Environment and Ecology 40 (3C) : 1643—1652, July—September 2022
ISSN 0970-0420

Physico-Biochemical Growth Responses of DIfferent Rice Genotypes to Elevated Heat Stress

Kabita Saikia, P. C. Dey, Sangita Das

Received 12 March 2022, Accepted 11 June 2022, Published 26 August 2022

ABSTRACT

The present experiment was taken up entitled 'Physico-biochemical growth responses of different rice genotypes to elevated heat stress', at Regional Agricultural Research Station, AAU, Titabar during *kharif* 2017 in split-plot design with treatments (control and high temperature stress) as main plot treatments and 33 genotypes as sub-plot treatments. The high temperature treatment was imposed by covering the one set of genotypes with polyethylene sheet to raise the temperature and allowed to grow inside the enclosure from panicle initiation until physiological maturity. The increase in maximum temperature was 1-3.5^{0}C over the ambient temperature and minimum temperature had increased by 0.5-1.5^{0}C. The elevated temperature showed significant decrease in leaf weight, stem weight and effective tiller number. The mean grain yield declined by 28% under heat stress condition followed by harvest index (4%) and test weight (15%). The number of filled grains per panicle is an important yield determining character which was significantly affected by high temperature stress. The sterility percentage were minimum (2-7%) for 175-2K, S-458, IET 26778 under heat stress. From the studies, it is concluded that superior performance in terms of crop phenology, morphological, physiological and biochemical traits, reproductive characters and yield components were significantly affected by the high temperature stress and such affects varied with rice genotypes. The varieties 175-2K, S-458, IET 26778 reflected the inherent capabilities to tolerate high temperature stress with less reduction in grain yield and yield components and grain sterility percentage, could be used as a donor in various breeding program and adopted in farmer's field to increase the economic yield.

Keywords Rice, Heat stress, Total dry matter, Harvest index, Yield.

Kabita Saikia[1]*, Sangita Das[3]
[1]Research Schalor,
Department of Crop Physiology
Assam Agricultural University, Jorhat 785013, Assam, India

P. C.Dey[2]
[2] Principal, Scientist
Regional Agricultural Research Station, Titabar, Jorhat,Assam, India
Email : kabitasaikia75@gmail.com
*Corresponding author

INTRODUCTION

Rising temperature are posing serious threat to global rice production (Schleussner *et al.* 2018). Conversely, frequent occurrence of heat waves reported at regional scale in last decade had catastrophic impact on agricultural crop production across the globe (Kadam *et al.* 2014). The impact of rising temperature in production of rice leading to reduce its yield irreversibly. Elevated CO_2 and heat stress during flowering and early grain filling significantly reduced seed-set and 1000 grain weight, respectively (Chaturvedi *et al.* 2017). It also reduces grain quality of rice during grain filling stage. The overall effects of multiple climate variables on yield depend on both the sensitivity of yield to the climate variables and the magnitude of change in the climate variables, where temperature and solar radiation duration plays a crucial role in affecting rice growth and productivity (Tao *et al.* 2012). Global climatic predictions indicated increased frequency of heat spikes and warmer nights, exerting additional challenges towards achieving higher crop yields (IPCC 2013). Sensitive phases of growth and development of rice and wheat crops may lead to drastic reduction in economic yield above 35^0C. Enormous amount of green house gases are increasing every day due to both natural and anthropogenic activities that leads to gaseous emissions of carbon dioxide, methane, chlorofluorocarbons and nitrous oxide, which gradually increase world's average ambient temperature. Heat stress due to high ambient temperature effect inevitably on crop production worldwide.

Thus, keeping in view the effect of high temperature stress on different Sali rice genotypes the present investigation was carried out with the objective to identify the significance of genetic variability in thermo-tolerance.

MATERIALS AND METHODS

The study was conducted in the Regional Agricultural Research Station, Titabar during the year 2017 in *kharif* season. The meteorological data during crop season is shown in Fig 1. A total of 33 genotypes which were collected from Indian Institute of Rice Research, Hyderabad were included in the study and it was conducted in split plot design with treatments as main plot and genotypes as sub plot. Two sets of rice genotypes were kept, one for control and the other one for imposing high temperature stress. One month old rice seedlings were transplanted in two blocks or stripes, one for control and another block for imposing heat stress by covering the block with polythene sheet (<92% transmittance), supported by bamboo sticks like a tunnel immediately after panicle initiation stage until maturity. The increase in maximum temperature was 1-3.5^0C over the ambient temperature and minimum temperature had increased by 0.5-1.5^0C. Control block was kept uncovered. Each entry was sown in 3 rows of 3 m length maintaining 20 cm spacing between rows and plant to plant distance. Each row was treated as a replication and all the observations were recorded for each row separately. A minimum-maximum thermometer was installed inside the tunnel and both minimum and maximum temperatures were recorded everyday inside the tunnel. Similarly a max-min thermometer was kept outside for recording both temperatures everyday outside the tunnel as shown in Fig 2.

