Influence of Temperature and Humidity on Physiology, Phenology and Yield Traits of Rice

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Abstract

Eighteen promising rice cultivars involving tall & semi dwarf plant types were grown with different transplanting dates to expose the crop at varying temperature & humidity range. The effects of temperature on physiological, growth & yield traits of different cultivars was noted. In general, thermal stress reduced the flag leaf area, leaf angle, canopy temperature, relative water content, membrane stability index, apparent translocation rate, chlorophyll content & reducing sugar in grains to varying extent in all the cultivars. Among the yield determining traits high temperature posed penalty through reduced panicle length, filled grains, and percentage seed set, seed filling, as well as the grain yield. Among the cultivars tested MR-185, Nippon bare, Shennong-89366 showed greater stability in growth & yield attributes & eventually recorded higher grain yield than those of others under varying transplanting dates & could be classified relatively more temperature tolerant cultivars for high temperature regions.

Temperature is one of the most important component of the anticipated climate changes that is likely to affect agriculture over the coming years. High temperatures during late post anthesis phase are a common feature of many cereals growing areas of the world like USA, Australia & India (Wardaw & Wrigley, 1994). Rise in global mean temperature along with altered humidity may further articulate the major constraints in realization of the potential yield of genotypes (Abrol *et al.* 1991). Post anthesis heat stress is known to influence the phenological and physiological traits. Increased temperatures is known to hasten the phenological development of the crop and reduce the grain filling period thus finally lowering the grain yield (Wang *et al.* 1997). Identification of contributing traits towards stability of yield performance would certainly be of great significance in order to stabilize and sustain the rice productivity. Efforts are being made to enhance the plant tolerance to high temperature environments through identification of cultivars with greater stability in physiological, growth & yield attributes. Studies conducted so for are mostly restricted to controlled condition as well as with limited materials. Thus, information on the response of new cultivars to high temperature is inadequate and keeping all these facts in view the present study was conducted to note influence of high temperatures on the physiological growth & yield attributing traits in high temperature regions.

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Materials and Methods

The experiment was conducted at the research farm, IGAU, Raipur (CG) consisted three transplanting dates to ensure the exposure of crop to varying temperature and humidity levels under dry season in the year 2005-2006. The experiment was laid out using Randomized Complete Block Design (RCBD) with three replications in each date of transplanting. The experiment was conducted with the rice varieties viz., Danteshwari, Dagad deshi, IR-36, Abhaya, mahamaya, Azucina, Poornima, Deshilal Dhan, Deshi no-17, MTU 1010, IR 42253, IR64, Shennong-89366, Nipponbare, Bamleshwari, MR-185, Bhata jhooli and Laloo-14. The observations were recorded on sixteen characters i.e., flag leaf area, leaf angle, canopy temperature, relative water content, membrane stability index, apparent translocation rate, total chlorophyll content, reducing sugar, panicle length, number of filled grains, number of unfilled grains, grain yield per plant, seed set, 1000 grain weight, sterility percent and harvest index.

