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SHORT COMMUNICATION

VARIATION IN PHYSIOLOGICAL TRAITS FOR THERMOTOLERANCE IN WHEAT

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The wheat cultivars grown under elevated temperature of 3.5^{0}C showed significant increase in average leaf area (LA), leaf area per shoot, leaf weight ratio (LWR) and leaf length, whereas it reduced the specific leaf weight (SLW), leaf width, plant height, total dry weight and days to flowering and maturity of wheat cultivars. The mean grain yield declined by 36% under warmer condition, which was attributed to maximum reduction in biological yield (35%) followed by grain growth rate per spike (24%), number of grains/spike (20%), number of spikes/pot (12%), 1000 grain weight (4%) and harvest index. The biological and economic yields of wheat were reduced at the rate of about 10% per ^{0}C increase in temperature. Amongst the cultivars, C 306, K 68, Kundan, HD 2329 and HD 2687 manifested higher productivity under warmer condition. High temperature also increased nitrogen content both in leaf and stem at flowering and maturity as well. However, the content of total sugar reduced drastically in shoots both at flowering and maturity stages. The starch content, however, increased markedly in leaf both at flowering and maturity.

Key words: **Biological yield, harvest index, heat stress, leaf weight ratio, specific leaf weight**

The global atmospheric temperature is likely to increase between 1.8 - 4.0 °C by the end of 21st century (IPCC, 2007). It can reduce the growth, productivity and quality of crops through hastening the rate of developmental processes, shortening of crop growth duration and reduction in yield attributes (Gibson and Paulsen 1999, Reddy and Hodges 2000, Singh *et al*. 2001, Tahir and Nakata 2005). Wheat cultivars show marked variability in heat tolerance for grain growth and yield (Prakash *et al*. 2003, Singh *et al.* 2001, 2003). High temperature stress has been reported to enhance the content of chlorophyll a and b, and organic nitrogen, but reduces the level of sugars, starch, RNA, and hemi-cellulose and modifies the level of cellulose in rice genotypes (Singh 2000). In order to offset the adverse effects of global warming on crop production, genotypes capable of coping with the stresses associated with climate change need to be examined (Chauhan *et al.* 2005). Keeping in view the significance of genotypic variability in heat tolerance, promising wheat cultivars widely differing in phenological behaviour were assessed for sensitivity to heat stress.

A pot experiment was conducted with fifteen wheat (*Triticum aestivum* L.) cultivars comprising traditional tall (C 306 and K 68), semi-dwarf (Sonalika, Kalyansona, HD 2285, HD 2329, Kundan, HD 2687, HD 2643, UP 2338, PBW 343, DL 1266-1, DL 1266-2 and DT 46) and dwarf (Moti) during the year 2007-08 at IARI, New Delhi to assess the effect of warming (+3.5 ^{0}C) on their growth, yield and morpho-physiological traits. Seeds of all the fifteen cultivars were sown separately in cement pots (30x30x30 cm) filled with sandy loam soil and pre-fertilized with one-fourth dose of N and full dose of P and K with ten pots of each cultivar. After sowing, five pots of each cultivar were kept as normal under ambient condition and rest five pots were transferred to the glass house, which remained warmer (+3.5 ^{0}C) than the ambient condition throughout the crop growing period. Remaining three-fourth dose of N was applied in three splits at tillering, panicle initiation and Booting stages. Plant sampling was done both at flowering and maturity stages for recording various morphological, physiological, biochemical, growth and yield parameters. Nitrogen, total sugars and starch contents were estimated following Yoshida *et al*. (1976). The remobilization of nitrogen, total sugar and starch was calculated in terms of their percent depletion in shoots from flowering to maturity. The daily maximum and minimum temperature of both ambient and glasshouse were recorded using maximum-minimum thermometer throughout the growing season of wheat plants.

The growth and morphological characters of shoot at anthesis presented in Table 1 & 2 revealed that continuous exposure of heat stress (+3.5°C) caused marked increase in mean leaf weight ratio (55%), leaf area per shoot (17 %), leaf length (11%) and average leaf size (4%), while reduced the total dry weight per pot (48%), specific leaf weight (19%), leaf width (13%) and plant height (7%) of wheat plants at flowering. The marked increase in leaf weight ratio under heat stress (55%) indicates an increase in the proportion of leaf weight (source) to total biomass. The extent of increase in the length of leaves (11%) was almost at par to the extent of decrease in leaf width (14%) under warmer condition. Although the cultivars showed marked degree of variation in their response to heat stress in respect of leaf traits, but the pattern of change under warmer condition was similar in almost all the cultivars (Table 1 & 2). Such type of heat stress induced changes in leaf characters of wheat cultivars have been reported by Singh *et al.* (2001 & 2003).