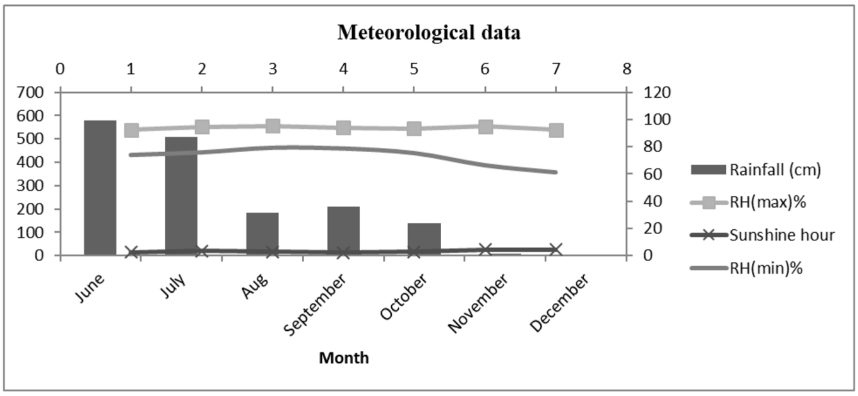

Fig. 1. Meteorological data during crop season 2017.

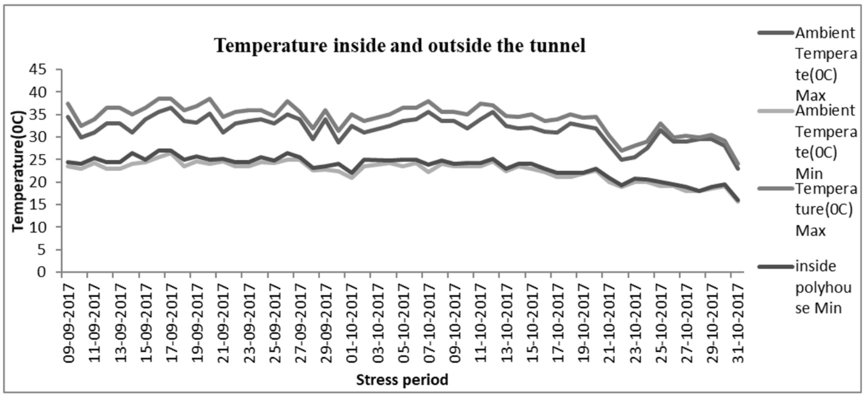

Fig. 2. Temperature inside and outside polythene tunnel during reproductive stage of the crop.

Parameters recorded

Leaf weight: After removing the leaf blade, leaf weight were taken and expressed in g/m^2.

Stem weight: After removing leaf sheath and leaf blade, above ground parts were dried and weight was recorded in g/m^2.

Effective tiller number per hill: Panicle bearing tillers were counted at flowering stage and expressed as tiller number per hill.

Total dry matter (TDM): Total dry matter was obtained by adding leaf weight, panicle weight and stem weight from each replication in both control and treated set at flowering and maturity stage.

Grain yield: At physiological maturity, panicles from both the treated and ambient condition were harvested, sun dried, threshed, winnowed, cleaned and weight of grains were taken and expressed in g m^{-2}.

Harvest index (HI) = Harvest index was calculated to quantify the yield of a crop versus the total amount of biomass. Harvest index of rice was worked out by using the following formula

HI (%) = Grain yield/ (Grain yield + Straw yield) x 100.

Panicle number per sq meter: The number of panicles per sq meter in rice per replication in both control and treated sets were taken in all genotypes.

Grain number per panicle: At the time of harvest, panicles were collected randomly from each replication and filled grains were counted in each panicle and average was taken for record.

Spikelet number per panicle: Both filled and unfilled grains per panicle were collected from each replication.

Chlorophyll content

Chlorophyll content was estimated in leaves by colorimetric method suggested by Arnon (1949).

Nitrate reductase activity

In vivo nitrate reductase (NR, EC 1.6.6.1) activity was estimated spectrophotometrically at 540 nm (Thimmaiah, 1999).

Determination of starch

Starch content was determined by Anthrone method (McCready *et al.* 1950).

Test weight: Test weight (g) was recorded by weighing 1000 filled grains from plant after harvest.

Table 1. Effect of high temperature stress on leaf weight , stem weight and effective tiller number hill^{-1}.

