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Study the effect of high temperature stress on pollen viability, stigma exertion, sterility in rice

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Abstract

Present experiment was taken up entitled "study the effect of high temperature stress on pollen viability, stigma exertion, sterility in rice" at Indian Institute of Rice Research, Rajendranagar, Hyderabad during *Kharif,* 2012-2013 and 2013-2014 in split-plot design with treatments (Normal temperature and 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, reproductive traits such as pollen viability, stigma exertion were significantly affected by high temperature stress conditions.

Keywords: pollen viability, stigma exertion, genotypes

Introduction

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) [1].

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) [2]. 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) [5], global mean temperature will rise 0.3°C per decade (Jones *et al.* 1999) [6] reaching to approximately 1 and 3°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 1^0C in night temperature will reduce rice yields by 0.3 tons per hectare (IPCC, 2007) [5]. Similarly, 90% decrease in yield was reported when rice plants were exposing to high night temperatures (32°C) (Mohammed and Tarpley, 2009) [9]. 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 ^{0}C, respectively, for the period of 1979-2003 at International Rice Research Institute, Manila, Philippines (Peng *et al.*, 2004) [12].

Under changing climate, developing temperature tolerant rice genotypes is of prime importance. Keeping in view of this, the present study is undertaken addressing the high temperature tolerance in rice to evaluation of rice genotypes for high temperature tolerance under field conditions.

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° 19' N latitude and 78° 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

Pollen Viability

At flowering ten individual florets from ten different plants were collected from each cultivar. Number of pollen grains on the stigma (pollen reception) was recorded. For pollen count, the samples were collected early in the morning just before anthesis (07:00-08:00 am), while number of pollen germinating on stigma were collected in late afternoon (01:00-02:00 pm). Spikelets were selected from the second or third branch from top on the primary rachis. Third or fourth spikelets on the branch were used to estimate the number of pollen grains on the stigma and pollen viability.

The number of pollen grains on the surface of the stigma (pollen reception) was counted. The spikelets were fixed in 50 per cent ethanol soon after collection and stigma from these spikelets were excised on glass slide and stained with 1 per cent iodine potassium iodide (IKI) solution. Later the number of pollen grains stained with IKI was counted. Pollen viability was estimated using 1 per cent IKI stain. Pollen grains stained uniformly with IKI were considered viable. For pollen viability, ten anthers from ten different plants were collected early in the morning before anthesis, and anthers were opened with a needle and pollen grains were immediately brushed on glass slide and covered with a drop of IKI. Pollen viability was counted as the ratio of number of stained pollen to total number of pollen grains and expressed as percentage (Prasad *et al*., 2006) [13].

Stigma exsertion

In the late afternoon (after 3 p.m.) when flowering is complete for the day, the spikelet number with exserted stigma in one side (single stigma exsertion, SStgE), and two sides (dual stigma exsertion, DStgE), and no stigma in either sides (NStgE) among the marked spikelets in each of 10 sampled panicles were recorded for the 10 sampled panicles (Yan *et al*., 2009) [18]. Then, these counts were converted to:
SStgE(%)=[SStgE/(SStgE+DStgE+NStgE)]x 100;
DStgE(%)=[DStgE/(SStgE+DStgE+NStgE)]x 100;
Total stigma exsertion
(TStgE)(%)= SStgE(%) + DStgE(%)

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) $m^{-2}s^{-1}$.

Statistical analysis

The experimental data were analyzed statistically by following standard procedure outlined by Panse and Sukhatme (1985) [11]. Significance was tested by comparing "F" value at 5 per cent level of probability. The percentage values were transferred.

Results and discussion

Physico-chemical properties of the experimental field (main field) contains Sand 29%, Silt 23 %, Clay 48%, Textural class Clayey vertisol. Chemical properties: Soil reaction (pH) 8.33 alkaline, Electrical conductivity (dSm^{-1}):0.22, Organic Carbon (%): 0.54(medium), Available nitrogen (kg ha^{-1}): 175(low), Available phosphorus (kg ha^{-1}):75(high), Available potassium (kg ha^{-1}):317 (high).