Table 1. Effect of heat stress on plant height and leaf characters of wheat cultivars at anthesis stage.

Cultivar	Plant height (cm)			Av. leaf size (cm^2)			Leaf area/shoot (cm^2)			SLW (mg/cm^2)		
	N	S	TSI	N	S	TSI	N	S	TSI	N	S	TSI
C 306	115	93	-19	25	26	+04	76	91	+20	5.57	4.23	-24
K 68	108	92	-15	33	26	-21	74	100	+35	5.52	4.00	-28
Sonalika	94	83	-12	20	27	+35	50	67	+34	5.40	3.87	-28
Kalyansona	75	78	+4	36	32	-11	93	96	+03	4.70	3.70	-22
HD 2285	80	74	-8	26	25	-4	73	70	-04	4.72	3.90	-17
HD 2329	80	75	-6	24	20	-17	65	67	+03	5.36	4.00	-25
Kundan	85	78	-8	25	30	+20	83	86	+04	5.22	4.38	-16
Moti	64	58	-9	25	24	-4	58	72	+24	5.80	3.75	-36
HD 2687	75	68	-9	28	32	+14	114	106	-7	4.71	3.90	-17
HD 2643	78	75	-4	34	30	-12	94	86	-9	5.25	4.38	-17
UP 2338	80	73	-9	35	30	-14	62	106	+71	7.00	4.50	-36
PBW 343	73	76	+4	23	27	+17	72	96	+33	5.10	4.27	-16
DL 1266-1	70	75	+7	28	24	-14	74	100	+35	6.58	4.60	-30
DL 1266-2	85	80	-6	27	27	0	80	133	+66	9.14	5.24	-43
DT 46	90	83	-8	35	27	-23	100	90	-10	4.82	3.87	-20
Mean	83	77	-7	26	27	+04	78	91	+17	5.15	4.17	-19
LSD at 5%												
Treatment	6			NS			8			0.65		
Cultivar	12			5			15			1.20		
T x C	15			7			23			7.75		

N: Normal condition; S: Heat stress condition (+ 3 0C above normal temp.); TSI: Thermal sensitivity index (% increase/decrease over normal)

Table 2. Effect heat stress on leaf characters of wheat cultivars at anthesis stage.

Cultivar	Leaf weight ratio			Leaf length/width (L/W)			Total dry wt./pot (g)			Days to flowering		
	N	S	TSI	N	S	TSI	N	S	TSI	N	S	TSI
C 306	0.16	0.28	+75	28/1.2	32/1.1	+14/-8	42.9	16.2	-62	75	75	00
K 68	0.19	0.34	+78	31/1.4	31/1.1	00/-22	31.6	15.5	-51	80	80	00
Sonalika	0.18	0.22	+22	24/1.1	30/1.0	+25/-09	35.6	13.5	-62	70	65	-7
Kalyansona	0.18	0.32	+78	30/1.5	33/1.3	+10/-13	33.4	15.0	-55	85	80	-6
HD 2285	0.16	0.29	+81	25/1.3	28/1.2	+12/-08	31.1	14.8	-53	75	70	-7
HD 2329	0.18	0.28	+55	25/1.2	26/1.1	+04/-08	25.2	17.1	-32	80	75	-6
Kundan	0.21	0.25	+19	26/1.3	31/1.2	+19/-08	28.3	18.3	-35	80	75	-6
Moti	0.21	0.31	+47	24/1.4	28/1.1	+17/-22	27.9	15.0	-46	75	70	-7
HD 2687	0.18	0.31	+72	25/1.5	30/1.3	+20/-14	39.7	18.5	-54	85	80	-6
HD 2643	0.20	0.25	+25	29/1.5	32/1.3	+10/-13	33.6	18.3	-46	85	80	-6
UP 2338	0.18	0.32	+77	27/1.8	29/1.4	+07/-22	24.7	16.2	-35	85	80	-6
PBW 343	0.16	0.29	+81	23/1.3	29/1.3	+26/00	35.2	22.6	-36	85	80	-6
DL 1266-1	0.12	0.20	+66	25/1.5	25/1.2	00/-20	24.3	18.7	-46	70	65	-7
DL 1266-2	0.18	0.25	+39	25/1.5	27/1.2	+08/-19	22.9	14.5	-37	80	75	-6
DT 46	0.21	0.28	+33	31/1.3	30/1.2	-03/-08	41.6	19.5	-53	75	70	-7
Mean	0.18	0.28	+55	26/1.4	29/1.2	+11/-14	31.8	16.5	-48	80	75	-6
LSD at 5%												
Treatment	0.05			1.5/0.05			6.5			3		
Cultivar	0.03			2.5/0.06			4.0			5		
T x C	0.07			3.5/0.08			7.5			7		

