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Research article

Comparative response of rice cultivars to elevated air temperature in Bhabar region of Indian Himalaya: status on yield attributes

Narendra Kumar [a,*], Neha Jeena [b], Amit Kumar [c], Rowndel Khwairakpam [d], Hukum Singh [c]

[a] Department of Plant Physiology, College of Basic Science and Humanities, G.B. Pant University of Agriculture & Technology, Pantnagar, 263145 Uttarakhand, India
[b] Department of Biotechnology, Bhimtal Campus Kumaun University, Nainital, Uttarakhand, India
[c] Forest Ecology and Climate Change Division, Forest Research Institute, P.O. New Forest, Dehradun, 248006 Uttarakhand, India
[d] Graphic Era Hill University, Dehradun, Uttarakhand, India

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ABSTRACT

Increasing atmospheric temperature is the consequence of global warming, which is expected to influence crop growth and development, resulting in declining productivity in the tropical agriculture system. The selection of temperature tolerant crop cultivars with higher productivity to meet the future demand of the world expanding human population requires a thorough understanding of crop growth feedback to increasing temperature. Therefore, a field experiment was conducted during *the Kharif* season of 2012 and 2013 to understand the response of yield and yield-related traits of eleven rice cultivars to elevated temperature grown inside field mounted temperature gradient tunnel (TGT) in the Bhabar region of the Indian Himalayas. The elevated temperature significantly impacted growth and yield and yield-related traits, especially tillers, panicles, filled and chaffy grains, grain, and 1000 grain weight, yield, and harvest index of all the cultivars during both years. The cultivars, *i.e.*, IET 21404 and IET 21577, were reported to produced more tillers in 2012, whereas IET 21411 and KRH 2 had a maximum 2013. Likewise, maximum panicles were reported in IET 21404 and IET 21577 in 2012, while IET 21411, IET 21582, and KRH 2 in 2013 under elevated temperature. The highest grain filling under high temperature in 2012 was found in IET 21577, then IET 21404; however, IET 21411 and IET 21405 were the highest filled grains in 2013. Consequently, the cultivars IET 21577 and IET 21404 were reported as more tolerant towards yielding higher grain weight and Harvest Index. This study offers an opportunity to screen temperature tolerant cultivars with increased productivity for fulfilling the demand of rice-dependent regions in future changing climatic conditions.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) in Fifth Assessment Report (AR5) stated that the global mean surface air temperature has risen by 0.74 °C in the last century and is expected to rise by 1.1–6.4 °C by 21st century. The maximum daily rise in temperature has been less than the daily minimum temperature rise, and this trend is projected to continue (Lobell and Field 2007). Rising temperature has caused global warming that poses a severe threat to food security. It has been considered a significant concern in the twenty-first century about producing enough food for the growing population in a stressful environment. Rice is one of the indispensable cereal crops of the world population, will suffer greater detrimental consequences as the diurnal temperature range decreases in the future climate. This temperature effect has been reported to reduce cereal crop productivity considerably (Wang et al., 2018; Zhao et al., 2017). For instance, a forecast 1 °C increase in night-time air temperature might result in a 10% reduction in rice yield (Peng et al., 2009). Increases in CO_2 concentration, one of the significant factors of the rising temperature that directly and indirectly affect several crop physiological and agronomic traits, including rice (Bahuguna et al., 2017; Raza et al., 2019). It inhibits pollen grain dehiscence and germination, suppresses spikelet fertility and thereby induces sterility, degrades grain quality, shortens grain filling duration and grain filling rate, resulting in a low harvest index and grain yield (Rani and Maragatham, 2013; Kumar et al., 2017, 2019). In rice crops, the upper three functional leaves/flag leaves are the primary photosynthetic organs. Most of the crop biomass/photosynthate is allocated and helps in grain filling, finally determining an economic yield. However,

* Corresponding author.
E-mail address: narendra.physiol@gmail.com (N. Kumar).

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the temperature beyond the threshold affects the electron transport rate, thereby declining the photosynthetic rate of these upper flag leaves and led to declining fertility (Zhao et al., 2017).

Previous research revealed that reduction in rice photosynthesis by 11.2–35.5% from early to intermediate ripening stage grown under a higher temperature of 3.6 and 7.0 °C affecting the structural organization of thylakoids, specifically the stacking of grana in the chloroplast or its propensity to swell (Wahid et al., 2007; Mohammed and Tarpley, 2009). Wassmann et al. (2009) found that high temperatures induce a considerable loss in grain size and yield, lower grain weight, lower grain filling, and a more significant percentage of chalky white rice and milky white rice. As a result of the elevated night temperature, Yoshida et al. (1981) and Cheng et al. (2009) showed a drop in plant height, the number of tillers, and total biomass for rice cultivar 'IR72' (*Indica* cultivar). Elevated temperatures during the flowering and grain-filling phases of rice impair yield by producing spikelet sterility and shortening the grain-filling period (Cai et al., 2018). Temperatures above 35 °C at anthesis for more than 1 h had been observed to cause high sterility in rice (Jagadish et al., 2007). The cause of high male sterility in rice was observed due to temperature above 35 °C for more than 1 h at anthesis (Jagadish et al., 2007).

Elevated temperature caused an increase in the number of spikelets containing inviable pollen, *i.e.,* sterile pollen attributed to abnormal anther dehiscence, impaired pollination, and pollen germination. At the same time, untreated plants had 75 % pollen viability (Jagadish et al., 2007).

