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High Temperature Stress Effected the Biochemical Parameters of Rice (*Oryza sativa* L.) Varieties and Hybrids

R. Ramesh[1*], T. Ramesh[1], P. R. Rao[2], V. G. Shankar[3] and M.H.V. Bhave[4]

[1]Department of Crop Physiology, [3]Department of Genetics and Plant breeding,

[4]Department of Statistics and Mathematics,

College of Agriculture PJTSAU, Rajendranagar, Hyderabad-500030, Telangana, India

[2]Division of Plant Physiology, Indian Institute of Rice Research, Rajendranagar, Hyderabad - Telangana, India

*Corresponding Author E-mail: rameshpphy@gmail.com

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ABSTRACT

Climate change associated phenomenon especially high temperature has become an important constraint for rice production. To develop high temperature tolerant rice genotypes, thorough understanding of genetics, biochemical and physiological processeshas become essential for identification and selection of traits and to enhance tolerance mechanism. In this connection, an experiment was formulated to study the effect of high temperature stress onbiochemical parameters of rice (Oryza sativa L.) varieties and hybrids. This was conducted for two consecutive kharif seasons 2012 and 2013 at Indian Institute of Rice Research, Rajendranagar, Hyderabad. The biochemical parameters like Enzyme activity- Peroxidase(POD),Superoxide dismutase (SOD), and Catalase (CAT) activity was estimated in control as well as stressed condition at vegetative stage and reproductive stages. The results revealed that the temperature acclimated plantscompared to non-induced (control) showed higher peroxidase, super oxide dismutase and catalase activityat both vegetative and reproductive stages compared to check variety N-22. From this study, it can be inferred that high temperature stress is associated with increased activity of antioxidant enzymes in leaves may lead to withstand of heat tolerant rice genotypesfor stressthat in turn results in relative high yield.

Key words: *Peroxidase (POD), Superoxide dismutase (SOD), Catalase (CAT)*

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 of the major crop species including cereals. Rice production has also been intensified in rainfed-lowland and dryland (upland) cropping systems, however many of which are prone to high temperature stress[4].Different global circulation models predict that greenhouse gases will gradually increase world's average ambient temperature.

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By the end of the 21st century, the earth's climate is predicted to warm by an average 1.8 to 4.0°C[10] due to both anthropogenic and natural factors[6].Raising temperatures hence lead 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 by every 1°C in night temperature, consequently reduce rice yields by 0.3 tons per hectare[10].Similarly, 90 percent decrease in yield was reported when rice plants were exposed to high (32°C) night temperatures [12]. 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°C, respectively, for the period of 1979-2003 at International Rice Research Institute, Manila, Philippines [14].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.The main objective of the present investigation was tostudy the effect of high temperature stress onbiochemical parameters of rice (*Oryza sativa* L.) varieties and hybrids.

MATERIAL AND METHODS

The present investigation was conducted during *kharif*, 2012 and 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 physio-chemical properties by adopting standard procedures.

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 withtreatments (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:

Enzyme activity: Peroxidase (POD), Superoxide dismutase (SOD) and Catalase (CAT) activity was measured in leaf at vegetative stage and reproductive stage.

Enzyme assays: -

Preparation of enzyme extract:

Enzyme extract forperoxidase, superoxide dismutase and catalase was prepared by first freezing the weighed amount of leaf samples (0.2g) in liquid nitrogen to prevent proteolytic activity followed by grinding with 5 ml extraction buffer (0.1 M phosphate buffer, pH7.5, containing 0.5 mM EDTA in case of SOD, CAT, and POD).The enzyme extract was centrifuged for 20 min at 15000 rpm and the supernatant was used as enzyme source.

Peroxidase (POD) activity:

Peroxidase assay was carried out according to Castillo *et al*., (1984)[3]. The 3.0 ml of assay mixture consisting of 1.0ml phosphate buffer (pH 6.1), Guaicol 0.5ml, H_2O_2 0.5ml and enzyme 0.1ml and water 0.9ml. Increase in the absorbance due to formation of tetra guaicol was recorded at 470nm up to 3 minutes and it was expressed in µmol H_2O_2 reduced $min^{-1}g^{-1}$ protein.

Superoxide dismutase (SOD) activity:

The SOD activity was measured according to Dhindsa *et al*., (1981)[5]. The 3.0 ml of reaction mixture consisted of Methionine (200 mM), Nitroblue tetrazolium chloride (NBT) (2.25 mM), EDTA (3.0 mM), Riboflavin (60 µM), Sodium carbonate (1.5 M) and Phosphate buffer (100 mM, pH 7.8). The absorbance was recorded at 560 nm and the enzyme activity was expressed in units/ min/gram of protein.

Catalase (CAT) activity:

The same leaf extract, prepared for SOD assay was used for catalase assay. The catalase activity was measured according to Aebi *et al*., (1984)[1]. The assay mixture of 3.0 ml was consisted of 0.05 ml leaf extract, 1.5 ml phosphate buffer (100mM buffer, pH 7.0) 0.5ml H_2O_2 and 0.95ml of distilled water. Decrease in the absorbance was recorded at 240nm up to 3minutes and it was expressed in µmol H_2O_2oxidised $min^{-1}g^{-1}$ protein.

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 DISCUSSIONS

Plants protect the cellular and sub-cellular systems from the cytotoxic effects of reactive oxygen species (ROS) in the form of enzymes such as superoxide dismutase (SOD), peroxidase (POX) and catalase (CAT).

