attack due to its weak internal defense system (Singh *et al.*, 2014). In severe drought years, total losses to rice production in Chhattisgarh, Orissa, and Jharkhand have been reported to be as much as 40%, valued at US$ 650 million (Pandey *et al.*, 2005).

The identification or development of rice cultivars that could resist drought stress and produce economic yields is imperative in order to alleviate that increasing food crisis. Most improved cultivars grown in drought prone rainfed lowlands were originally bred for irrigated

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conditions and were never selected for drought tolerance (Kumar *et al.*, 2008).

Traditional as well as high yielding varieties of the eastern region are also highly susceptible to drought, particularly at reproductive stage. Degree and duration of drought stress during the reproductive stage in rainfed lowland rice is in need of development of drought tolerant rice cultivars (Kamoshita *et al.*, 2008) which must survive under water deficit stress at reproductive stage, quickly recover, and grow rapidly upon renewed availability of soil moisture (De Datta *et al.*, 1988). Grain yield may drastically reduce when water deficit coincides with reproductive or intermittent stage. Rice plants respond to drought through alternation in morphological, physiological and metabolic traits. Hence, traits associated with improved performance under water limited condition or improved survivals to extremely low water availability are diverse (Slafer *et al.*, 2005). Drought impacts include growth, yield, membrane integrity, pigment content, osmotic adjustment, water relation and photosynthetic activities (Praba *et al.*, 2009). Physiological basis of yield gap between drought stress and irrigated condition has not been studied extensively. Understanding of physiological and biochemical mechanism that enable plants to adapt to water deficit and maintain growth and productivity during stress period could help in screening and selection of tolerant genotypes and using these traits in breeding programme (Zaharieva *et al.*, 2001). Therefore, selection using morph-physiological and metabolic traits can improved the drought tolerance at reproductive stage in rice. Variation in maintaining internal plant water status at flowering was associated with grain yield under drought condition (Pantuwan *et al.*, 2001). The maintenance of plant water status, more than plant functions, controls crop performance under drought (Blum, 2002). Leaf rolling is one of the visible physiological responses to plant water deficit. It is an adaptive response to water deficit which helps in maintaining favourable water balance within plant tissues with resultant benefit to plants under conditions of water scarcity and depleting soil moisture (Singh and Singh, 2000). Plant recovery from desiccation in agricultural crops is primarily a function of the capacity for maintaining higher RWC during desiccation (Blum *et al.*, 1999).

MATERIALS AND METHODS

Experimental site and plant materials

Field experiments were carried out at the experimental farm of the ICAR Research Complex for Eastern Region, Patna, India (latitude 25.30^{0}N, longitude 85.15^{0}E) during *kharif* season 2013 and 2014. The experimental site was typical rainfed having clay loam soil with pH 7.5. Twelve rice genotypes comprising of advanced breeding lines and check varieties of the eastern region *viz.*, Swarna, Sambha Mahsuri, Rajendra Sweta and Lalat were used for testing under irrigated and stress condition. The rice genotypes used under present study were collected under Stress-Tolerant Rice for Africa and South Asia (STRASA) project from International Rice Research Institute (IRRI), Philippines.

Field and lab experiments

The field experiments were conducted under reproductive stage water stress and irrigated non-stress (control) condition. The experiment was laid out in an alpha lattice design with three replications. Field was thoroughly prepared and levelled with laser leveller before transplanting so that if rainfall occurred at reproductive stage, water should not be stagnant in drought stress field. Twenty one days old seedlings were transplanted. Each genotype was raised in a 5.6 m^2 plot by transplanting. The single rice seedlings were transplanted manually in puddled field spaced 15 cm apart. Row to row space was maintained at 20 cm. After 7 days, missing hills were again re-transplanted fresh. In each plot a uniform plant stand were maintained and standard agronomic practices were followed for raising and maintenance of plants. Both water stress and non-stress control field were fertilized at the rate of 90, 50 and 50 kg/ha N, P_2O_5 and K_2O, respectively. Nitrogen was applied on three occasion (1/3rd each at basal, maximum tillering and panicle initiation stage), while the P_2O_5 and K_2O were applied as a basal application. Non-stress irrigated experimental field was kept continuously flooded with 5 cm water after transplanting until 25 days before harvest. Under drought stress experimental field, the crop was grown under normal irrigation for four weeks after transplanting and then irrigation was withdrawn for next one month and beyond, till the susceptible checks showed permanent wilting. During the reproductive stage stress period soil moisture content status was monitored through periodical soil sampling at 15 and 30 cm soil depth after suspension water. Water table depth was also monitored during the stress period. Observations of yield and yield contributing traits i.e. days to 50% flowering (DFF), plant height (PH), tiller numbers /plant (TN/P), biological yield (BY), percentage spikelet sterility and harvest index (HI) while grain yield (GY) in t/ha recorded on plot basis. 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 population. The drought scores, leaf rolling, leaf drying and stress recovery observations were taken as per SES method, 1 to 9 scales (IRRI, 1996).

