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IMPACT OF WATER DEFICIT STRESS ON VARIOUS PHYSIOLOGICAL AND AGRONOMIC TRAITS OF THREE BASMATI RICE (*Oryza sativa L.*) CULTIVARS

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ABSTRACT

Scarcity of water for irrigation is an alarming issue limiting crop production worldwide and is becoming increasingly severe with the passage of time in Pakistan. Rice production in Pakistan is thus, being adversely hampered by the shortage of water. The study was therefore, contemplated to determine the effect of drought stress on some physiological and agronomic parameters of three rice cultivars naming Basmati-Super, Shaheen-Basmati and Basmati-385. The field experiment was laid out in split plot design with randomized complete block arrangement, keeping cultivars in main and water stress stages viz; panicle initiation, anthesis and grain filling along with control in sub-plots. Cultivar Shaheen-Basmati exhibited comparatively more tolerance to drought stress at all the three growth stages under study with less reduction in various physiological and agronomic traits. Similarly, less increase in transpiration rate and sterile tillers per hill were observed in Shaheen-Basmati under drought stress at all the three stages. Growth stage panicle initiation was the most sensitive one exhibiting more adverse effects on all the physiological and agronomic parameters under study., PAR, photosynthetic rate, RWC and stomatal conductance showed strong and positive correlation with WUE whereas; transpiration rate expressed negative correlation with WUE. Similarly, all the physiological and yield components under study except transpiration rate and number of sterile grains per panicle had a strong and positive correlation with paddy yield.

Key words: *Oryza sativa,* Water deficit, PAR, Photosynthetic rate, Transpiration rate, Stomatal conductance, Water use efficiency, Panicle, Anthesis, Grain filling, Hill, Physiological traits, Agronomic parameters, Yield components, Pakistan

INTRODUCTION

Rice (*Oryza sativa L.*) is a major and staple food crop in many parts of the world, feeding more than three billion people and providing 50-80 % of their daily calories intake (Khush, 2005). It is a drought susceptible crop exhibiting serious deleterious effects when exposed to water stress at critical growth stages especially at reproductive stage (Suriyan *et al*., 2010). Shortage of water for irrigation is one of the most crucial factors limiting growth and production of almost all the crops including rice worldwide and intensity of the issue is aggravating with the passage of time (Passioura, 1996**,** Passioura, 2007, Anonymous, 2010). Thus, the percentage of drought affected land has approximately doubled from the 1970s to the early 2000s, affecting grain yield and quality of various crops resulting in food shortages in the world (Isendahl and Schmidt, 2006). Global climate change and arithmetically multiplying world populace augmented with drought stress are making the situation more serious and to cope with the ever growing food, feed and shelter needs of human beings is becoming more difficult day by day (Hogbo *et al*., 2005, Akram, 2007). In contrast with other crops, rice is particularly more sensitive to water stress especially at critical growth stages such as panicle initiation, anthesis and grain filling (Tao et.al**,** 2006, Yang et.al, 2008). Thus, drought stress is affecting about 50% of rice production in the world (Mostajean and Eichi, 2009). Pakistan's Agriculture is currently facing acute shortage of irrigation water and inadequate soil moisture is a stumbling block in rice paddy yield in of Pakistan. Whereas, use of tube well water is also not feasible because of it being injurious for soil health due to of saline / sodic nature (Khan, 2003).The issue of scarcity of water for growing crops is getting horrowsome with the passage of time. The shortage of water during the year 2000 was 40.30 MAF which has jumped up to 107.80 MFA in 2013. If special attention is not paid to resolve the issue and the situation continues as such it is feared that crop growing in Pakistan will be totally flopped (Anonymous, 2001).