Rice cultivation and production in Eastern and Southern Asia have been many limitations. This limitation is caused by changing climatic conditions, reduced nutrient sources, and water availability (Tao and Zhang, 2013), despite rising demand for rice food grain, and is expected to reach 2000 million metric tonnes by 2030 (Bodirsky et al., 2015). To fulfill this vast demand requires improvement in our understanding of elevated temperature on rice production and requires changes in conventional methods to improve the biological and economic yields. Furthermore, In the near future, the Indian Himalayan agro-ecosystem will likely experience more warming due to climate change. These changes will bring alteration to the morpho-physiological response and crop productivity ultimately. The Bhabar agro-ecosystem of the Indian Himalayan is the dominant area for rice cultivation.

Such a study of rice crop response towards rising atmospheric temperature could recommend an urgent need to understand the response of rice crops towards rising atmospheric temperature for the screening of heat-tolerant rice genotype cultivar with a high yield for future cultivation. Hence, to consider this problem, a field experiment was carried out to hypothesize whether rice productivity would increase with elevated temperature in field conditions.

2. Materials and methods

2.1. Description of the study area

The field study was performed in the Kharif seasons (June–November) of 2012 and 2013 at Norman E. Borlaug Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar, US Nagar (Uttarakhand), India. Geographically, it is the area of bhabar which lies in Tarai plains about 30 km southwards of the foothills of the Shivalik range of the Himalayas at 29°3′N latitude, 79°29′E longitude and an altitude of 243.8 m above the mean sea level. In the Tarai region, the climate is humid and sub-tropical, with hot summers to cool winters. Monsoon showers here in the mid of June up to the end of September. Moreover, the soil of the experimental field had physicochemical properties such as loamy soil texture, 7.0 pH, 0.278 dS m^{-1} EC at 25 °C, and 10.3 g organic carbon kg^{-1}.

2.2. Rice cultivars

The seeds of eleven rice cultivars were obtained from the Directorate of Rice Research, Rajendranagar, Hyderabad. These rice cultivars have different categories, such as some were inbred lines (*i.e.,* IET 21404, IET 21405, IET 21411, IET 21415, IET 21577, and IET 21582), and the rest was hybrids (*i.e.,* KRH-2, PA 6129, PA 6201, PA 6444 and PHB 71).

2.3. Temperature treatments

The sapling of all rice cultivars was transplanted in the field with three replicate in Kharif season 2012 & 2013. Treatment, *i.e.,* elevated temperature, was exposed to the crop on instigating the flowering stage (~60 days). For raising the temperature, a temperature gradient tunnel (TGT) was constructed in field conditions at the reproductive stage of rice crops (Kumar et al., 2015, 2016, 2017, 2019). An automatic thermometer was used to record the daily temperature (minimum & maximum), which records the temperature inside and outside the TGT (Figure 1). During full flowering, the average temperature within the tunnel was varied ~12 °C compared to ambient (Kumar, 2014; Kumar et al., 2019). After that, at sixty days of flowering, yield and yield traits of rice cultivars were recorded from each plot in triplicates.

2.4. Estimating response of growth and agronomic traits parameters

The growth response in terms of tiller production, panicle, grain yield, and 1000 grain weight, while agronomic parameters response *viz.* harvest index (HI), and spikelet fertility (filled grain) and sterility (unfilled grain) to ambient and elevated temperature were monitored. The number of tillers and panicles per hill was counted manually from the

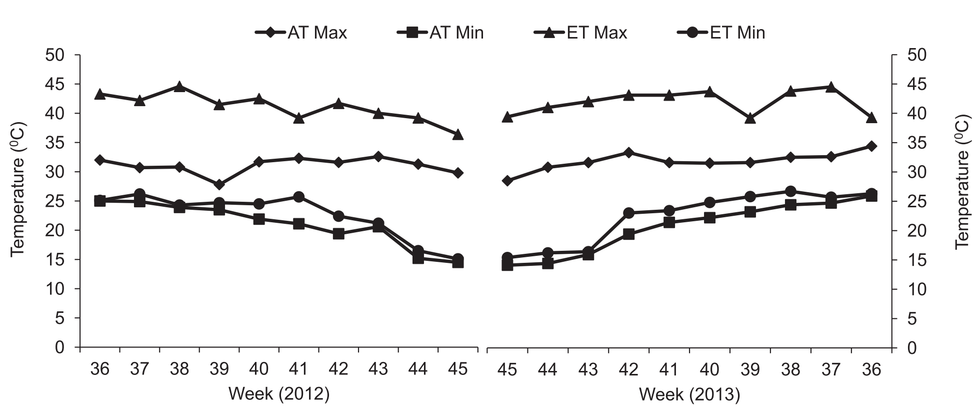

Figure 1. Weekly average ambient and elevated temperature during study period of 2012 and 2013.

three randomly selected hills from each replicate during the flowering stage. Effective tillers were considered for counting panicles. Grain yield was calculated after harvesting the crop. The grains from the hills from each replication were separated and subsequently subjected to measure weight using the digital calibrated balance. The grain weight was expressed in gm m^{-2}. For calculating 1000 grain weight, a random sample of 500 grains was taken from each replicate, and their weight was recorded and computed to present 1000- grain weight in grams (Singh et al., 2014). The ratio of economic and biological yield multiplied by 100 was considered to obtain the harvest index (HI) of the rice cultivars (Donald and Hamblin, 1976).

2.5. Estimation of spikelet fertility of panicle

Air temperature plays a critical role in the milky stage of crops during anthesis, which decides the grain filling process in a spikelet. Therefore, the yield depends on suitable air temperature during this stage. In this study, spikelet fertility (filled grains) and sterility (unfilled or chaffy grains) of panicle due to elevated temperature was investigated using a method described by Singh et al. (2014). For counting filled grains per panicle, the grains were separated from randomly selected five panicles from each replicate. The separated grains were poured into NaCl solution by dissolving 315 g of NaCl in one liter distilled water (1.20 specific gravity), then stirred and counted the grains that settle down. These grains were considered high-density grains having more than 1.20 specific gravity. Besides, the floating grains over the surface of the same solution were further transferred to the 1.06 specific gravity NaCl solution (by dissolving 90 g NaCl in one liter distilled water) and repeated the process of counting. Floating and sunken grains were considered sterile grains (unfilled grain or chaffy grains) and fertile grains (filled grains).