Peroxidase content (µmol H_2O_2reduced $min^{-1}g^{-1}$protein)

a) Vegetative stage:

The peroxidase content of the leaves during vegetative stage was found to increase under elevated temperature (Table.1). During first season, IET-21411 recorded maximum (15.43, 21.60) and IET-22116 (6.73), PA-6444 (12.33) recorded minimum values under ambient temperature and elevated temperature stress respectively. During second season, DRRH-3 recorded maximum (18.40, 24.37) and IET-22100 (8.53), IET-22218 (12.53) recorded minimum values under ambient temperature and elevated temperature stress respectively. Pooled data revealed that the genotypes DRRH-3 recorded maximum (16.85, 22.32) and IET-22116 (9.38), IET-22218 (12.95) recorded minimum values under ambient temperature and elevated temperature stress respectively.

Nine genotypes DRRH-3 (16.85), PHB-71 (15.57), IET-21411 (15.40), MTU-1010 (14.55), PA-6444 (14.33), KPH-2 (13.78), IET-22218 (13.47), US-382 (13.33) and IET-21415 (13.28) registered significantly more peroxidase content activity at vegetative stage than check N-22 under controlled conditions in pooled data. However, under temperature stress conditions, all the genotypes had significantly more peroxidase than check N-22 except IET-21415 (15.40), IET-21404 (15.00), PA-6444 (14.22) and IET-22218 (12.95). Pooled data revealed that the genotype DRRH-3 (22.32) had maximum peroxidase content activity under temperature stress.

The increase percentage range of peroxidase content activity at vegetative stage was 15-109 per cent in pooled data. In general, greater increase in percentage of peroxidase (POD) activity was observed in rice genotypes IET-22116 (108.3), IET-21582 (102.2), IET-22100 (84.1) and US-312 (68.9). In contrast, less increase was recorded in IET-21415 (15.9), N-22 (20.9), PHB-71 (21.8) and LALAT (25.2). PA-6444 (-0.8) and IET-22218 (-3.8) genotypes recorded negative values range from 0 to 5 per cent.

b) Reproductive stage:

The peroxidase content of the leaves during maturity stage was found to increase under elevated temperature (Table.2). During first season, IET-21411 (129.47) and IET-21415 (296.43) recorded maximum value while, IET-22116 (53.50), PR-113 (195.30) recorded minimum values under ambient temperature and elevated temperature stress respectively. During second season, IET-22100 (77.37) and IET-21582 (321.30) recorded maximum while, IET-22116 (40.50, 180.50) recorded minimum values under ambient temperature and elevated temperature stress respectively. Pooled data revealed that the genotypes IET-21411 (99.45) and IET-21582 (294.80) recorded maximum values while, IET-22116 (47.00), PR-113 (192.97) recorded minimum values under ambient temperature and elevated temperature stress respectively.

All the studied genotypes had significantly higher peroxidase activity at reproductive stage than N-22 except IET-22116 (47.00), IET-22218 (66.23), and PHB-71 (66.90) under controlled conditions in pooled data. However, under temperature stress only five genotypes IET-21582 (294.80), IET-22218 (274.97), IET-21415 (260.87), PA-6201 (257.40) and IET-21404 (253.92) had significantly higher peroxidase activity than check N-22.

The increase percentage range of peroxidase content activity at reproductive stage was 118-338 per cent in pooled data. In general, less increase in peroxidase (POD) activity was observed in rice genotypes IET-21411 (118.6), PR-113 (126.2), IR-64 (134.2) and LALAT (139.3). In contrast, greater increase was recorded in IET-22116 (337.3), IET-22218 (315.1), IET-21582 (282.9) and IET-21415 (282.0).

SOD content (U $min^{-1}g^{-1}$fresh weight protein)

a) Vegetative stage:

The SOD content of the leaves during vegetative stage was found to increase under elevated temperature (Table.3). During first season, IET-21415 (27.32) and IET-21582 (31.63) recorded maximum while, PR-113 (15.41) and PA-6129 (16.33) recorded minimum values under ambient temperature and elevated temperature stress respectively. During second season, IET-21415 (27.35)and N-22 (29.37) recorded maximum while, PR-113 (17.28, 18.43) recorded minimum values under ambient temperature and elevated temperature stress respectively. Pooled data revealed that the genotypes IET-21415(27.34) and IET-21582 (30.06) recorded maximum while, PR-113 (16.35, 17.88) recorded minimum values under ambient temperature and elevated temperature stress respectively.

Two genotypes IET-21415 (27.34), and IET-21515 (26.48) under controlled conditions and three genotypes IET-21582 (30.06), IET-21577 (28.87) and PA-6201 (28.47) under temperature stress conditions recorded significantly higher super oxide dismuatase content activity at vegetative stage in pooled data.

The increase in percentage range of super oxide dismutase content activity at vegetative stage was 2-37 per cent in pooled data. In general, greater increase in super oxide dismutase (SOD) activity in rice genotypes was observed in IET-22218 (36.9), IET-22100 (29.5), IET-21582 (18.2) and IET-21577 (17.9). In contrast, less increase was recorded in IET-21415 (2.0), US-312 (3.0), US-382 (3.0), IET-21515 (5.3) and IET-21411 (6.7).

b) Reproductive stage:

The SOD content of the leaves during maturity stage was found to increase under elevated temperature (Table.4). During first season, IR-64 (28.43) and N-22 (31.51) recorded maximum while, PHB-71 (17.32) and LALAT (14.53) recorded minimum values under ambient temperature and elevated temperature stress respectively. During second season, IR-64 (26.27) and IET-22100 (30.56) recorded maximum while, LALAT (19.47) and IET-21582 (19.61) recorded minimum values under ambient temperature and elevated temperature stress respectively. Pooled data revealed that the genotypes IR-64(27.35) and IET-21515 (29.87) recorded maximum while, LALAT (19.15) and IET-21582 (18.06) recorded minimum values under ambient temperature and elevated temperature stress respectively.