Pollen viability

This parameter is important under elevated temperature stress by as there exists a strong significant positive correlation between percent change in pollen viability and percent change in spikelet fertility under elevated temperature. Elevated temperature during flowering decreased the ability of the pollen grains to swell resulting in poor anther dehiscence (Matsui *et al*., 2000) [8]. Pollen viability has been considered as an important parameter of pollen quality (Dafni and Firmage, 2000) [3]. In this study the pollen viability was found to be decreased under elevated temperature and significant difference was observed for the genotypes and treatment and their interaction (Table 1). During first season, IR-64 (93.4) and PHB-71 (77.0) recorded maximum and minimum pollen viability under ambient temperature while, PHB-71 (63.8) and PA-6444 (50.2) recorded the maximum and minimum under elevated temperature stress respectively. During second season, the genotypes LALAT (92.9) and PHB-71 (63.3) recorded maximum pollen viability while, IET-21515 (80.3) and DRRH-3 (50.3) recorded minimum value under ambient and elevated temperature stress respectively. Pooled data revealed that the genotypes IET-22100 (92.4) and PHB-71 (63.5) recorded maximum pollen viability while, IET-21582 (80.7) and US-312 (50.4) recorded minimum value under ambient and elevated temperature stress.

Under controlled conditions, no genotype recorded significantly higher pollen viability than N-22. Ten genotypes PHB-71 (63.5), IR-64 (62.1), IET-21582 (61.7), IET-22218 (61.6), IET-22100 (61.5), PA-6129 (61.0), LALAT (60.7), IET-21404 (60.6), IET-21415 (60.4) and PR-113 (58.4) recorded significantly higher pollen viability than check N-22 under temperature stress conditions in pooled data.

The percentage reduction range of pollen viability was 23-40 per cent in pooled data. Greater reduction was recorded in genotypes N-22 (-39.9), US-312 (-39.8), IET-21577 (-39.3), DRRH-3 (-37.7).In contrast, IET-21582 (-23.6), PHB-71 (-24.0), IET-21415 (-26.4) and IET-22218 (-28.3) recorded less reduction of pollen viability. (Prasad *et al*., 2006) [13] reported 16-40 percent reduction in pollen viability under ambient +5ºC, Tang *et al*., (2008) [17] reported 65 percent reduction in pollen fertility under 32/39ºC day night temperature. This study unequivocally proved that elevated temperature reduces pollen viability and genotypic variation exists for this trait and hence it is important to identify the genotypes with high pollen viability under high temperature so as to use them in crop breeding programs as donors respectively.

Stigma exertion

Stigma exertion is an important trait that contributes to the improvement of seed production in rice. In the present study the stigma exertion was found to be decreased under elevated temperature and significant difference was observed for the genotypes, treatment and their interaction (Table 2). During first season, the genotypes IET-21415 (63.7) and IET-22218 (46.2) recorded maximum and minimum value stigma exertion under ambient temperature while, IET-22116 (23.7) and IET-21577 (13.7) recorded the maximum and minimum value under elevated temperature stress respectively. The genotypes IET-22218 (64.7) and DRRH-3 (25.0) recorded maximum pollen viability while, PR-113 (48.7) and PHB-71 (14.8) recorded minimum value under ambient and elevated temperature stress respectively during second season. Pooled data revealed that the genotypes IET-21415 (61.4) and IET-22116 (23.6) recorded maximum stigma exertion while, KPH-2 (48.9) and N-22 (15.9) recorded minimum value under ambient and elevated temperature stress respectively.

No genotype recorded more stigma exertion than N-22 under both controlled and temperature stress conditions in pooled data. Among all the genotypes, IET-22116 (23.6) was recorded maximum stigma exertion under temperature stress in pooled data compared to control.