Studies of Physiological parameters

Leaf relative water content (RWC) was estimated by recording the turgid weight of 0.5 g fresh leaf sample by keeping in water for 4h, followed by drying in hot air oven till constant weight is achieved (Weatherly, 1950). It is given as (Eq. 1):

$$\text{Relative water content (\%)} = \frac{[(\text{Fresh weight- Oven dry weight}) \times 100}{(\text{turgid weight- Oven dry weight})]} \qquad \text{[Eq. 1]}$$

Chlorophyll content was estimated by extracting 0.05 g of leaf material in 10 ml dimethyl sulfoxide (DMSO) (Hiscox and Israelstam, 1979). Chlorophyll content was expressed as mg/g freshweight (Eq. 2).

Total chlorophyll =

$$(20.2 \text{ X OD}_{645} + 8.02 \text{ X OD}_{663}) \text{ X V } /1000 \text{ X w.} \qquad \text{[Eq. 2]}$$

OD 645= absorbance value at 645nm

OD 663= absorbance value at 633nm

W= weight of sample in mg

V = Volume of solvent used (ml)

Membrane stability index (MSI) was estimated as per Sairam *et al*., (1997). For estimation of membrane stability index 100 mg leaf material, in two sets, was taken in test tubes containing 10 ml of double distilled water. One set was heated at 40 ºC for 30 min in a metabolic water bath, and the electrical conductivity of the solution was recorded on a conductivity bridge (C_1). Second set was boiled at 100 ºC on a boiling water bath for 10 min, and its conductivity was measured on a conductivity bridge (C_2). Membrane stability index was calculated as (Eq. 3).

$$\text{MSI (\%)} = [1 - (C_1/C_2)] \times 100 \qquad \text{[Eq. 3]}$$

Data analysis

The agro-morphological data were analyzed by appropriate statistical analysis (Gomez and Gomez, 1984) using CropStat 7.2 (IRRI, 2009) programme. Physiological data was analyzed using OPSTAT software of Hisar Agricultural University, Hisar.

RESULTS AND DISCUSSION

Yield and yield attributes performance under drought stress and irrigated (non-stress)

The results related to yield and yield attributes performance of rice genotypes under drought stress at reproductive stage and irrigated condition has been presented in Table 1. Rice genotypes grown under water stress condition produced significantly lower grain yields than irrigated condition. Yield decline was observed almost in all the rice genotypes grown under stress condition. The range of yield declined was 1.36 to 5.53 t/ ha under water stress condition as compared to non-stress (irrigated). The yield reduction difference between drought stress and non-stress rice ranged between 27.31 to 67.7% (Fig. 1). The minimum yield reduction was observed in IR88964-43-1-1-4 (24.2%) followed by IR88964-11-2-2-3 (34.7%) whereas maximum yield reduction recorded in Swarna (81.5%). A similar result of yield reduction under drought stress condition was reported by Ouk *et al.,* (2006). They reported 12 to 46% reduction in grain yield under drought affect condition. In other studies in Cambodia, Basnayake *et al.* (2004) estimated yield reduction due to drought from 9 to 51% in rice genotypes in multi-locational trial conducted in three year in the target environment. Under drought stress condition, the highest grain yields was observed in IR88964-24-2-1-4 (4.88 t/ha) followed by IR88964-43-1-1-4 (4.26 t/ ha) and IR88964-11-2-2-3 (4.15 t/ha). The grain yield of check varieties Lalat, Swarna, Samba Mahsuri and Rajendra Sweta in drought stress condition were 2.47 t/ ha, 1.25 t /ha, 1.30 t /ha and 1.47 t /ha respectively. The difference in grain yield between drought stress and non-stress rice was 40.2 % in IR88964-24-2-1-4. Under irrigated condition, maximum grain yield was observed in IR88964-24-2-1-4 (8.16 t / ha) followed by Swarna (6.78 t /ha) and IR84895-B-127-CRA-5-1-1 (6.65 t /ha).

