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Impact of heat stress on growth of rice genotypes under greenhouse condition

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Abstract
Crop productivity is seriously threatened by heat stress, which is caused by high ambient temperatures, on a global scale. Particularly CO_2, methane, chlorofluorocarbons, and nitrous oxides are greenhouse gases emitted as a result of human activities in agriculture. Presently, rice is cultivated in areas where temperatures are already close to their optimum levels; hence, a further rise in global temperature at vulnerable periods may be supra-optimal and may decrease grain production. The impact of heat stress on the morphology and growth of rice must be understood in light of the aforementioned facts. Therefore, the following objectives were established for this study, i.e., to analyze the effects of heat stress on rice growth and morphology, and to assess the response of various rice cultivars for growth and grain yield across growing environments. Normal growing (25 °C±2) and heat stress (42 °C±2 daytime and 25 °C±2 night time) experiment was set up. Stress has been imposed for 6 continuous days during the panicle initiation stage for ten rice cultivars (IG-333, IG-235, IG-354, IG-170, ARB-6-11, Nagina-22, MTU-1010, Swarna, Dagaddeshi, and R-RF-127). Using a measuring scale, the Flag leaf's length, flag leaf width, panicle length, plant height, and panicle exertion were determined. Five primary tillers randomly chosen were taken & counted. Plant height, number of tillers, panicle length, & 50% flowering are found high in control when compared with stress conditions. Flag leaf length, flag leaf width, flag leaf area, and panicle exertion were increased in stressed genotypes. On the basis of morphology and yield, IG-333 and R-RF-127 (table 1 and table 2) are found to show heat stress tolerance when compared with check. No major change in plant height was recorded in heat stress and control, especially in Nagina-22. MTU-1010 genotype was found to be susceptible on the basis of yield and morphological analysis. A highly significant and positive correlation was found between flag leaf length and flag leaf area, and flag leaf width and flag leaf area in both control and heat stress conditions. A significant and positive correlation was observed between the number of tillers and days to 50% flowering under control and heat stress conditions.

Keywords: Heat stress, rice, panicle initiation, flag leaf, panicle exertion, 50% flowering

Introduction
Rice (*Oryza sativa* L.) is a key global staple crop that provides food security and creates income, particularly in underdeveloped nations. Both the production of rice and the quality of the rice that is produced are at grave risk from the predicted global warming. Temperature stress and water stress are expected to worsen in tropical and subtropical regions, which are the main rice-producing regions [1]. High-temperature stress or drought conditions have detrimental effects on plant development, including irreversible damage to plant growth and development, decreased photosynthesis [2], a reduction in the number of panicles on each plant and an extension of the peduncle, limited pollen production, no pollen grain swelling, and decreased spikelet sterility [3]. Low temperatures result in stunted seedling growth, slowed panicle growth, delayed heading, poor panicle exertion, low spikelet fertility, and poor grain quality. In addition to affecting growth and grain output, water and temperature stresses change the chemical makeup and quality of rice. By the years 2025 and 2100, respectively, the global temperature will climb to a point where it will be 1 and 3ºC higher than it is today [4]. A crop will reach an early maturity due to the temperature increase [5]. Although rice has long been a significant grain crop, researchers still don't fully understand how its growth responds to high temperatures [6].
The sequence of morphological, biochemical, and physiological changes brought on by high-temperature stress also significantly hinders plant growth and development [7]. Heat shocks are currently the main global limiting factors for crop output due to rising air temperatures. The stages of growth and distribution of agricultural plants may vary as a result of this rising temperature [8]. High-temperature stress can seriously harm proteins, halt protein synthesis,

deactivate vital enzymes, and harm membranes. The process of cell division can be significantly impacted by high temperature stress [9]. All of these negative effects can significantly impede plant development and encourage oxidative injury. Additionally, brief exposure to high temperatures during seed filling might result in a fast filling, which lowers yield and lowers quality. The temperature increase is lethal when there is a limited supply of water. Overall, increased transpiration during the daytime contributes significantly to water loss owing to heat stress, which eventually harms some physiological processes in crops. Additionally, heat stress reduces the quantity, weight, and root growth and eventually reduces the availability of water and nutrients to the above-ground plant parts [10, 11]. The principal sites of damage resulting from increased heat stress are light-dependent chemical processes that take place in the stroma of the thylakoid and the carbon metabolism. PSII leaf temperature and photon flux density can be adjusted to a greater extent [12]. Due to its extraordinary sensitivity to temperature, the PSII's activity is significantly impacted by high temperatures and can even be partially terminated [13].