The percentage reduction range of stigma exertion was 56-73 per cent in pooled data. The genotypes IET-22116 (-56.7), IET-22100 (-60.8), IET-21515 (-61.0) and DRRH-3 (-61.6) recorded less reduction. In contrast greater reduction was reported in IET-21577 (-72.7), N-22 (-71.5), IET-22218 (-69.3) and PHB-71 (-69.2). From the studies it can be inferred that genotypes showing higher stigma exertion under stress have less thermo tolerant nature.

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

Stomatal conductance plays an important rolein plant adaptation to elevated temperature stress. High stomatal conductance enables increased CO_2 diffusion into leaf and favourshigh photosynthetic rate which in turn leads to high biomass and grain yield (Taiz and Zegier, 2002) [16]. 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) [14]. 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) [10] 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.

Spikelet fertility

Flowering (anthesis and fertilization) and to a lesser extent booting (microsporogenesis), are the most susceptible stages of development to temperature in rice (Farrell *et al*., 2006) [4]. Spikelets at anthesis that are exposed to temperatures >35ºC for about 5 days during the flowering period show sterility and set no seed (Satake and Yoshida, 1978) [15].

In the present study, spikelet fertility was found to decrease under elevated temperature and significant difference was observed for the genotypes, treatment and their interaction (Table 4). During first season, the genotypes PA-6201 (87.0) and IET-21411 (31.6) recorded maximum and minimum spikelet fertility under ambient temperature while, N22 (78.2) and IET-21577 (11.5) recorded the maximum and minimum under elevated temperature stress respectively. During second season, the genotypes PHB-71 (86.9) and N22 (79.7) recorded maximum spikelet fertility while, IET-21404 (27.9) and IET-22218 (13.1) recorded minimum value under ambient and elevated temperature stress respectively. Pooled data revealed that the genotypes IR-64 (84.4) and N-22 (79.0) recorded maximum spikelet fertility under ambient and elevated temperature stress while, IET-21411 (42.1) and IET-21577 (13.4) recorded minimum value under ambient and elevated temperature stress.

No genotype recorded significantly higher spikelet fertility under both controlled and temperature stress conditions than check N-22 (82.0 under control and 79.0 under stress).

The percentage reduction range of spikelet fertility was 3-82per cent in pooled data. Higher reduction was recorded in IR-64 (-81.6) followed by MTU-1010 (-75.0), IET-21577 (-71.0), PA-6444 (-60.6). In contrast less reduction was reported in N-22 (-3.7), IET-21404 (-26.4), IET-21411 (-31.7) and PA-6129(-34.8). The decline in the spikelet fertility might be due to decreased ability of the pollen grains to swell, resulting in poor dehiscence (KeHui, 2014) [7].

Spikelet sterility

There exists genotypic variation in spikelet sterility at elevated temperature (Prasad *et al*., 2006) [13]. In the present study the spikelet sterility was found to increase under elevated temperature and significant difference were recorded for the genotypes, treatments and their interaction (Table 5). During first season, the genotypes IET-21411 (68.4) and PA-6201 (13.0) recorded maximum and minimum spikelet sterility under ambient temperature while, IET-21577 (88.5) and N-22 (21.8) recorded the maximum and minimum sterility under elevated temperature stress respectively. During second season, the genotypes IET-21404 (72.1) and IET-22218 (86.9) recorded maximum spikelet sterility under ambient while, PHB-71 (13.1) and N-22 (20.3) recorded minimum value under elevated temperature stress. Pooled data revealed that the genotypes IET-21411 (57.9) and IET-21577 (86.6) recorded maximum spikelet sterility while, IR-64 (15.6) and N-22 (21) recorded minimum value under ambient and elevated temperature stress respectively.

All the test genotypes recorded higher spikelet sterility under controlled and temperature stress except MTU-1010 (19.9) and IR-64 (15.6) under controlled conditions than check N-22 (18.0 under control and 21.0 under stress).

Among all genotypes, the genotype IET-21577 (86.6) recorded maximum spikelet sterility under elevated temperature stress in pooled data, followed by IR-64 (84.4), MTU-1010 (80.0), IET-21515 (77.6) and PA-6444 (77.6) compared to control.

