EFFECT OF ELEVATED TEMPERATURE AND LOW RADIATION ON GROWTH AND YIELD OF BASMATI RICE (*ORYZA SATIVA* L.)

T.A. JOHNSON, S. SINGH, S. MISRA AND S. KALPANA

Division of Environmental Sciences, Indian Agricultural Research Institute, New Delhi-110012

Received on 09th Dec., 2010, Revised and Accepted on 24th April, 2011

SUMMARY

Five basmati rice varieties were subjected to high thermal and low light stress (3 ^{0}C higher than ambient temperature and 20% reduction in light intensity) during various growth phases to assess the effect of high temperature and low radiation on growth, yield and yield attributes of these varieties. High thermal and low light stress throughout the entire growth period (tillering to maturity) caused highest reduction in grain yield followed by plant exposure to such stress from tillering to anthesis, while heat and low light stress from anthesis to maturity did not show any detrimental effect on grain yield. Among varieties, Taraori Basmati and Pusa Basmati 1 showed greater tolerance to high thermal and low radiation stress and thereby manifested higher grain yield under such stress. The reduction in grain yield was mainly due to significant reduction in grains/panicle owing to marked increase in spikelet sterility under high temperature and low light stress as the number of panicles/pot and 1000 grain weight were least affected by such stress.

Key words: **Anthesis, maturity, panicles, spikelet sterility, thermal stress, tillering**

INTRODUCTION

Rice is the staple food for more than half of the world population. There are several varieties of fragrant rice, of which Basmati which originated in India is the most popular. Basmati characterised by exquisite aroma, super fine slender grain, soft texture and extra elongation with least breadth wise swelling on cooking makes it superior over other scented rice varieties. The aroma, which makes basmati unique, is best developed when grown in areas where temperature is cooler during grain filling duration.

Heat stress often causes irreversible damage to plant function or development and this acceleration substantially reduces total fruit or grain yield. High temperature can increase the rate of reproductive development and shorten the duration of photosynthesis to contribute to fruit or seed production. Global warming can reduce tropical rice yields due to increased respiration rate, spikelet sterility, shorter growth duration, and reduced assimilates (Yoshida, 1981, Matsui *et al.* 2000). Increasing mean minimum night time temperature may be particularly significant in lowering the yield of rice plants (Peng *et al.* 2004). In rice, permanent damage to the reproductive mechanism of the plant reduces grain yield by 10% for every 1^{0}C increase in temperature from 30 to 40^{0}C during flowering (IRRI, 2004).

Rice growth and yield are climatically controlled. Temperature affects rate and duration of growth and development (Yoshida 1981, Kim *et al.* 1996). Different growth phases of rice plant showed differential growth and yield response to high temperature and low light stress (Yoshida 1981). Low light coupled with high temperature (38^{0}C) and humidity (RH 94%) induced

*Corresponding author, E-mail: sdsingh14d@yahoo.co.uk

complete spikelet sterility, enhanced foliage growth and impaired the biological yield (Singh 2000). High temperature reduced days to flowering, days to maturity and panicle weight, while increasing tiller production (Horie *et al.* 2000).

Under current conditions, it is generally accepted that the main limitation of leaf photosynthesis at high photon flux density is the concentration of CO_2, but when photon flux densities decrease to approximately 30% of that at full sunlight then photosynthesis becomes light limited (Taiz and Zeiger 2009). This might suggest that plants would be insensitive to changes in solar radiation at high light, but since plant canopies usually consist of several leaf layers, in which radiation decreases exponentially from layer to layer, low light levels at which photosynthesis is light limited are common in crop canopies. Thus, a decrease in solar radiation may decrease productivity.

In view of these observations, the present study was aimed to examine the impact of rise in ambient temperature and low radiation on growth, yield and yield attributes of basmati rice varieties, which are widely cultivated in northern India.