At high temperatures, the oxygen-evolving complex also suffers severe damage, which can cause an unbalanced flow of electrons to the PSII acceptor site [14]. The proteins D1 and D2 also become denaturized at higher temperatures [15]. Significant enzymes such as sucrose phosphate synthase, invertase, adenosine diphosphate-glucose pyrophosphorylase, and starch and sucrose synthesis are significantly affected by high heat stress [16]. Rubisco, a CO_2-binding enzyme with low activation status, restricts net photosynthesis in many plant species. Although Rubisco's catalytic activity increases with temperature, the increase in net photosynthetic speed is constrained by its poor CO_2 affinity and poor O_2 binding capacity [17]. Despite all these detrimental effects on photosynthesis caused by high temperatures, optimum photosynthesis temperature requirements are anticipated with high CO_2 levels in the atmosphere.

Materials & Methods

At the Department of Plant Molecular Biology and Biotechnology, Indira Gandhi Agricultural University in Raipur, the greenhouse study was set up in 2022 (Fig.1). The growing treatments included normal growth (25°C±2) and heat stress conditions (42°C±2 daytime and 25°C±2 night time). Heat stress was induced for 6 continuous days from the beginning of the Panicle initiation stage in the ten rice cultivars (IG-333, IG-235, IG-354, IG-170, ARB-6-11, Nagina-22, MTU-1010, Swarna, Dagaddeshi, and R-RF-127). Heater settings were set at 42°C (day) and 25°C ± 2 in the heating chamber. The panicle initiation stage was the time for the heat treatment. Using a measuring scale, the length and width of the flag leaf were determined. A meter scale was used to measure the plant height from the base to the tip of the panicle, using five primary tillers that were randomly chosen. The mean value was then calculated. The same plants were chosen to count each plant's tillers and panicles. Using a meter stick, the length of the panicle was calculated from the base to the tip. The length of the flag leaf, from the base to the tip, was measured with a meter stick. Flag leaf width by taking a horizontal measurements with a cm stick. Flag leaf area is calculated by multiplying Flag leaf length and flag leaf width and constant factor (0.75).

Results & Discussion

Maximum (10.6) tillers overall was found in Swarna cultivated under normal circumstances. By recording 10.2 tillers under heat stress, this cultivar also outperformed MTU-1010 (8.4) cultivated under normal conditions and the same MTU-1010 (7.4) under heat stress. However, IG-170 under stress showed the lowest number of tillers (3.0), followed by Dagadadeshi (4.2) (Table 1). A similar finding was reported by Aghamolki *et al*. (1999). In Neda grown in normal condition, there were more total tillers (24.8). Additionally, this cultivar outperformed Hovaze by producing 23.8 tillers per hill produced under heat stress, while Hovaze recorded 23.5 tillers per hill cultivated under normal conditions. However, Hashemi, which was growing under normal conditions, had the fewest number of tillers (10.5). As a result of stress being imposed during the reproductive phase, the results also showed that the majority of cultivars had minor variations in the values of effective tillers [18]. As a result of the stress being injected at the panicle initiation stage, the results also showed that the majority of the cultivars exhibited minor variations in the values of panicle exertion. In MTU-1010 and Nagina-22 of the data set, the highest panicle exertion (11.8 and 11.5 cm) was reported in normal condition respectively. Same genotypes, Nagina-22 (10.7 cm) and MTU-1010 (10.6 cm) showed high panicle exertion during the stressful condition. Heat stress, however, significantly decreased the values of panicle exertion (3.3 cm) in Swarna, and IG-170 (3.3 cm) (Table 2). In good condition, Swarna (3.6 cm) is followed by IG-170 (4.2 cm). Similar findings were reported in Domsiah's and Tarom's normal states, the maximal panicle exertion measurements were 14.3 and 13.5 cm, respectively. Heat stress, however, markedly decreased the levels of panicle exertion (1.3 cm) in Fajr [19].