Drought stress results in various physiological changes in plants that may include, reduction in PAR, photosynthetic rate, transpiration rate, stomatal conductance, pigment degradation and relative water content (RWC) resulting in decreased water use efficiency (WUE) and growth reduction prior to plant senescence (Chaves and Oliveira, 2004; Cattivelli *et al*., 2008; Tuna *et al*., 2010). These physiological parameters in addition to yield components may be used as criteria for improving drought stress in different crops (Ashraf, 2010). In rice water stress at vegetative growth especially booting stage (Pantuwan *et al*., 2002) , flowering and terminal period can interrupt floret initiation causing spikelet sterility and grain filling resulting in lower grain weight and ultimately poor paddy yield (Kamoshita *et al*., 2004; Botwright *et al*., 2008). Response of different plants to water stress is much complex and various mechanisms are adopted by plants when they encounter drought stress at various growth stages (Levitt, 1980; Jones, 2004). Even behavior of genotypes within a species is also different so, one of the strategies to abate drought stress is selection of a genotype expressing comparatively better drought tolerance (Suriyan *et al*., 2010). It is, therefore, imperative to understand the mechanism of plant responses to water deficit conditions and to study the performance of new genotypes under water stress with the objective of improving crop performance in the drought prone areas of the world. Hence, the present study was conducted to study the impacts of drought stress at various growth stages on some physiological and yield traits of three local rice cultivars.

MATERIALS AND METHODS

On the basis of performance in an earlier experiment on screening of fine rice cultivars against drought tolerance comprising of 15 cultivars conducted during 2004-05, Basmati-super, Shaheen-basmati and Basmati-385 were selected and used as test varieties in this study. Thirty days old nursery plants of the said fine rice cultivars were transplanted in 30 cm apart rows with 20 cm plant to plant distance during 2nd fortnight of July in both the years of study. Fertilizer @ 115-75-50 kg ha^{-1}NPk was applied to the crop at nursery plants transplanting. Soil water content was adjusted to 52 acre inches in normal irrigation treatment and 40 acre inches in water stress treatments at panicle initiation, anthesis and grain filling stages simply by withholding irrigation for 14 days. Soil moisture content was measured using moisture meter (Type HH2), Delta –T Devices Ltd. UK, using Theta Probe Sensor. Water deficit was calculated using the following Formula.

D= R (FWC-VWC) Where, D= Water deficit (m^3m^{-3}), R= Rooting depth (mm), FWC= Field water capacity (m^3m^{-3}), VWC=Measured volumetric water content (m^3m^{-3}).

Chlorophyll fluorescence emission from the adaxial surface of the leaves was measured using a fluorescence monitoring system (Handy PEA; Hansatech Instruments Ltd. Norfolk, UK) in the pulse amplitude modulation mode, as described by Loggini *et al*., (1999).A leaf, adapted to dark conditions for 05 minutes using leaf-clips, was initially exposed to the modulated measuring beam of far-red light (LED source with typical peak at wavelength of 735 nm). The ratio of variable to maximum fluorescence (F_v / F_m) was noted as maximum quantum yield of PSII photochemistry which was calculated by the equipment measuring original (F_o) and the maximum (F_m) and determining F_v by deducting F_o from F_m and dividing F_v with F_m using FMS software.

Net photosynthetic rate (μ mol m^{-2} s^{-1}), stomatal conductance (mmol H_2O m^{-2} s^{-1}), transpiration (mmol m^{-2} s^{-1}) rate and photo synthetically active radiations (mmol m-2 s-1) were measured using Infra-Red Gas Analyzer (Model CI-340 Photosynthesis System, CID, Inc., USA). Water use efficiency (WUE) was calculated using equation (P_n / E) X 100 as described by Cha-um *et al*., (2007). Relative water content (RWC) was calculated from fresh weight (FW), dry weight (DW) and turgid weight (TW) using the equation as described by Bonnet *et al*., (2000) as follows.

RWC (%) = [(FW-DW) / (TW-DW)] X 100

P_n reduction, F_v / F_m diminution, number of tillers per hill, panicles per hill, panicle length, shoot dry weight, panicle dry weight, number of fertile grains, sterile grains & total grains per panicle, 1000-grain weight, paddy yield per hectare and yield stability index was taken.

Data thus collected were subjected to statistical analysis using the method described by Steel *et al.*, (1997) and mean values were compared using Duncan’s Multiple Range Test and analyzed with SPSS software. Whereas, the correlation between physiological parameters and WUE and different yield traits with paddy yield were evaluated using Pearson’s correlation coefficients.

The experiment was laid out in split-plot design with randomized complete block arrangement, maintaining a plot size of 1.20 X 3.00 m^2 and replicating thrice. The study was conducted in the Research Area of Plant Physiology, Ayub Agricultural Research Institute, Faisalabad (Pakistan) during 2006 & 2007.

