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Evaluation of rice genotypes for high temperature tolerance under field conditions

R Ramesh, T Ramesh, PR Rao, VG Shankar and MHV Bhave

Abstract

Present experiment was taken up entitled "evaluation of rice genotypes for high temperature tolerance under field conditions in rice at Indian Institute of Rice Research, Rajendranagar, Hyderabad during *kharif,* 2012-2013 and 2013-2014 in split-plot design with treatments (control and high temperature stress) as main plot treatments and 22 genotypes as sub-plot treatments. The high temperature treatment was imposed by covering the one set of genotypes with polyethylene sheet to raise the temperature and allowed to grow inside the enclosure from panicle initiation until physiological maturity. From the studies, it is concluded that superior performance in terms, Crop phenology, morphological, physiological traits, reproductive characters and yield components were significantly affected by the high temperature stress and such affects varied with rice genotypes. Under high temperature stress conditions crop duration was reduced where such reduction was maximum in IET-22116(134), while it was least affected in N-22(118).

Keywords: Genotypes, temperatures, phenology, grainyield

Introduction

The rising temperatures associated with global warming may have serious direct and indirect consequences on crop production especially in cereals. Abiotic stress such as extreme temperatures frequently limits the growth and productivity the major crop species including cereals. Rice production has also intensified in rainfed-lowland and dryland (upland) cropping systems, many of which are prone to high temperature (Coffman, 1977) [4]. Different global circulation models predict that greenhouse gases will gradually increase world's average ambient temperature. According to a report of the Intergovernmental Panel on Climatic Change (IPCC, 2007) [7], global mean temperature will rise 0.3ºC per decade (Jones *et al.* 1999) [8] reaching to approximately 1 and 3^{0}C above the present value by years 2025 and 2100, respectively, and leading to global warming. Raising temperatures leads to altered geographical distribution and growing season of agricultural crops by allowing the threshold temperature for the start of the season and crop maturity to reach earlier. General circulation models predict that global mean air temperatures are likely to increase every 1ºC in night temperature will reduce rice yields by 0.3 tons per hectare (IPCC, 2007) [7] similarly, 90% decrease in yield was reported when rice plants were exposing to high night temperatures (32 ºC) (Mohammed and Tarpley, 2009) [10]. In addition, climate is expected to be more variable with frequent episodes of stressful temperatures during crop-growing season. Recent studies have shown that annual mean maximum and minimum temperatures have increased by 0.35 and 1.13 ºC, respectively, for the period of 1979-2003 at International Rice Research Institute, Manila, Philippines (Peng *et al.*, 2004) [14].

Rice is a staple food for more than half the world's population. It is grown worldwide over an area of 153 million hectares with an annual production of 600 million tonnes. It is cultivated in 114 of the 193 countries of the world. Among all the crops it is highest in global production but second to wheat (214 million ha.) in global area. Rice is one of the most important cereal crops and occupies second position in global agriculture. It is the foremost crop of India belonging to the family poaceae. Rice accounts for about 42% of total food grain production and >55% of diet in India. It is widely grown in India due to its wide adaptability. In India, rice is grown in an area of 44.1 m ha producing 106.7 m tones with a productivity of 2.42t ha^{-1}. In Telangana, it covers an area of 2.01m ha with a production of 6.62m tones with average productivity of 3.29t ha^{-1} (CMIE, 2016) [3].

Transitory or constantly high temperatures cause an array of morpho-anatomical, physiological and biochemical changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield. High temperature affects plant growth throughout its ontogeny, though heat-threshold level varies considerably at different developmental stages.

For instance, during seed germination, high temperature may slow down or totally inhibit germination, depending on plant species and the intensity of the stress. At later stages, high temperature may adversely affect photosynthesis, respiration, water relations and membrane stability, and also modulate levels of hormones and primary and secondary metabolites. Furthermore, throughout plant ontogeny, enhanced expression of a variety of heat shock proteins, other stress-related proteins, and production of reactive oxygen species (ROS) constitute major plant responses to high temperature.

Material and Methods

The present investigation entitled "study the effect of high temperature on pollen viability, stigma exertion, sterility in rice'' was conducted during *kharif* -2012 and kharif-2013 at Indian Institute of Rice Research farm, Rajendranagar, Hyderabad. The farm is geographically situated at an altitude of 542.7 m above mean sea level on 17^o 19 ' N latitude and 78^o 29 ' E longitude. It comes under the Southern Telangana agro-climatic region of Telangana.

Weather Conditions during Crop Growth Period

Weather data recorded at the meteorological observatory of IIRR, Rajendranagar during the crop growth period. From the day of imposition of high temperature, daily weather parameters such as temperature and RH was recorded using the maximum and minimum thermometers and also by the portable weather recorder in both control and treated plots

Soil characteristics of the experimental Site

Soil samples were drawn from the experimental site from top 0-30 cm depth. The composite soil sample was air-dried and ground to pass through 2 mm sieve. The sample was analyzed for different physico-chemical properties by adopting standard procedures and presented below.

Design, treatments and layout of the experiment

The rice crop during wet season is grown under normal, recommended package of practices with plant protection methods. The experiment conducted in Split-Plot design with treatments (Normal Temperature and Temperature stress) as main plot treatments and genotypes as sub-plot with 3 replications. Each sub plot measured 1.5×0.6 m^2 and a spacing of 20×10 cm was followed. When the crop attained maximum tillering stage (50 days after transplanting-DAT) in one of the crop sets heat stress was imposed by enclosing the crop with transparent polyethylene sheet supported by metal or bamboo frame. To reduce relative humidity accumulation in the enclosure, at regular intervals openings were made to allow free flow of air.

Genetic materials used in the Experiment

The following are the 21 rice cultures with Nagina-22 as check Genotypes used in evaluation studies.

Varieties (14): IET- 21404, IET- 21411, IET- 21415, IET -21515, IET-21577, IET -22100, IET -22116, IR-64, MTU-1010, PR-113, US-312, US-382

Hybrids (7): IET- 21582, IET- 22218, LALAT, PA- 6129, PA-6201, KPH-2, PA-6444, PHB-71, DRRH-3.