	Leaf weight , stem weight, effective tiller number hill^{-1}								
	Leaf weight (gm^{-2})			Stem weight (gm^{-2})			Effective tiller no./hill		
Genotypes	Control	High temperature	Per cent reduction	Control	High temperature	Per cent reduction	Control	High temperature	Per cent reduction
IET 26755	105.33	80.00	24.05	247.33	160.00	35.31	11.67	10.00	14.29
IET 26756	138.67	104.00	25.00	348.33	220.00	36.84	11.00	9.67	12.12
IET 26757	122.67	91.00	25.82	344.33	225.00	34.66	11.33	10.00	11.76
IET 26758	100.00	75.00	25.00	250.33	160.00	36.09	10.00	8.67	13.33
IET 26759	134.33	100.00	25.56	357.33	230.00	35.63	12.33	10.67	13.51
IET 26760	101.33	72.67	28.29	341.33	220.00	35.55	7.00	6.00	14.29
IET 26761	141.33	104.00	26.41	321.67	210.00	34.72	8.67	7.67	11.54
IET 26762	81.00	55.00	32.10	196.67	120.00	38.98	6.00	5.00	16.67
IET 26763	153.33	123.00	19.78	358.33	240.00	33.02	11.67	10.33	11.43
IET 23354	106.33	85.00	20.06	299.33	170.00	43.21	12.67	11.00	13.16
IET 24911	139.33	110.00	21.05	249.33	180.00	27.81	9.00	8.00	11.11
IET 24914	128.00	100.00	21.88	265.33	220.00	17.09	11.00	9.67	12.12
IET 24904	133.00	105.00	21.05	314.33	170.00	45.92	12.67	11.00	13.16
IET 26764	126.33	100.00	20.84	254.33	210.00	17.43	10.00	8.67	13.33
IET 26765	115.67	90.00	22.19	297.33	220.00	26.01	9.00	8.00	11.11
IET 26766	150.67	115.00	23.67	311.67	221.00	29.09	9.33	8.00	14.28
IET 26767	106.00	81.33	23.27	312.67	260.00	16.84	9.67	8.67	10.34
IET 26768	160.67	125.00	22.20	380.33	200.00	47.41	7.33	6.33	13.64
IET 26771	128.33	102.67	20.00	294.33	248.33	15.63	12.33	10.67	13.51
IET 26772	162.67	126.00	22.54	412.33	281.67	31.69	9.00	8.00	11.11
IET 26773	85.67	60.00	29.96	209.33	130.00	37.90	6.00	5.00	16.67
IET 26774	151.00	140.00	7.28	277.33	250.00	9.86	10.67	9.67	9.37
IET 26775	128.67	118.33	8.03	255.33	227.67	10.84	11.00	10.00	9.09
IET 26776	169.00	158.00	6.51	422.00	390.00	7.58	8.67	8.00	7.70
IET 26777	114.67	103.00	10.17	290.33	260.00	10.45	12.00	11.00	8.33
IET 26778	170.00	160.00	5.88	421.67	392.00	7.04	13.00	12.00	7.69
IET 26780	150.00	135.00	10.00	320.33	280.00	12.59	14.00	13.00	7.14
IET 24705	148.00	131.00	11.49	280.67	245.00	12.71	11.33	10.33	8.82
Gontra Bidhan-3	128.00	115.00	10.16	320.00	290.00	9.38	14.67	13.67	6.82
IET 24708	104.33	92.00	11.82	217.33	190.00	12.58	8.33	7.67	7.99
175-2K	171.00	164.00	4.09	430.67	405.00	5.96	13.33	12.00	10.00
S-458	180.00	170.00	5.56	479.33	454.00	5.29	11.00	10.00	9.09
N22	184.33	175.00	5.06	506.00	480.00	5.14	14.67	13.67	6.82
Mean	133.93	111.09	17.05	320.83	247.26	22.9	10.62	9.46	10.92
		CD (0.05)	SEd (±)		CD (0.05)	SEd (±)		CD (0.05)	SEd (±)
Mainplot		0.307	0.066		0.261	0.056		NS	0.58
Subplot		0.392	0.198		0.468	0.236		0.94	0.47
Subplot at same level of mainplot		0.596	0.28		0.688	0.334		NS	0.67
Mainplot at same level of subplot		0.603	0.284		0.687	0.334		NS	0.88

Sterility: Sterility was recorded by subtracting grain number per panicle from spikelet number per panicle and expressed in percentage.

RESULTS AND DISCUSSION

The uninterrupted heat stress (3-4^{0}C over the ambient temperature) caused distinct decrease in leaf weight, stem weight and effective tiller number hill^{-1} that are presented in Table 1. A significant difference in effective tiller number hill^{-1} was noted among the tested cultivars.

High temperature stress reduced 17% leaf weight

Table 2. Effect of high temperature stress on total dry matter, grain yield and harvest index.