RESULTS

Physiological parameters. Value of photo synthetically active radiation (PAR) was significantly dropped under water stress in all the cultivars and at all the growth stages; however, a differential response of genotypes and growth stages was observed (Table 1). Thus, reduction in PAR value was more pronounced (24.63%) in case of water stress at panicle initiation followed by anthesis (23.13 %) and grain filling (15.57%) stages, irrespective of cultivars. Similarly, cultivars Super- Basmati showed significantly more dropage (24.57%) in PAR value followed by Basmati-385 (23.40 %) and Shaheen-Basmati (12.50 %), irrespective of stages of water stress. Interaction of cultivars and stages of water stress was also significant in respect of PAR value (Table 6). Eventually, cultivar Shaheen- Basmati expressed the minimum reduction in PAR value of 9.98 % in case of drought stress at grain filling stage.

Photosynthetic rate was significantly decreased by drought stress at all the growth stages and in all the cultivars under study (Table 1). The maximum reduction in photosynthetic rate (21.92%) was observed in Super-Basmati followed by Basmati-385 (18.07%) and Shaheen-Basmati (14.96%). Similarly, water stress at panicle initiation showed the maximum reduction of 30.69 % in photosynthetic rate followed by stress at anthesis and grain filling with reduction in photosynthetic rate of 28.00 and 12.26 %, respectively. Interaction of stress stages and cultivars was also significant with the minimum reduction in photosynthetic rate of 7.43% in cultivar Shaheen-Basmati under stress at grain filling stage (Table 6).

Transpiration rate was adversely affected by water stress at all growth stages and in all the cultivars under study (Table 1). Cultivar Basmati-Super exhibited significantly more reduction of 36% in transpiration rate as compared with Basmati-385 (34.67%) and Shaheen-Basmati (30.33 %). Panicle initiation was more sensitive to drought stress in respect of transpiration rate with maximum reduction of 48.11% followed by anthesis and grain filling with reduction of 28.51 and 5.54 % , respectively. Interaction of cultivars and stages showed a significant response to water deficit (Table 6), thus, the minimum decrease in transpiration rate of 25.00% was recorded in cultivar Shaheen-Basmati under moisture stress at grain filling stage.

Stomatal conductance was significantly impaired by water deficit at all growth stages and in all the genotypes under study (Table 1).The maximum reduction in conductance of 48.19% was observed under moisture stress at grain filling stage which was followed by anthesis and panicle initiation with decrease in conductance of 38.11 and 16.53 %, respectively. In the similar manner, cultivar Basmati-Super showed the minimum dropage of 22.21% in stomatal conductance of rice leaves followed by Basmati-385 and Super-Basmati with decrease of 24.63 and 26.67 %, respectively. Interactional means of rice cultivars and stress stages were also significant (Table 6) with minimum decrease in stomatal conductance of 4.16% was noted in Basmati-Super under drought stress at grain filling stage.

Water use efficiency (WUE) of rice plants was enhanced significantly under moisture stress at all the three growth stages and in all the genotypes under study (Table 1). Promotion in WUE was 31.00, 26.33 and 22.66 % in Shaheen-Basmati, Basmati-385 and Super-Basmati, respectively. Water use efficiency was the maximum (33.15%) in case of drought stress at grain filling stage and it was followed by moisture stress at anthesis and panicle initiation with increase in WUE of 26.06 and 23.88 %, respectively. Interaction of rice genotypes and stress stages exhibited greater significance with the maximum increase in WUE of 35.00 % in Shaheen-Basmati under moisture stress at grain filling stage (Table 6).

Water deficit at all the three growth stages in all the three cultivars hampered relative water content (RWC) of rice plant leaves significantly (Table 2). Thus, the maximum decrease in RWC (35.16 %) was noted in case of drought stress at panicle initiation which was followed by anthesis and grain filling with the decrease of 26.22 and 17.03 %, respectively. Similarly, rice genotype Super-Basmati exhibited significantly more (28.56 %) decrease in RWC and it was followed by Basmati-385 and Shaheen-Basmati with the decrease of 26.17 and 23.10 %, respectively. There was significant interaction between rice cultivars and stress stages with the minimum decrease in RWC of 16.14 % in Shaheen-Basmati when exposed to water stress at grain filling stage (Table 6).