Tolerance to extreme temperature stress is significantly influenced by plant architecture. Therefore, creating plant types with the proper design will aid in adjusting to the rise in temperature. For instance, if the distance between the exerting panicle and the flag leaf is higher, the panicle may experience severe heat stress [20]. Dagaddeshi reported an increase in flag leaf length (54.1 cm) and then R-RF-127 (47.5 cm) in stress. Dagaddeshi (53 cm), shown the the highest flag leaf length followed by R-RF-127(44.3 cm) grown under normal circumstances. The minimum flag leaf length, however, was in IG-333 (16.2 cm), followed by Nagina-22 (24.3 cm) under control, and in IG-333 (17.5 cm), followed by Nagina-22 (26.5 cm) under stress. Similar findings were reported in Domsiah and Tarom grown under heat stress showed an increase in flag leaf length (43.5 cm), while Hovaze cultivated under normal conditions showed a decrease (43.0 cm). However, in MR219 under heat stress, the shortest flag leaf length is 29.0 cm [18]. The largest flag leaf width (1.7 cm) in this interaction was observed in IG-354, and ARB-6-11, under heat stress (Table 2). IG-235 recorded the smallest flag leaf width (0.6 cm) among the examined rice cultivars, followed by N-22 (0.8 cm), which was followed by IG-333 (0.8 cm) under control condition during the panicle initiation phase (Table 1). Maximum flag leaf area was reported in stress condition, in Dagaddeshi (72.5 cm^2), followed by IG-354(52.3 cm^2). Lowest was found in IG-333 (10.8 cm2) followed by N-22(19.0 cm^2) in stress conditions. A high flag leaf area was reported in Dagaddeshi (57.3 cm^2) followed by IG-354 (45.6 cm^2). Low flag leaf area was reported in IG-333 (11.6 cm^2)

followed by N-22 (15.8 cm^2) under control conditions. Similar findings were reported that Hovaze had the widest flag leaf (2.0 cm), which was followed by 1.9 cm in the same cultivar grown under heat stress. The rice cultivar Hashemi received the lowest flag leaf width (1.3 cm) during the reproductive phase of the studied cultivars [19].

The primary plant organ that engages in photosynthesis is the leaf. In rice, photosynthesis in functional leaves after blooming is the primary source of grain-filling materials, accounting for between 70 and 80 percent of the grain-filling matter [21]. Heat stress particularly damages leaves [22], which ultimately reduces crop output [23]. The tallest plant was measured at Dagaddeshi (105.6 cm) in the normal condition, and the same line (102.3 cm) under stress. In stress conditions, ARB-6-11 reported the lowest plant height (63.9 cm), followed by R-RF-127 (66.5 cm), and under control conditions, ARB-6-11 (66.2 cm), followed by IG-235 (62.4 cm). The panicle length was highest in the Dagaddeshi (41.0 cm) followed by R-RF-127 (66.5 cm) in the control condition. ARB-6-11 (63.9 cm) followed by R-RF-127 (26 cm) in a stressed state. Nagina-22 (16.6 cm), followed by R-RF-127 (26 cm), had the shortest panicle length when under stress. In the control condition, N-22 (17.6 cm) followed by R-RF-127 (27.3 cm) had the shortest panicle lengths (Table 1). The average amount of time to reach 50% flowering was 99.7 days under stress and 102.4 days under normal condition. Swarna is found to be late maturing in both control (132.4 days) and stress (129 days) condition. IG-235 (93 days) in control and IG-354 (91.4 days) are found to be early maturing genotypes. The maximum yield/plant was recorded in IG-333(23.2 g) and minimum in IG-235(8.3 g) in case of stress when compared to the control. Plant height and the length of the flag leaf had a significant negative link with grain yield per plant, while days to 50% flowering, days to maturity, and the number of tillers per plant had a significant positive correlation [24].

In their 2015 evaluation of 96 rice accessions [25], researchers found that the leaf width, days to 50% blooming, plant height, panicle length, number of filled grains per panicle, 100 seed weight, and paddy length all had a positive significant link with grain production per plant. The number of filled grains per panicle, leaf breadth, days till 50% flowering, and milling percentage all showed a positive and substantial link with the head rice recovery percentage.

