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Effect of Heat Stress during Reproductive Stage on Plant Growth, Total Biomass Production and their Correlation with Grain Yield in Rice

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Rice (*Oryza sativa L.*) is highly sensitive to high temperature during its reproductive stages. This study aims to elucidate the effects of heat stress during reproductive stage on plant growth, total dry matter accumulation, and their correlation with grain yield in diverse rice genotypes. A field experiment in split plot design was conducted at G.B.P.U.A.& T., Pantnagar during rainy season 2022-23, where high temperature stress was imposed on 15 rice genotypes during reproductive stage (after panicle initiation till maturity) using a polytunnel. The results showed that heat stress

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lead to reduction in dry matter accumulation and harvest index in 10 genotypes, although with different magnitude. The genotypes were screened into tolerant and susceptible based on yield reduction by comparing with the genotype N-22, which was used as a check for heat stress. It was observed that the genotypes, IET 29415, MTU-1282, MTU-1121, NLR-40042 and US-314 maintaining higher biomass and HI under heat stress conditions were able to maintain grain yield. The identified genotypes with better performance under heat stress conditions offer valuable genetic resources for breeding programs aimed at improving heat tolerance in rice.

Keywords: Rice; dry matter accumulation; grain yield; heat stress tolerance.

1. INTRODUCTION

Climate change is significantly impacting cereal crops through high temperature stress, threatening global food security [1]. Due to increasing population and industrialization, the issue of global warming has become too significant to overlook [2]. The IPCC's assessment report forecasts an increase of 3 to 5°C in global mean surface temperature across Southeast Asia by the year 2100 [3]. In India also, there has been a parallel increase of 0.63°C since 1986, triggering intermittent heatwaves, and this is predicted to increase to 4.7°C by the end of 21st century. The intensity of heatwave events is anticipated to increase, especially in the Indo-Gangetic plains of India, where the rice-wheat cropping system is predominant [4, 5]. Global warming is coming, and heat waves will be more frequent and longer lasting [6]. As it has become a serious threat to the productivity of agricultural crops worldwide [7], it is projected that in the absence of CO_2 fertilization, effective adaptation strategies, and genetic advancements, a 1°C rise in global average temperature will result in a 3.2% decrease in rice yield [8].

Rice (*Oryza sativa* L.) is a staple food crop for over half of the growing global population, it provides 76% of the calorific intake of the population of Southeast Asia [9]. It is estimated [10] that by 2030, 16% of the rice harvested area will be exposed to at least 5 reproductive days of temperatures above T_{crit} (physiologically critical temperatures in the reproductive stage), and this area will increase to 27% by 2050. Thus, there is an urgent need to consistently increase rice production to ensure food security [11]. In the present study, an attempt was made to evaluate the effect of heat stress during reproductive stages on plant growth and total biomass production, and their correlation with yield on 15 rice genotypes under field conditions.

2. MATERIALS AND METHODS

A field experiment was conducted at the Dr. Norman E. Borlaug Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar, (Uttarakhand), India during 2022 kharif season. The experimental site is located in the tarai region at 29ºN latitude and 79º 29'E longitude, at a height of 243.84 meters above sea level with humid and hot climate in summers. 15 rice genotypes namely, IET 29197, IET 29415, IET 29421, MTU-1010, MTU-1121, MTU-1153, MTU-1156, MTU-1282, MTU-1290, MTU-1341, NLR-3354, NLR-34449, NLR-40024 and US- 314, obtained from ICAR-IIRR, Hyderabad were used in the study. The genotype N-22 was used as a check for tolerance to heat stress.

The rice genotypes were transplanted in the first week of July in two plots. One plot was used as the control with ambient temperature. The second one was used for imposing high temperature stress during reproductive stage by covering the block with 100 microns (0.1mm) thick UV transparent PVC film over a bamboo frame-work with open air inlet and outlet for sufficient ventilation. The height of the polytunnel was kept about two metres for proper aeration and plant growth. Heat stress was imposed from panicle initiation to maturity. The experiment was laid out in split plot design with three replications. Daily minimum and maximum temperature was recorded with the help of maximum-minimum thermometer installed inside the polytunnel. The maximum daytime temperature inside the polytunnel was about 10-12°C higher than ambient temperature. Plant height and leaf dry weight was measured 10 days after the stress treatment at flowering. Shoot weight, harvest index and grain yield were taken at harvest. Total dry biomass production was recorded at both the stages, flowering and harvest.