Maximum quantum yield of PSII (F_v/F_m) was severely diminished in all the cultivars when subjected to water deficit at different growth stages (Table 2). Variety Shaheen-Basmati and growth stage grain filling showed relatively less diminution (1.82 % and 1.21%, respectively) in F_v/F_m in response to water stress. Interaction of both the factors i.e. cultivars and stress stages was significant whereas variety Shaheen-Basmati subjected to water stress at grain filling maintained more F_v/F_m with the least diminution of 0.36 % (Table 6).

Agronomic traits. Moisture stress at all growth stages in all cultivars had non-significant effect on number of tillers per hill (Table 2). However, cultivar Shaheen-Basmati expressed the minimum reduction in tiller numbers per hill due to drought stress irrespective of stress stages. As regards interaction of cultivars and stress stages, variety Shaheen-Basmati when exposed to water stress at grain filling stage showed the least reduction in tiller numbers per hill (Table 7). Minimum reduction in tiller numbers per hill was due to the fact that at the time of water stress maximum tillers had been developed by the plants. Panicles per hill were adversely affected by water stress at panicle initiation whereas the effect was non-significant in case of stress at anthesis and grain filling stages (Table 2). Amongst cultivars, Shaheen-Basmati accepted the least adverse effect of drought stress on panicle numbers per hill irrespective of stress stages. Effect of moisture stress on interactional means of varieties and stress stages was significant however; cultivar Shaheen-Basmati exhibited the minimum reduction in panicle numbers per hill in case of water deficit at grain filling (Table 7).

Panicle length was drastically decreased when water stress was applied at panicle initiation in all the varieties but there was no considerable effect on panicle length in case of water stress at anthesis and grain filling (Table 2). Reduction in panicle length due to water deficit was the minimum in Shaheen-Basmati irrespective of stress stages. Interaction among cultivars and stress stages was significant, thus, genotype Shaheen-Basmati showed the minimum decrease in panicle length due to water stress at grain filling stage (Table 7). Panicle dry weight was severely affected by water deficit at all stress stages and in all the varieties (Table 2). Eventually, effect of water stress at panicle initiation was more adverse (30.80 %) as it caused the maximum decrease in panicle dry weight apart from varieties. Similarly, variety Super-Basmati was more (25.58 %) affected by water stress irrespective of stress stages. Interaction of stress stages and varieties was significant (Table 6). Thus, variety Shaheen-Basmati showed the minimum decrease (9.45 %) in panicle dry weight in case of water stress at grain filling stage.

Table 1. PAR, photosynthesis, transpiration, conductance and water use efficiency of three rice cultivars under drought stress.

	Factors	PAR (μ mol m^{-2} $^{-1}$s)	% Decrease	Photosynthesis (μ mol m^{-2} $^{-1}$s)	% Decrease	Transpiration (m mol m^{-2} $^{-1}$s)	% Decrease	Conductance (m molH$_2$Om^{-2} $^{-1}$s)	% Decrease	WUE	% Increase
Variety	Basmati- Super	518.89	24.57	30.94	21.92	3.95	36.00	35.25	22.21	9.42	22.66
	Shaheen-Basmati	355.70	12.50	46.69	14.96	4.06	30.33	32.50	26.66	13.48	31.00
	Basmati-385	557.63	23.40	36.68	18.07	4.11	34.66	35.50	24.63	10.34	26.33
Stress Stages	Control	628.05	-	46.32	-	5.05	-	46.33	-	9.17	-
	Stress at Panicle	473.30	24.63	32.10	30.69	2.62	48.11	38.67	16.53	11.56	26.06
	Stress at Anthesis	482.78	23.13	33.35	28.00	3.61	28.11	28.67	38.11	11.36	23.88
	Stress at Grain Filling	530.25	15.57	40.46	12.26	4.77	5.54	24.00	48.19	12.21	33.15
LSD at 5 % prob.	Cultivars	**38.09**	**-**	**5.97**	**-**	**0.13**	**-**	**2.33**	**-**	**1.09**	**-**
	Stress St.	**47.07**	**-**	**5.62**	**-**	**0.96**	**-**	**3.19**	**-**	**2.08**	**-**
	Interaction CxS	**117.17**	**-**	**2.78**	**-**	**1.07**	**-**	**8.72**	**-**	**2.35**	**-**

Table 2. Relative water content (WUE), panicle length, number of Panicles & tillers per hill and shoot & panicle dry weight per hill of three rice cultivars under drought stress.