The increase in percentage range of spikelet sterility was 16-95 per cent in pooled data. Among the genotypes PR-113 (94.5) exhibited greater increase in spikelet sterility. In contrast less increase was observed in N-22 (16.7), IET-21404 (22.5), IET-21411 (23.0) and US-382 (29.8).

Sterility has been attributed to poor anther dehiscence and low pollen production, which possibly result in lower number of germinating pollen grains on the stigma (Prasad *et al*., 2006) [13].

Table 1: Effect of high temperature tolerance on pollen viability (%) 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	88.1	61.0	(-30.8)	74.5	90.8	60.3	(-33.6)	75.6	89.5	60.6	(-32.2)	75.1
2	IET-21411	81.2	62.4	(-23.1)	71.8	91.6	51.4	(-43.9)	71.5	86.4	56.9	(-34.1)	71.7
3	IET-21415	81.9	60.3	(-26.4)	71.1	82.1	60.5	(-26.3)	71.3	82.0	60.4	(-26.4)	71.2
4	IET-21515	84.9	50.4	(-40.6)	67.7	80.3	62.0	(-22.8)	71.2	82.6	56.2	(-32.0)	69.4
5	IET-21577	80.3	52.8	(-34.2)	66.6	90.1	50.5	(-43.9)	70.3	85.2	51.7	(-39.3)	68.4
6	IET-21582	81.0	61.2	(-24.4)	71.1	80.4	62.1	(-22.7)	71.2	80.7	61.7	(-23.6)	71.2
7	IET-22100	92.2	62.7	(-32.0)	77.4	92.6	60.4	(-34.7)	76.5	92.4	61.5	(-33.4)	77.0
8	IET-22116	90.2	62.0	(-31.3)	76.1	90.2	51.4	(-43.0)	70.8	90.2	56.7	(-37.2)	73.5
9	IET-22218	91.4	62.5	(-31.6)	77.0	80.4	60.7	(-24.6)	70.6	85.9	61.6	(-28.3)	73.8
10	IR-64	93.4	63.3	(-32.2)	78.3	82.5	61.0	(-26.1)	71.8	88.0	62.1	(-29.4)	75.0
11	KPH-2	80.2	61.6	(-23.2)	70.9	90.3	50.5	(-44.1)	70.4	85.3	56.1	(-34.3)	70.7
12	LALAT	80.4	60.9	(-24.2)	70.7	92.9	60.5	(-34.9)	76.7	86.7	60.7	(-29.9)	73.7
13	MTU-1010	83.6	50.4	(-39.6)	67.0	91.2	61.4	(-32.7)	76.3	87.4	55.9	(-36.0)	71.6
14	PA-6129	90.2	61.9	(-31.4)	76.0	90.2	60.2	(-33.3)	75.2	90.2	61.0	(-32.4)	75.6
15	PA-6201	80.4	60.4	(-24.9)	70.4	91.2	50.5	(-44.6)	70.9	85.8	55.5	(-35.4)	70.7
16	PA-6444	80.2	50.2	(-37.4)	65.2	83.7	60.5	(-27.7)	72.1	82.0	55.4	(-32.5)	68.7
17	PHB-71	77.0	63.8	(-17.2)	70.4	90.2	63.3	(-29.9)	76.7	83.6	63.5	(-24.0)	73.6
18	DRRH-3	80.6	57.2	(-29.0)	68.9	91.8	50.3	(-45.2)	71.1	86.2	53.7	(-37.7)	70.0
19	PR-113	90.2	63.7	(-29.4)	77.0	90.3	53.2	(-41.1)	71.7	90.3	58.4	(-35.3)	74.3
20	US-312	83.8	50.4	(-39.8)	67.1	83.7	50.5	(-39.7)	67.1	83.7	50.4	(-39.8)	67.1
21	US-382	80.4	63.6	(-20.9)	72.0	92.7	50.4	(-45.6)	71.6	86.6	57.0	(-34.1)	71.8
22	N-22	90.2	57.0	(-36.8)	73.6	90.4	51.6	(-42.9)	71.0	90.3	54.3	(-39.9)	72.3
	Mean	84.6	59.1		71.9	88.2	56.5		72.3	86.4	57.8		72.1
	SEm±	T=1.21	G=3.60	T×G=5.10	T=0.84	G=3.75	T×G=5.25	T=0.52	G=3.31	T×G=4.61			
	CD at 5%	T=7.413	G=10.143	T×G=14.345	T=5.112	G=10.550	T×G=14.920	T=3.196	G=9.335	T×G=13.178			