Check (1): Nagina-22.

Experimental observation

Phenological Data

Days to 50% flowering

Date at which 50% ear heads was noted for each variety, days to heading was calculated by subtracting date of sowing from date of heading.

Days to maturity

Date at which 50 to 60% crop matured was noted separately from each variety. Days to maturity was calculated by difference between dates of sowing date of maturity. Final reading was taken as mean of three replications.

Physiological studies

Following morpho physiological attributes were recorded at 50 % anthesis and 15 days after anthesis. All the observations had three different plants and replications unless other wise stated.

Photosynthetic characteristics

Photosynthetic characteristics such as Photosynthetic rate (P_N), Stomatal conductance (g_s),and Transpiration rate (E) were recorded at maximum vegetative and reproductive stages by using Li-Cor 6400 (IRGA) portable photosynthesis measurement system attached to leaf chamber fluorometer (LCF Model 6400-1, LICOR, USA) which was used as artificial light source. During measurements the PAR (Photosynthetically Active Radiation) was kept at 1200 µmol m^{-2} s^{-1}. The CO_2 concentration was kept at 387 ± 6 ppm. These measurements were made between 10.00 am to 12.00 noon at all the sampling dates.

Photosynthetic rate (P_N)

Photosynthetic rate measurements were recorded at maximum vegetative and reproductive stages with Li-Cor 6400 portable photosynthesis measurement system. P_N was expressed as µmol (CO_2) m^{-2} s^{-1}.

Stomatal conductance (g_s)

Measurements were made by LiCor 6400 portable photosynthesis measurement system at maximum vegetative and reproductive stages. Stomatal conductance (g_s) was expressed as mol (H_2O) $m^{-2}s^{-1}$.

Transpiration rate (E)

Transpiration rate was measured using Li-Cor 6400 portable photosynthesis measurement system. Transpiration rate was measured at maximum vegetative and reproductive stages and was expressed in mmol (H_2O) m^2 s^{-1}.

CO_2 exchange rate (CER or A mole m^{-2} sec^{-1}), photosynthetic active radiation (PAR or Q, µmole m^{-2} sec $^{-1}$), transpiration rate (E, mmole m^{-2} sec $^{-1}$), ambient temp and leaf temp (CT and LT, ^{0}C) and stomatal conductance (SC, mmole m^{-2} sec^{-1}) and internal CO_2 concentration (C, µlit sec^{-1}) were recorded seperately for upper and lower surface of leaves using portable IRGA (photosynthetic system mode, CIRAS-1). Leaf cuvette was first clamped on the upper surface of leaf. In this position PAR sensor faces sunlight and was facing upward) and its position was changed in such a way that maximum PAR was obtained and minimum differences in CO_2 and water vapours between reference and analytical cells were obtained. At this stage exchange switch was pressed when readings were stable and values were recorded. Values for SC, E and A were added and for temperature, mean value was taken. At each sampling stage, 3 tagged fully expanded leaves were used. All the measurements were recorded between 10:00 AM to 11:30 AM.

Grain yield (kg ha^{-1})

At physiological maturity, panicles from each treatments were harvested, sun dried, threshed, cleaned and weight of grains was recorded and expressed in kg ha^{-1}.

Statistical analysis

The experimental data were analyzed statistically by following standard procedure outlined by Panse and Sukhatme (1985) [13]. Significance was tested by comparing "F" value at 5 per cent level of probability. The percentage values were transferred.

Results and Discussion

Phenological studies

Observation of changes in plant phenology in response to heat stress can reveal a better understanding of interactions between stress atmosphere and the plant. Different phenological stages differ in their sensitivity to high temperature. However, this depends on species and genotype owing to great inter and intra-specific variations (Wardlaw *et al.*1989) [22]. Heat stress has been a major factor affecting the rate of plant development in several of the crop plants (Hall, 1992).

Effect of high temperature tolerance on Days to 50% flowering

Flowering time plays an important role in regulating the biomass of crops by affecting their duration of basic vegetative growth, and thereby grain yield (Andres and Coupland 2012) [1]. In the present study significant difference was observed for days to 50% flowering among genotypes, treatments and their interactions in both seasons as well as pooled data (Table 1). During first season, the genotype IET-22116 and PR-113 (106 days) recorded maximum days under control and IET-22218 (104 days) recorded maximum days under stress while, N-22 (87 days) recorded minimum days for 50% flowering under ambient and elevated temperature stress. During second season, the genotype IET-22116(108 days), PR-113 (108 days) and IET-22116 (105 days) recorded maximum value under ambient temperature and elevated temperature stress respectively while, N-22 recorded (87, 88 days) minimum value under ambient temperature and elevated temperature stress respectively. Pooled data revealed that IET- 22116and PR-113 showed maximum value under control (107 days) while, IET-22218(104 days), PR-113 (104 days) under stress. The minimum value was recorded under control and elevated temperature in the genotype N-22 (87 days).

Among all genotypes, the days to 50% flowering was maximum in IET-22218 (104 days) followed by PR-113 (104 days), IET-22116 (103 days) and KPH-2 (103 days) under temperature stress compared to control in pooled data. Early flowering was recorded in N-22 (87 days). No genotype recorded significantly superior performance for this trait both under stress and controlled conditions (earliness is desirable) when compared to control N-22.

The percentage reduction range of days to 50% flowering was 0-4 per cent in pooled data. The percentage reduction was higher in IET-22116 (-3.3), PR-113 (-3.2), IET-21415, KPH-2 (-2.3) PA-6129 (-2.2) genotypes while, less percentage reduction was in PA-6444, MTU-1010 (-0.2), IET-21411 (-0.3), PA-6201 (-0.4) and IET-22100 (-0.7). The genotype N-22 (0.3) showed slight increase in days to 50% flowering.