	Total dry matter (g/m^2)			Grain yield (gm^{-2})			Harvest index (%)		
Genotypes	Control	High temperature	Per cent reduction	Control	High temperature	Per cent reduction	Control	High temperature	Per cent reduction
IET 26755	1240.33	900.00	27.44	426.67	300.00	29.69	34.40	33.33	1.07
IET 26756	1090.67	864.33	20.75	398.00	304.67	23.45	36.49	35.25	1.24
IET 26757	1022.67	871.33	14.80	410.00	354.00	13.66	25.85	21.61	4.23
IET 26758	1185.67	980.00	17.35	372.33	258.00	30.71	31.40	26.33	5.08
IET 26759	799.00	706.33	11.60	325.00	200.00	38.46	40.68	28.32	12.36
IET 26760	1022.67	871.33	14.80	264.33	188.33	28.75	25.85	21.61	4.23
IET 26761	1186.00	980.00	17.37	363.33	201.67	44.50	30.64	20.58	10.06
IET 26762	799.00	706.33	11.60	296.00	134.00	54.73	37.05	18.97	18.08
IET 26763	1275.00	910.00	28.63	442.00	300.00	32.13	34.67	32.97	1.70
IET 23354	1219.33	940.00	22.91	439.67	330.00	24.94	36.06	35.11	0.95
IET 24911	1116.33	856.33	23.29	359.67	234.33	34.85	32.22	27.37	4.85
IET 24914	1219.33	940.00	22.91	412.67	256.00	37.96	33.84	27.23	6.61
IET 24904	1242.33	999.00	19.59	434.33	265.00	38.99	34.96	26.53	8.43
IET 26764	1233.33	832.67	32.49	450.00	268.33	40.37	36.49	32.23	4.26
IET 26765	1277.33	971.33	23.96	420.00	315.00	25.00	32.88	32.43	0.45
IET 26766	1326.00	1096.33	17.32	325.67	190.67	41.45	24.56	17.39	7.17
IET 26767	1329.00	1050.00	20.99	363.33	280.00	22.94	27.34	26.67	0.67
IET 26768	1368.33	900.33	34.20	420.00	270.00	35.71	30.69	29.99	0.70
IET 26771	1329.00	1050.00	20.99	343.33	263.00	23.40	25.83	25.05	0.79
IET 26772	1410.00	1100.33	21.96	485.00	375.00	22.68	34.40	34.08	0.32
IET 26773	842.67	672.67	20.17	218.33	115.00	47.33	25.91	17.10	8.81
IET 26774	1316.00	979.00	25.61	426.67	256.67	39.84	32.42	26.22	6.20
IET 26775	1227.67	957.33	22.02	329.00	248.00	24.62	26.80	25.91	0.89
IET 26776	1450.00	1250.00	13.79	475.67	390.00	18.01	32.81	31.20	1.61
IET 26777	1338.33	782.67	41.52	430.33	250.00	41.91	32.15	31.94	0.21
IET 26778	1445.00	1300.00	10.03	456.00	400.00	12.28	31.56	30.77	0.79
IET 26780	1175.33	861.33	26.72	421.00	266.67	36.66	35.82	30.96	4.86
IET 24705	1190.33	1022.67	14.09	398.67	321.67	19.31	33.49	31.45	2.04
Gontra Bidhan-3	1296.33	1100.00	15.15	320.33	260.00	18.83	24.71	23.64	1.08
IET 24708	1164.00	861.67	25.97	322.00	226.67	29.61	27.66	26.31	1.36
175-2K	1500.00	1350.00	10.00	507.00	450.00	11.24	33.80	33.33	0.47
S-458	1450.00	1310.00	9.66	487.00	430.00	11.70	33.59	32.82	0.76
N22	1480.00	1380.00	6.76	520.00	460.00	11.54	35.14	33.33	1.80
Mean	1229.30	980.40	20.24	395.85	283.71	28.32	31.88	28.12	3.76
		CD (0.05)	SEd (±)		CD (0.05)	SEd (±)		CD (0.05)	SEd (±)
Mainplot		0.31	0.06		0.04	0.01		0.08	0.01
Subplot		0.46	0.23		0.28	0.14		0.03	0.01
Subplot at same level of mainplot		0.69	0.33		0.39	0.2		0.07	0.02
Mainplot at same level of subplot		0.69	0.33		0.39	0.19		0.09	0.03

significantly as compared to control. The reduction was lowest in 175-2K, S-458, N22, IET 26778. The decreased leaf weight was due to reduction in green leaf area resulted from rapid increase of senescence under elevated temperature (Rahman *et al.* 2009). Under, high temperature stress due to altered cell division and cell elongation rates, leaf size and weight were affected. Although the cultivars showed noticeable variations in response to heat stress in respect of stem weight, but it revealed the similar pattern of change in all genotypes. Severe heat stress decreased stem growth, stem characters such as stem weight, stem density might play an important role in stabilization of grain yield. High temperature stress reduced stem weight (22.9%) at flowering stage as compared to control. N22, S-458, 175-2K showed lower reduction (5%) as compared to control. The reduction in effective tiller number $hill^{-1}$ might be

Table 3. Effect of high temperature stress on yield components.

	Panicle number m^{-2}, Grain number panicle^{-1}, spikelet number panicle^{-1}								
	Panicle number m^{-2}			Grain number panicle^{-1}			Spikelet number panicle^{-1}		
Genotypes	Control	High temperature	Per cent reduction	Control	High temperature	Per cent reduction	Control	High temperature	Per cent reduction
IET 26755	294.67	241.33	18.10	129.67	86.00	33.67	157.00	112.33	28.45
IET 26756	235.67	189.33	19.66	143.33	95.00	33.72	170.00	122.00	28.23
IET 26757	233.33	204.33	12.43	157.33	114.00	27.54	183.33	140.00	23.64
IET 26758	251.67	220.00	12.58	157.33	114.00	27.54	183.33	140.00	23.64
IET 26759	282.00	243.33	13.71	166.33	122.33	26.45	193.33	150.00	22.41
IET 26760	293.00	250.00	14.68	113.67	89.33	21.41	140.67	116.00	17.54
IET 26761	273.00	238.33	12.70	113.67	89.33	21.41	140.67	116.00	17.54
IET 26762	203.00	143.33	29.39	93.33	41.67	55.36	123.67	70.00	43.40
IET 26763	281.33	245.67	12.68	146.00	120.00	17.80	172.33	145.67	15.47
IET 23354	280.33	240.00	14.39	126.67	101.33	20.00	154.00	127.67	17.09
IET 24911	244.33	215.00	12.01	120.00	100.33	16.39	145.67	127.33	12.59
IET 24914	265.67	230.00	13.43	132.67	117.67	11.31	156.67	144.67	7.66
IET 24904	273.67	240.00	12.30	120.00	100.33	16.39	145.67	127.33	12.59
IET 26764	266.67	220.00	17.50	152.67	128.33	15.94	179.33	155.00	13.57
IET 26765	255.33	220.67	13.58	119.67	97.67	18.38	146.67	124.00	15.45
IET 26766	287.33	250.67	12.76	142.00	119.33	15.96	168.67	146.00	13.44
IET 26767	275.67	240.00	12.94	157.67	133.00	15.64	184.00	160.00	13.04
IET 26768	298.33	251.67	15.64	160.00	126.67	20.83	186.00	151.67	18.46
IET 26771	260.00	220.00	15.38	136.33	107.33	21.27	163.33	134.00	17.95
IET 26772	276.00	245.00	11.23	167.67	141.00	15.90	194.00	167.33	13.75
IET 26773	213.33	170.00	20.31	110.00	60.00	45.45	140.00	90.00	35.71
IET 26774	234.67	200.00	14.77	166.67	134.67	19.19	193.66	161.00	16.86
IET 26775	235.33	200.00	15.01	157.00	121.67	22.51	183.33	148.67	18.91
IET 26776	300.33	267.00	11.10	215.67	204.00	5.41	233.33	223.33	4.29
IET 26777	277.33	234.67	15.38	171.00	141.00	17.54	194.00	167.33	13.75
IET 26778	300.33	266.67	11.21	240.00	228.00	5.00	257.67	246.00	4.53
IET 26780	284.67	237.33	16.63	215.67	204.00	5.40	233.33	223.33	4.28
IET 24705	245.67	210.00	14.52	166.67	152.33	8.60	193.33	180.00	6.89
Gontra Bidhan-3	280.33	230.00	17.95	146.00	120.00	17.81	172.33	145.67	15.47
IET 24708	240.33	205.33	14.56	149.67	134.67	10.02	175.67	162.00	7.78
175-2K	312.67	273.67	12.47	255.00	243.33	4.58	272.67	260.67	4.40
S-458	305.00	272.00	10.82	240.00	228.00	5.00	257.67	246.00	4.53
N22	303.00	280.33	7.48	255.00	243.33	4.58	272.67	260.67	4.40
Mean	268.61	230.17	14.3	158.92	132.11	16.8	183.88	157.32	14.4
		CD (0.05)	SEd (±)		CD (0.05)	SEd (±)		CD (0.05)	SEd (±)
Mainplot		0.68	0.14		22.25	4.8		5.21	1.12
Subplot		0.60	0.30		21.16	10.68		14.81	7.47
Subplot at same level of mainplot		0.97	0.43		NS	15.11		NS	10.57
Mainplot at same level of subplot		1.01	0.45		NS	15.63		NS	10.47