	Factors	RWC	% Decrease	Tiller/ hill	% Decrease	Panicle length (cm)	% Decrease	Panicles/hill	% Decrease	F_v/F_m	% Decrease
Variety	Basmati- Super	82.41	23.10	18.98	4.25	25.95	8.86	6.93	16.46	0.83	2.13
	Shaheen-Basmati	78.13	26.17	18.28	5.08	25.30	9.76	7.03	16.66	0.81	1.82
	Basmati- 385	75.87	28.56	18.28	4.40	25.58	9.67	6.80	18.56	0.78	5.15
Stress Stages	Control	98.02	-	19.17	-	27.53	-	8.07	-	0.82	-
	Stress at Panicle	63.55	35.16	18.20	5.05	23.87	13.29	5.97	26.02	0.79	3.65
	Stress at Anthesis	72.31	26.22	18.20	5.05	25.13	8.71	6.60	18.21	0.80	2.43
	Stress at Grain Filling	81.32	17.03	18.47	3.65	25.90	5.92	7.37	8.67	0.81	1.21
LSD at 5 % prob.	Cultivars	2.91	-	0.15	-	0.09	-	0.14	-	0.07	-
	Stress St.	8.99	-	0.18	-	2.37	-	1.39	-	0.03	-
	Interaction CxS	4.54	-	0.07	-	1.67	-	1.06	-	0.04	-

Water deficit at all stress stages and in all rice genotypes caused a significant decrease in shoot dry weight (Table 2). Nevertheless, panicle initiation was more sensitive to water stress as the maximum decrease (16.45 %) in shoot dry weight was noted in this case whereas, decrease in shoot dry weight was the minimum (3.51 %) in case of stress at grain filling irrespective of cultivars. In the similar manner, variety Shaheen-Basmati exhibited the minimum (8.48 %) decrease in shoot dry weight due to water stress apart from stress stages followed by Basmati-385 and Super-Basmati with the decrease of 10.64 and 10.80 %, respectively. Amongst the interactional means which were significant, cultivar Shaheen-Basmati under water stress at grain filling showed the minimum (3.18 %) decrease in shoot dry weight (Table 6).

Grain fertility was significantly affected by moisture stress at all stress stages and in all varieties (Table 3). Nonetheless, anthesis stage was more sensitive to water stress for grain fertility as maximum reduction (10.54 %) in grain fertility was noted in this case, it was followed by grain filling with 5.67 % decrease whereas; panicle initiation was less sensitive and exhibited the minimum (3.65 %) decrease in grain fertility. Interaction of cultivars and stress stages was significant with maximum fertile grains (65.4) in Shaheen-Basmati under normal moisture supply and in case of moisture stress too, it produced significantly more fertile grains (63.5) per spike (Table 7).

Table 3. Fertile & sterile grains per panicle, 1000-grain weight, paddy yield and yield stability index of three rice cultivars under drought stress.

	Factors	Shoot Dry Weight	% Decrease	Panicle Dry Weight	% Decrease	Fertile grains per panicle	% Decrease	Sterile grains per panicle	% Increase	Total Grains per panicle	% Decrease
Variety	**Basmati- Super**	6.47	8.48	1.76	16.74	62.25	6.41	13.00	15.2	72.83	3.30
	Shaheen-Basmati	5.41	10.80	1.63	22.61	58.55	7.41	14.28	13.0	74.03	3.86
	Basmati-385	5.50	10.64	1.60	25.58	58.53	6.03	13.45	14.7	72.10	4.05
Stress Stages	**Control**	6.26	-	1.98	-	62.90	-	12.57	-	75.17	-
	Stress at Panicle	5.23	16.45	1.37	30.80	56.27	10.54	14.53	15.59	70.80	5.81
	Stress at Anthesis	5.65	9.74	1.57	20.70	59.33	5.67	13.80	9.78	72.67	3.32
	Stress at Grain Filling	6.04	3.51	1.72	13.13	60.60	3.65	13.40	6.60	73.30	2.48
LSD at 5 % prob.	**Cultivars**	0.73	-	0.12	-	3.85	-	1.19	-	1.82	-
	Stress St.	0.43	-	0.27	-	3.04	-	1.22	-	2.47	-
	Interaction CxS	0.29	-	0.23	-	2.47	-	2.37	-	3.21	-