2.1 Measurement of Plant Height, Total Dry Matter, Harvest Index and Grain Yield

At the time of flowering, plant height was measured using a measuring tape from the base at soil level to the highest point of the plant on a representative sample. The entire above-ground portion of the plants were harvested for Total dry matter (TDM), oven dried at 65°C until a constant weight is obtained and then weighed. All the leaves were collected from the sampled plants and Leaf dry weight was measured after oven drying. The harvest index was computed as the ratio of yield of economic interest (grain yield) and biological yield and was calculated by using the formula:

$$Harvest\ Index\ (\%) = \frac{\text{Grain Yield}}{\text{Biological Yield}} X\ 100$$

At the time of harvest, grain yield was determined by harvesting grain from a representative sample of each genotype within a plot. The harvested grain was dried to a constant moisture content, then weighed to determine the yield in grams per square meter (g/m²).

2.2 Statistical Analysis

The data collected were statistically analysed and subjected to Analysis of Variance (ANOVA). Statistical analysis was done using Microsoft Excel Software, the graphs and Pearson correlation between the parameters were plotted with Origin Pro. Standard error of means (S.Em.±) and critical difference (CD) was evaluated at 5% level of significance (p =0.05).

3. RESULTS

3.1 Effect of Heat Stress on Plant Height

In most of the genotypes there was significant reduction in plant height at flowering stage due to heat stress which ranged from 0.33% to 9.57% as compared to that at ambient temperature (Table 1). N-22, the check genotype had almost no change in plant height under heat stress. Two genotypes were exceptions; MTU-1290, which showed no change and MTU-1282 in which plant height increased by 2.91%. The maximum reduction in plant height (9.57%) was exhibited by IET 29415 followed by IET 29197, IET 29415, MTU-1010, MTU-1153, MTU-1156, MTU-1341, NLR-34449, NLR-40042 and US-314 under high temperature conditions when compared with check, N-22.

3.2 Effect of Heat Stress on Leaf Dry Weight and Total Biomass Production at Flowering

The leaf dry weight as well as total biomass accumulation significantly decreased at flowering stage in all the genotypes after 10 days exposure to heat stress (Table 2). However, in the genotypes IET 29415 and MTU-1282, increase in leaf dry weight and total biomass production was recorded. In N-22, there was a decrease of 21.64% in leaf dry weight and 16.95% in total biomass under high temperature conditions. Among the genotypes, it was observed that MTU-1153, MTU-1290, MTU-1341, US-314, IET 29421, IET 29197 and NLR-3354, showed greater reduction ranging from 24.23% to 44.57 % in leaf dry weight, accompanied by further reduction in total biomass by 17.27% to 34.93% under heat stress. On the other hand, genotypes NLR-40042, NLR-34449, MTU-1156 and MTU-1010 showed less reduction in leaf dry weight and total biomass accumulation than N-22.

3.3 Effect of Heat Stress on Shoot Dry Weight and Total Dry Matter at Harvest

Under heat stress conditions, the shoot dry weight at harvest significantly decreased in all the genotypes, ranging between 4.25% to 38.17% (Table 3). N-22, the check recorded 7.41 % reduction in shoot dry weight under heat stress. Among the genotypes, the reduction in IET 29421, MTU-1290, MTU-1153, MTU-1156 and NLR-3354 was much higher ranging from 15.45% to 38.17% under heat stress. On the other hand, the genotypes IET 29197, MTU-1010, MTU-1121 and MTU-1341 recorded less reduction than the check in shoot weight, ranging between 4.23% to 7.03% under heat stress.

The total aboveground dry matter at harvest also decreased significantly in all the genotypes ranging between 8.70% to 38.50% under heat stress (Fig. 1). The genotype, NLR-40042 was exception which recorded increase in total dry matter by 9.99%. N-22 showed reduction in total biomass by 8.11%. The genotypes MTU-1290, IET 29415, MTU-1341, MTU-1121, MTU-1153, MTU-1156 and NLR-3354 showed higher reduction in total biomass when compared with reduction in check, under heat stress. While on the other hand, MTU-1282, MTU-1010, IET 29421, NLR-34449 and NLR-40042 performed better than N-22.