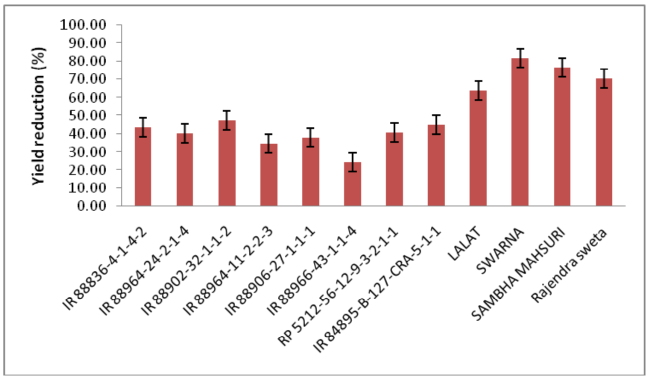

Fig.1. Percentage yield reduction in promising rice genotypes and check varieties under reproductive stage drought stress condition compared to control.

Table 1: Yield and yield attributes response of rice genotypes and check varieties to drought stress and irrigated condition

Promising Genotypes	DFF		PH (cm)		Grain yield in (t/ha)		Test weight (g)		**HI**	
	RSS	IC	RSS	IC	RSS	IC	RSS	IC	RSS	IC
IR 88836-4-1-4-2	73	77	113	121	3.57	6.32	27.9	30.0	0.35	0.47
IR 88964-24-2-1-4	80	80	105	109	4.88	8.16	29.1	29.0	0.34	0.52
IR 88902-32-1-1-2	74	76	102	116	2.93	5.57	23.9	26.0	0.31	0.44
IR 88964-11-2-2-3	75	78	111	117	4.15	6.36	27.7	28.0	0.32	0.44
IR 88906-27-1-1-1	89	80	115	121	3.78	6.10	24.4	29.0	0.32	0.52
IR 88966-43-1-1-4	75	78	102	117	4.26	5.62	25.3	27.0	0.36	0.45
RP 5212-56-12-9-3-2-1-1	76	77	115	136	3.55	6.01	25.0	27.0	0.31	0.42
IR 84895-B-127-CRA-5-1-1	79	84	116	124	3.66	6.65	25.2	30.0	0.30	0.48
LALAT	81	88	111	112	2.42	6.64	20.1	27.0	0.23	0.50
SWARNA	99	103	90	104	1.25	6.78	12.9	22.0	0.17	0.46
SAMBHA MAHSURI	109	106	95	102	1.30	5.49	14.1	21.0	0.12	0.36
Rajendra sweta	98	106	89	96	1.47	4.98	11.6	23.0	0.15	0.38
Mean	84.0	85.9	105.3	114.4	3.10	6.23	22.01	26.5	0.27	0.45
CV (%)	5.90	4.86	4.54	4.09	12.9	6.47	12.6	6.64	10.7	9.16
LSD (5%)	8.09	6.47	8.48	8.72	0.68	0.80	4.49	3.46	0.05	0.09

RSS (Reproductive stage stress), IC (Irrigated condition), DFF (Days to fifty percent flowering), Plant height (PH) and Harvest Index (HI)