Results and Discussion

Flag leaf area: The results (Table 1) related to flag leaf area showed reduced flag leaf area in both the treatments T_1 and T_2 (i.e. temperature stress and humidity at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). However, higher reduction among the treatments was recorded in T_1 (high temperature stress and humidity at one week after anthesis) (15.43%) over T_2. Among the varieties, Azucina registered highest flag leaf area reduction (38.62%) due to high temperature stress followed by IR-42253 (27.35%) with T_1. While the varieties MTU-1010 (19.50%) and Danteshwari (15.70%) appear to be the most sensitive for T2 (high temperature stress and humidity at two week after anthesis). The reduction in flag leaf area were recorded least in Deshilal dhan (1.29%) and IR-36 (4.31%) in T_1 but in T_2 minimum reduction was noticed in IR-64 (1.39%) and Bamleshwari (4.79%), respectively. Singh (2001) reported that flag leaf area was significantly reduced due to high temperature in wheat cultivars. The higher flag leaf area increases the grain yield and decreases spikelet sterility in rice (Ghosh and Saran, 1990). The amount of photosynthate present in second and third leaves was less when compared to flag leaf because the flag leaf supplies current photosythates mainly to the panicle at the time of grain filling. (Yoshida, 1981), lesser quantity of photosynthates was present in the second and third leaves which might also be due to translocation of photosynthates and nutrients preferentially to the flag leaf (Subbaramamma *et al.* 2005). Flag leaf area contributes significantly to grain yield in rice (Padmaja Rao, 1991). It was observed that average flag leaf area reduced in T_1 and T_2 (under high temperature at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). The maximum flag leaf area was observed in MR-185 and Nipponbare under T_1 and T_2 (at one week after anthesis and two week after anthesis). Highest reduction in flag leaf area was recorded in Bamleshwari along with highest yield reduction. Such result indicates that stability in flag leaf area under T_1 and T_2 (at one week after anthesis and two week after anthesis) contribute significantly to the yield.

Leaf angle : The results related to leaf angle showed that it reduced in both the treatments T_1 and T_2 (i.e. temperature stress and humidity at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). However, higher reduction among the treatment was recorded in T_1 (high temperature stress and humidity at one week after anthesis) (16.17%) over T_2. Among the varieties, IR-42253 registered highest reduction in leaf angle (42.77%) due to high temperature stress followed by Azucina (31.30%) with T_1 (at one week after anthesis). While the varieties Bamleshwari and Azucina (23.12% and 21.95%) appears to be the most sensitive for T_2 (high temperature stress and humidity at two week after anthesis). The reduction in leaf angle were recorded least varieties in Deshi No-17 (1.25%) and Deshilal dhan (1.36%) in T_1 but in T_2 minimum reduction was noticed varieties in IR-42253 (0.93%) followed by shennong-89266 (2.69%).

Canopy temperature : The results showed that canopy temperature was reduced in all the stages, however, maximum reduction was noticed in flowering stage. In T_1 treatment (high temperature at one week after anthesis) maximum reduction in canopy temperature was noticed varieties in Deshilal dhan (44.8%) followed by IR-36 (404%) and Bamleshwari (32.0%) while with T_2 maximum reduction was observed varieities in bhatajhooli (46.8%) followed by Deshilal dhan (43.1%). The minimum reduction in canopy temperature was noticed in varieties Danteshwari and MR-185 (0% and 5.0%) with T_1 while with T_2 it was observed minimum with varieties Deshi No-17, Mahamaya and IR-64 (1.9%, 4.3% and 9.3% respectively). Canopy temperature was increased with the advancement of high temperature stress. These results are in closer conformity with Singh *et al.*

Table 1: Influence of different dates of transplanting on physiological and yield parameters of rice cultivers