Only two genotypes IET-21411 (26.31) and IR-64 (27.35) had recorded significantly higher super oxide dismutase content activity at reproductive stage than the check N-22 under controlled conditions, whereas, none of the genotype recorded significantly higher SOD content activity under temperature stress conditions than check N-22. Pooled data revealed that the genotype IET-21515 (29.87) had recorded maximum super oxide dismutase content activity under temperature stress followed by N-22 (29.57) and IET-22100 (29.56).

The increase in percentage range of super oxide dismutase content activity at reproductive stage was 1-45 per cent in pooled data. In general, less increase in super oxide dismutase (SOD) activity in rice genotypes was observed in IET-22116 (1.6), IET-21415 (2.1), IET-22218 (2.8) and IET-21411 (4.2). In contrast, greater increase was recorded in PHB-71 (41.6), KPH-2 (24.7), PA-6444 (19.3) and IET-21577 (18.4). In the present investigation, there was marginal decrease (0-22 per cent less) in the super oxide dismutase content activity at reproductive stage with high temperature stress was observed in IET-21404 (-0.8), LALAT (-1.2), PA-6201 (-1.8), US-382 (-3.7), US-312 (-6.5) and IET-21582 (-22.0).

Catalase content (µmolH_2O_2oxidized $min^{-1}g^{-1}$protein)

a) Vegetativestage:

The catalase content of the leaves during vegetative stage was found to increase under elevated temperature stress (Table.5). During first season, US-382 recorded maximum (18.3) and MTU-1010 recorded minimum values (7.93) under ambient temperature while,IR-64 (19.50) recorded maximum and IET-21411 recorded minimum (5.83) values under elevated temperature stress. During second season, US-382 recorded maximum (16.43) and MTU-1010 recorded minimum value (7.27) under ambient temperature while,IET-21515 (18.27) and IET-21411 (7.40) recorded maximum and minimum values during elevated temperature respectively. Pooled data revealed that the genotypes US-382(17.37, 16.88) recorded maximum while, MTU-1010 (7.60) and IET-21411 (6.62) recorded minimum values under ambient temperature and elevated temperature stress respectively.

Only four genotypes US-382 (17.37), IET-22218 (14.40), PR-113 (13.77) and IET-21415 (12.78) had significantly more catalase content activity at vegetative stage under controlled conditions than check N-22 in pooled data. Under temperature stress conditions, all the genotypes had significantly higher catalase content activity than check N-22 except IET-21404 (12.95), IET-21577 (12.82), LALAT (12.55), KPH-2 (12.50), PA-6444 (12.33), PA-6129 (12.20), IET-21415 (11.93) and IET-21411 (6.62). Pooled data revealed that the genotype US-382 (16.88) recorded maximum catalase content activity under temperature stress.

The increase in percentage range of catalase content activity at vegetative stage was 0-84 per cent in pooled data. In general, the genotypes recorded greater increase in percentage catalase (CAT) activity was MTU-1010 (83.3), IR-64 (62.4), IET-21515 (58.2) and IET-22116 (41.1). In contrast, less increase catalase content activity was observed in KPH-2(0.5), IET-21577 (3.6) and PR-113 (3.6), N-22 (5.4) and IET-22218 (5.8). In the present investigation, there was marginal decrease (0-33 per cent less) in the catalase content activity at vegetative stage with high temperature stress in genotypes PA-6129 (-0.7), US-382 (-2.8), IET-21415 (-6.6) and IET-21411 (-32.6) respectively.

b) Reproductive stage:

The catalase content of the leaves during maturity stage was found to increase under elevated temperature stress (Table.6). During first season, IET-21411 recorded maximum (11.37) and IR-64 recorded minimum values (5.40) under ambient temperature while, PA-6201 (24.97) recorded maximum and IET-21582, US-382 recorded minimum (7.53) values under elevated temperature stress. During second season, IET-21411 recorded maximum (10.53) and DRRH-3 recorded minimum value (4.47) under ambient temperature while, KPH-2 (18.40) and LALAT (9.47) recorded maximum and minimum values during elevated temperature respectively. Pooled data revealed that the genotypes IET-21411(10.95) and PA-6201 (18.00) recorded maximum while, IR-64 (4.98) and PA-6129 (9.30) recorded minimum values under ambient temperature and elevated temperature stress respectively.

All the genotypes except IET-21577 (7.03), IET-21515 (6.95), US-382 (6.95), PR-113 (6.72), PHB-71 (5.62), PA-6201 (5.55), DRRH-3 (5.43) and IR-64 (4.98) recorded significantly higher catalase content activity at reproductive stage under controlled conditions than check N-22. Under temperature stress conditions, only three genotypes recorded PA-6201 (18.00), KPH-2 (15.78) and IET-21404 (14.93) recorded significantly more catalase content activity.

The increase in percentage range of catalase content activity at reproductive stage was 1-225 per cent in pooled data. In general, less percentage increase in catalase (CAT) activity was observed in PA-6129 (1.6), IET-21411 (23.7), LALAT (28.7) and IET-21582 (29.7). In contrast, greater increase in catalase content activity was observed in PA-6201 (224.3), IR-64 (138.8), PHB-71 (127.0) and DRRH-3 (123.9).