In all other genotypes the days to 50% flowering was reduced with high temperature stress. This could be due to the reason that genotypes have received the required heat units for panicle emergence which resulted in earliness in panicle initiation.Similar observations on earliness were also made in rice germplasm by the Prasad *et al.*, (2006) [15] and Keerthana (2012) [9].

Days to maturity

The crop duration was reduced under elevated temperature (Rani and Maragatham, 2013) [17]. In the present study significant difference was observed among the genotypes for days to maturity under high temperature, genotype-temperature interactions as well as in pooled data. During first season, PR-113 (139,132 days) recorded maximum while, N-22 (118 days) recorded minimum under ambient and elevated temperature stress respectively. During second season, PR-113 (141 days) and IET-22116 andPR-113 (134 days) recorded maximum value while, N-22 (121 days) and N-22 and PA-6201 (122 days) recorded minimum value under ambient temperature and elevated temperature stress respectively. Pooled data revealed that PR-113 showed maximum value (140, 133 days) while, minimum in N-22 (119, 120 days) under control as well as elevated temperature respectively (Table 2).

Among all the genotypes, PR-113 (133 days) showed less number of days to maturity under temperature stress compared to control in pooled data followed by IET-22116 (132 days) and IET-22218 (132 days) genotypes respectively. No genotype registered significantly superior performance than control N-22 both under stress and controlled conditions.

The percentage reduction range of days to maturity was 0-5 per cent in pooled data. The percentage reduction was higher in PR-113 (-5.0), IET-21411 (-4.4), IET-22116 (-4.0), DRRH-3 (-3.8) genotypes while, less percentage reduction was observed in IET-22100 (-0.6), IET-21577 and PA-6129 (-0.8), MTU-1010 (-1.0), PA-6201 (-1.1) genotypes respectively. The genotype N-22 (0.4) showed slight increase in days to maturity.

This reduction in days to maturity might be due to earliness in the flowering in the elevated temperature stress environment. Similar observations were also reported by Venkatramanan and Singh (2009) [21].

Stomatal conductance (mol H_2O m^{-2}s^{-1})

Stomatal conductance plays an important role in plant adaptation to elevated temperature stress. High stomatal conductance enables increased CO_2 diffusion into leaf and favours high photosynthetic rate which in turn leads to high biomass and grain yield (Taiz and Zegier, 2002) [19]. Under normal conditions these physiological traits had poor relation with grain yield but under elevated temperature stress conditions, stomatal conductance appears to be more important (Rane *et al.*, 2003) [16]. In the present study, a decreasing trend was found in all the rice genotypes under elevated temperature stress compared to the ambient temperature for stomatal conductance (Table 3).

Significant difference was observed among the genotypes under ambient and elevated temperatures. Significant differences were also seen in their GxT interaction.

The genotypes IET-22100 (223.8) and IET-21411 (188.4) recorded maximum value while, PR-113 (101.4) and IET-22100 (104.4) recorded minimum value at flowering stage under ambient and elevated temperature respectively during first season. IET-22116 (225.4) and IR-64 (211.5) recorded maximum value and IET-21415 (166.2) and PA-6201 and PA-6444 (148.4) recorded minimum values under ambient and elevated temperature stress in second season respectively. Pooled data revealed that the genotype IET-22100 (209.2) and MTU-1010 (187.4) recorded maximum stomatal conductance while, PR-113(148.4) and PA-6201 (136.3) recorded minimum under ambient and elevated temperature stress respectively.

For the character stomatal conductance, nine genotypes IET-22100 (209.2), IET-22116 (199.9), IR-64 (193.8), PA-6201 (193.4), IET-21582 (187.7), PA-6129 (187.4), DRRH-3 (184.9), MTU-1010 (184.6) and IET-21411 (183.5) recorded significantly higher values than the check N-22 under controlled conditions. Under temperature stress conditions, eleven genotypes MTU-1010 (187.4), IR-64(186.4), KPH-2 (184.8), IET-22218 (177.4), IET-21411 (176.9), IET-22116 (174.8), IET-21515 (171.8), US-312 (171.4), PA-6129 (167.4), PA-6444 (165.8) and PHB-71 (163.9) showed significantly higher stomatal conductance in pooled data.

The percentage reduction range of stomatal conductance was 0-33 per cent in pooled data. Less reduction was observed in IET-21515 (-0.5), PA-6444 (-0.9), IET-21411 (-3.6) and IR-64 (-3.8). In contrast, greater reduction was observed in IET-22100 (-32.4), PA-6201 (-29.5), IET-21582 (-19.0), DRRH-3 (-18.2). In the present investigation there was marginal increase (0-5% higher) in the stomatal conductance with high temperature stress in genotypes in IET-22218 (0.1), MTU-1010 (1.5), US-312 (1.8) and KPH-2 (4.8).

Munjal and Dhanda (2004) [11] reported, a reduction in stomatal conductance in rice under high temperature stress due to closure of stomata, which is the noted mechanism of plant to conserve water and retain its functional integrity under stress.

Transpiration rate (mmol H_2O m^{-2} s^{-1})

It is well known that high transpiration results in canopy cooling which helps in thermo-tolerance and contributes towards improved biomass and crop yield Munjal and Dhanda (2004) [11]. Back crossing genotypes with superior transpiration efficiency into locally adopted cultivars have shown 10 per cent better yield in rice (Turner, 1997) [20]. Data on difference observed among the genotypes for transpiration rate under elevated temperature compared to ambient temperature are presented (Table 4). All the genotypes showed an increasing trend under elevated temperature. Maximum values were recorded by genotypes MTU-1010 (2.80) and PA-6201 (3.18) while, PR-113 (1.02) and US-312 (1.51) recorded minimum value during flowering under ambient and elevated temperature respectively in first season. The genotypes IET-22116 (3.12, 3.24) recorded maximum values while, IET-21411 (1.21) and LALAT (1.75) recorded minimum values under ambient and elevated temperature stress respectively during second season. Pooled data revealed that the genotype MTU-1010 (2.67) and IET-22218 (3.04) recorded maximum transpiration rate while, LALAT (1.43, 1.66) recorded minimum under ambient and elevated temperature stress respectively.