2.6. Statistical analysis

The data of different traits were analyzed in triplicates and subjected to ANOVA (Analysis of variance) following the two factorial RBD (randomized block design) using SPSS-16 statistical package to quantify and evaluate the source of variation. The means were tested using the Duncan's test. The treatment means were compared at a significance level of 5%, and the ranking of treatments denoted by alphabets. The correlations between all the parameters were calculated using 'Pearson's correlation coefficient'. The differences in means and correlations were considered statistically significant at a 5% level of significance (Figures 2 and 3).

3. Results

3.1. Growth and agronomic parameters response towards elevated temperature

Effect of increased temperature on the number of tillers shown in Table 1. The yield traits, *i.e.,* tiller numbers, were increased significantly ($p \leq 0.05$) for the rice cultivar, which was grown under elevated temperature compared to control, where the number of tillers declined. Increased number of tillers of rice cultivars IET 21404 and IET 21577 were reported under. (Rice cultivars IET 21404 and IET 21577 recorded an increased number of tillers under)elevated temperature compared to ambient temperature (Table 1). Rice cultivar IET 21404 recorded ~33 % increased number of tillers over control. In contrast, the number of tillers in rice cultivar IET 21577 showed only ~30 % improvement over control, showing a tolerant effect towards elevated temperature. However, other rice cultivars showed a significant reduction in the number of tillers in those growing in the elevated temperature over ambient conditions. The results reported that the highest reduction (60 %) was recorded in IET 21415 followed by IET 21405 (~44%), IET 21411 (~41%), PA 6129 (~40%), IET 21582 (~38 %), PA 6201 (~30 %), PA 6444 (~17 %), KRH 2 (~14%) and least (~3%) was recorded in PHB 71 over those rice cultivars of ambient condition during the year 2012. However, in contrast to the year 2012, the number of tillers of rice cultivar grown under elevated temperature was significantly ($p \leq 0.05$) declined compared to those grown in the ambient condition in 2013. The rice cultivar PHB 71 (3.55 %) showed a significant decline in the tillers number, followed by KRH 2 (1.88%) over control. The results show rest of the cultivar was highly tolerant under elevated temperature during 2013.

Although, the panicle numbers declined compared to the ambient grown cultivars. The panicles were significantly higher in rice cultivars IET 21404 and IET 21577 under elevated temperature than cultivars are grown in the ambient (Table 1). These two rice cultivars showed a tolerant effect towards elevated temperature. The findings also showed the number of panicles under high temperature significantly reduced in KRH 2, and the least decline was recorded in the PA 6201 compared to ambient while other cultivars were at par during 2012 (Table 1).

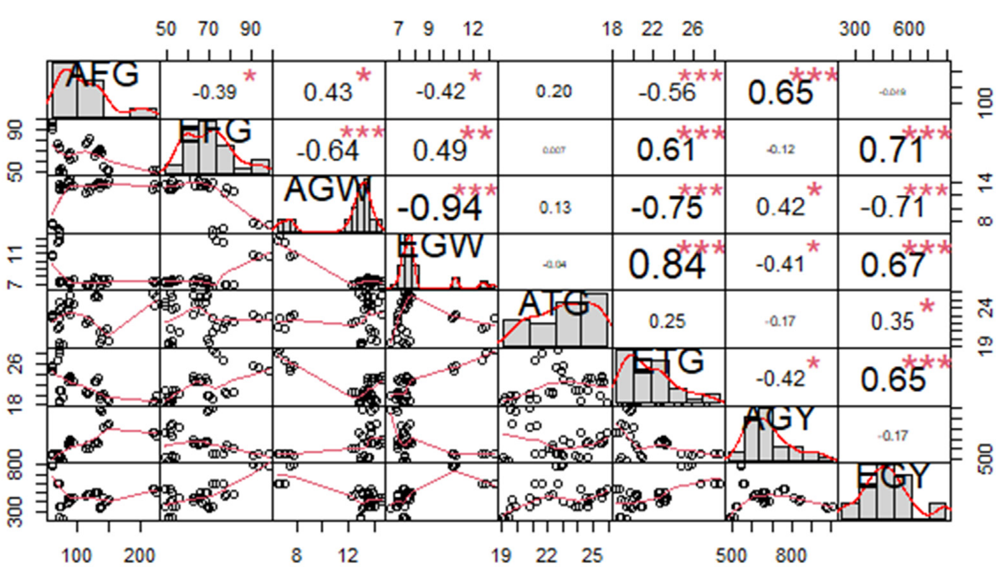

Figure 2. Pearson correlation of different parameters under ambient and elevated temperature during study period of 2012. In the figure AFG: filled grain per panicle at ambient temperature, EFG: filled grain per panicle at elevated temperature, AGW: grain weight per panicle at ambient temperature, EGW: grain weight per panicle at elevated temperature, ATG: 1000 grain weight at ambient temperature, ETG:1000 grain weight at elevated temperature, AGY: grain yield at ambient temperature and EGY: grain yield at elevated temperature.