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

Table 2: Effect of elevated temperature tolerance on stigma exertion (%) 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	54.8	19.0	(-65.3)	36.9	53.0	20.0	(-62.3)	36.5	53.9	19.5	(-63.8)	36.7
2	IET-21411	60.5	20.2	(-66.7)	40.3	60.5	19.3	(-68.0)	39.9	60.5	19.8	(-67.4)	40.1
3	IET-21415	63.7	20.0	(-68.6)	41.8	59.2	19.8	(-66.5)	39.5	61.4	19.9	(-67.6)	40.7
4	IET-21515	59.2	20.8	(-64.8)	40.0	57.0	24.5	(-57.0)	40.8	58.1	22.7	(-61.0)	40.4
5	IET-21577	57.5	13.7	(-76.2)	35.6	60.8	18.7	(-69.3)	39.8	59.2	16.2	(-72.7)	37.7
6	IET-21582	53.3	17.0	(-68.1)	35.2	51.7	20.8	(-59.7)	36.3	52.5	18.9	(-64.0)	35.7
7	IET-22100	58.7	22.3	(-61.9)	40.5	49.3	20.0	(-59.5)	34.7	54.0	21.2	(-60.8)	37.6
8	IET-22116	54.0	23.7	(-56.2)	38.8	55.0	23.5	(-57.3)	39.3	54.5	23.6	(-56.7)	39.0
9	IET-22218	46.2	18.2	(-60.6)	32.2	64.7	15.8	(-75.5)	40.3	55.4	17.0	(-69.3)	36.2
10	IR-64	47.0	17.0	(-63.8)	32.0	60.3	19.5	(-67.7)	39.9	53.7	18.3	(-66.0)	36.0
11	KPH-2	48.8	16.0	(-67.2)	32.4	49.0	18.2	(-62.9)	33.6	48.9	17.1	(-65.1)	33.0

12	LALAT	56.0	20.0	(-64.3)	38.0	50.8	18.0	(-64.6)	34.4	53.4	19.0	(-64.4)	36.2
13	MTU-1010	57.0	21.0	(-63.2)	39.0	56.7	16.7	(-70.6)	36.7	56.8	18.8	(-66.9)	37.8
14	PA-6129	58.3	18.3	(-68.6)	38.3	63.8	22.5	(-64.8)	43.2	61.1	20.4	(-66.6)	40.8
15	PA-6201	56.7	18.0	(-68.2)	37.3	49.0	20.7	(-57.8)	34.8	52.8	19.3	(-63.4)	36.1
16	PA-6444	59.5	20.7	(-65.3)	40.1	53.7	22.3	(-58.4)	38.0	56.6	21.5	(-62.0)	39.0
17	PHB-71	52.8	19.7	(-62.8)	36.3	59.0	14.8	(-74.9)	36.9	55.9	17.3	(-69.2)	36.6
18	DRRH-3	56.0	16.8	(-69.9)	36.4	52.8	25.0	(-52.7)	38.9	54.4	20.9	(-61.6)	37.7
19	PR-113	54.2	16.3	(-69.8)	35.3	48.7	20.3	(-58.2)	34.5	51.4	18.3	(-64.3)	34.9
20	US-312	56.7	19.0	(-66.5)	37.8	51.3	17.0	(-66.9)	34.2	54.0	18.0	(-66.7)	36.0
21	US-382	52.8	17.5	(-66.9)	35.2	53.5	18.3	(-65.7)	35.9	53.2	17.9	(-66.3)	35.5
22	N-22	54.2	14.3	(-73.5)	34.3	57.7	17.5	(-69.7)	37.6	55.9	15.9	(-71.5)	35.9
	Mean	55.4	18.6		37.0	55.3	19.7		37.5	55.3	19.2		37.3
	SEm±	T=2.42	G=3.24		T×G=4.59	T=0.99	G=2.68		T×G=3.79	T=1.47	G=2.07		T×G=2.93
	CD at 5%	T=14.727	G=9.138		T×G=12.923	T=6.079	G=7.552		T×G=10.680	T=8.951	G=5.846		T×G=8.267