Table 1. Effect of elevated temperature on plant height (cm) at flowering in 15 rice genotypes. ± indicates standard error of mean. (↓) and (↑) show percent decrease or increase under heat stress as compared to control

	Plant Height (cm)		
Genotype (G)	**Ambient Temperature**	**Heat Stress**	**% Change**
N-22	102±0.01	101±0.07	0.98 (↓)
IET 29197	104±1.53	96 ±3.06	7.64(↓)
IET 29415	94±1.00	85±1.00	9.57(↓)
IET 29421	108±1.00	108±1.53	0.62(↑)
MTU-1010	104±2.00	102±1.15	1.60(↓)
MTU-1121	102±1.53	102±1.00	0.33(↓)
MTU-1153	109±1.53	106±2.08	2.74(↓)
MTU-1156	100±2.08	96 ±1.15	3.97(↓)
MTU-1282	103±3.00	106±4.36	2.91(↑)
MTU-1290	100±1.00	100 ±1.73	0.00
MTU-1341	98±1.00	93 ±2.00	5.10(↓)
NLR-3354	113±3.00	113±2.52	0.59(↑)
NLR-34449	114±3.51	113±2.65	1.17(↓)
NLR-40042	108±1.53	106±2.00	2.15(↓)
US-314	126±1.00	117±3.00	7.14(↓)
	T	**G**	**T*G**
SEm±	0.39	0.87	1.23
CD at 5%	2.34	2.46	3.49

Table 2. Effect of elevated temperature on leaf dry weight (g/m²) and total dry matter (g/m²) at flowering in 15 rice genotypes. ± indicates standard error of mean. (↓) and (↑) show percent decrease or increase under heat stress as compared to control

Genotype (G)	Leaf Dry Weight (g/m²)			Total Dry Matter (g/m²)		
	Ambient temperature	**Heat stress**	**% change**	**Ambient temperature**	**Heat stress**	**% change**
N-22	207±11	162±3	21.64 (↓)	895±27	743±19	16.95 (↓)
IET 29197	278±26	166±11	40.48 (↓)	1341±39	970±36	27.71 (↓)
IET 29415	126±13	156±24	24.04 (↑)	528±29	532±42	0.74 (↑)
IET 29421	213±30	126±14	41.08 (↓)	961±40	795±33	17.27 (↓)
MTU-1010	198±8	173±20	12.53 (↓)	1001±38	853±55	14.86 (↓)
MTU-1121	226±19	231±6	2.14 (↓)	980±55	894±52	8.82 (↓)
MTU-1153	215±28	168±13	21.87 (↓)	967±36	719±52	25.59 (↓)
MTU-1156	196±26	197±8	0.68 (↑)	944±48	849±57	10.04 (↓)
MTU-1282	233±20	241±20	3.58 (↑)	1012±20	1094±34	8.09 (↑)
MTU-1290	242±17	183±30	24.23 (↓)	1152±27	827±47	28.23 (↓)
MTU-1341	290±22	182±6	37.11 (↓)	1085±44	764±40	29.58 (↓)
NLR-3354	582±19	322±15	44.57 (↓)	2027±36	1319±25	34.93 (↓)
NLR-34449	273±7	276±33	0.85 (↑)	1296±42	1146±63	11.62 (↓)
NLR-40042	191±17	156±22	18.20 (↓)	694±49	634±32	8.69 (↓)
US-314	244±1	152±13	37.71 (↓)	1074±17	768±41	28.51 (↓)
	T	**G**	**T*G**	**T**	**G**	**T*G**
SEm±	1.49	13.36	18.90	6.78	29.13	41.20
CD at 5%	9.07	37.85	53.53	41.26	82.53	116.71

Table 3. Effect of elevated temperature on shoot dry weight (g/m^2) at harvest in 15 rice genotypes. ± indicates standard error of mean. (↓) and (↑) show percent decrease or increase under heat stress as compared to control