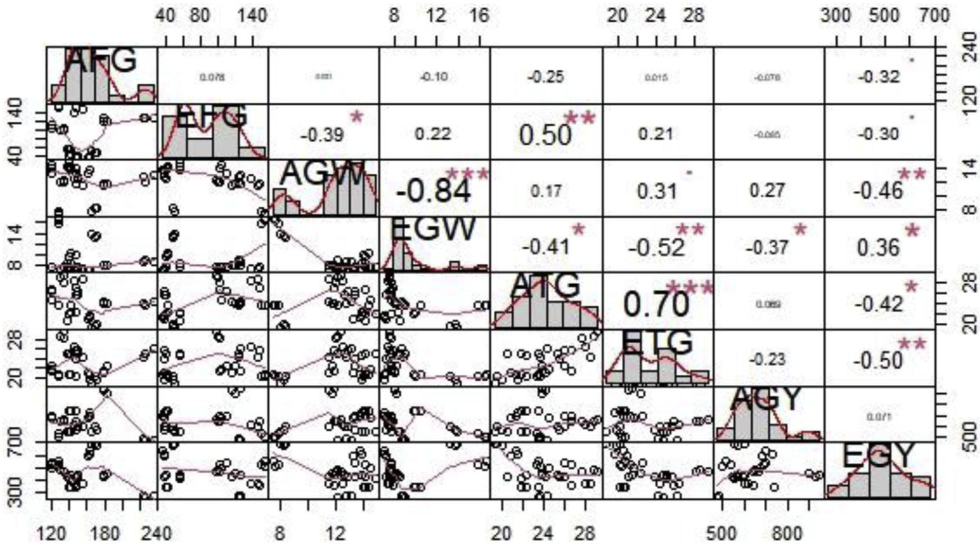

Figure 3. Pearson correlation of different parameters under ambient and elevated temperature during study period of 2013. In the figure AFG: filled grain per panicle at ambient temperature, EFG: filled grain per panicle at elevated temperature, AGW: grain weight per panicle at ambient temperature, EGW: grain weight per panicle at elevated temperature, ATG: 1000 grain weight at ambient temperature, ETG:1000 grain weight at elevated temperature, AGY: grain yield at ambient temperature and EGY: grain yield at elevated temperature.

Table 1. Effect of ambient (AT) and elevated temperature (ET) on the number of tillers and panicles (Mean ± SE) in eleven cultivars of rice at the time of flowering.

Genotype	Number of tillers				Number of panicles			
	2012		2013		2012		2013	
	AT	ET	AT	ET	AT	ET	AT	ET
IET 21404	6.0 ± 1.15b	10.7 ± 1.20a	5.0 ± 0.21 b	5.0 ± 0.57c	5.8 ± 0.66cd	8.7 ± 0.93a	6.38 ± 0.07c	5.00 ± 0.28c
IET 21405	7.5 ± 0.28ab	6.0 ± 0.57bc	6.3 ± 0.66ab	6.0 ± 0.57abc	7.2 ± 0.88abc	5.0 ± 0.28bc	7.38 ± 0.07b	6.00 ± 0.28bc
IET 21411	10.7 ± 0.66a	7.7 ± 0.33b	7.3 ± 0.33a	7.0 ± 0.31a	8.5 ± 0.86a	6.0 ± 0.28bc	7.75 ± 0.14a	7.17 ± 0.44a
IET 21415	10.7 ± 1.20a	7.0 ± 0.57bc	6.0 ± 0.57ab	6.3 ± 0.33abc	8.0 ± 1.04ab	5.0 ± 0.28bc	6.00 ± 0.00d	5.67 ± 0.16bc
IET 21577	5.3 ± 0.88b	8.0 ± 1.15b	6.0 ± 0.57ab	6.0 ± 0.57abc	4.7 ± 0.44d	6.8 ± 0.88b	6.00 ± 0.00d	6.00 ± 0.28bc
IET 21582	10.7 ± 1.45a	7.0 ± 0.57bc	6.3 ± 0.33ab	7.0 ± 0.57a	8.3 ± 0.16ab	6.0 ± 0.57bc	6.38 ± 0.07c	6.33 ± 0.33ab
KRH 2	8.3 ± 0.88ab	5.0 ± 0.57c	6.7 ± 0.66ab	7.0 ± 0.57a	7.2 ± 0.16abc	6.3 ± 1.09bc	6.38 ± 0.07c	6.50 ± 0.28ab
PA 6129	7.3 ± 0.88ab	4.7 ± 0.33c	5.3 ± 0.33b	6.7 ± 0.33ab	6.3 ± 0.33bcd	4.5 ± 0.28c	6.38 ± 0.07c	5.83 ± 0.33bc
PA 6201	7.3 ± 1.33ab	6.0 ± 0.57bc	6.3 ± 0.88ab	5.3 ± 0.33bc	7.2 ± 0.44abc	5.5 ± 0.28bc	6.13 ± 0.21cd	5.00 ± 0.28c
PA 6444	7.7 ± 1.76ab	5.0 ± 0.57c	7.3 ± 0.33a	5.0 ± 0.21c	6.8 ± 0.88bcd	5.8 ± 0.60bc	8.00 ± 0.00a	5.17 ± 0.16c
PHB 71	7.0 ± 0.57ab	5.0 ± 0.57c	5.7 ± 0.33ab	6.3 ± 0.66abc	5.5 ± 0.28cd	5.3 ± 0.16bc	5.63 ± 0.07e	5.83 ± 0.44bc

