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Effect of elevated temperature regimes on growth and yield of rice cultivars under temperature gradient tunnel (TGT) environments

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ABSTRACT

The effect of elevated temperature on rice were studied during *kharif* 2013 and 2014 using six cultivars of rice (PR-116, PR-118, PR-113, PR-115, PR-121 and PR-122) with two replications within a temperature gradient tunnel in which temperature was elevated from the ambient level (+4.5, +5.0, +5.3, +5.5 and +5.8 °C) for the entire crop growth period. The results revealed that the plant height increased under elevated temperature regimes, although the rate of change varied with cultivars as well as the stages of the crop. Amongst the six cultivars, the plant height was maximum for cv PR-118 (13.9 cm in vegetative stage (VS) and for cv PR-113 (58.5 cm in grain development stage (GDS) and minimum for cv PR-121 (12.4 cm in VS and 51.8 cm in GDS). The overall tiller number under elevated temperature regimes was maximum for cv PR-122 followed by PR-121, PR-113, PR-116, PR-115 and PR-118 in decreasing order. The 1000-grain weight was reduced from the ambient temperature regime by 8.7 to 14.5 per cent and number of grains per panicle was reduced by 30.6 to 46.7 per cent under elevated temperature of 4.5 to 5.8 °C from ambient. Similarly, the grain yield was reduced by 38.3 to 54.5 per cent and biomass yield reduced by 19.7 to 33.6 per cent with increase under temperature 4.5 to 5.8 °C from the ambient environment. Amongst the six cultivars the harvest index was maximum in cv PR-122 (33.0%), i.e., it is most tolerant to heat stress followed by PR-121 (28.3%) and least tolerant were cv PR-116 (20.2%) and PR-115 (18.9%).

Keywords: Rice, stress, temperature gradient tunnel, plant height, tiller, yield

Rice is the most important food crop of the world and India is world's second biggest rice producer contributing 26% in world rice production. In tropical regions, it is cultivated as a summer crop despite relatively high temperatures that occur during its growth period (Sung *et al.,* 2003; Bal *et al.,* 2018) and heat stress is a common constraint during anthesis and grain-filling stages (Kobata and Uemuki, 2004). Global circulation models project that the global average surface air temperature at the end of the 21st century relative to 1980–1999 will be around 1.8–4.0 °C, with a likely range of 1.1–6.4 °C (IPCC, 2007). Under high temperature induced atmospheric stress, the challenge to improve the rice productivity will be of an immense challenge for the farming community (Bal and Minhas, 2017).

The rise in temperature affects the phenology, growth, yield, and quality of the rice crop (Sheehy *et al.,* 2005). Yoshida (1981) revealed that within the temperature range of 22-31°C the growth rate of rice crop increases linearly and further increase in temperature adversely affect the growth and yield of rice. Studies have shown that under high temperature the rate of increase in plant height was steeper (Oh-e *et al.,* 2007) and it increased with the rise of temperature within the range of 30-35 °C (Osada *et al.,* 1973). The results of studies revealed that that in rice the tillering rate increases with rising temperature within the range of 15-33 °C, the optimum temperature during daytime is 25 °C and during night time is 20 °C (Sato, 1972) and further temperature above 33 °C were unfavourable for tillering (Chaudhary and Ghildyal, 1970). Yoshida (1981) revealed that the yield potential of a rice cultivar may be directly related to its capacity to produce tillers, however, more tillers in rice plant lead to more inconsistency in mobilizing assimilates and nutrients amongst the tillers resulting to more variability in development of grain within the tillers. An increase in temperatures may affect the mobilization / availability of photosynthates and nutrients amongst the tillers.

Shouichi (1973) in a control experiment study observed that at early growth stages, growth rate is increased as temperature rise from 22-31 °C. Later, Baker and Allen (1993) reported that in day/night temperatures above 28/21 °C, the grain yields decline by an average of approximately 10% per 1°C. Several workers have reported that with 1 ºC increase in minimum temperature and mean temperature the rice yield are reduced by 10% (Peng *et al*., 2004) and 6 % (Saseendran *et al*., 2000), respectively. Under anticipated climate change scenarios, adoption of high temperature-tolerant cultivars for rice is one of the most viable option to sustain high productivity of rice (Horie *et al.,* 1996). Genetic variability to high temperature tolerance per se has been reported in rice as early as in the late 1970s. Jennings *et al.* (1979) found some varieties, such as Hoveyzeh from southern Iran, which still remained fertile at the temperature over 45 °C, while other varieties were already completely sterile.