Rice Varieties	Flag leaf area (cm)			Leaf angle (⁰)			RWC (%)			ATR			TChC (mg⁻¹ g fresh wt.)			RS (%)			PL (cm)		
	T0	T1	T2	T0	T1	T0	T1	T2	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2	T0	T1	T2
Danteshwari	23.81	22.53	91.13	83.69	87.63	20.07	9.25	8.39	15.23	0.22	0	0.16	39.63	41.63	38	0.87	0.62	0.57	25.55	22.5	23.19
Dagad Deshi	29.66	27.8	87.29	87.13	85.98	26.27	15.49	13.36	13.51	0.29	0.61	0.07	38.66	40.46	39.7	0.83	0.63	0.56	23.67	21.53	21.36
IR-36	23.2	22.2	88.43	83.48	87.33	21.37	14.43	11.44	19.34	0.23	0.31	0.26	30.26	37.06	38.7	0.84	0.64	0.57	24.28	23.62	22.09
Abhaya	23.14	31.06	81.13	82.48	84.83	20.37	12.56	12.3	13.36	0.37	0.17	0.02	38.53	37.5	38.2	0.84	0.63	0.56	22.17	21.71	22.4
Mahamaya	34.34	35.6	81.61	83.37	83.62	31.63	15.25	10.67	12.45	0.05	0.15	0.26	42.53	37.4	40.53	0.87	0.64	0.57	24.3	22.52	20.77
Azucina	36.27	22.26	85.54	87.46	87.76	34.9	18.4	12.64	14.36	0.56	0	0.32	32.33	34.06	35.3	0.73	0.65	0.57	30.43	29.58	26.47
Poornima	20.42	36.74	91.22	86.61	88.7	17.28	10.63	9.64	15.21	0.22	0.03	0.26	41.31	39.22	39.73	0.74	0.66	0.59	22.18	22.24	22.1
Desilal Dhan	22.32	22.03	86.6	90.38	90.41	23.7	11.76	11.6	10.37	0.15	0.15	0.35	42.6	36.56	37.5	0.75	0.63	0.57	24.5	20.27	21.23
Desi No-17	36.14	36.2	86.97	92.84	90.54	36.36	13.5	13.33	12.46	0.88	0.72	0.18	37.3	32	34.33	0.75	0.65	0.57	21.55	24.41	23.32
MTU-1010	24.1	26.4	84.54	85.86	85.75	19.4	12.67	18.6	17.17	0.27	0.13	0.17	39.66	34.6	39.16	0.77	0.66	0.57	24.57	22.74	24.05
IR-42253	38.27	27.8	85.98	81.68	84.61	38.73	23.54	13.47	23.32	0.17	0.57	0.13	40.56	35.63	37.6	0.77	0.56	0.56	26.34	22.3	26.31
IR-64	25.02	35.96	90.18	87.41	90.71	24.67	16.54	23.71	19.55	0.05	0.23	0.73	38.46	41.36	38	0.82	0.55	0.57	22.48	22.4	24.61
Shennong-89366	30.05	22	90.68	87.08	88.62	30.67	17.08	22.61	16.62	0.14	0.02	0.57	25.6	28.53	27.43	0.76	0.56	0.53	19.62	19.69	20.62
Nipponbare	34.16	41.27	87.45	85.33	85.27	35.34	15.51	15.52	14.34	0.28	0.6	0.21	40.6	41.8	41	0.8	0.58	0.64	25.27	24.49	23.39
Bamleshwari	26.74	21.4	88.45	82.5	87.81	25.47	12.37	18.63	9.51	0.37	0.2	0.52	33.6	34	33.6	0.9	0.57	0.56	27.6	24.5	27.39
MR-185	39.33	39.73	76.48	76.45	78.54	40.37	19.33	20.22	21.24	0.42	0.25	0.51	43.24	40.76	37.21	0.86	0.63	0.54	23.37	22.53	22.13
Bhatajhooli	28.81	25.03	90.14	91.34	91.4	25.74	14.72	12.58	22.12	0.2	0.05	0.9	28.56	31.6	23.66	0.85	0.86	0.5	25.42	27.04	24.39
Laloo-14	31.4	27.87	84.78	87.28	89.7	26.75	19.48	16.02	16.52	0.23	0.32	0.71	33.63	38.4	32.66	0.62	0.65	0.5	21.33	20.32	17.4
Sem+	**1.16**	**1.15**	**1.56**	**1.28**	**1.38**	**1.17**	**0.27**	**0.31**	**0.38**	**0.01**	**0.01**	**0.007**	**0.26**	**0.81**	**0.27**	**0.06**	**0.03**	**0.05**	**0.24**	**0.41**	**0.42**
CD at 5%	**3.34**	**3.32**	**4.51**	**3.68**	**3.99**	**3.39**	**0.8**	**0.91**	**1.11**	**0.03**	**0.04**	**0.02**	**0.76**	**2.35**	**0.79**	**NS**	**NS**	**NS**	**0.71**	**1.2**	**1.22**