MATERIALS AND METHODS

The rice nursery was raised with five basmati rice varieties namely Basmati 370, Taraori Basmati, Basmati 386, Pusa Sugandh 2 and Pusa Basmati 1 in the glass house premise of the Environmental Science Division, IARI, New Delhi. Thirty days old seedlings were transplanted in plastic pots (20 cm diameter) containing pre-fertilised and puddled soil. Each variety had thirty-six pots comprising four treatments with nine pots each. Following the establishment of transplanted seedlings (15 days after transplanting), the planted pots of all five varieties were divided into four sets with nine pots each. Out of four sets of each variety, the first, second and third sets were subjected to high temperature and low radiation stress (+3 ^oC and 20% reduced light) during tillering to maturity (T_1), tillering to flowering (T_2) and flowering to maturity (T_3), respectively in a glasshouse. The fourth set was kept as control where plants were allowed to grow under normal ambient temperature throughout their entire growth period (T_0). Daily maximum and minimum temperature, RH and light intensity were recorded throughout the entire growth period outside and inside the glasshouse using digital max./min. thermometer and Lux meter. The normal ambient temperature during the experimental period was 26.2^0C and the temperature inside the glass house during the experimental period was 29.2^0C (3^0C higher than normal ambient temperature). The light intensity outside and inside the glasshouse was recorded to be about 80 Klux and 64 Klux (20% lower than outside), respectively. The experiment was laid out in a Completely Randomised Design (CRD).

The leaf length (cm) and leaf width (cm) was measured by using graduated meter scale at mm/cm levels. The leaf area of each leaf was calculated by multiplying their (max. length x max. width) x factor (0.75) as stated by Yoshida *et al* (1976). The dry weight of different plant parts such as stem, leaf, panicle and total biomass were also recorded at flowering. Specific leaf area was calculated by dividing the leaf area with their respective dry weight. Specific leaf weight was determined by dividing leaf dry weight with their respective area. The productive tiller percent refers to the proportion of tillers bearing the panicles, which indirectly refers to the tiller mortality percent which was also recorded.

Dry weight of different plant parts such as stem, leaf and panicle and total dry weight per pot were recorded. Yield components such as number of panicle per pot, number of spikelets and filled grains per panicle, straw weight, spikelet percent, 1000grain weight, grain yield, biological yield and harvest index were measured at maturity. Leaf area, specific leaf area, specific leaf weight, leaf weight ratio and productive tiller percent were recorded at flowering.

RESULTS AND DISCUSSION

***Effect of high temperature and low radiation on phenology of basmati rice varieties*:** Number of growing days were reduced in all varieties of basmati rice when subjected to high temperature and low radiation. The decrease was higher in days to flowering than in flowering to maturity. Thus heat stress showed greater influence on days to flowering than on days to ripening and resulted in shortening of maturity duration. Total number of days to maturity were lowest in treatment T_1 followed by T_2 and T_3. Among the cultivars, maximum reduction in days to maturity was recorded in Taraori Basmati followed by Basmati 370 and Pusa sugandh 2. The number of days from flowering to maturity reduced in treatment T_1 and T_3 with respect to control. In treatment T_1 and T_3, the variety Taraori basmati showed maximum reduction followed by Pusa sugandh 2 and Basmati 370. It indicates that Taraori Basmati has greater threat from possible global warming, while high temperature had little influence on phenology of Basmati 386, which shows relatively greater phonological stability to thermal stress (Table 1). It is well known that the rate of growth and metabolic processes increase with rise in temperature, thus high thermal stress under the present study might have reduced the number of growing days of the rice plant (Yoshida 1981, Morita *et al.* 2005). Conroy *et al.* (1994) has observed that rice development is accelerated by high temperature and consequently grain yield is reduced because there is less time for radiation to be intercepted during the vegetative growth phase. The finding under present study is consistent with these observations.

Both the thermal and radiation requirement of rice plants vary from one growth stage to another. In general, the optimum mean temperature throughout the growing period of Indica rice has been reported to be 26-28 °C with a range of 25-30 °C during tillering to flowering and 22-25 °C during ripening growth phase. Thermal requirement of rice gradually decreases with the advancement of life cycle and its requirement is lower during grain filling period than during preanthesis duration (Yoshida 1981). Thermal requirement of basmati rice is supposed to be further lower as compared to other rice varieties as the chemical responsible for aroma in the grains of these rice varieties are retained better under cool temperature, which are generally lost under higher temperature. That is why basmati rice is endemic to north India and East Pakistan because of lowering of temperature during grain filling period of basmati rice in these areas. Similarly, radiation requirement of rice plants varies with the growth stage of crop, which is reported to be the highest during reproductive growth phase followed by ripening and lowest during the vegetative growth phase (Yoshida 1981).