Earlier studies on rice and other crops have been conducted under TGT environments to evaluate the effect of increase in temperature on crop (Raj *et al.,* 2016 and Singh *et al.,* 2017). Keeping this in view, experiments on rice under TGT environments were conducted to analyse the growth and yield of rice cultivars and to identify the high temperature tolerant cultivars which may be further adopted to sustain rice productivity in Punjab state of India.

MATERIAL AND METHODS

The present investigation was carried out during *kharif* 2013 and 2014 at the Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana. The experiment was conducted in a Temperature Gradient Tunnel (TGT) of the dimensions 30m in length, 5 m in breadth and 3 m in height. The TGT is tunnel like structure which is made up of galvanized iron pipes and covered with polythene sheets. It has cooling pads at the backside wherein water is sprinkled with the pump to produce a cool draft. The two exhaust fans installed at the other end of TGT suck in the cool air draft from the backside, thereby producing a gentle gradient of the temperature. The meteorological data within and outside the TGT was monitored with a set of five temperature and relative humidity sensors installed within and one set outside the TGT. The data was sensed by the data logger (Delta-T devices make) at five minutes interval and logged at half an hour interval.

The experiment conducted during *kharif* 2013 and 2014 comprised of 12 treatments combinations viz. 6 temperature regimes (+4.5, +5.0, +5.3, +5.5 and +5.8 °C) and 6 rice cultivars (PR-113, PR-115, PR-116, PR-118, PR-121 and PR-122) transplanted at the age of 30 days with a row-row spacing of 20 cm and plant-plant spacing of 15 cm was laid out in Randomized Block Design (RBD) with two replications. The recommended doses of fertilizers were applied to the crop as per the Package of Practices of Punjab Agricultural University. The nitrogen was applied at the rate of 125 kg ha^{-1} through urea in three equal splits. The whole dose of 30 kg ha^{-1} of P_2O_5 through single super phosphate and 30 kg ha^{-1} of K_2O through muriate of potash along with 25 kg of $ZnSO_4$ ha^{-1} was applied at the time of field preparation as basal dose.

The data on yield and yield attributes of rice cultivars was recorded from all the treatment combinations and further analyzed and to identify the high temperature tolerant cultivars for rice. The periodic data on plant height and tiller development were recorded at biweekly interval from five tagged plants of each cultivar of rice from all six sensors within and outside the TGT. The plant height growth rate was computed as under:

$$\text{Plant height growth rate (cm/day)} = \frac{H2-H1}{T2-T1}$$

H2 = Plant height on T2 days after transplanting (DAT) H1 = Plant height on T1 DAT

The tiller number growth rate was computed as under:

$$\text{Tiller number growth rate (\#/day)} = \frac{TN2-TN1}{T2-T1}$$

TN2 = Number of tillers on T2 DAT, TN1 = Number of tillers on T1 DAT

RESULTS AND DISCUSSION

Effect of elevated temperature regimes on plant height

Plant height is an index of growth and development of the crop representing the infrastructure builds up over a period of crop duration. The changes in plant height under ambient and different temperature regimes recorded at different growth periods are given in (Table 1) for six cultivars of rice. The perusal of the data showed that plant height increased with advancement of age (up to harvest). In general, the plant height growth rate was high under elevated temperature regimes and as a result more plant height was attained by all the cultivars of the rice under elevated temperature regimes. Similar results on increase in plant height under elevated temperature environments were reported by Khondo and Okamura (1931), Osada *et al.* (1973) and Oh-e *et al.* (2007).

The plant height during vegetative stage (VS) under ambient temperature was 6.9 and 12.3 cm at 30 and 60 DAS, respectively. In general, during the vegetative phase plant height was 34.5, 47.6, 46.2, 51.9 and 51.5% more under elevated temperature regime of +4.5, +5.0, +5.3, +5.5 and +5.8 °C, respectively from the ambient. The plant height during grain development stage (GDS) under ambient temperature was 23.4 and 40.8 cm at 90 DAS and at harvest, respectively. In general, during the grain development phase plant height was 71.9, 91.6, 61.4, 113.9 and 113.0 %, more under elevated temperature regime of +4.5, +5.0, +5.3, +5.5 and +5.8 °C, respectively from ambient.