	Shoot Dry Weight (g/m^2)		
Genotype(G)	**Ambient Temperature**	**Heat Stress**	**% Change**
N-22	1148±12	1063±20	7.41 (↓)
IET 29197	1154±31	1105±42	4.25 (↓)
IET 29415	1173±57	1041±27	11.29 (↓)
IET 29421	817±26	691±60	15.45 (↓)
MTU-1010	797±25	763±32	4.23 (↓)
MTU-1121	1177±43	1114±24	5.42 (↓)
MTU-1153	1618±30	1126±44	30.40 (↓)
MTU-1156	978±71	650±17	33.55 (↓)
MTU-1282	886±13	915±43	3.30 (↑)
MTU-1290	1130±21	820±43	27.43 (↓)
MTU-1341	1326±23	1233±14	7.03 (↓)
NLR-3354	1975±43	1221±54	38.17 (↓)
NLR-34449	821±37	738±35	10.13 (↓)
NLR-40042	859±90	891±54	3.73 (↑)
US-314	1094±38	960±5	12.32 (↓)
	T	**G**	**T*G**
SEm±	9.97	28.37	40.12
CD at 5%	60.69	80.37	113.66

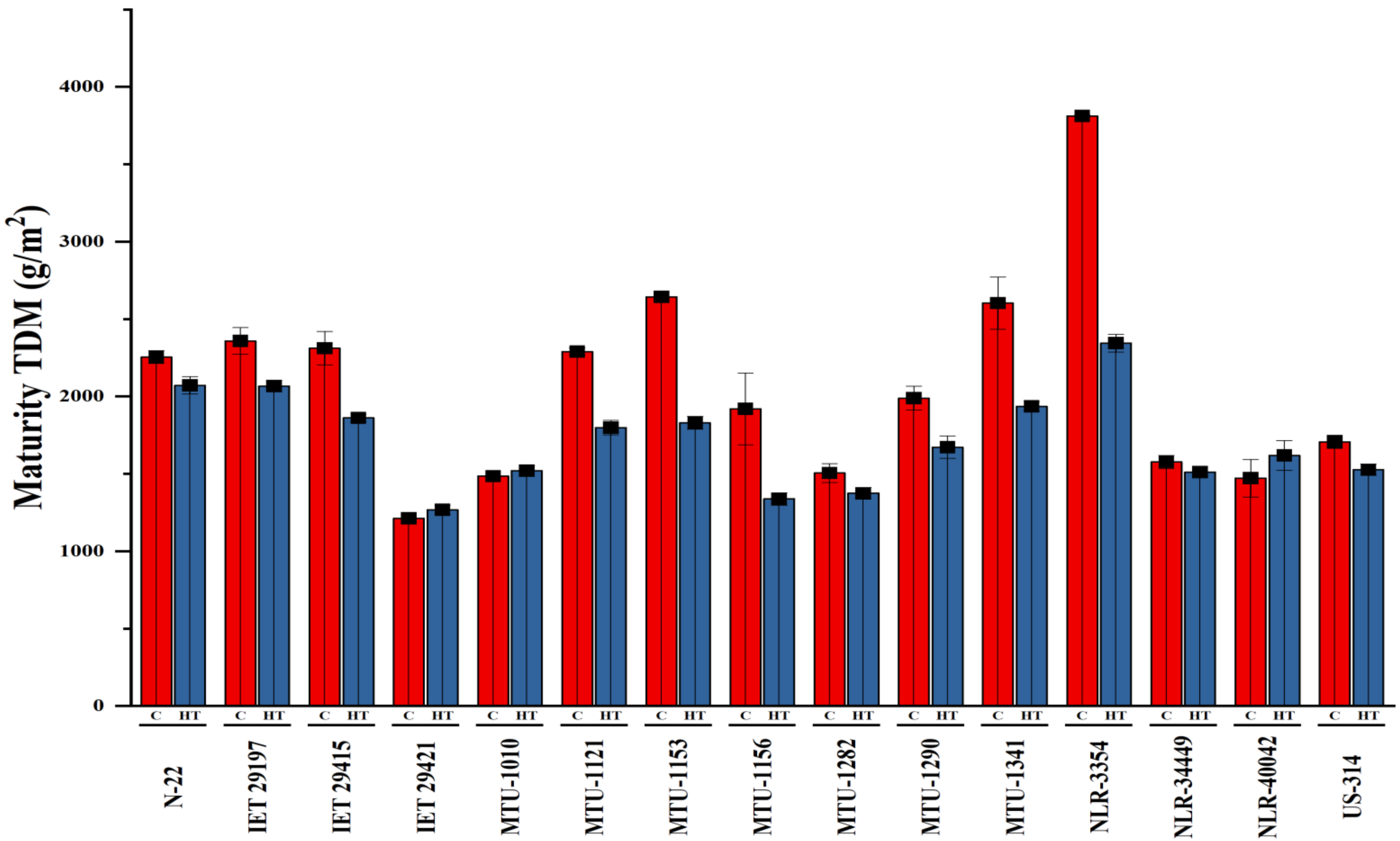

Fig. 1.Effect of elevated temperature on total above ground dry matter (g/m^2) at maturity in 15 rice genotypes