T0 - Control; T1 & T2 are high temperature and humidity stress at one and two weeks after anthesis, respectively.
RWC - Relative water content; ATR - Apparent translocation rate; TCHC - Total chlorophyll content; RS - Reducing sugar; PL - Panicle length

(1993). Ehrler and Van Buvel (1967) demonstrated that irrigated sorghum maintained leaf temperature 2°C to 6°C below air temperature has also been related to yield reduction in sorghum, spring wheat, pearl millet and rice. Diaz *et al.*(1983). Blum et.al. (1982) reported significant variation in leaf temperature of wheat breeding material under moderate to severe stress. The crop canopy air temperature of wheat breeding material under moderate to severe stress. The crop canopy air temperature differences (CCATD) in cotton decreased following irrigation because of leaf hydration.

Relative water content : The results of relative water content showed that it reduced in both the treatments T_1 and T_2 (i.e. temperature stress and humidity at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). However, higher reduction among the treatment was recorded in T_1 (high temperature stress and humidity at one week after anthesis) (4.01%) over T_2. Among the varieties, Danteshwari registered maximum reduction in relative water content (8.16%) due to high temperature stress followed by Bamleshwari (6.72%) with T_1. While the varieties Danteshwari and Shennong-42253 (3.84% and 2.27%) appeared to be the most sensitive for T_2 (high temperature stress and humidity at two weeks after anthesis). The reduction in relative water content was recorded least in varieties MR-185 (0.03%) and Dagad deshi (0.18%) in T_1 but in T_2 minimum reduction was noticed in Bamleshwari (0.72%) and IR-42253 (1.59%) respectively). Singh *et al.* (2004) reported increase in relative water content under early planting as compared to late planting due to high temperature that significantly reduced relative water content values which were recorded in late planting as compared to early planting.

Membrane stability index : The results of membrane stability index showed reduction in both the flowering and maturity stages. At the flowering stage, however higher reduction among the treatments was recorded in T_2 (high temperature stress and humidity at two week after anthesis) (19.57%) over T_1. Among the varieties, IR-36 (40.10%) registered highest reduction in membrane stability due to high temperature stress followed by Mahamaya (25.88%)and IR-42253 (22.54%) with T_1 while the varieties Azucina (45.40%) and IR-42253 (40.81%) appeared to be most sensitive at T_2 (high temperature stress and humidity at two weeks after anthesis). The reduction in membrane stability were observed least in varieties IR-64 (3.36%) and Deshi No-17 (3.72%) with T_1 but in T_2 minimum reduction was noticed varieties Laloo-14 in (16.47%) and Deshi No-17 (20.21%) respectively. At the maturity stage, however, higher reduction among the treatments was recorded in T_2 (high temperature stress and humidity at two weeks after anthesis) (19.19%) over T_1. Among the varieties, IR-42253 (18.13%) registered highest reduction in membrane stability which was noticed due to high temperature stress followed by Laloo-14 (15.02%) with T_1, while the varieties Desilal dhan (35.25%) and MTU-1010 (34.16%) appeared to be the most sensitive for T_2 (high temperature stress and humidity at two weeks after anthesis). The reduction in membrane stability was observed least in varieties Bamleshwari (0.44%) and MR-185 (0.35%) with T_1 but in T_2 minimum reduction was noticed varieties Bhatajhooli (7.40%) and Bamleshwari (13.16%) respectively. Deshmukh *et al.* (2000) reported that delay in planting resulted in higher % membrane injury or lower membrane stability at all the stages of growth and development, the increase being more in released varieties than advanced line under thermal stress. Islam et.al. (1998) reported that membrane injury was higher in delayed planting at all the phenophases. The delay in planting of wheat resulted in increased % membrane injury (higher ion leakage). Similar views have been expressed by Singh (2004).