Amongst the vegetative stage (VS) the plant height was maximum in cv PR-118 followed by PR-116, PR-113, PR-115, PR-122 and PR-121 (13.9, 13.4, 13.4, 12.7, 12.6 and 12.4 cm, respectively). Similarly, amongst grain development stage (GDS) the plant height was maximum in cv PR-113 followed by PR-118, PR-122, PR-116, PR-115 and PR-121 (58.5, 56.4, 56.3, 55.1, 52.9 and 51.8 cm, respectively).

Tiller number

Tillering is one of the most important phases of crop growth. The data on periodic tiller count at biweekly interval for six cultivars of rice under ambient and elevated temperature regimes during *kharif* 2013 and 2014 was recorded and were analysed to work out the tiller number growth rate during the vegetative and grain development stage of rice (Table 1). In general, the tiller number growth rates were higher under ambient temperature and declined with the increase in temperature. Earlier studies have reported that tillering is maximum at 25 °C (day-time) and 20 °C (night-time) temperature and the temperature above 33 °C are unfavourable for tillering in rice crop (Chaudhary and Ghildyal, 1970 and Sato, 1972). Lalitha *et al.* (2000) have reported that the tiller production stopped abruptly when the mean temperature exceeded 26 °C by 5th week after planting.

The tiller number during vegetative stage (VS) under ambient temperature was 388 and 588 per m^2 at 30 and 60 DAS, respectively. In general, during the vegetative phase tiller number was -26.3, -28.3, -21.6, -25.7 and -25.5 %, lesser under elevated temperature regime of +4.5, +5.0, +5.3, +5.5 and +5.8 °C, respectively from the ambient. The tiller number during grain development stage (GDS) under ambient temperature was 429 and 386 per m^2 at 90 DAS and at harvest, respectively. In general, during the grain development phase tiller number was 24.9, -22.9, -21.6, -25.6 and -24.9 %, lesser under elevated temperature regime of +4.5, +5.0, +5.3, +5.5 and +5.8 °C, respectively from ambient. The decline in tiller number was less under elevated temperature regimes and these results are in agreement with study conducted by Yang and Heilman (1993) wherein they reported that more tillers and leaves appeared than senesced in the plants that were heat stressed.

The tiller number during VS was maximum for cv PR-122 followed by PR- 121, PR-113, PR-116, PR-115 and PR-118 (444.8, 405.7, 380.8, 360.2, 351.9 and 330.8 m^2, respectively). Similar trend for tiller development was observed during grain development stage (GDS) i.e. tiller number was maximum for cv PR-122 followed by PR- 121, PR-113, PR-116, PR-115 and PR-118 (367.5, 338.3, 327.9, 316.8, 315.1 and 293.7 m^2, respectively).

So amongst the six cultivars for rice, in cv PR-118 the tiller number decline rate were least under all the temperature regimes, i.e., tillering is slow under ambient temperature conditions as well as most tolerant to temperature stress. On other hand, in cv PR-122 the tiller number were maximum under ambient temperature while reasonable tolerant to elevated temperature regimes, i.e., tillering is fast under ambient temperature conditions as well reasonably tolerant to temperature stress.

Effect on yield and yield attributes of rice cultivars

The data on yield and yield attributing characters of rice cultivars under different treatments were collected and are presented in Table 2. Rise in temperature results in the advancement in grain development stage in rice which lead to reduction in number of grains and their weight and ultimately the grain yield.

1000-grain weight

The data on 1000-grain weight (g) of rice cultivars under different temperature regimes during two crop years are presented in Table 2. Grain development in rice is highly susceptible to high temperature stress and the perusal of the data revealed that 1000-grain weight was significantly higher under ambient conditions as compared to elevated temperature levels. The 1000-grain weight was reduced from the ambient temperature regime by 8.71, 8.11, 11.33, 16.39 and 14.85% under +4.5, +5.0, +5.3, +5.5 and +5.8 °C, respectively. This may be due to prolonged reproductive phase and more efficient translocation of photosynthates to the grain as under elevated temperature regimes the growth phases are reduced and the partitioning of photosynthates is disturbed. Murata (1976) in a control experiment observed that the 1000-grain weight varied from about 24 g at a mean temperature (T_{mean}) of 22 °C in the 3-week period after heading

Table 1: Effect of different temperature regimes within and outside the temperature gradient tunnel on plant height and tiller number of rice cultivars (Pooled data of *kharif* 2013 and 2014)