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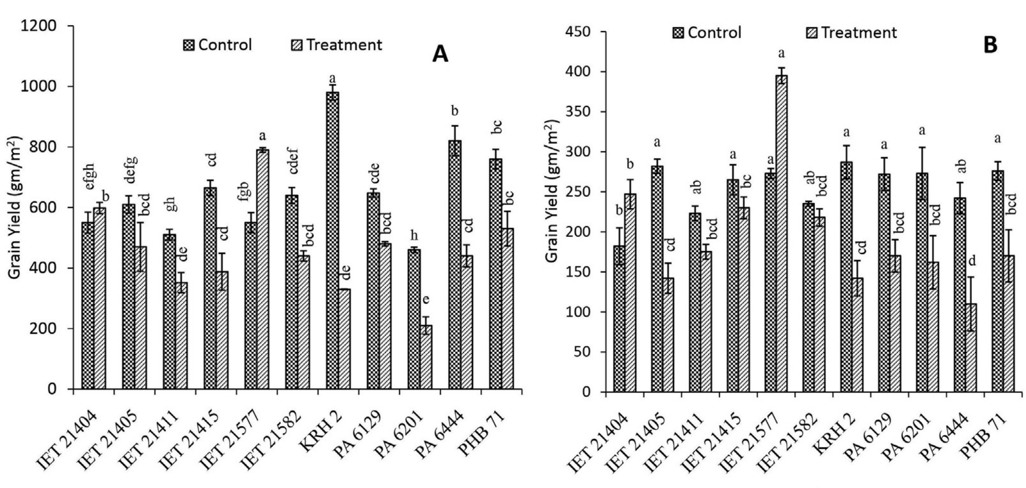

Figure 4. Effect of elevated temperature on grain yield (g/plant) in eleven cultivars of rice in the planting season of 2012 (A) and 2013 (B). The values written after plus- minus indicate the deviation from the mean value.

However, in the next year, *i.e.,* 2013, the results revealed that rice cultivar performance with elevated temperature conditions was not up to the mark. No significant difference was recorded between cultivars IET 21404 and IET 21577 compared to cultivars grown at ambient condition. The result showed that grain weight, 1000 grain weight, and grain yield significantly ($p \leq 0.05$) declined under rising temperature from the ambient temperature. In this study, grain weight was achieved maximum during 2012 in cultivar IET 21404 (12.92 ± 0.58) followed by IET 21577 (10.67 ± 0.22) as compared to control (6.75 ± 0.25 and 7.58 ± 0.46). Similarly, in 2013, grain weight was recorded maximum in the same rice cultivar *i.e.,* IET 21404 (16.33 ± 0.71 gm) followed by IET 21577 (13.58 ± 0.60 gm) over ambient one *i.e.,* control (7.58 ± 0.46 gm & 8.17 ± 0.22 gm, respectively). These cultivars can be considered tolerant concerning elevated temperature, and the percent increase was more in 2013 than that of 2012. During 2013, rice cultivars IET 21404 (~53%) & IET 21577 (~39 %) showed maximum grain weight compared to 2012 which was ~47% & ~28 % respectively. Similarly, other cultivars were found to decrease their grain weight under elevated temperature over control during the two successive years of 2012 & 2013 (Table 3).

However, grain yield of cultivars IET 21404 (245.18 gm) and IET 21577(400.74 gm) was also significantly obtained higher as compared to control (183.52 gm and 275.92 gm) during the year 2013. Whereas some of the cultivars *viz*. IET 21405, IET 21411, PA 6129, and PHB 71 have a reduction in grain yield and 1000 grain weight when exposed to high temperatures stress of about >30 °C as compared to control in the year 2012, while others were at par (Figure 4 A & B). Besides this, during the year 2013, 1000 grain weight of cultivars *viz*. IET 21411(24.96 gm) and IET PA 6201 (25.10 gm) were significantly superior to that of control (21.54 gm and 23.86 gm), and some were very sensitive such as IET 21404, IET 21415, KRH 2, and PA 6129 under elevated temperature as compared to control during the year 2013 (Figure 5A & B).

3.2. Grain filling under elevated temperature

Here in this study, under elevated temperature, most of the rice cultivars were significantly affected compared to the control. In high temperatures among all the cultivars, two rice cultivars (IET 21404 and IET 21577) were tolerant compared to control. During 2012, it was recorded that the number of filled grain was found to be maximum in IET 21577 (94.3 ± 0.84) and IET 21404 (74.0 ± 0.24) as compared to control (59.7 ± 0.60 & 71.0 ± 0.54). The percent increase in filled grain was recorded IET 21577 (~57%) & IET 21404 (~4 %), showing a tolerant effect towards rising temperature. Similarly, a minimum number of grain-filled was observed in PHB 71 (51.0 ± 0.73), which was approximately 77% reduction compared to control (222.0 ± 5.30). However, in the next year, 2013, only a single cultivar showed a tolerant effect on elevated temperature over control. In the rest of the rice cultivars number of grains significantly ($p \leq 0.05$) declined (In rice cultivar) IET 21404 recorded the maximum number of grains among the treatments (152.67 ± 2.43), which was ~18 % more than control (128.33 ± 1.80). Under elevated conditions, IET 21404 showed a tolerant effect. Besides that, PHB 71 was observed as highly sensitive (37.00 ± 0.50) towards elevated temperature over control (163.00 ± 3.53), and the number of filled grain was declined ~77% with the exposer of rising temperature. Similarly, the rest of the rice cultivars were also reduced with elevated temperature (Table 2).