Significant decrease in plant height was also observed in rice genotypes grown under drought stress condition. Singh (2000) also reported that plant height reduced significantly due to drought in rice cultivars. Rice grown in drought stress condition produced significantly less total biomass than irrigated rice (Table 2). The Similar trends were also observed for harvest index and test weight. Drought stress had lower test weight (1000 grain weight) and high grain sterility percentage than irrigated rice. Drought tolerant genotypes IR88964-24-2-1-4 (9.5%) followed by IR88902-32-1-1-2 (11.3%) and IR88964-43-1-1-4 (11.4%) showed less per cent spikelet sterility than susceptible and checks varieties. Significant variations were observed among genotypes for drought tolerance parameters leaf rolling, leaf drying and stress recovery. Drought tolerance genotypes viz., IR88964-24-2-1-4, IR88964-43-1-1-4, IR88964-11-2-2-3 and IR 88836-4-1-4-2 had lesser leaf rolling, leaf drying and better stress recovery (Table 2). They showed delayed leaf rolling and drying. Leaf rolling was induced by the loss of turgor and poor osmotic adjustment in rice (Hsiao, 1982) and delayed leaf rolling is an indication of turgor maintenance and dehydration avoidance (Blum, 1989).

Response of physiological parameters

Physiological traits *viz.*, relative water content (RWC), membrane stability index (MSI) and total chlorophyll content influence greatly under drought stress at reproductive stage condition. The capacity to maintain higher relative water content (RWC) under drought stress condition has been suggested as a possible water scarcity tolerance mechanism in rice (O'Toole and Moya 1978). A significant difference in RWC was observed among genotypes between drought stress and irrigated condition. In water stress condition, higher value of RWC was recorded in water deficit stress tolerant rice genotypes as compared to susceptible one at reproductive stage. Highest value of RWC was observed in IR88964-11-2-2-3 (76.5%) followed by IR88964-24-2-1-4 (75.2%) and IR84895-B-127-CRA-5-1-1 (74.1%) (Fig.2). Study revealed that relative water content of all genotypes reduced significantly under drought stress situation as compared to non-stress irrigated condition. Kumar *et al.* (2014), Gupta and Guhey (2011) and Jongdee *et al.* (1998) also reported the similar findings. Membrane stability index (MSI %) is a widely used criterion to assess crop drought tolerance, since water stress caused water loss from plant tissues which seriously impairs both membrane structure and function. Under drought

Table 2: Plant biomass, Test weight, grain sterility percentage, leaf rolling and tip drying of rice genotypes and check varieties to drought stress and irrigated condition.

Promising Genotypes	Plant biomass (g/plant)		Sterility (%)		Leaf rolling (LR), leaf drying (LD) and stress recovery (SR) under RSS		
	RSS	IC	RSS	IC	LR	LD	SR
IR 88836-4-1-4-2	21.7	28.2	14.1	7.4	1.67	1.33	6.33
IR 88964-24-2-1-4	24.9	30.4	9.5	5.9	1.00	1.70	7.00
IR 88902-32-1-1-2	20.7	26.8	11.3	5.2	2.67	2.67	4.77
IR 88964-11-2-2-3	23.5	29.1	12.9	8.1	3.0	3.00	7.00
IR 88906-27-1-1-1	21.8	27.7	16.2	4.8	3.67	3.00	5.70
IR 88966-43-1-1-4	22.8	26.5	11.4	4.0	1.00	2.67	6.30
RP 5212-56-12-9-3-2-1-1	20.2	28.3	14.5	7.2	3.00	3.00	5.00
IR 84895-B-127-CRA-5-1-1	20.9	29.0	17.5	7.7	3.33	2.67	4.70
LALAT	16.5	26.9	24.9	8.1	4.70	4.70	5.00
SWARNA	14.3	28.2	32.2	6.3	5.00	5.00	4.70
SAMBHA MAHSURI	12.9	27.0	34.3	7.7	6.33	5.00	4.70
Rajendra Sweta	11.6	26.6	40.6	6.4	6.33	5.00	4.70
Mean	19.32	27.89	19.95	6.57	3.48	3.31	5.49
CV (%)	5.85	4.77	7.81	8.11	4.28	6.11	5.79
LSD (5%)	1.63	1.59	2.33	1.86	0.21	0.34	0.26

RSS (Reproductive stage stress), IC (Irrigated condition)