Water stress at anthesis and grain filling substantially enhanced grain sterility (15.59 and 9.78 %, respectively) in all rice genotypes whereas; increase in sterility was less (6.60 %) in case of stress at panicle initiation (Table 3). Increase in grain sterility rate was more sever in Super –Basmati (13.07 %) followed by Basmati-385 (10.13 %) and Shaheen-Basmati (8.73 %). Interaction of stress stages and varieties was significant; nonetheless, Shaheen-Basmati under stress at panicle initiation had the minimum (4.91 %) increase grain sterility; whereas, it was maximum (16.92 %) in Super-Basmati under stress at anthesis (Table 7).

Total number of grains per panicle was severely impaired by moisture stress at all the stress stages and in all the rice genotypes under study (Table 3). Nonetheless, the minimum decrease of 3.3 % in total grains per panicle was observed in Shaheen-Basmati as compared with other cultivars apart from stress stages. Similarly, reduction in total grains per panicle was the minimum (2.48 %) in case of water stress at grain filling as compared with other stages irrespective of varieties. Likewise, interaction of stress stages and cultivars was significant (Table 7) thus; Shahen-Basmati under water stress at grain filling showed the minimum reduction (2.08 %) in total grain numbers per panicle.

Water stress drastically reduced 1000-grain weight in all the three rice cultivars at all growth stages under study (Table 3). Eventually, reduction in 1000-grain weight was significantly more (9.43 %) in Super-Basmati which was followed by Basmati-385 and Shaheen-Basmati with reduction of 6.83 and 5.06 %, respectively apart from stress stages. Similarly, decrease in 1000-grain weight was maximum (9.78 %) due to water stress at grain filling, it was followed by anthesis and panicle initiation with decrease of 7.69 and 4.87 %, respectively. Amongst the significant interactional means, Shaheen-Basmati under water deficit at panicle initiation exhibited the minimum decrease (3.34 %) in 1000-grain weight; whereas, Super-Basmati showed the maximum decrease (12.13 %) under water stress at grain filling (Table 7).

Paddy yield per hectare was severely affected by water deficit at all stress stages and in all cultivars (Table 3). Thus, moisture stress at panicle initiation was more drastic as regards per hectare paddy yield as reduction was maximum (39.79 %) in this case. It was followed by stress at anthesis and grain filling with decrease in per hectare paddy yield of 24.11 and 11.72 %, respectively. Similarly, decrease in paddy yield was significantly more (28.35 %) in Super-Basmati as compared with Basmati-385 and Shaheen-Basmati with decrease of 25.28 and 24.26 %, respectively. Impact of water deficit on interaction of stress stages and cultivars was significant, eventually, Shaheen-Basmati under moisture stress at grain filling showed the minimum (9.99 %) decrease in paddy yield whereas; Super-Basmati under water stress at panicle initiation exhibited the maximum (40.44 %) reduction in paddy yield (Table 7).

DISCUSSION

Physiological parameters. Owing to genetic variation, the rice cultivars showed differential response towards water stress at panicle initiation, anthesis and grain filling stages. Growth stages also expressed varied response regarding impact of water stress on physiological performance of rice cultivars. Differential response of upland rice varieties was also observed by Botwright *et al.,* (2008), Kamoshita *et al.,* (2004) and Basu *et al* (2008). Panicle initiation was found to be the most crucial one for affecting various physiological attributes. Water stress at panicle initiation due to disturbed biochemical, physiological processes and adverse effect on enzymatic activities drastically reduced stomatal conductance and degraded chlorophyll pigments leading to severe decrease in PAR, photosynthetic rate, transpiration rate and relative water content. Eventually, it diminished the maximum quantum yield of PSII (F_v/F_m) in flag leaves of all the three rice cultivars viz; Basmati-Super, Shaheen-Basmati and Basmati-385 irrespective of stages at which water stress was imposed. Rice cultivar, Shaheen-Basmati exhibited less decrease in the above said physiological parameters under drought stress conditions while; the maximum reduction in various parameters under the study was noted in Super-Basmati. Similarly, Bonnet *et al* (2000) has reported drastic effect of water stress on chlorophyll a, fluorescence, and antioxidant enzyme activities of ryegrass. Whereas, Loggini *et al.,* (1990) has observed an adverse impact of water stress on antioxidant defense system, pigment composition and photosynthetic efficiency in wheat. Unlike the other physiological parameters water use efficiency was significantly enhanced in all the three cultivars under water stress. The finding is supported that of Jones (2004) who has reported enhanced WUE under water stress in various crops.