In Rampur, Chitwan, Nepal, during the rainy season in 2017 and 2018 [26], studied 24 rice genotypes. They found that grain output was adversely and strongly connected with 50% blooming days.

In the present study, a significant and positive correlation was found between the number of tillers and days to 50% flowering under both control (0.664*) and stress (0.638*) conditions. A highly significant and positive correlation was found between flag leaf length and flag leaf area in both control (0.855**) and stress (0.845**) conditions, and flag leaf width and flag leaf area in both control (0.886**) and stress (0.857**) conditions. A negative significant correlation was found between flag leaf length and yield in the control (-0.688*) condition, and in between flag leaf width and panicle exertion in control (-0.714*) and stress (-0.735*) conditions. A significant and positive correlation between the number of grains per panicle, grains yield per hill, and length, but a highly significant and negative correlation between the number of tillers per hill and days to 50% flowering at both the genotypic and phenotypic levels in 33 rice genotypes [27].

Table 1: Morphological traits & statistical analysis of ten rice genotypes under control and heat stress condition

Genotypes	Plant height (cm) (Control)	Plant height (cm) (Stress)	No. of Tillers (Control)	No. of Tillers (Stress)	Panicle length (cm) (Control)	Panicle length (cm) (Stress)	Days to 50% Flowering (Control)	Days to 50% Flowering (Stress)
	Mean±S.E.	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**
IG-333	82.8±1.1	81.9±1.2	4.8±0.3	4.6±0.4	44.2±0.7	43.1±0.9	101.2±0.2	96.4±0.2
IG-235	84.4±0.9	83.6±0.6	5.4±0.2	4.8±0.2	41.7±0.6	41.3±0.4	93.0±0.6	91.4±0.5
IG-354	72.3±0.7	71.1±0.8	5.8±0.4	5.0±0.4	33.2±0.9	32.4±0.9	93.4±0.4	91.4±0.4
IG-170	97.4±0.7	96.0±0.5	3.8±0.4	3.0±0.3	34.9±0.9	33.1±0.9	104.8±0.2	105.4±0.4
ARB-6-11	66.2±0.2	63.8±0.5	5.6±0.2	4.8±0.3	34.2±0.7	33.0±0.6	97.0±0.3	93.2±0.4
Nagina-22	77.2±0.7	75.7±0.7	7.6±0.4	7.2±0.3	17.6±0.7	16.6±0.7	110.6±0.4	105.4±0.4
MTU-1010	76.8±0.7	75.2±0.5	8.4±0.2	7.4±0.2	35.7±1.1	34.1±0.9	94.8±0.4	92.0±0.3
Dagaddeshi	105.5±0.4	102.2±0.7	5.4±0.2	4.2±0.2	50.3±1.1	48.4±1.1	103.6±0.4	100.8±0.2
Swarna	76.8±0.7	75.9±0.9	10.6±0.4	10.2±0.2	27.5±0.8	26.3±0.6	132.4±0.4	129.0±0.3
R-RF-127	67.1±1.0	66.5±1.0	5.0±0.3	4.8±0.5	27.3±1.3	26.0±1.0	93.4±0.4	92.4±0.5
Mean	80.7	79.2	6.2	5.7	34.7	33.4	102.4	99.7
Maximum	105.6	102.2	10.6	10.2	50.3	48.5	132.4	129.0
Minimum	66.2	63.9	3.8	3.0	17.6	16.6	93.0	91.4
C.D.	2.2	2.3	0.9	1.0	2.7	2.4	1.1	1.1
SE(m)	0.7	0.8	0.3	0.3	0.9	0.8	0.4	0.4
SE(d)	1.1	1.2	0.5	0.5	1.3	1.2	0.6	0.5
C.V.	2.2	2.3	11.8	13.6	6.1	5.6	0.9	0.9

Note: Each average indicates: average of five independent replicates at each time for each trait. cm=centimeter.