Apart from that, having chaffy grains in rice panicles means a significantly ($p \leq 0.05$) declining of rice productivity in both the successive years, *i.e.,* 2012 & 2013. Rising temperature most drastically affected the rice cultivar KRH 2, which was considered very sensitive towards temperature. It was a ~78 % significant reduction in chaffy grains was recorded in KRH 2 (148.0 ± 5.71) compared to control (31.0 ± 0.30). Similarly, other cultivars also declined with elevated temperatures. Besides that, one cultivar, IET 21405 (~5%), showed a tolerance that showed more chaffy grains in treatment compared to ambient conditions during 2012. However, next year rise in temperatures directly affected the grain filling capacity of the crop. As the temperature increase(s) 2–3 °C more from the ambient, the grain filling potential of the crop was declined in almost all the rice cultivars. In the present study, a maximum reduction (~83 %) recorded in PA 6444 (211.67 ± 5.23) in terms of chaffy grain over the control (34.00 ± 0.16), and in KRH 2 (130.67 ± 4.19) minimum reduction (~46%) recorded in KRH 2 (130.67 ± 4.19) compared to control (69.33 ± 0.85). At the same time, the rice cultivar IET 21411 was found tolerant among all the rice cultivars under elevated temperature (Table 2).

3.3. Response of harvest index to elevated temperature

Overall harvest index during 2012 & 2013 of eleven rice cultivars was significantly declined with increasing the temperature over ambient (Table 3). In this study, it was recorded that IET 21404 (47.81 ± 0.22) and IET 21577 (49.14 ± 0.25) showed a significant increase (~22 and 15%, respectively) in harvest index over ambient temperature, *i.e.,* IET 21404 (36.91 ± 0.10) and IET 21577 (41.36 ± 0.13) during 2012 and considered as a tolerant cultivar. Similar results were also recorded during the year 2013 and observed that the harvest index of two identical cultivars IET 21404 (46.45 ± 0.27) and IET 21577 (45.20 ± 1.96) was significantly increased ~19 and 21 % respectively as compared to the ambient condition of the similar rice cultivars IET 21404 (37.24 ± 0.39) and IET 21577 (35.65 ± 0.93). Therefore these cultivars were considered as tolerant towards elevated temperature over control. On the other hand, rest of the cultivar recorded a decrease in harvest index, which is sensitive towards rising temperatures during two successive years, *i.e.,* 2012 & 2013 (Table 3).

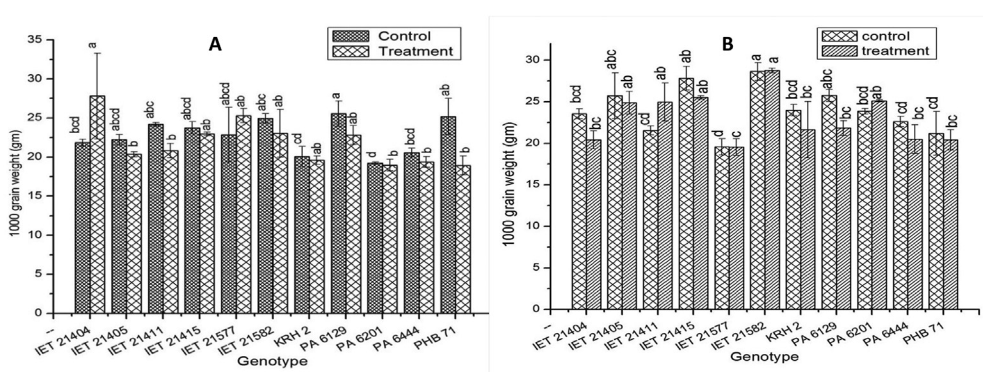

Figure 5. Effect of elevated temperature on 1000 grain weight (gm) in eleven cultivars of rice in the planting season of 2012 (A) and 2013 (B). The values written after plus- minus indicate the deviation from the mean value.

Table 2. Effect of ambient (AT) and elevated temperature (ET) on filled grain/panicle and chaffy grain/panicle (Mean ± SE) in eleven cultivars of rice at the time of flowering.

Genotype	Number of filled grain/panicle				Number of chaffy grain/panicle			
	2012		2013		2012		2013	
	AT	ET	AT	ET	AT	ET	AT	ET
IET 21404	71.0 ± 0.54ef	74.0 ± 0.24abc	128.33 ± 1.80b	152.67 ± 2.43a	60.3 ± 0.41cd	158.3 ± 2.16b	38.00 ± 0.41ab	81.33 ± 0.80bc
IET 21405	116.0 ± 0.19cd	79.3 ± 0.54ab	149.00 ± 2.02ab	39.00 ± 0.30bc	124.0 ± 3.19b	118.0 ± 3.47bc	27.67 ± 0.21ab	100.67 ± 4.68bc
IET 21411	73.0 ± 0.88ef	52.0 ± 0.60c	139.67 ± 3.77ab	56.67 ± 0.11a	150.7 ± 3.27a	226.3 ± 5.12a	53.33 ± 0.47ab	34.33 ± 0.83c
IET 21415	88.3 ± 0.16def	66.0 ± 0.32bc	149.33 ± 2.84ab	143.67 ± 5.90a	111.0 ± 2.81b	149.7 ± 3.92b	13.67 ± 0.04b	33.33 ± 0.17c
IET 21577	59.7 ± 0.60f	94.3 ± 0.84a	168.33 ± 7.85ab	49.33 ± 0.57a	57.7 ± 0.17cde	70.3 ± 0.33c	23.00 ± 0.51ab	56.33 ± 0.58c
IET 21582	90.0 ± 0.53de	64.0 ± 0.23bc	132.67 ± 4.83b	100.00 ± 3.17ab	61.0 ± 0.63cd	102.7 ± 3.25bc	10.67 ± 0.84b	56.67 ± 0.58c
KRH 2	137.0 ± 6.39bc	70.3 ± 0.75abc	180.67 ± 3.02ab	120.67 ± 4.62c	31.0 ± 0.30f	148.0 ± 5.71b	69.33 ± 0.85a	130.67 ± 4.19b
PA 6129	130.3 ± 4.33bc	67.7 ± 0.45bc	119.33 ± 3.31b	105.33 ± 3.67a	43.0 ± 0.61def	96.3 ± 0.49bc	18.00 ± 0.80b	60.33 ± 0.60c
PA 6201	74.0 ± 0.27ef	51.3 ± 0.37c	228.67 ± 5.98a	125.00 ± 3.00a	74.0 ± 0.64c	156.0 ± 4.50b	21.67 ± 0.60ab	74.33 ± 0.26bc
PA 6444	146.0 ± 0.59b	53.3 ± 0.17bc	143.00 ± 15.71ab	41.67 ± 0.75c	65.3 ± 0.75cd	136.0 ± 1.94b	34.00 ± 0.16ab	211.67 ± 5.23a
PHB 71	222.0 ± 5.03a	51.0 ± 0.73c	163.00 ± 14.53ab	37.00 ± 0.50bc	35.3 ± 0.84ef	122.0 ± 2.86bc	26.00 ± 0.45ab	81.00 ± 0.20bc