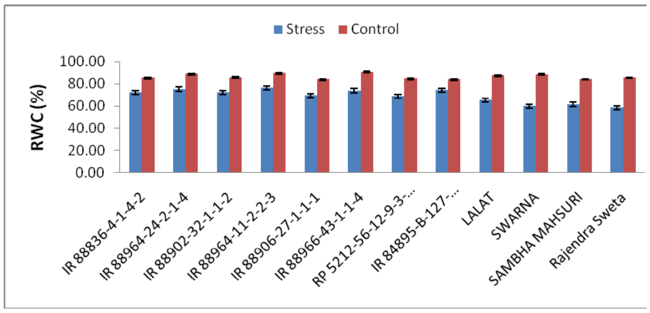

Fig. 2. Effect of drought stress on RWC% of rice genotypes

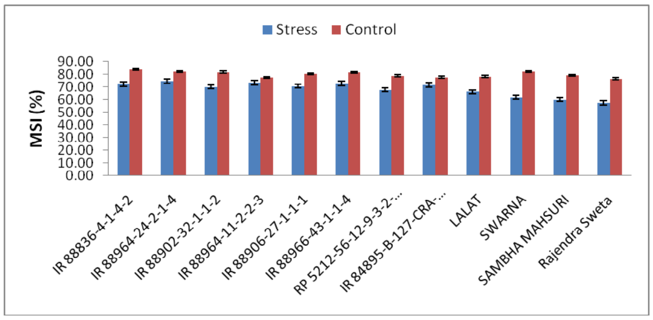

Fig. 3. Effect of drought stress on MSI% of rice genotypes.

stress condition, the higher membrane stability index was observed in IR88964-24-2-1-4 followed by IR88964-11-2-2-3 and IR88964-43-1-1-4 as compared to other high yielding and checks varieties. (Fig. 3).There was no any significant difference observed under control condition. Chlorophyll content of drought tolerance genotypes as well as check varieties (Swarna, Samba Mahsuri, Lalat and Rajendra Sweta) was higher under normal (irrigated) condition. Rice genotypes IR88964-24-2-1-4, IR88964-43-1-1-4, IR88964-11-2-2-3 and IR84895-B-127-CRA-5-1-1 have much higher chlorophyll content in comparison to other genotypes and check varieties under drought stress condition (Fig. 4). Higher genotypic differences

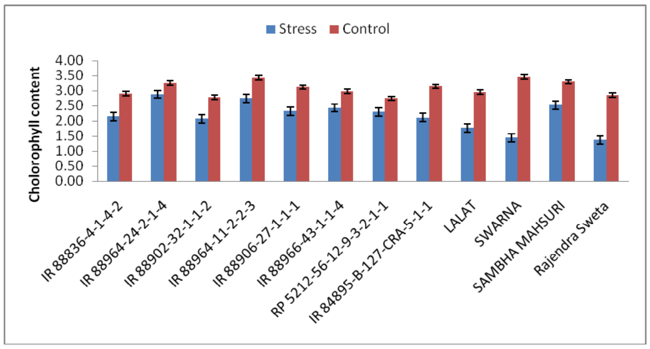

Fig.4. Effect of reproductive stage drought stress on cholorophyll content ( ) of rice genotypes.

in chlorophyll content were observed under stress condition. Mohan *et al.* (2000) stated that the chlorophyll content is an indication of stress tolerance capacity of plants and its high value means that the stress did not have much effect on chlorophyll content of tolerant plants. Gowri (2005) observed decrease in chlorophyll content under water scarcity situation than irrigated environment.

CONCLUSION

The present studies suggested the existence of variation among the genotypes for grain yield and yield contributing morpho-physiological traits showed differential response to drought stress environment at reproductive stage. Drought stress at reproductive stage caused significant reduction in plant height, grain yield, plant biomass, test weight, RWC (%), MSI (%) and increase in grain sterility percentage in rice genotypes; however, the responses varied among genotype. Further yield improvements in drought stress situation can be achieved by identifying physiological and biochemical traits contributing for tolerance against water stress. Selection of promising drought tolerant rice genotypes with desired physiological and biochemical attributes gives better performance under target rainfed environments. Rice genotypes IR88964-24-2-1-4, IR88964-43-1-1-4 and IR88964-11-2-2-3 genotypes showed significant yield advantage, higher content of desired morpho-physiological traits in terms of high plant biomass, RWC, MSI%, chlorophyll content in compared to check varieties under drought stress condition, can be adopted in large area in rainfed lowland ecosystem where drought is frequent, particularly at reproductive stage.

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