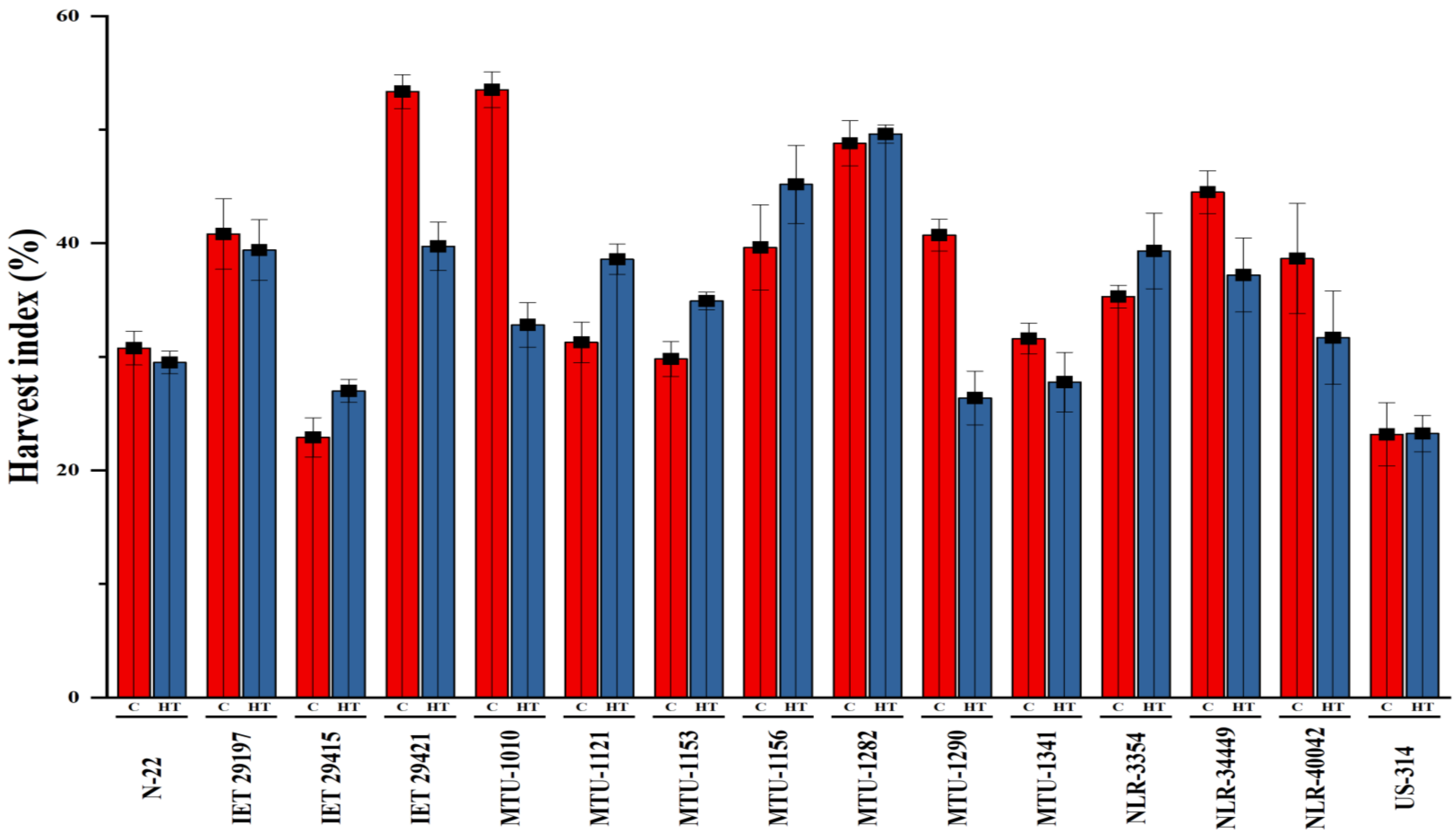

Fig. 2.Effect of elevated temperature on Harvest index (%) in 15 rice genotypes