***Effect of high temperature and low radiation on growth and growth parameters of rice cultivars*:** Plant height is generally controlled genetically, but it is also influenced to some extent by the environment. Data presented in (Table 1) showed that plant height at maturity was higher under heat stress plus low light as compared to control plants. All thermal treatments showed greater plant height as compared to control ones. Irrespective of cultivars, plant height increased maximum in T_1 (23.8%) followed by T_2 (15%) and the least in T_3

Table 1. Phenology of basmati rice varieties under elevated temperature and low light (+3°C and 64 Klux light) in a glasshouse as compared to normal temperature under open condition (80 Klux light)

Variety	Plant height (cm)				Days to flowering				Days to maturity			
	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3
Basmati 370	132	164	157	136	81	76	76	81	133	126	128	131
Taraori Basmati	130	166	149	132	80	74	74	80	133	123	127	129
Basmati 386	124	152	145	129	58	54	54	58	106	99	102	103
Pusa Sugandh 2	133	157	148	131	75	70	70	75	126	121	121	126
Pusa Basmati 1	121	153	137	122	67	62	62	67	105	100	100	104
Mean	**128**	**158**	**147**	**130**	**72**	**67**	**67**	**72**	**121**	**114**	**116**	**119**
LSD at 5%	T=5.1, V=5.7, TxV=11.5				T=4.9, V=5.7, TxV=11.5				T=4.9, V=5.7, TxV=11.5			

(1.6%). Rice is a tropical plant and high temperature and low light condition can enhance plant growth and elongation of stem. This may be one of the reasons for the increased height observed under high temperature and low radiation conditions. Low radiation in glasshouse might have also contributed to greater stem elongation. This is in full agreement with the study of other investigators (Singh 2000, Peng *et al.* 2004, Sheehy *et al.* 2005)). Productive tiller percent was found to be highest in T_2 followed by T_1 and T_0. This may be due to initial higher tiller number followed by less tiller mortality resulting from exposure to favorable normal temperature after flowering (Table 4).

During flowering leaf area per pot was more in all thermal treatments compared to control. Leaf area per pot was maximum in T_1 followed by T_2 and T_3. T_1 showed maximum of 27.3% increase, whereas T_2 and T_3 showed 18.8% and 12.5% increase respectively over control. Under normal conditions (T_0) leaf area per pot was found to be the highest in Pusa basmati 1 followed by Basmati 386 and Pusa sugandh 2, while in treatment T_1, it was maximum in Basmati 370 followed by Taraori basmati and Pusa sugandh 2. In treatment T_2 the maximum was recorded in Basmati 386 followed by Taraori basmati and Basmati 370. The average leaf area was recorded to be highest under T_1 followed by T_2 and T_3. The highest increase (15%) in average leaf area was observed under T_1 followed by T_2 (12%) and T3 (4%) (Table 2). High temperature induced leaf area expansion in rice which may be due to its adaptation to tropical humid environments since its origin. The findings of Singh (2000), Peng *et al*. (2004) and Sheehy *et al*. (2005) while working with similar environments support the present findings.

Data presented in (Table 2) showed that the SLA at flowering invariably increased in all treatments compared to control. The SLA was highest in T_3, followed by T_2 and T_1. Increase was highest in T_3 (16%) followed by T_2 (14.4%) and lowest in T_1 (3.4%). SLW declined in all thermal treatments compared to control. This may possibly be due to increased leaf area owing to leaf length under high temperature as reported by Singh (2000).

Specific leaf weight (SLW) is the inverse of specific leaf area (SLA) and indicates the relative thickness of leaf lamina. SLW decrease may be due to increased leaf expansion and subsequently reduced thickness of the lamina. SLW was highest in T_0 followed by T_1, T_2 and T_3. Treatment T_2 and T_3 showed maximum decrease (12.9%) followed by T_1 (4.8%) with respect to T_0. In general length/breadth ratio was increased to varying extent by different heat stress treatments. It was recorded maximum in treatment T_2 followed by T_1 and T_3. Maximum increase in leaf weight ratio was noticed in T_2 (21%) followed by T_1 (19.4%) and T_3 (3.2%) (Table 2).