(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 spikelet fertility (%) 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	64.1	47.1	(-26.6)	55.6	27.9	20.6	(-25.9)	24.3	46.0	33.9	(-26.4)	39.9
2	IET-21411	31.6	25.3	(-19.9)	28.5	52.5	32.2	(-38.8)	42.3	42.1	28.7	(-31.7)	35.4
3	IET-21415	58.6	21.4	(-63.4)	40.0	65.4	34.8	(-46.8)	50.1	62.0	28.1	(-54.7)	45.1
4	IET-21515	45.8	23.0	(-49.8)	34.4	59.8	21.9	(-63.4)	40.8	52.8	22.4	(-57.5)	37.6
5	IET-21577	41.6	11.5	(-72.4)	26.5	51.0	15.4	(-69.9)	33.2	46.3	13.4	(-71.0)	29.9
6	IET-21582	59.3	46.6	(-21.3)	53.0	51.8	15.0	(-71.0)	33.4	55.6	30.8	(-44.5)	43.2
7	IET-22100	46.9	20.7	(-55.9)	33.8	58.1	29.4	(-49.3)	43.7	52.5	25.1	(-52.2)	38.8
8	IET-22116	74.1	59.3	(-19.9)	66.7	69.4	16.2	(-76.6)	42.8	71.7	37.8	(-47.3)	54.8
9	IET-22218	58.5	48.7	(-16.7)	53.6	48.1	13.1	(-72.7)	30.6	53.3	30.9	(-42.0)	42.1
10	IR-64	85.2	15.2	(-82.2)	50.2	83.6	15.9	(-81.0)	49.7	84.4	15.6	(-81.6)	50.0
11	KPH-2	74.5	47.6	(-36.1)	61.1	62.4	35.1	(-43.7)	48.8	68.4	41.4	(-39.5)	54.9
12	LALAT	64.6	48.2	(-25.4)	56.4	69.7	32.9	(-52.7)	51.3	67.1	40.6	(-39.5)	53.8
13	MTU-1010	78.0	26.3	(-66.2)	52.2	82.2	13.6	(-83.4)	47.9	80.1	20.0	(-75.0)	50.0
14	PA-6129	68.1	56.8	(-16.5)	62.5	76.6	37.5	(-51.0)	57.0	72.3	47.2	(-34.8)	59.8
15	PA-6201	87.0	33.6	(-61.4)	60.3	32.6	16.8	(-48.5)	24.7	59.8	25.2	(-57.9)	42.5
16	PA-6444	41.9	18.7	(-55.4)	30.3	72.0	26.1	(-63.7)	49.1	57.0	22.4	(-60.6)	39.7
17	PHB-71	44.7	41.3	(-7.7)	43.0	86.9	40.2	(-53.7)	63.6	65.8	40.7	(-38.1)	53.3
18	DRRH-3	40.9	30.9	(-24.4)	35.9	86.2	29.3	(-66.0)	57.8	63.6	30.1	(-52.6)	46.9
19	PR-113	64.2	45.7	(-28.7)	54.9	79.6	45.0	(-43.5)	62.3	71.9	45.4	(-36.9)	58.6
20	US-312	48.3	37.3	(-22.6)	42.8	68.3	25.6	(-62.5)	46.9	58.3	31.5	(-46.0)	44.9
21	US-382	33.8	26.5	(-21.6)	30.1	55.3	29.6	(-46.5)	42.5	44.6	28.1	(-37.0)	36.3
22	N-22	82.0	78.2	(-4.6)	80.1	82.0	79.7	(-2.8)	80.8	82.0	79.0	(-3.7)	80.5
	Mean	58.8	36.8		47.8	64.6	28.5		46.5	61.7	32.6		47.2
	SEm±	T=1.11	G=6.47		T×G=9.01	T=2.07	G=5.96		T×G=8.43	T=1.59	G=4.63	T×G=6.55	
	CD at 5%	T=6.789	G=18.214		T×G=25.759	T=12.603	G=16.769		T×G=23.715	T=9.721	G=13.041	T×G=18.444	