Apparent translocation rate : The results related to apparent translocation rate showed that apparent translocation rate from stem was increased under both the treatments T1 and T2 (high temperature conditions at one week after anthesis and week after anthesis) as compared to T0 (control). Under T1 and T2 (high temperature stress at one week after anthesis and two weeks after anthesis) the highest increase in stem apparent translocation rate was observed in Mr-185 and Nipponbare as compared to other varieties. The increase in apparent translocation rate from stem under both T_1 and T_2 (high temperature stress at one week after anthesis and two week after anthesis) might be due to the lower availability of current photosynthates. Under such conditions plant is forced to depend on pre anthesis stored assimilates from stem under both T_1 and T_2 compared to T_0. The higher stem apparent translocation rate can be associated with yield stability in MR-185 and Nipponbare. Higher stem apparent translocation rate can be associated with yield stability in MR-185 and Nipponbare. Higher rate of dry matter translocation from stem under high temperature stress was also reported by Lu *et al.* (1998) in rice. An increase in stem apparent translocation rate under high temperature was related with yield stability particularly under reproductive stage high temperature (Kumar *et al.* 2000).

Total chlorophyll content : The results related to total chlorophyll content showed reduced chlorophyll content in both the treatments T_1 and T_2 (i.e. temperature stress and humidity at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). However, higher reduction was recorded in T_1 among the treatment (high temperature stress and humidity at one week after anthesis) (9.84%) over T_2. Among the varieties, Deshi No-17 registered highest chlorophyll content reduction (14.20%) due to high temperature stress followed by Deshilal dhan and MTU-1010 (14.17% and 12.75% respectively) with T_1. While the varieties Bhatajhooli and MR-185 appeared to be the most sensitive for T_2 (17.15%) and 13.94%) at two weeks after anthesis (high temperature stress and humidity). The reduction in chlorophyll content were recorded least in varieties Abhaya, Poornima and MR-185 (2.67%, 5.05% and 5.73% respectively) in T_1 but in T_2 minimum reduction was noticed in varieties Bamleshwari and Abhaya (0% and 0.85%). Singh *et al.* (2004) reported that total chlorophyll content was significantly reduced in late planting throughout the growth period as compared to early and medium planting due to high temperature in chickpea. Similar findings have been reported by Rajeswari (1995), Sharma *et al.* (2003) and Babitha *et al.* (2006). Overall decrease in chlorophyll and photosynthesis under high temperature stress in mainly correlated with the decline in chlorophyll and damage to photosynthesis (Arad and Richmand, 1976; Turner and Barch, 1982).

Reducing sugar : The results related to reducing sugar in stem showed that reducing sugar was reduced in both the treatments T_1 and T_2 (i.e. high temperature and humidity at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). However, higher reduction among the treatments was recorded in T_2 (high temperature stress and high humidity at two weeks after anthesis) (29.25%) over T_1. Among the varieties, Bamleshwari registered highest reduction in reducing sugar (36.66%) due to high temperature stress followed by Shennong-89366 (32.92%) and Danteshwari (28.73%) with T_1. While the varieties Bhatajhooli and Bamleshwari (41.17%) and 37.77%) appeared to be the most sensitive with T_2 (high temperature stress and high humidity at two weeks after anthesis). The reduction in reducing sugar was recorded least varieties, Poornima and Deshilal dhan (10.95% and 10.81%) in T_1 but in T_2 minimum reduction was noticed varieties, Laloo-14 and Nippon bare (19.35% and 2.0%) respectively. Michael and Tharnton (2002) reported that high temperature reduced specific gravity in stem and of tuber is often associated with high levels of reducing sugars. Singh (2000) reported that high temperature stress and humidity, however caused marked depletion in the level of total reducing sugar in rice.