Sato *et al.*,[15] reported that the level APX activity was higher on heated rice seedlings whereas CAT activity was decreased by heat stress. There was no significant difference in SOD activity between heated and unheated seedlings.

Kang and Salvet[11] studied the activity of antioxidant enzymes superoxide dismutase, catalase (CAT), ascorbate peroxidase (APX) was measured in heat-shocked rice seedling radicles. Heat shock slightly increased the activity of CAT, APX. Increased CAT, APX and protection of CAT activity during chilling appear to be correlated with heat shock-induced chilling tolerance.

To disclose the physiological mechanism of heat tolerance in rice (*Oryza sativa* L.)[2] investigated the activities of enzymes from rice leaves, which were involved in antioxidant system, significantly increased in heat-tolerant genotypes when treated with HT. The results suggested that the relative high yield in heat tolerant genotypes under high temperature stress is associated activities of antioxidant enzymes in leaves.

He (2010)[9] studied the antioxidant enzymes associated with cultivar variations in heat tolerance in kentucky bluegrass (*Poapratensis*) heat responses of activity of antioxidant enzymes in two cultivars contrasting in heat tolerance. The activities of superoxide dismutase (SOD) were significantly higher in ‘Eagleton’ than in ‘Brilliant’ by 28 days of heat stress. Catalase (CAT) activity significantly increased in ‘Brilliant’ but remained constant in ‘Eagleton’ during heat stress. Significant increases in ascorbate peroxidase (APX) activities occurred under heat stress, to a greater extent in ‘Eagleton’.

Gosavi *et al*.,[8] investigated the effect of heat stress on various biochemical and physical parameters at seedling stage in sorghum (*Sorghum bicolour* L.) genotypes. Under heat stress, significant increase in superoxide dismutase (SOD), peroxidase (POD) and catalase (CAT) enzymes were observed in stressed seedlings over control. Higher activities of antioxidant enzymes under stress condition might be useful for sorghum seedlings to cope up with oxidative damage of heat stress.

Many studies demonstrated that elevated temperature injury was caused by the excessive production of reactive oxygen radicals and consequent low activities of antioxidant enzymes and the membrane damage in plants[17&16].Decrease in antioxidant activity in stressed tissues results in higher levels of ROS that may contribute to injury[7]. It has been observed in the present study that the level of catalase, SOD and peroxidase activity increased over control indicating higher production of ROS under elevated temperature stress. Cao *et al.*,[2] reported an increase in catalase activity from 11.6 to 41.3 per cent under day and night temperature of 40/21^{o}C in rice. It was also explained that high activity of protective enzymes in the antioxidant system in plants might be one of the physiological mechanisms for heat tolerance in rice. This finding indicates the fact that tolerant genotypes showed higher catalase, SOD and peroxidase activity compared to susceptible genotypes. Similar results have been observed from the temperature induced seedlings where higher peroxidase activity correlated with acquired thermos-tolerance.

Table 1: Effect of elevated temperature tolerance on peroxidase(μmol H_2O_2 reduced min^{-1} g^{-1} protein) activity at vegetative stage 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**	10.60	14.77	(39.3)	12.68	12.40	15.23	(22.8)	13.82	11.50	15.00	(30.4)	13.25
2	**IET-21411**	15.43	21.60	(40.0)	18.52	15.37	21.43	(39.5)	18.40	15.40	21.52	(39.7)	18.46
3	**IET-21415**	12.17	14.33	(17.8)	13.25	14.40	16.47	(14.4)	15.43	13.28	15.40	(15.9)	14.34
4	**IET-21515**	11.40	12.53	(9.9)	11.97	14.07	23.43	(66.6)	18.75	12.73	17.98	(41.2)	15.36
5	**IET-21577**	12.50	16.63	(33.1)	14.57	11.20	18.27	(63.1)	14.73	11.85	17.45	(47.3)	14.65
6	**IET-21582**	10.90	20.37	(86.9)	15.63	10.30	22.50	(118.4)	16.40	10.60	21.43	(102.2)	16.02
7	**IET-22100**	11.60	16.33	(40.8)	13.97	8.53	21.80	(155.5)	15.17	10.07	18.53	(84.1)	14.30
8	**IET-22116**	6.73	17.40	(158.4)	12.07	12.03	21.70	(80.3)	16.87	9.38	19.55	(108.3)	14.47
9	**IET-22218**	10.43	13.37	(28.1)	11.90	16.50	12.53	(-24.0)	14.52	13.47	12.95	(-3.8)	13.21
10	**IR-64**	12.57	15.70	(24.9)	14.13	11.57	19.30	(66.9)	15.43	12.07	17.50	(45.0)	14.78
11	**KPH-2**	11.53	15.33	(32.9)	13.43	16.03	22.77	(42.0)	19.40	13.78	19.05	(38.2)	16.42
12	**LALAT**	12.27	15.47	(26.1)	13.87	12.77	15.87	(24.3)	14.32	12.52	15.67	(25.2)	14.09
13	**MTU-1010**	14.50	16.27	(12.2)	15.38	14.60	22.43	(53.7)	18.52	14.55	19.35	(33.0)	16.95
14	**PA-6129**	12.73	14.47	(13.6)	13.60	11.63	16.93	(45.6)	14.28	12.18	15.70	(28.9)	13.94
15	**PA-6201**	12.53	20.57	(64.1)	16.55	13.03	16.07	(23.3)	14.55	12.78	18.32	(43.3)	15.55
16	**PA-6444**	15.23	12.33	(-19.0)	13.78	13.43	16.10	(19.9)	14.77	14.33	14.22	(-0.8)	14.28
17	**PHB-71**	15.17	19.33	(27.5)	17.25	15.97	18.60	(16.5)	17.28	15.57	18.97	(21.8)	17.27
18	**DRRH-3**	15.30	20.27	(32.5)	17.78	18.40	24.37	(32.4)	21.38	16.85	22.32	(32.4)	19.58
19	**PR-113**	14.43	17.20	(19.2)	15.82	11.30	17.50	(54.9)	14.40	12.87	17.35	(34.8)	15.11
20	**US-312**	8.53	15.90	(86.3)	12.22	10.43	16.13	(54.6)	13.28	9.48	16.02	(68.9)	12.75
21	**US-382**	13.50	16.57	(22.7)	15.03	13.17	17.83	(35.4)	15.50	13.33	17.20	(29.0)	15.27
22	**N-22**	13.23	15.17	(14.6)	14.20	12.07	15.43	(27.9)	13.75	12.65	15.30	(20.9)	13.98
	Mean	**12.42**	**16.45**		**14.44**	**13.15**	**18.76**		**15.95**	**12.78**	**17.58**		**15.18**
	SEm±	**T=0.03**	**G=0.49**		**T×G=0.68**	**T=0.13**	**G=0.60**		**T×G=0.84**	**T=0.05**	**G=0.40**		**T×G=0.55**
	CD at 5%	**T=0.231**	**G=1.391**		**T×G=1.932**	**T=0.791**	**G=1.697**		**T×G=2.400**	**T=0.361**	**G=1.125**		**T×G=1.585**