The stem dry weight was higher at all three growth stages (vegetative, flowering and maturity) in plants subjected to high temperature and low radiation irrespective of the variety. This may be due to the longer stem caused by increased plant height when subjected to hyper thermal and low light stress in glass house (+3^{0}C and 20% low light). Vegetative growth was found to increase when subjected to such stress. Stem dry weight was highest in T_1 followed by T_2 and T_0. Increase was highest in T_1 (49.2%) followed by T2 (42.1%) while in T_3 there was a decrease in stem dry weight/pot (Table 3). At flowering and maturity, the partitioning of organic nutrients was low due to improper grain filling under high temperature and low radiation condition, which might have accumulated in vegetative shoots and finally added to the dry weight of stem. All these account for increased stem dry weight under high thermal stress.

Leaf dry weight was found to be highest in T_1 followed by T_2 and T_3. There was an increase in leaf dry weight per pot in treatment T_1 and T_2 (22.4% and 19.4% respectively) compared to control. T_3 showed a decrease of 3.9% in leaf dry weight over control plants. Panicle dry weight per pot was highest in T_1 followed by T_2 and T_0. In treatment T_1 and T_2 the biomass increased as compared to control (45.1% and 33.7% respectively), while in T3, it was reduced slightly (1.2%). This may perhaps be due to the increased plant growth and biomass accumulation under high thermal and low light condition. The experimental findings of other researchers (Yoshida, 1981, Singh, 2000, Peng *et al.*

Table 2. Growth parameters of basmati rice varieties under elevated temperature and low light (+3^{0}C and 64 Klux light) in a glasshouse as compared to normal temperature under open condition (80 Klux light)

Variety	Leaf area / pot (cm²)				Av. leaf area (cm²)				Specific leaf area				Specific leaf weight				Length/width ratio			
	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3
Basmati 370	1706	3146	2441	2367	50	53	53	49	169	177	178	185	6.1	5.7	5.7	5.5	46	53	56	47
Taraori Basmati	1537	2770	2448	2646	39	43	42	42	150	174	187	193	6.7	5.8	5.4	5.3	44	53	53	45
Basmati 386	1835	2421	2366	2324	49	60	58	52	161	169	191	200	6.3	5.9	5.3	5.1	24	31	31	26
Pusa Sugandh 2	2335	2354	2543	2197	36	42	40	38	169	168	200	196	6.0	6.0	5.0	5.3	41	53	53	43
Pusa Basmati 1	2782	2289	2319	1911	29	35	34	31	175	165	187	182	5.8	6.1	5.4	5.8	40	44	44	41
Mean	**2040**	**2596**	**2423**	**2293**	**41**	**47**	**45**	**42**	**166**	**171**	**189**	**191**	**6.2**	**5.9**	**5.4**	**5.4**	**39**	**47**	**47**	**40**
LSD at 5%	T=295, V=330, TxV=450				T=4.9, V=5.7, TxV=11.5				T=8.41, V=9.4, TxV=18.8				T=0.4, V=0.5, TxV=1.2				T=4, V=6, TxV=12			

Table 3. Growth parameters of basmati rice varieties under elevated temperature and low light (+3^{0}C and 64 Klux light) in a glasshouse as compared to normal temperature under open condition (80 Klux light)

Variety	Stem weight/pot (g)				Leaf weight/pot (g)				Panicle weight (g)				Total biomass/pot (g)				Leaf weight ratio			
	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3
Basmati 370	20.3	36.1	32.3	21.3	10.0	14.7	13.9	12.8	4.9	5.8	5.7	5.5	35.2	56.5	51.9	39.6	0.28	0.26	0.27	0.32
Taraori Basmati	19.8	25.0	27.9	21.1	10.1	15.9	13.4	11.6	4.5	6.9	6.4	4.5	32.9	48.8	48.7	37.2	0.31	0.33	0.28	0.31
Basmati 386	15.0	25.1	24.7	16.9	11.2	14.3	12.7	11.6	4.4	6.3	6.9	4.3	29.6	48.7	45.3	31.8	0.38	0.29	0.28	0.36
Pusa Sugandh 2	20.3	26.3	21.0	17.5	13.7	14.0	12.8	11.0	4.4	6.4	5.0	3.9	37.6	45.2	39.8	31.8	0.36	0.31	0.32	0.35
Pusa Basmati 1	15.1	25.5	22.7	13.3	14.5	13.9	12.3	10.2	4.6	6.9	6.0	4.3	33.5	45.8	40.0	26.4	0.43	0.30	0.31	0.39
Mean	**18.1**	**27**	**25.7**	**18**	**11.9**	**14.6**	**13.0**	**11.4**	**4.6**	**6.5**	**6.0**	**4.5**	**33.8**	**49.0**	**45.1**	**33.4**	**0.35**	**0.30**	**0.29**	**0.35**
LSD at 5%	T=3.61,V=4.03,TxV=NS				T=NS, V=NS, TxV=NS				T=1.14,V=1.28, TxV=2.56				T=4.9, V=5.7, TxV=11.5				T=0.05, V=0.07,TxV=0.15			