Means followed by a common letter in the columns are not significantly different.

3.4. Correlation analysis among the yield attributes

A correlation coefficient indicates whether the correlation between two variables is positive or negative and tells about how strong or weak the interaction is between the variables. Some parameters associated with the final yield of rice from plants were found to be closely related. Therefore, correlation analysis is important to decide the selection method, and it is necessary to consider the number of characteristics in improving any character, such as grain yield. The correlation conducted was to understand the relationship of grain yield with other yield parameters such as the number of filled grain, the weight of grain per plant, and 1000 grain weight for the study period 2012 & 2013. During 2012, among these selected parameters, AGY was found positive and highly correlated with the AFG ($r = 0.65$) followed by EGW ($r = 0.41$) and ETG ($r = 0.42$), and other parameters are non-significant with the AGY. Likewise EGY is highly significant with the EFG ($r = 0.71$), AGW ($r = 0.71$), EGW ($r = 0.67$), ETG ($r = 0.65$) followed by ATG ($r = 0.35$) (Figure 2). Similarly during 2013, AGY is highly correlated and significant with the EGW ($r = 0.37$) and EGY is highly significant with the ETG ($r = 0.50$), AGW ($r = 0.46$), ATG ($r = 0.42$) followed by EGW ($r = 0.36$). AGW and EGW with correlation coefficients ($r = 0.84$) are highly significant. Likewise, ATG and ETG are highly significant with correlation coefficients ($r = 0.70$) (Figure 3). A positive correlation between yield and yield attributes is required for efficient breeding of yield components to increase grain yield in rice. For plant breeders, it is therefore important to understand the degree of correlation between yield and its attributes.

4. Discussion

4.1. Response of growth and physiological behaviour to elevated temperature

Elevated temperature unfavourably affects plant growth, development, physio-chemical processes, and outcome (Hasanuzzaman et al., 2013; Fahad et al., 2017). The significant finding of this study was that tillers number and panicle number in all the cultivars were decreased except IET 21404 and IET21577 under higher temperatures. The threshold temperature for panicle differentiation generally occurs from 18 and 30 °C; this marked temperature reduced the tiller numbers. Similarly, air temperature <20 °C during the tillering stage determined increasing panicle number beyond that temperature, *i.e.*, >30 °C showed a negative impact on panicle number/plant, especially at maturity. Besides, floodwater temperature is an important key factor that directly influences panicle number/plant and spikelets/panicle. Active tillering determines the stage of yield, and if an elevated temperature is imposed at this stage, the number of panicles at maturity declined. Usually, elevated temperature increases the rate of leaf emergence and develops more tillers. Besides this, in low light conditions, scarcity of carbohydrate

Table 3. Effect of ambient (AT) and elevated temperature (ET) on grain weight/plant (gm) and harvest index (Mean ± SE) in eleven cultivars of rice after harvesting.

Genotype	Grain weight/plant (gm)				Harvest Index (%)			
	2012		2013		2012		2013	
	AT	ET	AT	ET	AT	ET	AT	ET
IET 21404	6.75 ± 0.25b	12.92 ± 0.58a	7.58 ± 0.46c	16.33 ± 0.71a	36.91 ± 0.10cd	47.81 ± 0.22ab	37.24 ± 0.39c	46.45 ± 0.27abc
IET 21405	12.58 ± 0.36a	6.83 ± 0.46c	12.92 ± 0.96ab	7.42 ± 0.50d	26.11 ± 0.14d	15.45 ± 0.04ab	42.88 ± 0.90abc	29.03 ± 0.21bc
IET 21411	13.42 ± 0.36a	7.33 ± 0.65c	14.25 ± 0.38a	8.15 ± 0.30d	37.23 ± 0.11cd	24.03 ± 0.14ab	36.87 ± 0.30abc	22.15 ± 0.79abc
IET 21415	13.92 ± 0.54a	7.00 ± 0.14c	11.92 ± 0.71ab	7.60 ± 0.44d	18.93 ± 0.16bc	11.7 ± 0.05a	41.02 ± 0.77ab	25.62 ± 0.39abc
IET 21577	7.58 ± 0.46b	10.67 ± 0.22b	8.17 ± 0.22c	13.58 ± 0.60b	41.36 ± 0.13bc	49.14 ± 0.25ab	35.65 ± 0.93abc	45.20 ± 1.96c
IET 21582	14.08 ± 0.41a	7.50 ± 0.28c	12.08 ± 0.16ab	7.58 ± 0.60d	38.1 ± 0.12bc	24.26 ± 0.64ab	38.53 ± 0.32a	31.26 ± 0.32abc
KRH 2	13.58 ± 0.60a	6.67 ± 0.58c	11.67 ± 0.82b	8.00 ± 0.52d	27.31 ± 0.22a	22.68 ± 0.91a	41.78 ± 0.47a	21.99 ± 0.05ab
PA 6129	13.58 ± 1.04a	7.67 ± 0.46c	13.92 ± 1.06ab	7.67 ± 0.58d	35.99 ± 0.18cd	20.12 ± 0.09bc	29.53 ± 0.10bc	19.80 ± 0.04abc
PA 6201	12.92 ± 0.44a	7.33 ± 0.30c	12.58 ± 0.22ab	8.83 ± 0.30cd	29.48 ± 0.47cd	19.3 ± 0.08c	49.9 ± 0.52abc	37.71 ± 0.86c
PA 6444	13.83 ± 0.65a	7.42 ± 0.44c	14.08 ± 1.08ab	10.08 ± 0.71c	29.48 ± 0.24b	21.01 ± 0.14ab	37.75 ± 0.63ab	25.82 ± 0.20a
PHB 71	13.17 ± 0.72a	7.33 ± 0.08c	13.58 ± 0.93ab	7.08 ± 0.44d	34.85 ± 0.03bc	22.95 ± 0.17ab	45.02 ± 0.47abc	26.89 ± 0.17a