Panicle length : The results related to panicle length showed that it reduced in both the treatments T_1 and T_2 (i.e. high temperature and humidity at one week after anthesis and two weeks after anthesis) as compared to To(control). However, higher reduction among the treatments was recorded in T_2 (high temperature stress and humidity at two weeks after anthesis) (7.67% over T_1. Among the varieties, Deshilal dhan registered highest reduction in panicle length (17.26%) due to high temperature stress followed by IR-42253 (15.33%) and Danteshwari (11.93%) with T_1 while Laloo-14 (18.42%) and Mahamaya (14.52%) appeared to be the most sensitive varieties with T_2 (high temperature stress and high humidity at two weeks after anthesis). The reduction in panicle length was recorded least in varieties IR-64 (0.35%) followed by Abhaya (2.07&) and IR-36 (2.71%) in T_1 but in T_2 minimum reduction was noticed in varieties IR-42253 (0.11%) followed by Poornima (0.36%) and Bamleshwari (0.76%). Singh *et al.* (2001) reported that panicle length was significantly reduced due to high temperature in wheat cultivars. Similar findings have been reported by Singh (2000).

Number of filled grains : The number of filled grains was reduced in both the treatments T_1 and T_2 (i.e. temperature and humidity at one week after anthesis) as compared to T_0 (control). However, higher reduction among the treatment was recorded in T_2 (high temperature and humidity at two weeks after anthesis) (18.64%) over T_1. Among the varieties Bhatajhooli registered highest reduction in number of filled grains (23.51%) due to high temperature stress followed by Bamleshwari (19.47%) and MTU-1010 (15.90%) with T_1 while the varieties Bamleshwari (33.04%) and Batajhooli (29.18% appeared to be the most sensitive for T_2 (high temperature stress and humidity at two weeks after anthesis). The reduction in number of filled grains was recorded least varieties in Deshilal dhan (2.97%) followed by Dagad Deshi (4.14%), IR-64 (5.53%) and MR-185 (5.59%) in T_1 but in T_2 minimum reduction was noticed varieties in IR-64 (5.53%) asnd MR-185 (5.59%) in T_1 but in T_2 minimum reduction was noticed varieties in IR-64 (9.09%) and IR-42253 (10.98% respectively). MR-185 and Nipponbare could be classified as relatively more temperature tolerant as highest stability in number of filled grains was recorded in both the environment with the exposure of crop to high temperature. Baker *et al.* (1995) also reported that the same trend of filled grains was observed with increasing temperature due to decrease in number of filled grains/panicle while Shukla *et al.* (1997) reported that the relatively more tolerant genotype exhibited lesser reduction in dry matter partitioning to the developing seeds. This might be due to a lesser reduction in number of filled grains during critical period i.e. II and III week of grain filling. As regular assimilate supply is concerned, the stem reserve mobilizations was also found to be more in relatively tolerant genotype during the critical phase of grain filling under heat stress. Similar findings have been reported by Patel (1976).

Number of unfilled grains : The results related to number of unfilled grains showed that number of unfilled grains was increased in both the treatments T_1 and T_2 (i.e. high temperature and humidity at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). However, increase among the treatments was pronounced in T_2 (high temperature stress and humidity at two weeks after anthesis) over T_1. Among the varieties, Abhaya registered highest increase in number of unfilled grains (96.39) due to high temperature stress followed by IR-42253 (96.20) and Poornima (65.61) with T_1 while the varieties IR-42253 (141.85), Abhaya (101.10) and Bhatajhooli (76.01) appeared to be the most sensitive for T_2 (high temperature stress and humidity at two week after anthesis). The increase in number of unfilled grains were recorded least in varieties Dagad Deshi (28.23), Deshi No-17 (30.33) and IR-64 (32.14) in T_1 but in T_2 negligible increase was noticed in varieties Dagad Deshi (36.29), MTU-1010 (37.30) and IR-64 (38.41) respectively. Zakria *et al.* (2002) also reported that the same trend of increase in number of unfilled grains with increased temperature (32°C to 40°C at harvesting) resulted decrease in panicle weight and increase in the number of unfilled grains. Similar views have been expressed by Singh (2000).