2004, Sheehy *et al.* 2005) also support the above reason. Leaf weight ratio was found to be maximum in T_0 and T_3 followed by T_1 and minimum in T_2 (Table 3). The reason for increase in leaf weight ratio during maturity may possibly be due to poor translocation of photosynthates from vegetative shoots to grain because of poor sink development. Thus, instead of contributing to grain weight, the organic nutrients might have accumulated in leaves and added to its dry weight.

Effect of high temperature and low radiation on yield and yield attributes of rice cultivars: The number of panicle per pot was found to be similar in T_0 and T_3 followed by T_1 and the lowest was in T_2. It is reported that high temperature and low radiation had no detrimental effect on the production of reproductive shoots (panicles). Data shown in (Table 4) revealed that exposure of high temperature and low light stress during various growth phases of basmati rice varieties caused marked reduction in the number of spikelets per panicle when compared to control. The highest number of spikelets per panicle were recorded in T_0 followed by T_3, T_1 and T_2. The number of filled grains per panicle showed the trend in the order of T0>T3>T2>T1. The significant reduction in the number of grains/panicle was mainly due to marked increase in spikelet sterility as indicated in (Table 4) and also reported by Yoshida (1981), Singh (2000) and Matsui *et al.* (2000).

Exposure of rice plants to high temperature and low radiation during various growth phases showed maximum spikelet sterility in T1 and T2 when compared to control. There was a slight decrease in 1000 grain weight in treatment T1 and T2 (2.9% and 4.2% respectively) as compared to control (T_0), while T_3 showed an increase in the 1000 grain weight (1.7%). The least vulnerable character to high temperature and low light stress was 1000 grain weight, which showed non significant difference between high temperature and control conditions (Singh *et al.* 2010). Yoshida (1981) and Thanomthin *et al.* (2002) have observed that 1000 grain weight of rice was almost similar under diverse environments. This validates the above finding. The high thermal and low light stress caused significant increase in spikelet sterility, irrespective of rice variety. Satake and Yoshida (1978) and Yoshida (1981) reported that high temperature above 35^{0}C at flowering caused high percentages of spikelet sterility in rice. The occurrence of sterility could be attributed to disturbed pollen shedding and impaired pollen germination.

Maximum economic yield was recorded in T_3 followed by T_0 and T_2 and least in T_1. The observed trend for straw weight per pot was in the order of T1>T0>T2>T3, which indicates least thermal sensitivity of ripening growth phase of rice cultivars in respect of grain yield. Similar finding has been reported in a rice variety, Pusa 44 by Singh *et al.* (2010). Wheeler *et al.* (2000) showed that high thermal regime at the time of flowering can subsequently reduce the crop yield. Singh (2000) reported complete spikelet sterility and zero grain yield in rice under heat stress (38 ^{0}C). In general, temperature above 25^{0}C result in poor grain filling by reduced grain filling duration which in turn results in reduced grain yield. Baker *et al.* (1993) reported that grain yield declined with increasing temperature above 26^{o}C to zero yield near 36^{o}C. According to their estimation rice yield declined by about 10% for each 1^{o}C rise in daily mean temperature above 26^{o}C. IRRI (2004) reported grain yield reduction of about 10% for each 1^{o}C rise in daily mean temperature above 30^{o}C. Ziska *et al.* (1997) reported significant yield reduction for the cultivar IR 72 caused by a 4^{o}C rise in air temperature above ambient temperature. High temperature induced the final grain weight by a reduction in grain growth rate in the early or middle stages of grain filling (Morita *et al.* 2005). These studies validate the reason for reduced economic yield observed under the present study. It is clearly evident from the present findings that rice plants showed greater hyper thermal sensitivity during vegetative and reproductive growth phase as compared to ripening growth phase.