due to exposure of plants to severe heat stress. High temperature stress reduced (10.9%) of effective tiller number per hill significantly as compared to control. Lower reduction were found in N22, Gontra Bidhan -3, IET 26780, IET 26778, IET 26776, IET 26777, IET 26774, IET 26775, S-458, 175-2K, IET 24705, IET 24708 within the range of 6-10% compared to control. Higher reduction (>16%) were observed in IET 26773 and IET 26762. The contrast between cultivars could be due to differences in genetic potential. The results to a greater extent revealed that most of the genotypes had small differences because stress was imposed during reproductive phase. Our results are in conformity with Ahamed *et al.* (2010). They opined that sowing time mediated heat stress reduced the number of tillers in wheat. Djanaguiraman *et al.*

Table 4. Effect of high temperature stress on leaf chlorophyll content, nitrate reductase in leaf and starch content in grain.

	Chlorophyll content, Nitrate reductase, Starch content								
	Chlorophyll content (mg g^{-1}fw)			Nitrate reductase (µ mole NO_2^- g^{-1} fw hr^{-1})			Starch (mg g^{-1} DW)		
Genotypes	Control	High temperature	Per cent reduction	Control	High temperature	Per cent reduction	Control	High temperature	Per cent reduction
IET 26755	2.47	1.59	35.71	2.16	1.69	21.65	60.20	50.17	16.67
IET 26756	2.43	2.12	12.77	2.10	1.50	28.47	61.10	50.83	16.80
IET 26757	2.98	1.64	45.07	2.15	1.78	17.23	61.67	51.07	17.19
IET 26758	2.93	2.09	28.77	2.43	2.10	13.69	62.13	52.17	16.04
IET 26759	3.01	2.72	9.54	2.24	1.97	12.19	59.11	50.07	15.30
IET 26760	2.94	2.19	25.43	2.45	2.16	11.73	62.33	52.23	16.20
IET 26761	2.59	1.87	28.00	2.37	2.05	13.39	61.07	51.07	16.38
IET 26762	1.89	1.43	24.22	2.33	1.85	20.37	57.33	50.73	11.51
IET 26763	2.87	2.27	20.82	2.60	2.00	23.08	58.33	52.07	10.74
IET 23354	2.52	2.07	17.76	2.28	1.94	14.80	61.67	50.50	18.11
IET 24911	2.77	1.78	35.67	2.32	2.00	14.03	60.67	50.17	17.31
IET 24914	2.62	2.34	10.58	2.36	2.07	12.53	63.14	53.43	15.38
IET 24904	2.83	2.15	24.13	2.29	1.91	16.70	57.33	50.13	12.56
IET 26764	2.78	2.43	12.59	2.26	1.91	15.51	57.17	50.30	12.01
IET 26765	2.95	2.11	28.58	2.30	1.91	16.93	61.33	51.17	16.58
IET 26766	2.63	2.52	4.18	2.41	2.16	10.26	63.50	60.17	5.25
IET 26767	2.52	1.73	31.27	2.49	2.14	14.16	60.67	50.30	17.09
IET 26768	3.00	2.00	33.50	2.84	2.51	11.42	60.17	50.50	16.08
IET 26771	2.59	2.50	3.48	2.53	2.29	9.26	62.43	58.10	6.94
IET 26772	3.08	1.60	48.05	2.46	2.00	18.58	62.87	58.83	6.42
IET 26773	1.98	1.50	24.24	2.34	1.74	25.64	60.33	51.10	15.30
IET 26774	2.55	2.42	5.22	2.35	2.16	8.20	60.29	51.17	15.14
IET 26775	3.06	2.40	21.59	2.41	2.08	13.46	63.00	60.10	4.60
IET 26776	3.16	2.92	7.51	2.78	2.55	8.27	64.67	58.07	10.21
IET 26777	2.74	2.50	8.66	2.88	2.65	7.98	60.50	51.80	14.38
IET 26778	3.24	3.00	7.41	2.86	2.65	7.25	61.57	53.10	13.75
IET 26780	3.08	2.72	11.60	2.78	2.59	6.83	58.17	48.07	17.36
IET 24705	2.10	1.80	14.29	2.43	2.04	16.17	57.40	48.10	16.20
Gontra Bidhan-3	3.16	2.97	6.01	2.51	2.20	12.46	57.00	49.27	13.57
IET 24708	2.51	2.17	13.65	2.30	2.00	13.04	58.83	48.33	17.85
175-2K	2.57	2.38	7.39	2.57	2.23	13.01	59.13	52.20	11.72
S-458	3.21	2.92	9.03	2.49	2.20	11.75	56.03	49.17	12.25
N22	3.16	2.89	8.46	2.87	2.68	6.62	63.83	57.17	10.44
Mean	2.75	2.23	18.9	2.45	2.11	13.87	60.45	52.17	13.70
		CD (0.05)	SEd (±)		CD (0.05)	SEd (±)		CD (0.05)	SEd (±)
Mainplot		0.31	0.06		NS	0.12		0.49	0.10
Subplot		0.38	0.19		0.35	0.17		1.07	0.54
Subplot at same level of mainplot		0.58	0.27		NS	0.25		1.56	0.77
Mainplot at same level of subplot		0.59	0.27		NS	0.27		1.55	0.76