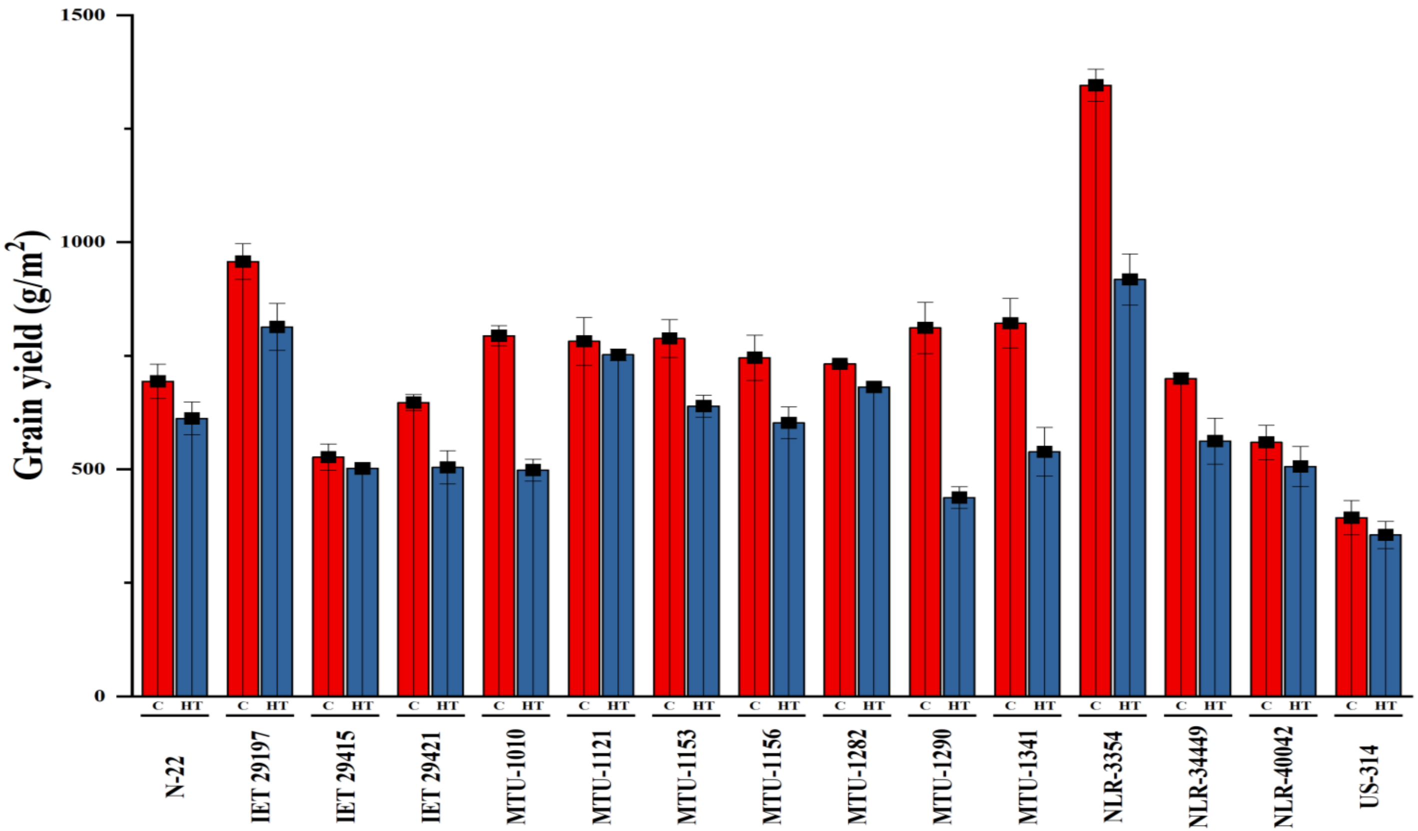

Fig. 3.Effect of elevated temperature on grain yield (g/m^2) at harvest in 15 rice genotypes