Treatment	Plant height (cm)				Tiller number (#)/m^2			
	Vegetative stage (VS)		Grain development stage (GDS)		Vegetative stage (VS)		Grain development stage (GDS)	
	30	60	90	At Harvest	30	60	90	At Harvest
Temperature regimes (°C)								
Ambient	6.85	12.28	23.39	40.83	388.85	588.16	429.22	386.83
+4.5	9.78	15.51	45.17	61.52	313.39	392.74	327.28	286.34
+5.0	10.78	16.92	52.43	64.93	298.68	392.00	330.60	298.6
+5.3	10.59	16.93	54.18	62.26	339.70	408.40	335.06	304.39
+5.5	10.91	17.75	61.45	67.39	310.5	404.00	318.88	287.95
+5.8	10.99	17.51	61.10	67.29	320.00	392.11	324.69	288.78
CD (p=0.05)	0.76	1.01	6.11	3.05	30.44	23.56	16.39	17.65
Cultivars								
PR – 113	10.42	16.46	52.18	64.79	326.57	435.03	341.67	314.10
PR – 115	9.81	15.54	44.89	60.92	298.64	405.23	332.72	297.46
PR – 116	10.31	16.49	50.82	59.29	294.11	426.26	339.08	294.58
PR – 118	10.32	17.51	53.80	59.04	280.46	381.23	307.42	279.98
PR – 121	9.33	15.42	47.03	56.64	364.95	446.46	357.04	319.51
PR – 122	9.73	15.49	48.99	63.53	406.39	483.22	387.79	347.28
CD (p=0.05)	0.76	1.01	NS	3.05	30.44	23.56	16.39	17.65

to 21 g at a T_{mean} of 28 °C.

Amongst the cultivars under different environments, maximum 1000 grain weight were recorded in cv PR-113 (23.69 g) followed by PR-121(21.91 g), PR-115 (21.15 g), PR-116 (20.52 g), PR-118 (19.53 g) and PR-122 (19.16 g) in decreasing order. Similar results have also been reported by Jeng *et al.* (2003) and Oh-e *et al.* (2007).

Number of grains per panicle

The number of grains per panicle was significantly higher under ambient environment than under elevated temperature regimes (Table 2). The number of grains per panicle was reduced from the ambient temperature regime by 30.63, 33.05, 40.87, 46.01 and 46.49% under +4.5, +5.0, +5.3, +5.5 and +5.8 °C, respectively. Amongst the cultivars, the number of grains per panicle recorded in cv PR-122 (48.77) were maximum followed by PR-118 (39.57), PR-116 (36.78), PR-113 (32.22), PR-115 (31.61) and PR-121 (28.76) in decreasing order. However, the interaction effect of the variety and elevated temperature regimes was non-significant. Similar results have been reported in earlier studies by (Newman *et al.,* 2001 and Oh-e *et al.,* 2007).

Grain yield

Grain yield is the most important character regarding the economic value of the crop. The grain yield was significantly high under ambient temperature conditions as compared to different elevated temperature regimes (Table 2). The analysis of the pooled data revealed that decrease in grain yield was 38.3, 41.5, 48.8, 57.7 and 54.5% with increase in temperature by +4.5, +5.0, +5.3, +5.5 and +5.8 °C, respectively from the ambient environment. The decline in grain yield with rise in temperature is in agreement with earlier study conducted by Singh *et al* (2013) in control experiments and by Raj *et al* (2016) under TGT environments. Amongst the six cultivars of rice under different environments, maximum grain yield were observed in cv PR-122 (3908 kg ha^{-1}) followed by PR-121 (3032 kg ha^{-1}), PR-118 (2645 kg ha^{-1}), PR-116 (2259 kg ha^{-1}), PR-113 (2121 kg ha^{-1}) and PR-115 (1900 kg ha^{-1}) in decreasing order. Grain yield varied non significantly amongst the interactive effect of temperature regimes and cultivars.

Straw yield

The analysis of the pooled data revealed that straw yield was reduced by nearly 10% with increase in temperature by up to 5.3 °C from the ambient environment (Table 2). Further increase in temperature by 5.5 and 5.8 °C from the ambient temperature decreased the straw yield by 14 and 23 %, respectively. Amongst the six cultivars of rice, under different environments the maximum straw yield were observed in cv PR-116 (8508 kg ha^{-1}) followed by PR-115 (7877 kg ha^{-1}), PR-122 (7847 kg ha^{-1}), PR-121 (7563 kg ha^{-1}), PR-118 (7480 kg ha^{-1}) and PR-113 (7338 kg ha^{-1}) in decreasing order. Straw yield varied non significantly amongst the interactive effect of temperature regimes and cultivars.