(2010) confirmed that in wheat green leaf area and productive tillers/plant were significantly reduced under high temperature stress.

Table 2 revealed that significant differences in TDM among the genotypes, treatments and interaction. The extent of decrease in TDM was (20.2%) as compared to control. The reduction in total dry matter was due to reduced leaf number, leaf area index and increased leaf senescence. Under high temperature stress in rice plants, lower photosynthetic activity, loss of turgor, lower photochemical efficiency were observed which caused significant declines in total dry matter content. High temperature stress reduced total dry matter or biomass production in maize (Zhang *et al*. 2013). The reduction in TDM was lowest in N22, 175-2K, S-458 and IET 26762. The elevated temperature reduced 28.32% grain yield compared to control. The exposure with increase of 1˚C seasonal average temperature, grain yield of cereals decreased by 4.1 to 10% (Wang *et al.* 2012). The unpropitious effect of heat stress in grain yield was minimum in N22, 175-2K, S-458, IET 26778 and IET 26757 (11-14%) compared to control. A significant decrease (4%) was observed in harvest index due to heat stress during grain filling stage denoting poor carbon partitioning into the developing grains. The reduction in HI was lower in IET 26755, IET 26756, IET 26757, IET 26758 and IET 26760. According to Prasad *et al.* (2011), spring wheat plants showed a significant reduction under elevated temperature (31/18°C) in harvest index (24%) as compared to optimum temperature (24/14°C).

High temperature did affect significantly on panicle no/m^2 (Table 3). High temperature stress reduced 14.3% panicle number/m2 significantly as compared to control. Due to increased number of sterile spikelet a significant reduction was observed in panicle number under elevated temperature stress imposed at reproductive stage had been reported earlier (Sailaja *et al.* 2015). Lower reduction was pronounced in N22, S-458, IET 26776, IET 26778 and IET 26772. A significant reduction of 16% with respect to ambient temperature in grain no/panicle was observed in genotypes grown under the high temperature stress. The possible reason might be due to reduction in number of filled grains with increased grain sterility. Prasad *et al.* (2011) observed that spring wheat plants grown under HT (31/18°C) showed a significant reduction in number of grains spike^{-1} as compared to optimum temperature (24/14°C). Genotypes like 175-2K, N22, IET 26776, IET 26778, IET 26780, S-458 and IET 24705, the reduction is relatively low which was within 4-10% compared to control. There were significant variations in respect of spikelet number panicle^{-1} among varieties and treatments but interaction was non-significant. High temperature stress increased the number of unfilled grains with greater reduction in filled grains per panicle. Lower reduction in spikelet number panicle-1 were observed in 175-2K, N22, IET 26776, IET 26778, IET 26780, S-458, IET 24705, IET 24708 (4-10%) compared to control.