The parameters such as PAR, F_v/F_m, Photosynthetic rate, RWC and water use efficiency were positively correlated at $P \leq 0.01$; in contrast, stomatal conductance and transpiration rate were negatively correlated with water use efficiency (Table 4). Eventually, rate of transpiration has been considered in rice cultivars subjected to water stress as an indicator for water deficit tolerance classification (Cabuslay *et al*., 2002). The similar results have been reported by Suriyan *et al*., (2010), Chaum *et al*., (2010) and Wang *et al*., (2010).

Agronomic traits. Yield of any crop is dependant on the combination of genetic makeup, physiological processes and agronomic attributes and any degree of imbalance in the said parameters may hamper the crop yield. Moreover, availability of sufficient water supply is inevitable to ensure maximum crop harvest in rice being a water loving crop (Basu *et al*., 2010). In the present research experiment all the yield parameters were adversely affected at all the stress stages and in all the rice cultivars under study. However, moisture stress at panicle initiation was more destructive regarding panicle numbers per hill, panicle length, panicle dry weight, shoot dry weight and total grains per panicle, irrespective of the cultivars resulting in drastic decrease in per hectare paddy yield. This may be due to the significant reduction in photo synthetic rate resulting in reduced production of assimilates for growth of panicles and filling of rice grains; ultimately paddy yield was drastically decreased. Mostajean and Eichi (2009) have reported the similar findings with the observations that water shortage adversely affected growth and paddy yield of rice in addition to accumulation of proline and soluble sugars in sheaths and blades of rice leaves.

Table 4. Correlation matrix between water use efficiency and physiological parameters.

Parameters	PAR	Photosynthesis	Transpiration	Conductance	F_v/F_m	RWC
Photosynthesis	-0.0557	-	-	-	-	-
Transpiration	0.6541*	0.5866*	-	-	-	-
Conductance	0.1964	0.7265**	0.7618**	-	-	-
F_v/F_m	0.1063	0.4143	0.1515	0.0988	-	-
RWC	0.7588**	0.3167	0.6390*	0.2201	0.6603*	-
WUE	-0.6618*	0.3743	-0.4750	-0.2388	0.3017	0.2371

Anthesis and grain filling stages were more sensitive to water stress for 1000- grain weight, fertile grains per panicle and sterile grains per panicle leading to substantial decrease in these parameters. Water stress at these stages caused a significant reduction in grain size and grain weight which may be due to hindered translocation of assimilates towards grain filling resulting in decreased paddy yield due to hampered stomatal and hydraulic conductance. Excessive accumulation of proline & ABA and reduced synthesis of Gibberellic acid may be another cause of significant decrease in paddy yield. Pantuwan *et al.,* (2002) and Cattivelli *et al.,* (2008) also have reported hampered paddy yield because of drought stress at critical growth stages

. **Table 5. Correlation matrix between yield and yield parameters**

Growth stage	Rice cultivar	PAR	A	E	gs	WUE	RWC	Fv/Fm	SDW	PDW
Stress at Panicle	Basmati-385	30.49	15.80	32	15.55	24	34.46	3.41	17.66	32.65
	Shaheen Basmati	15.04	9.38	30	10.41	24	30.61	2.96	15.62	24.87
	Basmati Super	26.54	12.75	29	19.56	23	38.54	7.56	16.05	34.84
Stress at anthesis	Basmati-385	25.61	14.21	27	11.11	17	26.77	1.70	11.03	20.91
	Shaheen Basmati	12.50	7.43	28	4.16	17	22.55	2.61	6.65	15.92
	Basmati Super	25.66	11.92	27	15.21	21	29.46	4.96	12.2	25.25
Stress at grain filling	Basmati-385	17.61	35.75	49	53.33	27	17.28	0.36	3.73	14.28
	Shaheen Basmati	9.98	28.08	46	52.08	27	16.14	0.82	3.18	9.45
	Basmati Super	18.02	29.55	48	39.13	35	17.70	2.97	3.67	16.67