SLW: Specific leaf weight; L/W: leaf length/width

Irrespective of cultivars, mean grain yield of wheat declined by 36% under heat stress of 3.5 ^{0}C, which was attributed to highest reduction in grain growth rate per spike (24%), followed by the number of grains per spike (20%), number of spikes per pot (12%) and lowest in 1000 grain weight (4%) and harvest index (2%) (Table 3 and 4). Singh *et al*. (2001) also reported less sensitivity of 1000 grain weight and harvest index to heat stress in wheat cultivars. The reduction in biological and economic yields of wheat was almost at par (35-36%) by heat stress, which indicates equal degree of sensitivity of vegetative and reproductive growth to warming (Table 4). Under the present study the grain yield and biomass reduced @ 10% per degree Celsius increase above the ambient temperature mainly through reduction in yield components to varying extent. Several researchers (Gibson and Paulsen 1999, Singh *et al*. 2001, Tahir and Nakata 2005) reported significant decrease in wheat yield and its associated characters under higher thermal regime. The significant varietal difference in growth and yield responses to heat stress observed under present findings has also been reported (Singh *et al*. 2001, Prakash *et al* 2003). It is clearly evident from the results that some cultivars, viz. C 306, K 68 and HD 2329 manifested relatively higher grain weight per pot under warmer condition as compared to other cultivars despite greater percentage of reduction in their grain weight by heat stress as their grain weight under normal condition was highest compared to other cultivars and thus may be designated as heat tolerant. Some cultivars namely HD 2285, Kundan, HD 2687, PBW 343 and DL 1266-2 maintained higher grain weight under warmer condition mainly because of less percentage of reduction in their grain weight by heat stress, although their grain weight

Table 3. Effect of heat stress on yield components of wheat cultivars

Cultivar	Days to maturity (days)			No. of spikes/pot			No. of grains/spike			1000 grain weight (g)			Grain growth rate (mg/spike/day)		
	N	S	TSI	N	S	TSI	N	S	TSI	N	S	TSI	N	S	TSI
C 306	120	115	-4	20	14	-30	39	33	-15	46.4	44.2	-05	40	37	-08
K 68	125	120	-4	23	17	-26	35	29	-17	44.7	39.3	-12	39	29	-26
Sonalika	115	110	-4	20	13	-35	34	21	-38	44.8	29.8	-33	34	23	-32
Kalyansona	125	120	-4	16	12	-25	38	33	-13	40.8	39.6	-03	38	33	-13
HD 2285	120	115	-4	17	17	00	35	29	-17	42.6	37.0	-13	33	23	-30
HD 2329	120	115	-4	16	17	+06	42	28	-33	42.2	41.5	-02	44	29	-34
Kundan	125	120	-4	16	16	00	32	26	-19	54.1	54.0	00	38	26	-32
Moti	120	115	-4	20	21	+05	35	21	-40	38.0	40.6	07	30	19	-37
HD 2687	125	120	-4	16	13	-19	46	43	-07	33.4	33.9	+01	39	37	-05
HD 2643	125	120	-4	17	15	-12	33	25	-24	44.4	46.5	+05	36	29	-20
UP 2338	130	125	-4	17	13	-24	42	30	-29	39.0	40.2	+03	37	27	-27
PBW 343	125	120	-4	17	16	-06	32	27	-16	42.5	43.7	+03	35	29	-17
DL 1266-1	115	110	-4	6	7	+17	52	52	00	50.7	46.8	-08	59	54	-09
DL 1266-2	120	115	-4	7	6	-14	67	62	-07	49.5	50.2	+01	83	77	-07
DT 46	125	115	-8	20	20	00	42	21	-50	38.3	36.3	-05	32	17	-47
Mean	122	117	-4	17	15	-12	40	32	-20	43.4	41.5	-04	41	31	-24
LSD at 5%															
Treatment	NS			NS			6			NS			6		
Cultivar	6			6			15			6			8		
T x C	8			8			18			9			12		

under normal condition was lower than the aforesaid cultivars and thus may be designated as heat resistant. The duration from sowing to maturity was reduced by 5 days mainly because of reduction in days to flowering (5 days) without affecting the grain filling duration (Table 3).