Nine genotypes MTU-1010 (2.67), IET-21577 (2.48), IET-22116 (2.34), PHB-71 (2.31), PA-6444 (2.17), IR-64 (2.05), IET-21582 (1.95), IET-22218 (1.94) and KPH-2 (1.82) registered significantly higher transpirational rate than the check N-22 (1.76) under controlled conditions. Under temperature stress conditions, all genotypes recorded higher transpirational rate than check N-22 (1.89) except IET-21415 (1.84) and LALAT (1.66).

The increase percentage range of transpiration rate was 3-85 per cent in pooled data. Greater increase was observed in rice genotypes PA-6201 (84.8), IET-22100 (73.4), IET-21411 (67.7) and US-382 (65.1). In contrast, less increase was observed in MTU-1010 (3.2), PA-6444 (4.0), IET-22116 (4.2) and N-22 (7.2).

This high transpiration rates enable canopy cooling which indicate thermo-tolerance ability and were associated with high biomass production and grain yield. Egeh *et al.*, (1992) [5] reported greater transpirational cooling of leaves to be a major contributor to the tolerance of high temperature stress. The above results suggested that transpirational cooling ability is probably a more important trait in germplasm with improved heat tolerance for selection in a plant breeding programme rather than in CO_2 assimilation rates alone as these traits has bearing a dry matter and seed yield.

Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})

Alterations in various photosynthetic attributes have been good indicators of plant thermo-tolerance as they show correlations with growth. Wise *et al.*, (2004) [23] reported that the photochemical reactions in thylakoid lamellae and carbon metabolism in the stroma of chloroplast are primary sites of injury at elevated temperatures in cotton. Elevated temperature can reduce photosynthetic rate by 40-60 per cent at mid-ripening, leading to more rapid senescence of the flag leaf (Oh-e *et al.*, 2007) [12].

Data on of the 22 genotypes showed a decline under elevated temperature stress when compared to ambient temperature. The reduction had significant difference on the genotype, treatment and their interaction (Table 5).

The genotype N-22(21.5) and IET-21582 (19.6) showed maximum photosynthetic rate during flowering stage under ambient and elevated temperature respectively while, minimum photosynthetic rate was recorded by US-382 (15.7) and PA-6444 (10.4) under ambient and elevated temperature respectively in first season. The genotypes IR-64 (21.2) and IET-21515 (17.3) recorded maximum values while, IET-21577 (16.5) and N-22 (12.1) recorded minimum values under ambient and elevated temperature stress respectively during second season. Pooled data revealed that the genotype N-22 (19.9) and IET-21582 (17.0) recorded maximum photosynthetic rate while, PA-6444 (17.1, 12.1) recorded minimum values under ambient and elevated temperature stress respectively.

No genotype recorded significantly higher photosynthetic rate than the check N-22 under controlled conditions, however, all the genotypes registered higher photosynthetic rate than check N-22 under temperature stress except KPH-2 (13.3), IET-22218 (12.6), IET-21404 (12.5) and PA-6444 (12.1) under stress. Pooled data revealed that the genotype IET-21582 (17.0) was recorded maximum photosynthetic rate under temperature stress.

The percentage reduction range of photosynthetic rate was 7-35 per cent in pooled data. Greater reduction was recorded in IET-21404 (-34.4), N-22 (-33.0), PA-6444 (-29.1), IET-22218 (-27.3) and IET-21515 (-27.2). In contrast, less reduction in photosynthetic rate was recorded in IET-21577 (-7.7), IET-21582(-10.0), LALAT (-10.4) and IR-64(-15.4).

The findings corroborate with the earlier reports of Gesch *et al.*, (2003) [6] who stated that photosynthetic rate declined to the extent of 15 to 25 per cent under day and night temperature of 40/30°C in the Soil-Plant-Atmosphere research (SPAR) facility. From the studies it can be concluded that lower reduction in photosynthetic rate under elevated temperature has been a good indicator of thermo-tolerance.

Grain yield (Kg ha^{-1})

Prasad *et al*., (2006) [15] reported grain yield reduction up to 70 per cent under ambient+5 ^{0}C. Cao *et al*., (2009) [2] observed reduction from 3.9 to 27.5 per cent under temperature treatment of 38/28 ºC compared to 33/27ºC. These findings corroborate the results of the present study where the grain yield was found to decrease under elevated temperature and significant difference was observed for the genotypes, treatment and their interaction (Table 6). During first season, the genotypes N-22 (7767 kg ha^{-1}, 7723 kg ha^{-1}) recorded maximum value while MTU-1010 (6310 kg ha^{-1}) and PA-6201 (983 kg ha^{-1}) recorded minimum grain yield under ambient temperature and elevated temperature stress respectively. During second season, the genotypes PR-113 (9193 kg ha^{-1}) and N-22 (7927 kg ha^{-1}) recorded the maximum total grain yield while, US-382 (5753 kg ha^{-1}) and US-312 (3277 kg ha^{-1}) recorded minimum value under ambient and elevated temperature stress respectively. Pooled data revealed that the genotype IET-21515 (7950 kg ha^{-1}) and IET-22116 (6338 kg ha^{-1}) recorded maximum grain yield while, US-382(6168 kg ha^{-1}) and LALAT (2918 kg ha^{-1}) recorded minimum under ambient and elevated temperature stress respectively.

No genotype out yielded the check N-22 both under control and temperature stress conditions. The genotype IET-22116 (6338 kg ha^{-1}) was recorded maximum grain yield followed by N-22 (6325 kg ha^{-1}) in pooled data.