Chlorophyll content at flowering was decreased which could be considered an indicator of heat injury and most sensitive physiological process to heat stress (Gosavi *et al.* 2014). High temperature stress reduced (18.9%) of chlorophyll content compared to control condition (Table 4). Less reduction were found in IET 26759, IET 26766, IET 26771, IET 26774, IET 26776, IET 26777, IET 26778, Gontra Bidhan-3, 175-2K, S-458 and N22 compared to control. One of the major reasons for reduction in chlorophyll content under heat stress might be due to enhanced activity of chlorophyllase, an enzyme that catalyses chlorophyll by removing the phytol group which result in chlorophyllide formation. On exposure to heat stress, a reduction in total chlorophyll content was reported in rice (Kumar *et al.* 2012). There was decrease in NR activity under high temperature stress

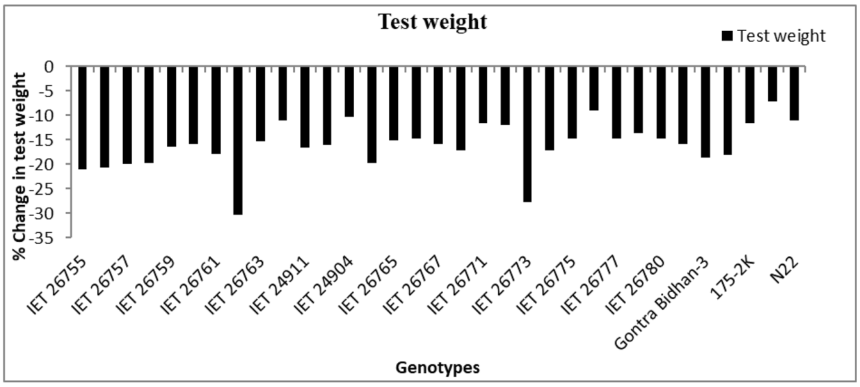

Fig. 3. Effect of high temperature stress on test weight.

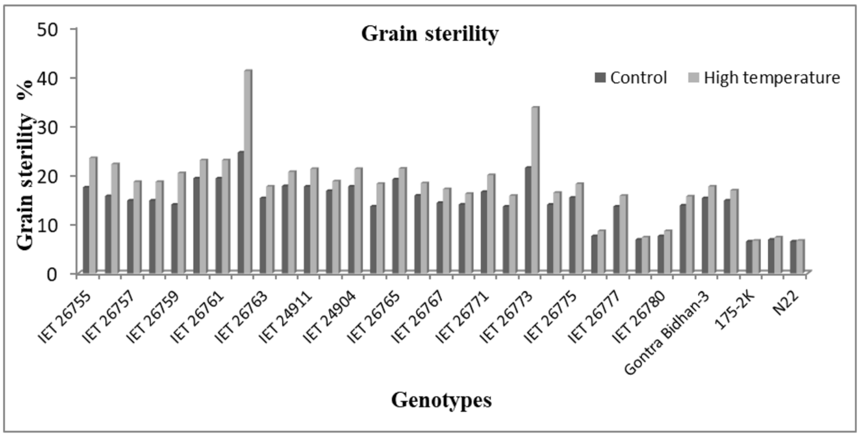

Fig. 4. Effect of high temperature stress on grain sterility.

condition. Less reduction were 0.3-10% observed in the varieties viz. 175-2K, N22, S-458, IET 26774, IET 26766, IET 26767, IET 26771 and IET 26760. Whereas, greater reduction were observed in the varieties viz. IET 26762, IET 26763, IET 26755, IET 26756 with >20% compared to control. It is shown, that the rise of temperature was accompanied by sharp decrease of activity nitrate reductase in leaves of winter wheat, apparently, occurred for the account deactivations of enzyme and due to its dissociation (Ayub *et al.* 2020). NRA acts as an essential enzyme in nitrogen metabolism and reduction of its activity affects it, which subsequently disturbs the synthesis of proteins and enzymes and also biomass production in plants. Significant decrease was also observed in case of starch content in grain under high temperature stress. The extent of reduction in starch was upto 13% compared to control. Less reduction were found in IET 26763, IET 26766, IET 26771, IET 26772, IET 26775, IET 26776, N22 compared to control. Due to reduced activity of sucrose phosphate synthase, ADP-glucose pyrophosphorylase, and invertase under elevated temperature, starch and sucrose synthesis were greatly affected (Djanaguiraman *et al.* 2009). Kaneko *et al.* 2014 reported that nucleotide pyrophosphatase or phosphodiesterase were up-regulated and had a great influence on starch accumulation under high temperature conditions mainly in the heat sensitive genotype.

Exposure to heat stress resulted in reduced test weight (Fig.3). According to Arshada *et al.* (2017), under high temperature a shortened grain filling period was noted which reduced the grain weight. Test weight might be reduced due to impaired conversion from sucrose to starch. The reduction was lowest in S-458, IET 26776, 175-2K, N22, IET 26772, IET 26771, IET 23354 and IET 24904 compared to control.

Exposure to high temperature had induced grain sterility (Fig. 4) in rice and due to decreased ability of pollen grains to swell resulting in poor anther dehiscence. There were significant variations among varieties, the lowest sterility was recorded in 175-2K, N22 (6.65%) followed by S-458, IET 26778 (7.31%) and IET 26776, IET 26780 (8.59%). Ahamed *et al* (2010) also reported, high temperature treatment (>33°C) at heading stage significantly reduced anther dehiscence and pollen fertility rate, leading to reduction in the number of pollens on the stigma which were the causes of reduced fertilization and subsequent spikelet fertility and sterile seed in rice where the sensitive varieties were more susceptible to this occurrence compared to the tolerant varieties.

From the foregoing discussion, under the present scenario of climate change, it could be concluded that, among the tested varieties 175-2K, S-458, IET 26778 were found physiologically efficient against high temperature stress condition. These three varieties had least reduction in grain yield and yield attributes among all tested varieties. Therefore, these varieties could be further used as donors in various breeding program indicating its adaptability for growing in the future years.