The biomass production of basmati rice varieties decreased significantly when subjected to high temperature and low radiation stress (Table 5). Maximum biological yield was registered in T_0 followed by T_3, T_1 and T_2. The photosynthates might have exhausted rapidly due to high respiration rate and so the biomass accumulation might have reduced remarkably. The reduction in biological yield by high thermal stress was mainly due to marked reduction in grain yield, as the vegetative mass (leaf and stem mass) was not much affected by heat stress. Wheeler *et al.* (2000) have

Table 4. Yield and yield attributes of basmati rice varieties under elevated temperature and low light (+3^{0}C and 64 Klux light) in a glasshouse as compared to normal temperature under open condition (80 Klux light)

Variety	Productive tiller (%)				No. of panicles/pot				No. of spikelets / panicle				No. of grains/panicle				Spikelet sterility (%)			
	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3
Basmati 370	70	85	78	71	22	19	20	18	103	100	86	115	97	23	71	94	11	16	20	18
Taraori Basmati	84	87	79	78	22	20	19	27	79	58	68	79	68	48	33	60	14	19	26	11
Basmati 386	81	81	75	64	16	28	14	19	91	64	92	86	60	16	56	56	33	74	42	35
Pusa Sugandh 2	76	75	82	84	24	16	24	24	102	75	54	68	74	36	34	58	27	50	42	15
Pusa Basmati 1	80	68	83	74	26	19	20	22	87	80	71	107	58	50	42	82	33	37	41	24
Mean	**78**	**79**	**80**	**74**	**22**	**20**	**19**	**22**	**92**	**76**	**69**	**89**	**71**	**34**	**47**	**70**	**24**	**39**	**34**	**21**
LSD at 5%	T=NS, V=5, TxV=6				T=2.5, V=2.8, TxV=5.6				T=9.6,V=10.8,TxV=21.1				T=9, V=10, TxV=20				T=7, V=8, TxV=15			

Table 5. Yield and yield attributes of basmati rice varieties under elevated temperature and low light (+3^{0}C and 64 Klux light) in a glasshouse as compared to normal temperature under open condition (80 Klux light)

Variety	1000 grain weight (g)				Grain weight/pot (g)				Straw weight/pot (g)				Biomass/pot (g)				Harvest index (%)			
	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3
Basmati 370	17	16	16	18	35.4	5.9	16.7	28.6	53.2	43.0	76.6	54.8	88.6	102	93.3	83.4	40	6	18	34
Taraori Basmati	18	18	17	20	23.5	16.3	8.9	32.7	54.1	50.0	54.4	55.5	77.6	66.3	63.3	88.2	30	25	14	37
Basmati 386	24	24	23	24	25.4	10.5	17.5	25.9	41.8	51.2	36.5	48.0	67.2	61.7	54.0	73.9	38	17	33	35
Pusa Sugandh 2	19	18	18	19	33.8	10.6	14.1	26.5	58.0	39.8	43.3	37.2	91.8	50.4	57.4	63.7	37	21	25	42
Pusa Basmati 1	19	19	20	19	28.5	18.4	16.7	33.6	42.8	38.2	37.6	40.4	71.3	56.6	54.3	74.0	40	33	31	45
Mean	**20**	**19**	**19**	**20**	**29.3**	**12.3**	**14.8**	**29.5**	**50**	**55.1**	**49.7**	**47.1**	**79.3**	**67.4**	**64.5**	**76.6**	**37**	**20**	**24**	**39**
LSD at 5%	T=NS, V=0.94,TxV=NS				T=3.5, V=4.5, TxV=7.94				T=4.5, V=5.5, TxV=10.9				T=4.9, V=5.7, TxV=11.5				T=5, V=6, TxV=12			

$\mathbf{T_0}$: Tillering to maturity under ambient temperature and radiation 80 Klux), $\mathbf{T_1}$: Tillering to maturity under high temperature and low radiation (+3ÚC and 64 Klux), $\mathbf{T_2}$: Tillering to flowering under high temperature and low radiation (+3 ÚC and 64 Klux), $\mathbf{T_3}$: Flowering to maturity under high temperature and low radiation (+3 ÚC and 64 Klux) shown that higher night temperature can increase the dark respiration of plants and thus diminishing net biomass production. Singh (2000) reported significant reduction in biological yield of rice by high thermal stress (38°C). Under the current study, plants were subjected throughout day and night to higher temperature than ambient ones. The maximum harvest index was noticed in T_3 and T_0 followed by T_2 and T_1. Poor grain development and diversion of nutrients from vegetative shoot to panicle may possibly be one of the reasons for poor harvest index in plants subjected to high temperature and low light stress.