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

Table 5: Effect of elevated temperature tolerance on spikelet sterility (%) 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	35.9	52.9	(47.6)	44.4	72.1	79.4	(10.0)	75.7	54.0	66.1	(22.5)	60.1
2	IET-21411	68.4	74.7	(9.2)	71.5	47.5	67.8	(42.8)	57.7	57.9	71.3	(23.0)	64.6
3	IET-21415	41.4	78.6	(89.9)	60.0	34.6	65.2	(88.5)	49.9	38.0	71.9	(89.3)	54.9
4	IET-21515	54.2	77.0	(42.0)	65.6	40.2	78.1	(94.2)	59.2	47.2	77.6	(64.2)	62.4
5	IET-21577	58.4	88.5	(51.5)	73.5	49.0	84.6	(72.8)	66.8	53.7	86.6	(61.2)	70.1
6	IET-21582	40.7	53.4	(31.0)	47.0	48.2	85.0	(76.5)	66.6	44.4	69.2	(55.6)	56.8
7	IET-22100	53.1	79.3	(49.4)	66.2	41.9	70.6	(68.2)	56.3	47.5	74.9	(57.7)	61.2
8	IET-22116	25.9	40.7	(57.0)	33.3	30.6	83.8	(173.6)	57.2	28.3	62.2	(120.2)	45.2
9	IET-22218	41.5	51.3	(23.6)	46.4	51.9	86.9	(67.5)	69.4	46.7	69.1	(48.0)	57.9
10	IR-64	14.8	84.8	(473.8)	49.8	16.4	84.1	(411.4)	50.3	15.6	84.4	(440.9)	50.0

11	KPH-2	25.5	52.4	(105.3)	38.9	37.6	64.9	(72.5)	51.2	31.6	58.6	(85.8)	45.1
12	LALAT	35.4	51.8	(46.3)	43.6	30.3	67.1	(120.9)	48.7	32.9	59.4	(80.7)	46.2
13	MTU-1010	22.0	73.7	(235.0)	47.8	17.8	86.4	(385.1)	52.1	19.9	80.0	(302.2)	50.0
14	PA-6129	31.9	43.2	(35.3)	37.5	23.4	62.5	(167.0)	43.0	27.7	52.8	(91.1)	40.2
15	PA-6201	13.0	66.4	(411.4)	39.7	67.4	83.2	(23.5)	75.3	40.2	74.8	(86.2)	57.5
16	PA-6444	58.1	81.3	(39.9)	69.7	28.0	73.9	(163.9)	50.9	43.0	77.6	(80.2)	60.3
17	PHB-71	55.3	58.7	(6.2)	57.0	13.1	59.8	(357.8)	36.4	34.2	59.3	(73.4)	46.7
18	DRRH-3	59.1	69.1	(16.9)	64.1	13.8	70.7	(413.7)	42.2	36.4	69.9	(91.9)	53.1
19	PR-113	35.8	54.3	(51.5)	45.1	20.4	55.0	(170.2)	37.7	28.1	54.6	(94.5)	41.4
20	US-312	51.7	62.7	(21.1)	57.2	31.7	74.4	(134.7)	53.1	41.7	68.5	(64.3)	55.1
21	US-382	66.2	73.5	(11.0)	69.9	44.7	70.4	(57.6)	57.5	55.4	71.9	(29.8)	63.7
22	N-22	18.0	21.8	(20.9)	19.9	18.0	20.3	(12.6)	19.2	18.0	21.0	(16.7)	19.5
	Mean	41.2	63.2		52.2	35.4	71.5		53.5	38.3	67.4		52.8
	SEm±	T=1.11	G=6.47	T×G=9.01		T=2.07	G=5.96		T×G=8.43	T=1.59	G=4.63		T×G=6.55
	CD at 5%	T=6.789	G=18.214	T×G=25.759		T=12.603	G=16.769		T×G=23.715	T=9.721	G=13.041		T×G=18.444