Grain yield plant : The results related to grain yield plant showed that grain yield plant reduced in both the treatments T_1 and T_2 (i.e. high temperature and humidity at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). However, higher reduction among the treatment was recorded in T_2 (high temperature and high humidity at two weeks after anthesis) (19.70%) over T_1. Among the varieties IR-36 registered highest reduction in grain yield plant (24.30%) due to high temperature stress followed by Bamleshwari (22.73%) and Mahamaya (21.39%) with T_1 while the varieties Mahamaya (36.99%), Bamleshwari (32.78%) and Danteshwari (31.68%) appeared to be the most sensitive for T_2 (high temperature stress and humidity at two weeks after anthesis). The reduction in grain yield plant was recorded least varieties IR-64 in (2.45%), Deshilal dhan (2.64%) and Nippon bare (3.36%) in T_1 but in T_2 minimum reduction was noticed varieties in Abhaya (4.89%), MTU-1010 (7.35%) and Dagad deshi (11.39%) respectively. MR-185, Nipponbare, Shennong-89366 and Poornima could be classified as relatively more temperature tolerant as highest stability in seed yield was recorded in both the environment with the exposure of crop to high temperature. Baker *et al.* (1995) also reported that the same trend of yield decrease with increasing temperature due to decrease in number of filled grains panicle while Horie *et al.* (1995) explained that floret sterility is the main cause of yield reduction due to high temperature stress Nagarajan and Raney (1997) also found that high temperature is a key constraint for rice yield in heat stress environment. Findings of Shukla *et al.* (1997) also suggested that in more tolerant genotypes less reduction in dry matter partitioning takes place. It could be attributed to less reduction in yield components (grain number). Findings of Deshmukh *et al.* (1996) are also in harmony with the other scientist reported earlier. The results showed that higher grain yield of MR-185 and Nipponbare under T_1 and T_2 (high temperature at one week after anthesis and two weeks after anthesis) might be due to maintenance of flag leaf photosynthesis, membrane thermostability, apparent translocation rate, stem sugar mobilization and days to anthesis and days to maturity (grain filling period). The lower yield of Bamleshwari under T_1 and T_2 (at one week after anthesis and two weeks after anthesis) could be associated with low yield.

Seed set : The results related to seed set % showed that it reduced in both the treatments T_1 and T_2 (i.e. high temperature and humidity at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). However, higher reduction among the treatments was recorded in T_2 (high temperature stress and humidity at two weeks after anthesis) (9.42%) over T_1. Among the varieties, Desi laldhan registered highest reduction (10.86%) in seed setting % due to high temperature stress followed by IR-36 (9.96%) and Bamleshwari (8.47%) with T_1 while the varieties Desilal dhan (18.65), MTU-1010 (16.74%) and Bamleshwari (10.69%) appeared to be the most sensitive for T_2 (high temperature stress and high humidity at two week after anthesis). The reduction in seed set % was recorded least in varieties Bhatajhooli (0.78%), IR-64 (1.54%) and Azucina (1.54%) in T_1 but in T_2 minimum reduction was noticed in varieties IR-42253 (3.74%) and Bhatajhooli (3.90%) respectively. Ziska and Manalo (2006) suggested that higher night temperature per se could increase the susceptibility of rice to sterility with a subsequent reduction in seed set and grain yield.