Biomass yield

The biomass yield was significantly higher under ambient conditions as compare to elevated temperature regimes (Table 2) and decreased due to significant decrease in grain yield of rice. The decrease in biomass yield was 19.7, 20.9, 23.2, 28.8 and 33.6 % with increase in temperature by +4.5, +5.0, +5.3, +5.5 and +5.8 °C, respectively from the ambient environment. Similar results on decrease in biomass yield of rice under temperature increase under TGT environments have reported by Raj *et al* (2016). Amongst the six cultivars of rice, under different environments the maximum biomass yield were observed in cv PR-122 (11755 kg ha^{-1}) followed by PR-116 (10770 kg ha^{-1}), PR-121 (10596 kg ha^{-1}), PR-118 (10125 kg ha^{-1}), PR-115 (9777 kg ha^{-1}) and PR-113 (9459 kg ha^{-1}) in decreasing order. Biomass yield varied non significantly amongst the interactive effect of temperature regimes and cultivars.

Harvest index (HI)

The harvest index (HI in percentage) is ratio of economic yield to the total biomass yield. In general, under high temperature environments not only the synthesis of the assimilates is decreased rather their partitioning towards grains are reduced and that towards the leaf and stem are increased. High HI in a cultivar indicates its tolerance towards high temperature stress and is one of the most desirable traits to be considered while screening the tolerance of the cultivar towards heat stress. The analysis of the data revealed that HI was reduced by 24.2, 26.3, 33.5, 40.4 and 31.7 % with increase in temperature by +4.5, +5.0, +5.3, +5.5 and +5.8 °C, respectively from the ambient environment (Table 2). Amongst the cultivars, the HI was maximum in cv PR-122 (33.0%), i.e., it is most tolerant to heat stress followed by PR-121 (28.3%), PR-118 (25.4%), PR-113 (21.9%), PR-116 (20.2%) and PR-115 (18.9%) in decreasing order. However, the harvest index varied non significantly amongst the interactive effect of temperature regimes and cultivars.

Table 2: Effect of different temperature regimes within and outside the temperature gradient tunnel on yield attributes, yield and harvest index of rice cultivars (Pooled data of *kharif* 2013 and 2014)

Treatment	1000 grain weight (g)	Number of grains per panicle (#)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	Harvest index (%)
Temperature regimes (°C)						
Ambient	23.30	54.03	4418.8	8770.6	13189.4	33.4
+4.5	21.27	37.48	2726.3	7866.1	10592.4	25.3
+5.0	21.41	36.17	2583.5	7847.4	10430.9	24.6
+5.3	20.66	31.95	2259.9	7869.7	10129.6	22.2
+5.5	19.48	29.17	1868.6	7521.5	9390.1	19.9
+5.8	19.84	28.91	2009.9	6738.9	8748.8	22.8
CD (p=0.05)	0.88	3.73	259.4	755.1	787.7	3.7
Cultivars						
PR – 113	20.52	36.78	2121.0	7338.3	9459.3	21.9
PR – 115	19.53	39.57	1900.0	7877.27	9777.3	18.9
PR – 116	23.69	32.22	2259.6	8508.4	10767.9	20.2
PR – 118	21.15	31.61	2645.4	7479.9	10125.3	25.4
PR – 121	21.91	28.76	3032.3	7563.4	10595.7	28.3
PR – 122	19.16	48.77	3908.5	7846.9	11755.5	33.0
CD (p=0.05)	0.88	3.73	259.4	755.1	787.7	3.7

CONCLUSION

Under elevated temperature regimes the plant height was maximum for cv PR-118 (13.9 cm during VS) and PR-113 (58.5 cm during GDS) and least for cv PR-121 (12.4 cm during VS and 51.8 cm during GDS), though the tiller number was maximum for cv PR-122 (444.8 m^2) and least for cv. PR-118 (330.8 m^2). The growth characters were also reflected in the yield (grain yield in cv PR-121 was 3032 kg $ha^{-1}$and in cv PR-116 was 2259 kg ha^{-1}) and yield attributes (1000 grain weight was 21.91 g for cv PR-121 and 20.52 g for cv PR-116), were more in cv PR-121 as compared to cv PR-116. In general with rise in temperature not only the production of the photosynthates is decreased but their partitioning towards grain are much more reduced than towards the leaf and stem. Under these situations, tolerant rice cultivars like cv PR-122 (HI 33.0%) and PR-121 (28.3%) for high-temperature stress will help to avert yield losses to some extent.

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