Thus it is concluded from the above findings that basmati rice cultivars showed differential growth and yield sensitivity to rise in temperature and low radiation during different growth phases. The reduction in grain yield was mainly attributed to marked decline in the number of grains per panicle owing to enhancement in spikelet sterility. Such information may be useful while assessing the loss of yield under climatic variability, and helpful in selecting the rice genotype with least hyper thermal and low light sensitivity in grain yield.

REFERENCES

Baker, J.T. and Allen, L.H. Jr. (1993). Contrasting crop species responses to CO_2 and temperature: rice, soybean and citrus. *Vegetation,* **104/105:** 239-260.

Conroy, J. P., Seneweera, S., Basra, A.S., Rogers, G. and Nissel-Wooller, B. (1994). Influence of rising atmospheric CO_2 concentrations and temperature on growth, yield and grain quality of cereal crops. *Australian J. Plant Physiol*. **21:** 741.

Horie, T., Baker, J.T., Nakagawa, H., Matsui, T. and Kim, H.Y. (2000). In climate change and global crop productivity, eds. Reddy, K.R. & Hodges, H.F. (CAB International, Wallingford, U.K.), 81-106.

IRRI. (2004). Climate change. In: IRRI's Environmental Agenda–an approach towards sustainable development, pp 11-33, IRRI, Philippines.

Kim, H.Y., Horie, T., Nakagawa, H. and Wada, K. (1996). Effects of elevated CO_2 concentration and high temperature on growth and yield of rice. II. The effect on yield and its components of Akihikari rice. *Jap. J Crop Sci.* **65:** 644-651.

Matsui, T., Osama, K. and Horie, T. (2000). High temperature at flowering inhibits swelling of pollen rrains, a driving force for thecae dehiscence in rice (*Oryza sativa*). *Plant Prod. Sci.* **3:** 430-434.

Morita, S., Yonemaru, J., Takahashi, J. (2005). Grain growth and endosperm cell size under high temperature in rice (*Oryza sativa* L.). *Ann. Bot.* **95:** 695-701.

Peng, S., Huang, J., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X., Centino, G.S., Khush, G.S., and Cassman, K.G. (2004). Rice yields decline with higher night temperature from global warming. *Proc. Natl. Acad. Sci.* **101:** 9971-9975.

Satake, T., Yoshida, S. (1978). High temperature induced sterility in Indica rice at flowering. *Jap. J. Crop Sci.* **47:** 6-17.

Sheehy, J.E., Elmido, A., Centeno, G. and Pablico, P. (2005). Searching for new plants for climate change. *J. Agric. Met.* **60:** 463-468.

Singh, S. (2000). Growth, yield and biochemical response of rice cultivars to low light and high temperature humidity stress. *Oryza.* **37:** 35-38.

Singh, S., Aggarwal, P.K. and Yadav, R.N. (2010). Growth and yield response of rice under heat stress during vegetative, reproductive and ripening growth phases. IRRN, 0117-4185

Taiz, L. and Zeiger, E. (2009). Plant Physiology. Sinauer Associate Inc. Publication, Massachusetts, USA

Thanomthin, C., Zada, A. and Said, A. (2002). Effect of high temperature at heading stage on growth and yield of four rice varieties. *Sarhad J. Agric. Pakistan*, **18:** 291-294.

Wheeler, T.R., Craufurd, P.Q., Ellis, R.H., Porter, J.R. and Vara Prasad, V. (2000). Temperature variability and the yield of annual crops. *Agric. Eco. Environ.* **82:** 159-167.

Yoshida, S. (1981). Fundamentals of rice crop science. International Rice Research Institute, Los Banos, Philippines.

Yoshida, S., Forno, D.A., Cock, J.H. and Gomez, K.A. (1976). Laboratory manual for physiological studies of rice. Pp. 72, IRRI, Manila, Philippines.

Ziska, L.H., Namuko, G. and Quilang, J. (1997). Growth and yield response of field grown tropical rice to increasing carbon dioxide and air temperature. *Agro. J.* **89:** 45-53.