High temperature stress caused marked increase in mean organic nitrogen content both in leaf and stem at flowering (48% and 104%) and maturity (54% and 35%). However, the content of total sugar reduced drastically both in leaf and stem at flowering (23% and 27%) and maturity (4% and 15%) under heat stress. Starch content, however increased markedly in leaf both at flowering and maturity (7% and 26%) and in stem at maturity (23%), while decreased substantially (38%) in stem at flowering by heat stress (Fig.1). Total non-structural carbohydrate content (sugars + starch) in general, reduced both in leaf and stem at flowering under heat stress, while the same did not show marked difference both in leaf and stem at maturity. Heat stress invariably suppressed the ratio of total non-structural carbohydrate to total organic nitrogen in shoots (leaf and stem) of wheat plants both at flowering and maturity. The remobilization of organic nitrogen and sugars both in leaves and stem from flowering to maturity were least affected by heat stress, while starch remobilization was reduced drastically both in leaves as well as stem by heat stress, probably due to poor sink growth under heat stress (Fig.1) The reduction in carbohydrate and increase in nitrogen contents of shoots under heat stress indicated the possibility of greater loss of carbohydrates through maintenance respiration, thereby decreasing total non-structural carbohydrate/organic nitrogen ratio (Fig.1). Tahir and Nakata (2005) also reported depletion in the ratio of total non-structural carbohydrate content to

Table 4. Effect of heat stress on dry matter production and partitioning in wheat cultivars

Cultivar	Grain yield/pot (g)			Biological yield /pot (g)			Harvest index (%)		
	N	S	TSI	N	S	TSI	N	S	TSI
C 306	35.0	21.1	-40	83.3	47.0	-44	42.0	45.0	+07
K 68	36.1	19.2	-47	82.3	49.3	-40	43.8	38.9	-11
Sonalika	29.2	15.1	-48	67.7	33.7	-50	43.1	43.3	-00
Kalyansona	25.2	16.2	-36	63.0	37.0	-41	40.0	43.8	+09
HD 2285	24.5	17.9	-31	56.0	41.0	-27	43.7	43.6	00
HD 2329	28.9	19.1	-34	61.0	43.3	-29	47.4	44.1	-07
Kundan	27.0	21.6	-20	64.6	47.3	-27	41.8	38.9	-07
Moti	26.0	17.4	-33	55.7	36.7	-34	46.7	47.4	+01
HD 2687	24.7	19.6	-21	59.0	44.0	-31	41.8	44.5	+06
HD 2643	24.1	17.5	-28	57.0	42.0	-26	42.3	41.7	-02
UP 2338	28.6	15.9	-44	70.0	40.7	-42	40.8	39.0	-05
PBW 343	23.7	18.5	-22	57.0	44.7	-22	41.5	41.4	00
DL 1266-1	16.9	16.3	-4	38.0	31.0	-19	44.5	52.6	+18
DL 1266-2	24.5	18.6	-24	54.0	39.3	-27	45.4	47.3	+04
DT 46	31.3	14.8	-53	77.0	45.0	-42	40.6	32.9	-19
Mean	27.0	17.4	-36	62.7	41.0	-35	43.0	42.0	-02
LSD at 5%									
Treatment	4.5			6.5			NS		
Cultivar	3.5			8.5			5.0		
T x C	5.5			12.0			7.0		

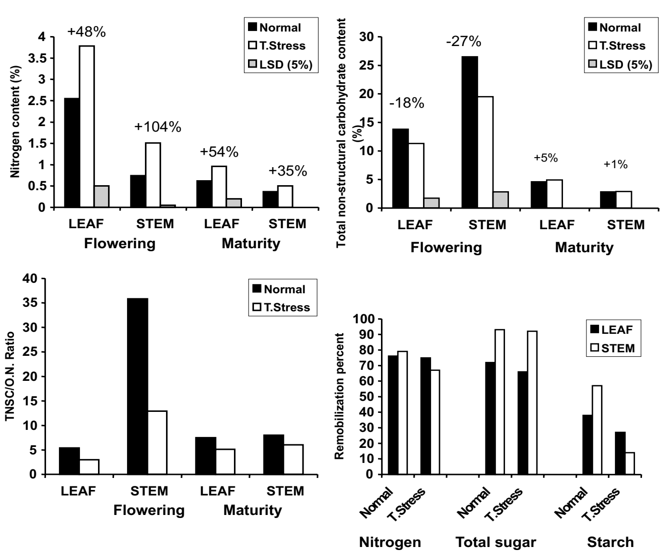

Fig. 1. Effect of heat stress on nitrogen and carbohydrate contents and their remobilization in wheat shoots

nitrogen content in wheat plants grown under warmer condition.

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