The percentage reduction range of grain yield was 18-60 per cent in pooled data. Less reduction of grain yield was recorded in IET-22116 (-18.9), N-22 (-20.3), IET-22218 (-20.9) and PA-6444 (-21.6). In contrast greater reduction in grain yield in rice genotypes was observed in LALAT (-60.0), US-312 (-59.1), PHB-71 (-56.8) and KPH-2 (-53.4).The reduction in yield has been attributed to reduction in grain weight. Saseendaran *et al*., (2000) [18] reported that for every one degree increase in mean temperature, there has been a decline in yield by about six per cent in rice.

Table 1: Effect of elevated temperature tolerance on Days to 50% flowering in rice genotypes during *kharif*, 2012&2013

			2012			**2013**				**Pooled**			
S. No	**Genotypes**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**
1	IET-21404	98	97	(-1.0)	98	97	96	(-1.0)	97	98	97	(-1.0)	97
2	IET-21411	97	96	(-0.3)	97	97	97	(0.0)	97	97	96	(-0.3)	97
3	IET-21415	98	95	(-3.1)	97	99	97	(-1.4)	98	98	96	(-2.3)	97
4	IET-21515	101	100	(-1.3)	100	102	101	(-1.0)	102	102	100	(-1.1)	101
5	IET-21577	97	95	(-2.1)	96	98	98	(0.0)	98	98	97	(-1.1)	97
6	IET-21582	98	98	(0.0)	98	98	96	(-2.0)	97	98	97	(-0.9)	98
7	IET-22100	98	97	(-1.0)	98	98	98	(-0.3)	98	98	97	(-0.7)	98
8	IET-22116	106	102	(-3.8)	104	108	105	(-2.8)	107	107	103	(-3.3)	105
9	IET-22218	104	104	(-0.6)	104	107	103	(-3.7)	105	106	104	(-1.8)	105
10	IR-64	99	97	(-2.0)	98	99	98	(-0.3)	99	99	97	(-1.4)	98
11	KPH-2	104	102	(-1.9)	103	107	104	(-2.8)	106	105	103	(-2.3)	104
12	LALAT	101	99	(-1.3)	100	101	100	(-0.7)	101	101	100	(-1.0)	100
13	MTU-1010	97	97	(0.0)	97	96	96	(-0.3)	96	97	97	(-0.2)	97
14	PA-6129	98	95	(-3.1)	97	97	96	(-1.0)	97	97	95	(-2.2)	96
15	PA-6201	98	98	(-0.7)	98	98	98	(0.0)	98	98	98	(-0.4)	98
16	PA-6444	101	101	(-0.7)	101	101	101	(0.3)	101	101	101	(-0.2)	101
17	PHB-71	101	98	(-3.0)	100	102	101	(-0.7)	102	102	99	(-2.0)	101
18	DRRH-3	101	100	(-1.0)	100	100	99	(-0.7)	100	100	100	(-0.9)	100
19	PR-113	106	103	(-2.8)	105	108	104	(-3.7)	106	107	104	(-3.2)	105
20	US-312	101	99	(-2.0)	100	102	101	(-0.7)	101	101	100	(-1.4)	101
21	US-382	102	101	(-0.7)	102	102	102	(-0.7)	102	102	101	(-0.8)	102
22	N-22	87	87	(0.0)	87	87	88	(0.8)	87	87	87	(0.3)	87
	Mean	100	98		99	100	99		100	100	99		99
	SEm±	T=0.04	G=0.38		T×G=0.21	T=0.01	G=0.40		T×G=0.05	T=0.04	G=0.33		T×G=0.23
	CD at 5%	T=0.288	G=1.079		T×G=1.510	T=0.066	G=1.148		T×G=1.587	T=0.302	G=0.930		T×G=1.310

(Figures in parenthesis are % increase/decrease) (T: Treatment, G: Genotype, T×G: Interaction)

Table 2: Effect of elevated temperature tolerance on Days to maturity in rice genotypes during *kharif*, 2012&2013

S. No	**Genotypes**		**2012**			**2013**				**Pooled**			
		Normal Temp.	**Temp. Stress**	**%Rdn**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**
1	IET-21404	130	126	(-3.1)	128	129	126	(-2.8)	128	130	126	(-3.0)	128
2	IET-21411	129	123	(-4.6)	126	130	124	(-4.1)	127	129	124	(-4.4)	127
3	IET-21415	128	126	(-1.6)	127	129	127	(-1.6)	128	128	126	(-1.6)	127
4	IET-21515	133	128	(-3.8)	131	134	129	(-3.7)	132	133	128	(-3.7)	131
5	IET-21577	129	128	(-0.8)	129	129	128	(-0.8)	129	129	128	(-0.8)	129
6	IET-21582	129	127	(-1.6)	128	129	126	(-2.3)	128	129	127	(-1.9)	128
7	IET-22100	130	128	(-1.0)	129	130	130	(0.0)	130	130	129	(-0.6)	130
8	IET-22116	137	131	(-4.4)	134	139	134	(-3.6)	137	138	132	(-4.0)	135
9	IET-22218	134	131	(-2.2)	133	138	133	(-3.6)	135	135	132	(-2.8)	134
10	IR-64	129	126	(-2.3)	128	129	125	(-3.1)	127	129	126	(-2.7)	127
11	KPH-2	135	131	(-3.0)	133	138	132	(-4.3)	135	136	131	(-3.6)	134

12	LALAT	133	131	(-1.5)	132	134	131	(-2.5)	133	133	131	(-1.9)	132
13	MTU-1010	126	126	(0.0)	126	127	124	(-2.4)	126	126	125	(-1.0)	126
14	PA-6129	128	127	(-0.8)	128	128	127	(-0.8)	128	128	127	(-0.8)	127
15	PA-6201	126	125	(-0.8)	126	124	122	(-1.6)	123	125	124	(-1.1)	124
16	PA-6444	131	128	(-2.5)	130	131	128	(-2.3)	130	131	128	(-2.3)	130
17	PHB-71	130	128	(-1.3)	129	131	129	(-1.5)	130	130	129	(-1.3)	130
18	DRRH-3	131	126	(-3.8)	129	130	125	(-3.8)	128	130	125	(-3.8)	128
19	PR-113	139	132	(-5.0)	136	141	134	(-5.0)	138	140	133	(-5.0)	136
20	US-312	132	129	(-2.3)	131	135	131	(-3.0)	133	133	130	(-2.6)	131
21	US-382	132	128	(-3.0)	130	134	130	(-3.0)	132	133	129	(-3.0)	131
22	N-22	118	118	(0.0)	118	121	122	(0.8)	122	119	120	(0.4)	119
	Mean	130	127		129	131	128		130	131	128		129
	SEm±	T=0.01	G=0.44	T×G=0.05		T=0.04	G=0.37		T×G=0.21	T=0.04	G=0.37		T×G=0.21
	CD at 5%	T=0.066	G=1.245	T×G=1.721		T=0.288	G=1.059		T×G=1.483	T=0.288	G=1.046		T×G=1.465