Table 4. Correlation of grain yield with TDM at flowering and harvest, and harvest index

Parameter	Correlation with Yield (r)
TDM at flowering	0.76
TDM at harvest	0.69
HI	0.41

3.4 Effect of Heat Stress on Harvest Index and Grain Yield

A reduction in harvest index (HI) was observed in eight genotypes which ranged between 3.46% to 38.67% under heat stress conditions **(**Fig. 2). The reduction in N-22 was 4.06% under high temperature. Among the genotypes, the maximum decrease was found in MTU-1010, followed by MTU-1290, IET 29421 and NLR-34449. While on the other hand, in NLR-3354, MTU-1156, MTU-1153, IET 29415 and MTU-1121, there was increase in HI by 11.53%, 14.02%, 17.14%, 17.92% and 23.42%, respectively under heat stress.

There was significant decrease in grain yield in all the genotypes under heat stress conditions as compared to ambient temperature, ranging from 3.8% to 46.05% (Fig. 3). Maximum decrease was found in MTU-1290 under heat stress condition as compared to ambient temperature. The decrease in grain yield when compared with decrease in N-22 (11.78%), it was observed that the genotypes, MTU-1153, MTU-1156, NLR-34449, IET 29421, NLR-3354, MTU-1341, MTU-1010 and MTU-1290 were more susceptible to high temperatures, as evident for a greater reduction in grain yield as compared to the check, N-22. On the other hand, the genotypes MTU-1121, IET 29415, MTU-1282, NLR-40042 and US-314 maintained their grain yield, and were more tolerant to heat stress as compared to N-22.

4. DISCUSSION

The effect of high temperature stress during reproductive growth in rice has been reported to adversely affect morphological, physiological and biochemical parameters which ultimately affects the grain yield of the crop [12,13]. In the present study, it was observed that genotypes like IET 29415, MTU-1282, MTU-1121, NLR-40042 and US-314 performed better than the check, N-22 while the genotypes, IET 29421, NLR-3354, MTU-1341, MTU-1010 and MTU-1290, were more susceptible to high temperature conditions. Grain yield of rice is reported to be positively correlated with total biomass production at flowering and harvest as well as with harvest index. In the present study also, a positive correlation of grain yield with total dry matter production at flowering (r= 0.76) and at harvest (r= 0.69) was observed. However it had a low correlation with HI (r=0.41) (Table 4). The decrease in grain yield in susceptible genotypes was due to either decrease in the total dry matter (TDM) accumulation or harvest index (HI) or both. In case of IET 29421 and MTU-1010, reduction in HI significantly decreased the grain yield, while in NLR-3354 the reduction in total biomass was the cause for decrease in grain yield. Yield losses in NLR-34449, MTU-1341 and MTU-1290, the most susceptible genotypes, was due to decreases in both total biomass accumulation and HI. Tolerant genotypes like IET 29415 and MTU-1121 could maintain yield by maintaining a balance between TDM and HI. The current finding which highlights the importance of both biomass production and HI in maintaining rice growth and productivity is supported by previous studies [14-17]. The decrease in total biomass production is attributed to reduction in leaf weight at flowering stage. This was caused by forced senescence in the lower leaves at high temperature, which reduced the number of leaves. High temperature induced leaf senescence has been reported earlier [18, 19].

5. CONCLUSION

In the present study, imposition of heat stress with 10-12°C higher daytime temperature during panicle initiation to maturity caused significant yield losses in susceptible genotypes. The effect of heat stress depends on both the intensity and the duration of increased temperature. The variation in yield losses among the genotypes could be attributed to the duration of heat stress due to differences in duration between flowering to maturity. High temperature adversely affected total above ground matter and harvest index, which caused reduction in grain yield. The tolerant genotypes were able to sustain their yield by maintaining a balance between TDM and HI. The observed differences in heat stress tolerance among the genotypes highlights the potential for selecting suitable genotypes to sustain rice productivity under high-temperature conditions. Additionally, this variability can be exploited to screen and breed rice varieties with comprehensive heat stress tolerance, ensuring resilience against future unpredictable heat events.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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