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

Table 2: Effect of elevated temperature tolerance on peroxidase activity (µmol H_2O_2 reduced min^{-1} g^{-1} protein) at reproductive stage 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	119.50	255.47	(113.8)	187.48	74.27	252.37	(239.8)	163.32	96.88	253.92	(162.1)	175.40
2	IET-21411	129.47	225.37	(74.1)	177.42	69.43	209.50	(201.7)	139.47	99.45	217.43	(118.6)	158.44
3	IET-21415	68.27	296.43	(334.2)	182.35	68.30	225.30	(229.9)	146.80	68.28	260.87	(282.0)	164.58
4	IET-21515	101.50	229.40	(126.0)	165.45	75.23	218.37	(190.3)	146.80	88.37	223.88	(153.4)	156.13
5	IET-21577	93.50	235.43	(151.8)	164.47	76.53	203.30	(165.6)	139.92	85.02	219.37	(158.0)	152.19
6	IET-21582	96.57	268.30	(177.8)	182.43	57.40	321.30	(459.8)	189.35	76.98	294.80	(282.9)	185.89
7	IET-22100	84.20	250.50	(197.5)	167.35	77.37	225.43	(191.4)	151.40	80.78	237.97	(194.6)	159.38
8	IET-22116	53.50	230.53	(330.9)	142.02	40.50	180.50	(345.7)	110.50	47.00	205.52	(337.3)	126.26
9	IET-22218	76.53	281.53	(267.9)	179.03	55.93	268.40	(379.9)	162.17	66.23	274.97	(315.1)	170.60
10	IR-64	116.50	228.50	(96.1)	172.50	73.50	216.43	(194.5)	144.97	95.00	222.47	(134.2)	158.73
11	KPH-2	72.50	202.50	(179.3)	137.50	70.47	186.27	(164.3)	128.37	71.48	194.38	(171.9)	132.93
12	LALAT	102.57	234.50	(128.6)	168.53	77.13	195.47	(153.4)	136.30	89.85	214.98	(139.3)	152.42
13	MTU-1010	78.40	243.47	(210.5)	160.93	59.93	199.47	(232.8)	129.70	69.17	221.47	(220.2)	145.32
14	PA-6129	102.53	219.57	(114.1)	161.05	58.43	232.43	(297.8)	145.43	80.48	226.00	(180.8)	153.24
15	PA-6201	92.47	268.40	(190.3)	180.43	54.30	246.40	(353.8)	150.35	73.38	257.40	(250.8)	165.39
16	PA-6444	94.43	253.43	(168.4)	173.93	55.97	196.30	(250.7)	126.13	75.20	224.87	(199.0)	150.03
17	PHB-71	70.43	234.47	(232.9)	152.45	63.37	214.40	(238.3)	138.88	66.90	224.43	(235.5)	145.67
18	DRRH-3	83.57	263.43	(215.2)	173.50	55.47	183.40	(230.6)	119.43	69.52	223.42	(221.4)	146.47
19	PR-113	117.30	195.30	(66.5)	156.30	53.30	190.63	(257.7)	121.97	85.30	192.97	(126.2)	139.13
20	US-312	75.40	218.40	(189.7)	146.90	67.73	202.53	(199.0)	135.13	71.57	210.47	(194.1)	141.02
21	US-382	88.50	252.37	(185.2)	170.43	51.23	194.60	(279.8)	122.92	69.87	223.48	(219.9)	146.68
22	N-22	73.33	254.77	(247.4)	164.05	60.30	233.47	(287.2)	146.88	66.82	244.12	(265.4)	155.47
	Mean	**90.50**	**242.82**		**166.66**	**63.46**	**218.01**		**140.74**	**76.98**	**230.42**		**153.70**
	SEm±	**T=0.02**	**G=0.46**		**T×G=0.64**	**T=0.10**	**G=0.62**		**T×G=0.87**	**T=0.05**	**G=0.39**		**T×G=0.54**
	CD at 5%	**T=0.127**	**G=1.305**		**T×G=1.807**	**T=0.627**	**G=1.770**		**T×G=2.502**	**T=0.310**	**G=1.107**		**T×G=1.552**