PAR=Photo-synthetically active radiation, A= Photosynthesis, E=Transpiration, g_s= Stomatal Conductance, WUE=Water use efficiency, RWC=Relative water contents, FV/Fm= Maximum quantum yield of PSII, SDW=Shoot dry weight, PDW=Panicle dry weight

Table 6. Physiological parameters as affected by water deficit stress on various growth stages (% decrease over control)

Parameters	Panicle length	No. of Panicles	No. of Tillers	Shoot D W	Panicle D W	Fertile Grains	Sterile Grains	Total grains	1000-grain wt
Panicle length	-	-	-	-	-	-	-	-	-
No. of Panicles	0.8832**	-	-	-	-	-	-	-	-
No. of Tillers	0.7571**	0.7862**	-	-	-	-	-	-	-
Shoot D W	0.4023	0.6560*	0.5887*	-	-	-	-	-	-
Panicle D W	0.4677	0.7287**	0.5059	0.7408**	-	-	-	-	-
Fertile Grains	0.8831**	0.8830**	0.8349**	0.7087**	0.6822*	-	-	-	-
Sterile Grains	-0.8913**	-0.8011**	-0.8152**	-0.5655	-0.4114	-0.8998**	-	-	-
Total grains	0.8919**	0.8861**	0.7976**	0.5475	0.7227**	0.9324**	-0.7866**	-	-
1000- grain wt	0.8264**	0.7533**	0.5722	0.2211	0.4456	0.6521*	-0.5199	0.7834**	-
Paddy yield	0.9593**	0.9184**	0.7499**	0.4957	0.5359	0.8980**	-0.8349**	0.8852**	0.8129**

* significant (P<0.05); ** significant (P<0.01)

Under water stress conditions all the said parameters were positively correlated with paddy yield whereas, grain sterility was negatively correlated with paddy yield (Table 5). Thus, yield traits such as paddy yield, 1000-grain weight, fertile grains per panicle and grain sterility per panicle are the most popular parameters used to identify water deficit tolerance in rice breeding programs. The findings are in harmony with those of Yang *et al*., (2001), Venuprasad *et al*., (2008) and Wang *et al.,* (2010) who have stressed upon taking into account of different agronomic parameters during screening of rice varieties or while developing new rice varieties for drought prone areas. Similarly, Suriyan *et al.,* (2010) has observed the ill effects of drought stress and reported that water deficit stress at the productive stage of four indica rice (*Oryza sativa* L.) genotypes adversely affected grain size, weight and ultimately paddy yield of all the varieties under study.

Table 7. Agronomic parameters as affected by water deficit stress on various growth stages (% decrease over control)

Growth stage	Rice cultivar	Panicle length	Panicle per hill	Tiller per hill	Fertile grains per panicle	Sterile grains per panicle	Total grains per panicle	1000-grain weight	Paddy yield
Stress at Panicle	Basmati-385	13.92	28.75	5.26	10.96	16.92	6.13	8.99	40.26
	Shaheen Basmati	12.94	22.89	4.59	10.24	14.75	5.09	8.17	38.65
	Basmati Super	13.09	26.58	5.29	10.44	15.20	6.01	12.13	40.44
Stress at anthesis	Basmati-385	9.15	13.75	7.37	6.61	13.07	3.20	6.83	25.50
	Shaheen Basmati	8.27	18.07	3.06	6.11	6.55	2.74	6.69	24.14
	Basmati Super	8.73	18.99	4.76	4.24	9.60	3.47	9.55	24.86
Stress at grain filling	Basmati-385	6.22	7.50	2.63	4.67	9.23	2.26	4.67	10.31
	Shaheen Basmati	5.39	8.43	5.10	2.90	4.91	2.08	3.34	9.99
	Basmati Super	7.19	10.13	3.17	3.42	5.60	2.67	6.61	10.54

Conclusion: It was concluded that Shaheen-Basmati was identified as a comparatively more drought tolerant rice cultivar apart from stress stages as it gave significantly more paddy yield so, this genotype can successful be cultivated in drone prone areas. Moreover, it was made out that water stress at panicle initiation was more crucial regarding plant growth and paddy yield hence; at this growth stage water stress may possibly be avoided.

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