(Figures in parenthesis are % increase/decrease) (T: Treatment, G: Genotype, T×G: Interaction)

Table 3: Effect of elevated temperature tolerance on stomatal conductance (mmol $m^{-2}s^{-1}$) in rice genotypes at flowering stage during *kharif*, 2012 & 2013

			2012				**2013**				**Pooled**		
S.No	**Genotypes**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn.**	**Mean**
1	IET-21404	126.5	121.4	(-4.0)	124.0	193.3	158.4	(-18.1)	175.9	159.9	139.9	(-12.5)	149.9
2	IET-21411	182.4	188.4	(3.3)	185.4	184.5	165.4	(-10.3)	175.0	183.5	176.9	(-3.6)	180.2
3	IET-21415	155.1	107.4	(-30.8)	131.3	166.2	169.4	(1.9)	167.8	160.7	138.4	(-13.9)	149.5
4	IET-21515	165.1	134.4	(-18.6)	149.8	180.4	209.3	(16.0)	194.9	172.8	171.8	(-0.5)	172.3
5	IET-21577	119.3	113.4	(-4.9)	116.3	198.3	175.3	(-11.6)	186.8	158.8	144.3	(-9.1)	151.6
6	IET-21582	191.0	129.9	(-32.0)	160.5	184.4	174.4	(-5.5)	179.4	187.7	152.1	(-19.0)	169.9
7	IET-22100	223.8	104.4	(-53.4)	164.1	194.5	178.3	(-8.4)	186.4	209.2	141.3	(-32.4)	175.2
8	IET-22116	174.3	160.1	(-8.1)	167.2	225.4	189.5	(-16.0)	207.5	199.9	174.8	(-12.5)	187.3
9	IET-22218	173.0	161.2	(-6.8)	167.1	181.3	193.5	(6.7)	187.4	177.2	177.4	(0.1)	177.3
10	IR-64	192.1	161.3	(-16.0)	176.7	195.5	211.5	(8.2)	203.5	193.8	186.4	(-3.8)	190.1
11	KPH-2	127.3	176.4	(38.5)	151.8	225.3	193.2	(-14.2)	209.3	176.3	184.8	(4.8)	180.6
12	LALAT	148.3	126.4	(-14.8)	137.3	193.4	184.3	(-4.7)	188.8	170.8	155.3	(-9.1)	163.1
13	MTU-1010	183.7	182.3	(-0.8)	183.0	185.5	192.5	(3.8)	189.0	184.6	187.4	(1.5)	186.0
14	PA-6129	173.4	160.6	(-7.4)	167.0	201.4	174.3	(-13.5)	187.9	187.4	167.4	(-10.7)	177.4
15	PA-6201	200.2	124.2	(-38.0)	162.2	186.5	148.4	(-20.4)	167.5	193.4	136.3	(-29.5)	164.8
16	PA-6444	142.4	183.2	(28.6)	162.8	192.3	148.4	(-22.8)	170.4	167.4	165.8	(-0.9)	166.6
17	PHB-71	168.3	154.5	(-8.2)	161.4	193.5	173.4	(-10.4)	183.4	180.9	163.9	(-9.4)	172.4
18	DRRH-3	169.4	124.0	(-26.8)	146.7	200.3	178.4	(-10.9)	189.4	184.9	151.2	(-18.2)	168.0
19	PR-113	101.4	109.6	(8.1)	105.5	195.5	164.3	(-16.0)	179.9	148.4	137.0	(-7.7)	142.7
20	US-312	153.4	187.4	(22.1)	170.4	183.4	155.5	(-15.2)	169.5	168.4	171.4	(1.8)	169.9
21	US-382	185.8	146.3	(-21.2)	166.1	175.4	163.3	(-6.9)	169.3	180.6	154.8	(-14.3)	167.7
22	N-22	169.2	146.5	(-13.4)	157.9	196.4	178.4	(-9.2)	187.4	182.8	162.5	(-11.1)	172.6
	Mean	164.8	145.6		155.2	192.4	176.3		184.4	178.6	161.0		169.8
	SEm±	T=0.04	G=0.56		T×G=0.78	T=0.004	G=0.41		T×G=0.57	T=0.02	G=0.10		T×G=0.14
	CD at 5%	T=0.291	G=1.590		T×G=2.211	T=0.029	G=1.176		T×G=1.625	T=0.158	G=0.290		T×G=0.411

(Figures in parenthesis are % increase/decrease) (T: Treatment, G: Genotype, T×G: Interaction)

Table 4: Effect of elevated temperature tolerance on transpiration rate (mmole $m^{-2}sec^{-1}$) in rice genotypes at flowering stage During *kharif*, 2012&2013