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

Table 3: Effect of elevated temperature tolerance on super oxide dismutase (U/min/gm fresh weight protein) activity at vegetative stage 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	24.67	27.42	(11.2)	26.04	25.59	27.63	(8.0)	26.61	25.13	27.53	(9.5)	26.33
2	IET-21411	18.33	18.43	(0.5)	18.38	23.55	26.28	(11.6)	24.91	20.94	22.35	(6.7)	21.65
3	IET-21415	27.32	26.45	(-3.2)	26.89	27.35	29.34	(7.3)	28.35	27.34	27.90	(2.0)	27.62
4	IET-21515	26.38	28.90	(9.5)	27.64	26.57	26.88	(1.2)	26.73	26.48	27.89	(5.3)	27.18
5	IET-21577	23.33	28.72	(23.1)	26.02	25.67	29.03	(13.1)	27.35	24.50	28.87	(17.9)	26.69
6	IET-21582	24.51	31.63	(29.1)	28.07	26.33	28.48	(8.1)	27.41	25.42	30.06	(18.2)	27.74
7	IET-22100	18.32	26.60	(45.2)	22.46	23.59	27.69	(17.3)	25.64	20.96	27.14	(29.5)	24.05
8	IET-22116	23.35	26.02	(11.4)	24.69	22.64	25.63	(13.2)	24.14	23.00	25.83	(12.3)	24.41
9	IET-22218	17.44	26.27	(50.6)	21.86	19.59	24.43	(24.7)	22.01	18.52	25.35	(36.9)	21.93
10	IR-64	21.47	23.70	(10.4)	22.59	21.49	23.53	(9.5)	22.51	21.48	23.62	(9.9)	22.55
11	KPH-2	24.61	25.44	(3.4)	25.02	22.61	25.43	(12.5)	24.02	23.61	25.43	(7.7)	24.52
12	LALAT	20.36	21.66	(6.4)	21.01	23.38	25.94	(10.9)	24.66	21.87	23.80	(8.8)	22.83
13	MTU-1010	25.34	28.54	(12.6)	26.94	24.43	26.29	(7.6)	25.36	24.88	27.42	(10.2)	26.15
14	PA-6129	16.39	16.33	(-0.4)	16.36	19.43	22.46	(15.6)	20.95	17.91	19.40	(8.3)	18.65
15	PA-6201	25.22	29.51	(17.0)	27.37	24.48	27.42	(12.0)	25.95	24.85	28.47	(14.5)	26.66
16	PA-6444	25.18	26.62	(5.7)	25.90	22.51	26.33	(17.0)	24.42	23.85	26.48	(11.0)	25.16
17	PHB-71	24.07	28.07	(16.7)	26.07	25.46	27.48	(7.9)	26.47	24.76	27.78	(12.2)	26.27
18	DRRH-3	23.86	29.26	(22.7)	26.56	25.14	26.47	(5.3)	25.81	24.50	27.87	(13.7)	26.18
19	PR-113	15.41	17.32	(12.4)	16.37	17.28	18.43	(6.7)	17.86	16.35	17.88	(9.4)	17.11
20	US-312	24.77	26.45	(6.8)	25.61	23.60	23.34	(-1.1)	23.47	24.18	24.90	(3.0)	24.54
21	US-382	19.31	19.48	(0.9)	19.39	20.35	21.39	(5.1)	20.87	19.83	20.43	(3.0)	20.13
22	N-22	23.72	25.85	(9.0)	24.78	26.46	29.37	(11.0)	27.92	25.09	27.61	(10.1)	26.35
	Mean	**22.43**	**25.40**		**23.91**	**23.52**	**25.88**		**24.70**	**22.97**	**25.64**		**24.30**
	SEm±	**T=0.05**	**G=0.57**		**T×G=0.79**	**T=0.12**	**G=0.59**		**T×G=0.82**	**T=0.07**	**G=0.55**		**T×G=0.77**
	CD at 5%	**T=0.310**	**G=1.614**		**T×G=2.245**	**T=0.787**	**G=1.666**		**T×G=2.356**	**T=0.486**	**G=1.569**		**T×G=2.207**