REFERENCES

Ahamed KU, Nahar K, Fujita M, Hasanuzzaman M (2010) Variation in plant growth, tiller dynamics and yield components of wheat (*Triticumae stivum* L.) due to high temperature stress. *Adv Agric Bot.* 2(3). In press.

Arnon DS, Morachan YB, Murugesan M (1971) Response of IR8 paddy strain to fertilizer in Coimbatore. *Madras Agricult J* 58(3): 379-384.

Arshada MS, Farooqa M, Aschb F, Jagadish SVK, Vara Prasad, PV, Siddique HMK (2017) Thermal stress impacts reproductive development and grain yield in rice. *Pl Physiolo Biochem1*15: 57-72.

Ayub M, Ashraf M, Kausar A, Saleem S, Anwar S, Altay V, Ozturk M (2020) Growth and physico-biochemical responses of maize (*Zea mays* L.) to drought and heat stresses. *Pl Biosyst- an Int J Dealing with all Aspects of Pl Biol*. 155(3) : 535-542

Chaturvedi AK, Bahuguna RN, Shah D, Pal M, Jagadish SK (2017) High temperature stress during flowering and grain filling offsets beneficial impact of elevated CO^2 on assimilate partitioning and sink-strength in rice. *Scientific Rep*. 7: 8227.

Djanaguiraman M, Annie Sheeba J, Durga Devi D, Bangarusamy U (2009) Cotton leaf senescence can be delayed by nitrophe nolate spray through enhanced antioxidant defence system. *J Agron Crop Sci* 195(3): 213-224.

Djanaguiraman M, Prasad PV, Seppanen M (2010) Selenium protects sorghum leaves from oxidative damage under high temperature stress by enhancing antioxidant defense system. *Pl Physiol Biochem* 48(12): 999-1007.

Gosavi GU, Jadhav AS, Kale AA, Gadakh SR, Pawar BD, Chimote VP (2014) Effect of heat stress on proline, chlorophyll content, heat shock proteins and antioxidant enzyme activity in sorghum (*Sorghum bicolor*) at seedling stage. *Ind J Biotech* 14: 356-63.

IPCC (2013) Working Group I contribution to the IPCC fifth assessment report on climate change 2013: The Physical Science Basis, Summary for Policymakers. pp 1-28.

Kadam NN, Xiao G, Melgar RJ, Bahuguna RN, Quinones C, Tamilselvan A, Prasad PVV, Jagadish KS (2014) Agronomic and physiological responses to high temperature, drought, and elevated CO_2 interactions in cereals. *Adv Agron* 127: 111–156.

Kaneko K, Inomata T, Masui T, Koshu T, Umezawa Y, Itoh K, Pozueta-Romero J, Mitsui T (2014) Nucleotide pyrophosphatase/ phosphodiesterase 1 exerts a negative effect on starch accumulation and growth in rice seedlings under high temperature and CO_2 concentration conditions. *Pl Cell Physiol* 55: 320-32.

Kumar S, Gupta D, Nayyar H (2012) Comparitive response of maize and rice genotypes to heat stress: Status of oxidative stress and antioxidants. *Acta Physiol Pl*. 34: 75-86.

McCready RM, Gugglog J, Silveria V, Owens HS (1950) Determination of starch and amylase in vegetables. *Anal Chem* 22:156-158.

Prasad PVV, Pisipati SR, Momcilovic I, Ristic Z (2011) Independent and combined effects of high temperature and drought stress during grain filling on plant yield and chloroplast EF-Tu Expression in spring wheat. *J Agron Crop Sci* 197: 430-441.

Rahman MA, Chikushi J, Yoshida S, Karim AJMS (2009) Growth and yield components of wheat genotypes exposed to high temperature stress under control environment. *Bangladesh J Agricult Res.* 34(3): 360-372.

Sailaja B, Subrahmanyam D, Neelamraju S, Vishnukiran T, Rao YV, Vijayalakshmi P, Mangrauthia SK (2015) Integrated physiological, biochemical and molecular analysis identifies important traits and mechanisms associated with differential response of rice genotypes to elevated temperature. *Frontiers Pl Sci* 6: 1044.

Schleussner CF, Deryng D, Müller C, Elliott J, Saeed F, Folberth C, Liu W, Wang X, Pugh TAM, Thiery W, Seneviratne SI, Rogelj J (2018) Crop productivity changes in 1.5 °C and 2 °C worlds under climate sensitivity uncertainty. *Environ Res Lett* 13: 064007.

Tao F, Zhang S, Zhang Z (2012) Spatiotemporal changes of wheat phenology in China under the effects of temperature, day length and cultivar thermal characteristics. *Eur J Agron* 43: 201-212.

Thimmaiah SK (1999) Standard method of Biochemical analysis. Kalyani Publisher, New Delhi pp 228-230.

Wang X, Cai J, Liu F, Jin M, Yu H, Jiang D, Cao W (2012) Pre-anthesis high temperature acclimation alleviates the negative effects of post-anthesis heat stress on stem stored carbohydrates remobilization and grain starch accumulation in wheat. *J Cereal Sci* 55(3): 331-336.

Zhang X, Cai J, Wollenweber B, Liu F, Dai T, Cao W, Jiang D (2013) Multiple heat and drought events affect grain yield and accumulations of high molecular weight glutenin subunits and glutenin macropolymers in wheat. *J Cereal Sci* 57(1): 134-140.