			2012				**2013**				**Pooled**		
S. No	**Genotypes**	**Normal Temp.**	**Temp. Stress**	**%Rdn.**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn.**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn.**	**Mean**
1	IET-21404	1.55	2.46	(59.3)	2.01	1.75	1.91	(9.3)	1.83	1.65	2.19	(32.8)	1.92
2	IET-21411	1.87	2.33	(24.6)	2.10	1.21	2.84	(134.1)	2.03	1.54	2.58	(67.7)	2.06
3	IET-21415	1.27	1.84	(44.6)	1.55	1.76	1.83	(4.2)	1.80	1.52	1.84	(21.1)	1.68
4	IET-21515	1.45	1.87	(29.5)	1.66	2.14	2.87	(34.3)	2.51	1.79	2.37	(32.3)	2.08
5	IET-21577	2.23	2.53	(13.5)	2.38	2.73	2.96	(8.7)	2.85	2.48	2.75	(10.8)	2.61
6	IET-21582	1.46	1.94	(32.8)	1.70	2.43	3.17	(30.1)	2.80	1.95	2.56	(31.1)	2.25
7	IET-22100	1.12	2.27	(102.7)	1.70	1.86	2.90	(55.8)	2.38	1.49	2.59	(73.4)	2.04
8	IET-22116	1.55	1.63	(4.9)	1.59	3.12	3.24	(3.8)	3.18	2.34	2.44	(4.2)	2.39
9	IET-22218	1.64	3.14	(91.6)	2.39	2.24	2.94	(31.1)	2.59	1.94	3.04	(56.7)	2.49
10	IR-64	1.55	2.75	(77.4)	2.15	2.55	2.56	(0.1)	2.56	2.05	2.65	(29.3)	2.35
11	KPH-2	1.22	2.43	(99.5)	1.82	2.43	2.65	(9.1)	2.54	1.82	2.54	(39.2)	2.18
12	LALAT	1.12	1.57	(40.1)	1.35	1.73	1.75	(1.0)	1.74	1.43	1.66	(16.3)	1.55
13	MTU-1010	2.80	2.96	(5.7)	2.88	2.54	2.55	(0.4)	2.55	2.67	2.76	(3.2)	2.71
14	PA-6129	1.22	2.18	(78.4)	1.70	2.37	2.88	(21.7)	2.62	1.79	2.53	(41.0)	2.16
15	PA-6201	1.46	3.18	(118.3)	2.32	1.66	2.57	(55.3)	2.12	1.56	2.88	(84.8)	2.22
16	PA-6444	1.97	1.98	(0.2)	1.98	2.37	2.54	(7.2)	2.46	2.17	2.26	(4.0)	2.22
17	PHB-71	2.08	2.63	(26.6)	2.35	2.53	2.72	(7.4)	2.63	2.31	2.68	(16.1)	2.49
18	DRRH-3	1.21	1.57	(30.1)	1.39	1.93	2.44	(26.6)	2.19	1.57	2.01	(27.9)	1.79
19	PR-113	1.02	1.82	(77.5)	1.42	2.13	2.36	(11.0)	2.24	1.58	2.09	(32.6)	1.83
20	US-312	1.26	1.51	(19.8)	1.39	2.27	2.55	(12.3)	2.41	1.77	2.03	(15.0)	1.90
21	US-382	1.36	2.92	(115.0)	2.14	1.83	2.34	(28.1)	2.08	1.59	2.63	(65.1)	2.11
22	N-22	1.29	1.53	(18.9)	1.41	2.24	2.25	(0.4)	2.25	1.76	1.89	(7.2)	1.83
	Mean	1.53	2.23		1.88	2.17	2.58		2.38	1.85	2.41		2.13
	SEm±	T=0.01	G=0.05		T×G=0.08	T=0.003	G=0.04		T×G=0.06	T=0.008	G=0.01		T×G=0.02
	CD at 5%	T=0.093	G=0.162		T×G=0.230	T=0.020	G=0.124		T×G=0.172	T=0.049	G=0.052		T×G=0.074

(Figures in parenthesis are % increase/decrease) (T: Treatment, G: Genotype, T×G: Interaction)

Table 5: Effect of elevated temperature tolerance on photosynthetic rate (µmol $CO_2m^{-2}s^{-1}$) in rice genotypes at flowering stage During *kharif*, 2012&2013

			2012					**2013**				**Pooled**	
S. No	**Genotypes**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**
1	IET-21404	18.6	11.4	(-38.5)	15.0	19.4	13.5	(-30.4)	16.5	19.0	12.5	(-34.4)	15.8
2	IET-21411	17.5	12.4	(-28.8)	15.0	20.4	15.5	(-24.2)	17.9	18.9	14.0	(-26.3)	16.4
3	IET-21415	17.4	12.5	(-28.2)	15.0	18.5	16.5	(-10.8)	17.5	18.0	14.5	(-19.2)	16.2
4	IET-21515	19.3	11.5	(-40.6)	15.4	20.2	17.3	(-14.5)	18.8	19.8	14.4	(-27.2)	17.1
5	IET-21577	18.5	16.5	(-10.8)	17.5	16.5	15.8	(-4.3)	16.1	17.5	16.1	(-7.7)	16.8
6	IET-21582	20.4	19.6	(-3.6)	20.0	17.4	14.4	(-17.4)	15.9	18.9	17.0	(-10.0)	18.0
7	IET-22100	18.7	16.3	(-12.5)	17.5	18.6	12.5	(-32.8)	15.6	18.6	14.4	(-22.6)	16.5
8	IET-22116	20.4	16.4	(-19.7)	18.4	18.1	13.1	(-27.4)	15.6	19.3	14.8	(-23.4)	17.0
9	IET-22218	17.4	12.3	(-29.3)	14.9	17.1	12.8	(-25.3)	15.0	17.3	12.6	(-27.3)	14.9
10	IR-64	16.6	16.2	(-2.8)	16.4	21.2	15.8	(-25.3)	18.5	18.9	16.0	(-15.4)	17.5