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

Table 4: Effect of elevated temperature tolerance on super oxide dismutase (U/min/gm fresh weight protein) activityat reproductive stage 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**	25.37	25.49	(0.5)	25.43	25.97	25.44	(-2.1)	25.71	25.67	25.47	(-0.8)	25.57
2	**IET-21411**	27.41	27.44	(0.1)	27.43	25.21	27.40	(8.7)	26.31	26.31	27.42	(4.2)	26.87
3	**IET-21415**	18.99	20.39	(7.4)	19.69	22.05	21.51	(-2.5)	21.78	20.52	20.95	(2.1)	20.74
4	**IET-21515**	26.75	30.42	(13.7)	28.59	24.03	29.32	(22.0)	26.67	25.39	29.87	(17.6)	27.63
5	**IET-21577**	26.45	29.43	(11.3)	27.94	22.93	29.01	(26.5)	25.97	24.69	29.22	(18.4)	26.95
6	**IET-21582**	24.27	16.50	(-32.0)	20.39	22.06	19.61	(-11.1)	20.84	23.16	18.06	(-22.0)	20.61
7	**IET-22100**	27.10	28.57	(5.4)	27.83	24.41	30.56	(25.2)	27.48	25.75	29.56	(14.8)	27.66
8	**IET-22116**	19.52	20.29	(4.0)	19.91	21.83	21.70	(-0.6)	21.76	20.67	21.00	(1.6)	20.84
9	**IET-22218**	24.75	24.45	(-1.2)	24.60	24.68	26.34	(6.7)	25.51	24.71	25.39	(2.8)	25.05
10	**IR-64**	28.43	29.39	(3.4)	28.91	26.27	28.35	(7.9)	27.31	27.35	28.87	(5.6)	28.11
11	**KPH-2**	23.67	30.33	(28.1)	27.00	23.65	28.68	(21.3)	26.16	23.66	29.50	(24.7)	26.58
12	**LALAT**	18.84	14.53	(-22.9)	16.68	19.47	23.31	(19.7)	21.39	19.15	18.92	(-1.2)	19.04
13	**MTU-1010**	24.54	27.79	(13.2)	26.17	24.32	28.28	(16.3)	26.30	24.43	28.04	(14.8)	26.23
14	**PA-6129**	25.72	27.78	(8.0)	26.75	23.89	28.05	(17.4)	25.97	24.81	27.92	(12.5)	26.36
15	**PA-6201**	25.62	23.64	(-7.7)	24.63	23.30	24.38	(4.7)	23.84	24.46	24.01	(-1.8)	24.24
16	**PA-6444**	22.45	25.95	(15.6)	24.20	21.18	26.10	(23.2)	23.64	21.81	26.03	(19.3)	23.92
17	**PHB-71**	17.32	28.43	(64.2)	22.88	23.24	29.00	(24.7)	26.12	20.28	28.72	(41.6)	24.50
18	**DRRH-3**	26.83	27.14	(1.2)	26.99	24.11	30.39	(26.1)	27.25	25.47	28.77	(12.9)	27.12
19	**PR-113**	26.01	27.97	(7.5)	26.99	25.55	28.39	(11.1)	26.97	25.78	28.18	(9.3)	26.98
20	**US-312**	22.94	21.13	(-7.9)	22.03	24.73	23.44	(-5.2)	24.09	23.84	22.29	(-6.5)	23.06
21	**US-382**	18.60	17.48	(-6.0)	18.04	23.48	23.05	(-1.8)	23.26	21.04	20.27	(-3.7)	20.65
22	**N-22**	25.90	31.51	(21.7)	28.70	25.07	27.63	(10.2)	26.35	25.49	29.57	(16.0)	27.53
	Mean	**23.97**	**25.28**		**24.63**	**23.70**	**26.36**		**25.03**	**23.84**	**25.82**		**24.83**
	SEm±	**T=0.05**	**G=0.68**		**T×G=0.94**	**T=0.11**	**G=0.63**		**T×G=0.87**	**T=0.05**	**G=0.56**		**T×G=0.78**
	CD at 5%	**T=0.349**	**G=1.928**		**T×G=2.680**	**T=0.720**	**G=1.774**		**T×G=2.509**	**T=0.320**	**G=1.599**		**T×G=2.226**

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

Table 5: Effect of elevated temperature tolerance on catalase (µmol H_2O_2 oxidized $min^{-1}g^{-1}$ protein) activity at vegetative stage 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	10.50	12.47	(18.7)	11.48	10.50	13.43	(27.9)	11.97	10.50	12.95	(23.3)	11.73
2	IET-21411	8.27	5.83	(-29.4)	7.05	11.37	7.40	(-34.9)	9.38	9.82	6.62	(-32.6)	8.22
3	IET-21415	11.10	14.47	(30.3)	12.78	14.47	9.40	(-35.0)	11.93	12.78	11.93	(-6.6)	12.36
4	IET-21515	10.27	13.17	(28.2)	11.72	9.60	18.27	(90.3)	13.93	9.93	15.72	(58.2)	12.83
5	IET-21577	11.50	15.50	(34.8)	13.50	13.23	10.13	(-23.4)	11.68	12.37	12.82	(3.6)	12.59
6	IET-21582	12.43	13.43	(8.0)	12.93	11.07	14.43	(30.4)	12.75	11.75	13.93	(18.6)	12.84
7	IET-22100	10.77	11.47	(6.5)	11.12	12.30	15.37	(24.9)	13.83	11.53	13.42	(16.3)	12.48
8	IET-22116	9.73	13.93	(43.2)	11.83	10.37	14.43	(39.2)	12.40	10.05	14.18	(41.1)	12.12
9	IET-22218	16.50	15.20	(-7.9)	15.85	12.30	15.27	(24.1)	13.78	14.40	15.23	(5.8)	14.82
10	IR-64	11.27	19.50	(73.1)	15.38	8.40	12.43	(48.0)	10.42	9.83	15.97	(62.4)	12.90
11	KPH-2	12.47	10.30	(-17.4)	11.38	12.40	14.70	(18.5)	13.55	12.43	12.50	(0.5)	12.47
12	LALAT	9.57	12.23	(27.9)	10.90	9.33	12.87	(37.9)	11.10	9.45	12.55	(32.8)	11.00
13	MTU-1010	7.93	12.73	(60.5)	10.33	7.27	15.13	(108.3)	11.20	7.60	13.93	(83.3)	10.77
14	PA-6129	14.30	14.13	(-1.2)	14.22	10.27	10.27	(0.0)	10.27	12.28	12.20	(-0.7)	12.24
15	PA-6201	15.70	14.47	(-7.9)	15.08	7.50	13.43	(79.1)	10.47	11.60	13.95	(20.3)	12.78
16	PA-6444	13.70	13.20	(-3.6)	13.45	9.47	11.47	(21.1)	10.47	11.58	12.33	(6.5)	11.96
17	PHB-71	13.07	12.07	(-7.7)	12.57	10.27	17.47	(70.1)	13.87	11.67	14.77	(26.6)	13.22
18	DRRH-3	10.53	14.17	(34.5)	12.35	12.47	13.90	(11.5)	13.18	11.50	14.03	(22.0)	12.77
19	PR-113	12.07	13.43	(11.3)	12.75	15.47	15.10	(-2.4)	15.28	13.77	14.27	(3.6)	14.02
20	US-312	14.20	15.20	(7.0)	14.70	10.37	13.23	(27.7)	11.80	12.28	14.22	(15.7)	13.25
21	US-382	18.30	16.80	(-8.2)	17.55	16.43	16.97	(3.2)	16.70	17.37	16.88	(-2.8)	17.13
22	N-22	13.53	13.13	(-3.0)	13.33	10.40	12.10	(16.3)	11.25	11.97	12.62	(5.4)	12.29
	Mean	12.17	13.49		12.83	11.15	13.51		12.33	11.66	13.50		12.58
	SEm±	T=0.16	G=0.80		T×G=1.12	T=0.03	G=0.54		T×G=0.75	T=0.08	G=0.63		T×G=0.88
	CD at 5%	T=0.999	G=2.269		T×G=3.209	T=0.187	G=1.526		T×G=2.114	T=0.545	G=1.794		T×G=2.521