1000 grain weight : The results of 1000 grain weight showed reduction in 1000 grain weight in both the treatments T_1 and T_2 (i.e. high temperature and humidity at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). However higher reduction among the treatment was recorded in T_2 (high temperature stress and high humidity at two weeks after anthesis) (4.19%) over T_1. Among the varieties, Mahamaya (6.45%) registered highest reduction in 1000 grain weight due to high temperature stress followed by Danteshwari (5.62%) and Azucina (5.35%) with T_1 while the varieties Mahamaya (9.03%), MR-185 (8.08%) and Danteshwari appeared to be the most sensitive for T_2 (high temperature stress and reduction humidity at two weeks after anthesis). The reduction in 1000 grain weight was recorded least in varieties MTU-1010 (0.32%), Deshilal dhan (0.34%) and IR-36 (0.71%) with T_1 but in T_2 minimum reduction was noticed varieties in IR-64 (0.09%) Laloo-14 (0.48%), Bhatajhooli (0.61%) and Deshilal dhan (0.64%) respectively. Shpiler and Blum (1991) reported that reduction in grain weight in response to heat stress during grain growth was related to reduction in grain growth rather than growth rate. Morita *et al.* (2002) observed that due to high temperature during day and night in rice, there is decrease in average grain weight Mehra *et al.* (1991) reported that under high temperature exposure was given during II and III weeks after anthesis there was significant reduction in grain weight in wheat. Singh *et al.* (2001) reported that the general hyper thermal stress caused reduction of 1000 grain weight in rice cultivars. Shukla *et al.* (1997) reported that under terimal heat stress the relatively more tolerant genotype exhibit less reduction in dry mater partitioning to the developing seeds. This happens due to less reduction in yield component like grain number and grain weight. Similar findings have been reported by Chopra and Chopra (2004).

Sterility percent : The results related to sterility % showed increased sterility % in both the treatments T_1 and T_2 (i.e. high temperature and humidity at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). However, higher increase among the treatments was recorded in T_2 (high temperature stress and humidity at two weeks after anthesis) over T_1. Among the varieties, IR-42253 (46.16) registered highest increase in sterility % due to high temperature stress followed by Deshilal dhan (39.12) and IR-36 (36.36) with T_1 while the varieties Abhaya (57.16), IR-42253 (56.34) and Bamleshwari (49.38) appears to be the most sensitive for T_2 (high temperature stress and humidity at two weeks after anthesis). The increase in sterility % was recorded least in varieties Nipponbare (18.13) MTU-1010 (22.20) and IR-64 (23.15) with T_1 but in T_2 minimum increase was noticed varieties in Nipponbare (25.10), MTU-1010 (28.34) and Shennong-89366 (30.21) respectively. Rowland *et al.*(1996) reported that induction of complete spikelet sterility in rice by high temperature and humidity. Grover *et al.* (2000) reported that the high temperature causes pollen and spikelet sterility in rice. Similar views have been expressed by Singh (2000). Sato (1960) observed that high temperature even upto 100% during the hot, dry season (April and May) due to the failure of pollination under high temperature. Patel (1976) reported more than 80% sterility at high temperature in wheat cultivars. Similar findings have been reported by Vankateswarlu *et al.* (1977). Grover *et al.* (2000) reported that high temperature causes pollen and spikelet sterility in rice. This effect of high temperature at the time of anthesis is so fatal that even 1^0C rise in ambient temperature for just one hour can lead to a high level of spikelet sterility, high temperature stress causes a significant degree of loss in grain production.

Harvest index : The results related to harvest index showed reduction in both the treatments T_1 and T_2 (i.e. high temperature and humidity at one week after anthesis and two weeks after anthesis) as compared to T_0 (control). However, higher reduction among the treatments was recorded in T_2 (high temperature stress and humidity at two week after anthesis) (19.29%) over T_1. Among the varieties, IR-36 (27.21%) registered highest reduction in harvest index.due to high temperature and high humidity followed by Bamleshwari (25.64%) and Mahamaya (22.88%) with T_1 while the varieties Mahamaya (38.30%), Danteshwari (31.39%) and Dagad deshi (30.26%) appears to be the most sensitive for T_2 (high temperature stress and humidity at two week after anthesis). The reduction in harvest index was recorded least in varieties IR-64 (1.81%), Shennong-89366 (5.61%) and Laloo-14 (6.16%) with T_1 but in T_2 minimum reduction was noticed in varieties Laloo-14 (4.61%), MTU-1010 (5.41%) and Poornima (7.30%) respectively. Singh *et al.* (2001) reported that thermal stress caused reduction of harvest index in wheat cultivars. Similar findings have been reported by Singh (2000).

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