Table 2: Morphological traits & statistical analysis of ten rice genotypes under control and heat stress Condition

Genotypes	Flag leaf length(cm) (Control)	Flag leaf length(cm) (Stress)	Flag leaf width(cm) (Control)	Flag leaf width(cm) (Stress)	Flag leaf area(cm2) (Control)	Flag leaf area(cm^2) (Stress)	Panicle exertion(cm) (Control)	Panicle exertion(cm) (Stress)	Yield/ plant (g) (Control)	Yield/ plant (g) (Stress)
	Mean±S.E.	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**	**Mean±S.E.**
IG-333	16.2±0.3	17.4±0.6	0.8±0.1	0.8±0.0	11.6±1.3	10.8±1.1	6.8±0.2	6.3±0.0	25.2±0.9	23.2±1.4
IG-235	36.2±1.0	39.5±0.5	0.6±0.1	0.6±0.1	16.6±1.9	19.4±2.5	13.6±0.4	13.8±0.3	15.6±0.6	8.3±1.0
IG-354	37.6±0.9	39.1±1.1	1.5±0.1	1.7±0.2	45.6±3.3	52.3±4.0	6.0±0.3	5.4±0.1	19.0±0.9	14.9±0.8
IG-170	33.3±0.9	33.7±1.0	1.4±0.1	1.5±0.1	37.4±3.1	39.3±3.3	4.2±0.0	3.3±0.1	21.8±1.1	15.4±3.0
ARB-6-11	36.1±0.6	37.1±1.1	1.5±0.1	1.7±0.1	42.7±1.8	50.3±2.0	5.5±0.1	5.1±0.1	20.2±0.6	16.5±0.4
Nagina-22	24.3±1.1	26.5±1.4	0.8±0.0	0.9±0.1	15.8± 1.4	19.0±3.4	11.5±0.5	10.7±0.2	19.9±0.3	17.8±1.0
MTU-1010	33.4±1.3	35.5±0.9	1.2±0.0	1.2±0.2	31.1±2.1	35.9±6.4	11.8±0.7	10.6±0.1	19.3±0.9	9.7±0.4
Dagaddeshi	52.9±0.8	54.0±0.7	1.3±0.0	1.6±0.1	57.3±7.6	72.5±8.5	6.3±0.1	5.6±0.1	11.2±1.2	9.5±0.5
Swarna	34.5±0.8	38.2±0.7	1.2±0.0	1.4±0.0	32.4±2.0	43.2±2.1	3.6±0.1	3.3±0.1	25.4±0.5	22.6±0.6
R-RF-127	44.3±0.8	47.5±0.7	1.2±0.0	1.3±0.0	42.8±1.3	51.2±2.6	6.3±0.0	5.7±0.1	20.9±1.0	20.0±0.3
Mean	35	36.7	1.2	1.3	33.4	39.4	7.6	6.6	19.8	15.8
Maximum	53	54.1	1.5	1.7	57.3	72.6	13.6	13.8	25.4	23.2
Minimum	17.4	16.2	0.6	0.6	11.6	10.8	3.6	3.3	11.2	8.3
C.D.	2.8	2.6	0.3	0.3	9	12	1	0.4	2.6	3.5
SE(m)	1	0.9	0.1	0.1	3.1	4.2	0.3	0.1	0.9	1.2
SE(d)	1.4	1.3	0.1	0.2	4.4	5.9	0.5	0.2	1.2	1.7
C.V.	6.2	5.5	16.8	19.4	21.1	23.8	9.8	4.6	7.5	13

Note: Each average indicates: average of five independent replicates at each time for each trait. cm=centimeter.

Fig 1: Morphological view of plants grown in greenhouse condition

The crops are negatively impacted by a wide range of abiotic stresses. Abiotic stresses like drought, salinity, high temperature, cold temperature, and metal toxicity are common in crops. Of course, the severity of stress affects the symptoms, which can range from elusive to disastrous. Abiotic stresses produce numerous crop alterations that might have negative consequences on a plant's ability to grow and develop. To achieve the many degrees of stress response regulation, it is best to apply broad, integrative, and interdisciplinary methodologies due to the complexity and variety of abiotic stress reactions. The crops are changing due to factors like reduced relative water content, increased ROS output, greater relative stress injury, cell electrolyte leakage, reduced amounts of photosynthetic pigment, shorter roots, and shoots, and decreased relative yield etc.

To combat the effects of high temperatures, the crops are experiencing multiple morphological, physiological, biochemical, and molecular changes. The management of abiotic stress in plants has gained a lot of attention recently. Crops have developed numerous new strategies to deal with abiotic stress as a result of the expansion of high-performance genomic tools.

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