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

Table 6: Effect of elevated temperature tolerance on catalase (µmol H_2O_2 oxidized $min^{-1}g^{-1}$ protein) activity at reproductive stage 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**	10.43	14.47	(38.7)	12.45	9.37	15.40	(64.4)	12.38	9.90	14.93	(50.8)	12.42
2	**IET-21411**	11.37	12.70	(11.7)	12.03	10.53	14.40	(36.7)	12.47	10.95	13.55	(23.7)	12.25
3	**IET-21415**	7.53	12.13	(61.1)	9.83	7.43	13.47	(81.2)	10.45	7.48	12.80	(71.0)	10.14
4	**IET-21515**	7.07	13.43	(90.1)	10.25	6.83	11.47	(67.8)	9.15	6.95	12.45	(79.1)	9.70
5	**IET-21577**	7.77	11.27	(45.1)	9.52	6.30	10.43	(65.6)	8.37	7.03	10.85	(54.3)	8.94
6	**IET-21582**	8.10	7.53	(-7.0)	7.82	8.27	13.70	(65.7)	10.98	8.18	10.62	(29.7)	9.40
7	**IET-22100**	8.47	10.37	(22.4)	9.42	7.53	10.60	(40.7)	9.07	8.00	10.48	(31.0)	9.24
8	**IET-22116**	7.77	12.07	(55.4)	9.92	7.83	12.60	(60.9)	10.22	7.80	12.33	(58.1)	10.07
9	**IET-22218**	8.43	13.13	(55.7)	10.78	6.70	10.33	(54.2)	8.52	7.57	11.73	(55.1)	9.65
10	**IR-64**	5.40	13.60	(151.9)	9.50	4.57	10.20	(123.4)	7.38	4.98	11.90	(138.8)	8.44
11	**KPH-2**	7.57	13.17	(74.0)	10.37	6.97	18.40	(164.1)	12.68	7.27	15.78	(117.2)	11.53
12	**LALAT**	8.50	9.50	(11.8)	9.00	6.23	9.47	(51.9)	7.85	7.37	9.48	(28.7)	8.43
13	**MTU-1010**	7.87	10.47	(33.1)	9.17	9.27	14.03	(51.4)	11.65	8.57	12.25	(43.0)	10.41
14	**PA-6129**	9.47	8.63	(-8.8)	9.05	8.83	9.97	(12.8)	9.40	9.15	9.30	(1.6)	9.23
15	**PA-6201**	5.60	24.97	(345.8)	15.28	5.50	11.03	(100.6)	8.27	5.55	18.00	(224.3)	11.78
16	**PA-6444**	8.80	14.53	(65.2)	11.67	6.37	14.47	(127.2)	10.42	7.58	14.50	(91.2)	11.04
17	**PHB-71**	5.83	13.03	(123.4)	9.43	5.40	12.47	(130.9)	8.93	5.62	12.75	(127.0)	9.18
18	**DRRH-3**	6.40	11.53	(80.2)	8.97	4.47	12.80	(186.6)	8.63	5.43	12.17	(123.9)	8.80
19	**PR-113**	6.53	8.93	(36.7)	7.73	6.90	14.53	(110.6)	10.72	6.72	11.73	(74.7)	9.23
20	**US-312**	8.77	9.20	(4.9)	8.98	6.13	11.90	(94.0)	9.02	7.45	10.55	(41.6)	9.00
21	**US-382**	7.17	7.53	(5.1)	7.35	6.73	12.27	(82.2)	9.50	6.95	9.90	(42.4)	8.43
22	**N-22**	6.17	17.40	(182.2)	11.78	7.23	11.23	(55.3)	9.23	6.70	14.32	(113.7)	10.51
	Mean	**7.77**	**12.25**		**10.01**	**7.06**	**12.51**		**9.79**	**7.42**	**12.38**		**9.90**
	SEm±	**T=0.11**	**G=0.71**		**T×G=0.99**	**T=0.07**	**G=0.58**		**T×G=0.81**	**T=0.08**	**G=0.62**		**T×G=0.86**
	CD at 5%	**T=0.708**	**G=2.020**		**T×G=2.854**	**T=0.436**	**G=1.648**		**T×G=2.306**	**T=0.499**	**G=1.744**		**T×G=2.447**

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

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