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

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References

1. CMIE. Area, production and productivity of rice in India and Andhra Pradesh. Centre for Monitoring Indian Economy Pvt. Ltd. Mumbai, 2016.
2. Coffman WR. Rice varietal development for cropping systems at IRRI. Proceedings of symposium on cropping systems research and development for the Asian rice farmers. Philippines: IRRI. 1977, 359-371.
3. Dafni A, Firmage D. Pollen viability and longevity practical, ecological and evolutionary implications. Plant System Evol**.** 2000; 222**:**113-132.
4. Farrell TC, Fox KM, Williams RL, Fukai S. Genotypic variation for cold tolerance during reproductive development in rice: screening with cold air and cold water. *Field Crops Researsh.* 2006; 98:178-194.
5. IPCC. (Intergovernmental Panel on Climate Change), Climate change and its impacts in the near and long term under different scenarios. 2007: Synthesis Report (Eds The Core Writing Team, Pachauri RK & Reisinger A), Geneva, Switzerland: IPCC. 2007, 43-54.
6. Jones PD, New M, Parker DE, Martin S, Rigor IG. Surface Air Temperature and Its Changes over the Past 150 Years. *Reviews of Geophysics*. 1999; 37(2):173-199.
7. KeHui WCC. Progress on effect of high temperature on rice yield formation. [Chinese]. Journal of Agricultural Science and Technology. 2014; 16(3):103-111.
8. Matsui T, Omasa K, Horie T. High temperature at flowering inhibits swelling of pollen grains, a driving force for thecae dehiscence in rice (*Oryza sativa* L.). Plant Production Science. 2000; 3:430-434.
9. Mohammed AR, Tarpley L. Impact of high night time temperature on respiration, membrane stability, antioxidant capacity, and yield of rice plants. Crop Science. 2009; 49(1):313-322.
10. Munjal R, Dhanda SS. Physiological and morphological traits associated in bread wheat under heat stress. In: Proceedings of 91st Indian Science Congress part III (advance abstracts). 1st -3rd January, P.U., Chandigarh, India, 2004.
11. Panse VG, Sukhatme PV. Statistical methods for agricultural workers, ICAR, New Delhi, 1985.
12. Peng S, Jianliang H, Sheehy JE, Laza RC, Visperas RM, Xuhua Z *et al*. Rice yields decline with higher night temperature from global warming. Proceedings of the National Academy of Sciences. 2004; 101:9971-9975.
13. Prasad PVV, Boote KJ, Allen LH Jr, Sheehy JE, Thomas JMG. Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice in response to high temperature stress. Field Crops Res. 2006; 95:398–411.
14. Rane J, Chauhan H, Shoran J. Stem reserve mobilization in wheat genotypes tolerant and susceptible to high temperature. Indian Journal of Plant Physiology (Special issue). 2003, 383-385.
15. Satake T, Yoshida S. High temperature induced sterility in indica rice at flowering. Japanese Journal of Crop Science. 1978; 47:6-17.
16. Taiz L, Zeiger E. Plant physiology. Sinuaer associates incorporation publishers, Saunderland, Manchuessets, 2002.
17. Tang RS, Zheng JC, Jin ZQ, Zhan, DD, Huang YH, Chen LH. Possible correlation between high temperature-induced floret sterility and endogenous levels of IAA, Gas and ABA in rice (*Oryza sativa* L.). Plant Growth Regulators. 2008; 54:37-43.
18. Yan WG, Li Y, Agrama HA, Luo D, Gao F, Lu X *et al*. Association mapping of stigma and spikelet characteristics in rice (*Oryza sativa* L.). Mol Breeding. 2009; 24:277-292.