11	KPH-2	16.6	11.5	(-30.9)	14.1	18.7	15.1	(-19.6)	16.9	17.7	13.3	(-24.9)	15.5
12	LALAT	18.6	17.4	(-6.6)	18.0	17.1	14.6	(-14.6)	15.9	17.9	16.0	(-10.4)	16.9
13	MTU-1010	18.4	13.5	(-26.3)	16.0	18.6	16.1	(-13.5)	17.3	18.5	14.8	(-19.9)	16.6
14	PA-6129	16.7	11.3	(-32.3)	14.0	17.8	16.8	(-5.8)	17.3	17.3	14.1	(-18.6)	15.7
15	PA-6201	18.6	14.5	(-22.1)	16.5	18.4	16.0	(-13.4)	17.2	18.5	15.2	(-17.7)	16.9
16	PA-6444	16.5	10.4	(-37.3)	13.5	17.7	13.9	(-21.5)	15.8	17.1	12.1	(-29.1)	14.6
17	PHB-71	17.5	14.2	(-19.0)	15.9	19.1	14.5	(-24.3)	16.8	18.3	14.3	(-21.7)	16.3
18	DRRH-3	19.3	13.3	(-31.0)	16.3	18.1	15.8	(-12.7)	16.9	18.7	14.5	(-22.1)	16.6
19	PR-113	18.4	15.4	(-16.5)	16.9	17.9	12.7	(-29.1)	15.3	18.2	14.0	(-22.7)	16.1
20	US-312	18.7	15.6	(-16.6)	17.1	18.1	14.6	(-19.0)	16.4	18.4	15.1	(-17.8)	16.7
21	US-382	15.7	12.4	(-20.9)	14.0	19.0	16.5	(-13.5)	17.8	17.4	14.4	(-16.8)	15.9
22	N-22	21.5	14.6	(-32.1)	18.0	18.3	12.1	(-34.0)	15.2	19.9	13.3	(-33.0)	16.6
	Mean	18.2	14.1		16.1	18.5	14.8		16.6	18.4	14.4		16.4
	SEm±	T=0.04	G=0.43		T×G=0.60	T=0.10	G=0.68		T×G=0.95	T=0.04	G=0.51		T×G=0.71
	CD at 5%	T=0.265	G=1.235		T×G=1.721	T=0.655	G=1.933		T×G=2.727	T=0.259	G=1.462		T×G=2.032

(Figures in parenthesis are % increase/decrease) (T: Treatment, G: Genotype, T×G: Interaction)

Table 6: Effect of elevated temperature tolerance on yield and yield attributes (Grain yield kg ha^{-1}) in rice genotypes during *kharif*, 2012&2013

			2012				**2013**				**Pooled**		
S.No	**Genotypes**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**	**Normal Temp.**	**Temp. Stress**	**%Rdn**	**Mean**
1	IET-21404	6940	4810	(-30.7)	5875	7193	4593	(-36.1)	5893	7067	4702	(-33.5)	5884
2	IET-21411	6540	4827	(-26.2)	5683	7963	6317	(-20.7)	7140	7252	5572	(-23.2)	6412
3	IET-21415	7510	4550	(-39.4)	6030	6470	3620	(-44.0)	5045	6990	4085	(-41.6)	5538
4	IET-21515	7060	6510	(-7.8)	6785	8840	5130	(-42.0)	6985	7950	5820	(-26.8)	6885
5	IET-21577	6753	3380	(-50.0)	5067	6860	5743	(-16.3)	6302	6807	4562	(-33.0)	5684
6	IET-21582	6943	2590	(-62.7)	4767	8867	6913	(-22.0)	7890	7905	4752	(-39.9)	6328
7	IET-22100	7163	3717	(-48.1)	5440	8040	6477	(-19.4)	7258	7602	5097	(-33.0)	6349
8	IET-22116	7627	7133	(-6.5)	7380	8007	5543	(-30.8)	6775	7817	6338	(-18.9)	7078
9	IET-22218	7080	5600	(-20.9)	6340	6117	4843	(-20.8)	5480	6598	5222	(-20.9)	5910
10	IR-64	6633	3597	(-45.8)	5115	8773	3897	(-55.6)	6335	7703	3747	(-51.4)	5725
11	KPH-2	7047	2183	(-69.0)	4615	8183	4920	(-39.9)	6552	7615	3552	(-53.4)	5583
12	LALAT	6653	1717	(-74.2)	4185	7947	4120	(-48.2)	6033	7300	2918	(-60.0)	5109
13	MTU-1010	6310	3510	(-44.4)	4910	9143	4987	(-45.5)	7065	7727	4248	(-45.0)	5988
14	PA-6129	6770	2373	(-64.9)	4572	8230	5647	(-31.4)	6938	7500	4010	(-46.5)	5755
15	PA-6201	6740	983	(-85.4)	3862	8620	7790	(-9.6)	8205	7680	4387	(-42.9)	6033
16	PA-6444	6583	4027	(-38.8)	5305	5757	5643	(-2.0)	5700	6170	4835	(-21.6)	5503
17	PHB-71	6387	2380	(-62.7)	4383	8050	3857	(-52.1)	5953	7218	3118	(-56.8)	5168
18	DRRH-3	6593	3890	(-41.0)	5242	7047	4140	(-41.2)	5593	6820	4015	(-41.1)	5418
19	PR-113	6383	4440	(-30.4)	5412	9193	5980	(-35.0)	7587	7788	5210	(-33.1)	6499
20	US-312	6723	2763	(-58.9)	4743	8047	3277	(-59.3)	5662	7385	3020	(-59.1)	5203
21	US-382	6583	2757	(-58.1)	4670	5753	4127	(-28.3)	4940	6168	3442	(-44.2)	4805
22	N-22	7767	7723	(-0.6)	7745	8107	7927	(-2.2)	8017	7937	6325	(-20.3)	7131
	Mean	6854	3885		5369	7782	5250		6516	7318	4499		5908
	SEm±	T=59.88	G=342.42		T×G=476.89	T=50.98	G=440.59		T×G=610.90	T=42.15	G=272.30		T×G=378.59
	CD at 5%	T=369.48	G=963.15		T×G=1366.66	T=314.56	G=1239.31		T×G=1732.63	T=260.04	G=765.94		T×G=1080.67

(Figures in parenthesis are % increase/decrease) (T: Treatment, G: Genotype, T×G: Interaction)

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