Means followed by a common letter in the columns are not significantly different.

which is necessary for growth decline tillers. Therefore, low temperatures may produce more tillers, whereas high temperatures >35 °C, during the vegetative stage reduces tiller number (Yoshida et al., 1981; Fu et al., 2016; Lindsey and Dlugokencky, 2018).

Elevated temperature sharply reduced grain yield and thousand-grain weight in rice cultivar. Reduction in yield and thousand-grain weights vary in cultivar. Under the elevated temperature, 1000-grain weight significantly reduced for some cultivars except, IET 21404 and IET 21577, which were tolerant among all the cultivar. Thousand-grain weight is resolute primarily by the development of hull and endosperm. Due to aberrant spikelet development in unfavorable environments, such as high temperatures, full size, and grain weight decreased (Fu et al., 2016).

Grain yield of cultivars *viz.* IET 21405, IET 21411, PA 6129, and PHB 71 showed a pronounced decline under elevated temperature except for tolerant cultivars, *i.e.,* IET 21404 and IET 21577. Thus, any short episodes of high temperature during flowering reduce grain yield (Shah et al., 2011). Elevated temperature showed a profound impact on rice yield attributes during flowering, and temperatures of 27 °C–32 °C reduce grain filling duration without increasing grain filling rate, which ultimately results in a significant decline in yield (Boden et al., 2013). The average daily temperature above 35 °C during the reproductive growth period of rice results in a substantial reduction of grain yield. An elevated temperature promotes the ripening and reduction in grain weight because of shortens the duration of grain filling, which ultimately reduces yield. Rice exposed to 10 °C elevated temperature than ambient, at heading and anthesis, reduced photosynthesis which might be due to structural changes in the organization of thylakoids and the loss of stacking of grana in the chloroplast (Kumar et al., 2015; Kiet and Nose, 2016).

4.2. Grain filling under elevated temperature

The grain-filling stage is very susceptible under elevated temperatures and could reduce rice grain quality, causing dry grain, thereby reducing quality and grain weight. Grain weight in rice is affected mainly by high night temperatures (22/34 °C, day/night) than elevated day temperatures (34/22 °C) and control conditions (22/22 °C) at optimum temperature in rice (Chaturvedi et al., 2017). In the present study, grain weight showed a tendency to decrease significantly in most of the cultivar when elevated temperature treatments continued. The rate and duration of grain growth are most important for the final grain weight. This is affected by high temperatures that increase growth rate in the early ripening period but reduce assimilated supply to grain, duration of grain growth, and finally decrease grain weight (Lee et al., 2015).

In the present study, temperature more than optimum during anthesis significantly decreases the number of filled grain whereas significantly increased the no of chaffy grain per plant. High temperature during reproductive and the grain-filling phase causes spikelet sterility, shortening the duration of the grain-filling phase and deleterious effects on the yield (Jung et al., 2015). At elevated temperatures, the grain-filling period was shorter, whereas the rate of grain growth was faster. The duration of the ripening period inversely correlates with daily mean temperature, and, therefore, grain filling is very sensitive when the temperature is rising (Krishnan et al., 2011).

4.3. Response of harvest index to elevated temperature

The harvest index depends upon the economic yield and biological yield of crop plants. When the grain yield and biological yield declined with an elevated temperature, the harvest index (%)also reduced. In our investigation, the effect of elevated temperature stress on harvest index (%) was observed. The maximum overall harvest index (%) was observed in IET 21404 and IET 21577 in both successive years as compared to control. The adverse effects of elevated temperature lead to reduced grain yield, leading to a significant decline in harvest index (Wu et al., 2016; Yang et al., 2017).

5. Conclusion

Elevated temperature beyond the threshold adversely affects the growth and development of rice crops, which ultimately determines yield. The elevated temperature at the terminal stage of rice affects the number of tillers, panicle and filled grain, and yield traits. High temperature significantly enhanced the number of the tiller as well as panicle. In contrast, grain weight, filled grains, 1000 grain weight declined in all cultivars except IET 21577 and IET 21404 under the present study. These two rice cultivars were reported more tolerant of elevated temperatures. The findings will help rice breeders to develop thermo-tolerant rice cultivars to cope with future climate change and obtain high yields to fulfill the demand of the rice-based community.

Declarations

Author contribution statement

Narendra Kumar: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Neha Jeena: Contributed reagents, materials, analysis tools or data.

Amit Kumar: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Rowndel Khwairakpam: Analyzed and interpreted the data.

Hukum Singh: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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