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HIGH TEMPERATURE EFFECT ON GRAIN GROWTH IN WHEAT CULTIVARS: AN EVALUATION OF RESPONSES

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SUMMARY

Wheat (*Triticum aestivum* L) cvs. DL 153-2, C306, HD 2329 and WH 542 were grown under normal (27 November) and late (28 December) sown conditions. In an another experiment these wheat cultivars, except that HD 2285 replaced C306, were grown under normal sowing and at anthesis stage were transferred to control and heated open top chambers (OTCs). Under late sowing, wheat cultivars were exposed to mean maximum temperature upto 3.6ºC higher than normal sowing, whereas, under heated OTCs, mean maximum temperature was 3.2ºC higher than control OTCs, during grain growth period. In spite of more or less similar increase in temperature during grain growth period by late sowing and in OTCs experiment, the magnitude of responses were different. All the cultivars showed a decrease in yield by late sowing and decrease was greater than OTCs experiment wherein the significant decrease in yield under elevated temperature (ET) was observed only in two cultivars. The main effect of high temperature in OTCs appeared to be on grain size, whereas, in late sowing experiment, different yield components including grain growth rate were differentially affected in different cultivars. Nonetheless, the varietal pattern of susceptibility remained more or less same in late sowing and OTCs experiments. DL 153-2, C306 and HD2285 were relatively heat stress tolerant for grain growth and yield compared to HD 2329 and WH542. The present study further emphasized that late sowing of wheat by end of December can bring down the grain yield by 30-40% compared to November sowing. The late sowing of wheat being generally practiced because of prevalence of rice-wheat cropping system could, therefore, be one of the reasons for overall decline in wheat productivity. It appears that from late sowing experiment, one may not be able to analyse precisely the effect of high temperature experienced exclusively during post anthesis period. By late sowing, pre-anthesis phenological events determining potential yield components would also be affected which were then carried over to grain growth phase and influenced the grain growth and yield.

***Key words*: Grain growth, heat susceptibility index, high temperature tolerance, yield components, wheat.**

INTRODUCTION

High temperature during grain filling stage is an important yield limiting factor in wheat (Howard 1924, Chinoy 1947, Asana and Williams 1965, Wardlaw *et al.* 1989). The Main effect of high temperature after anthesis is reduction in grain size. It has been reported that single grain weight falls by 3-5% for every 1ºC rise in temperature above 18ºC (Wiegand and Cuellar 1981, McDonald *et al.* 1983, Wardlaw *et al.* 1989). A heat wave for 3 or 4 days at 35-36ºC reduced grain size in wheat (Wardlaw and Wrigley 1994). With the prevalence

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of rice-wheat cropping system, late sowing of wheat is generally practiced which pushes grain development further to high temperature regime (Zhang-hu and Rajaram 1994). The situation may further aggravate with the increasing concentration of CO_2 and other greenhouse gases in the atmosphere which are expected to increase the global temperature (Bowes 1996, Ghildiyal and Sharma-Natu 2000, Ravi *et al.* 2001). There is a need, therefore, to develop wheat varieties having tolerance to high temperature during grain development. Significant genetic variability in high temperature tolerance for grain growth and yield in wheat has been reported (Hawker and Jenner 1993, Stone and Nicolas 1994, Prakash *et al.* 2003, 2004). Discrepancies, however, exist among various studies (Gibson and Paulsen 1999).

Late sowing is generally used to expose grain growth period to high temperature in order to analyse the high temperature effect on grain growth in wheat (Zhong-hu and Rajaram 1994, Calderini *et al.* 1999). Late sowing may, however, modify potential grain yield due to environmental changes occurring not only during the grain filling period but also before anthesis. In wheat, pre-anthesis phenological phases which determine potential yield components are quite sensitive to high temperature (Warrington *et al.* 1977, Shpiler and Blum 1986, 1991, Slafer *et al.* 1996, Abrol and Ingram 2005). An effect on one component of yield influences the other component because of yield components compensation (Slafer *et al.* 1996). Hence, late sowing studies may not necessarily reflect precisely the post anthesis high temperature effect. In the present study an attempt was made to analyse this aspect by comparing grain growth and yield response of wheat cultivars when high temperature exposure was given by late sowing and by post anthesis high temperature exposure in open top chambers.

MATERIALS AND METHODS

Wheat (*Triticum aestivum* L.) cvs. DL 153-2, C306, HD2329 and WH542 were grown in earthen pots (35×40cm) containing sandy loam soil under normal (27 November) and late (28 December) sown conditions. Minimum, maximum and mean temperatures on daily basis during grain development were obtained from meteorological lab of Indian Agricultural Research Institute, New Delhi. In another experiment, these wheat cultivars, except that HD 2285 replaced C306, were grown similarly in earthen pots under normal sowing and at anthesis stage transferred to control and heated open top chambers (OTCs) to provide elevated temperature (ET). The construction of OTCs (300×200 cm) was based on the design of Leadley and Drake (1993). The warm air supplied by hot air blower, bown by an axial fan entered the chamber through double walled plenum around the base perforated towards inside. To eliminate chamber environment effect, chambers in which only air is blown served as control. The maximum and minimum temperature of control and hot air blown OTCs were recorded daily to assess the temperature difference. Four healthy plants were kept in each pot. Standard cultural practices were followed (Singh 1983). The anthesis dates of main shoot (MS) ear were recorded on tags places on each pot.

The normal (N) and late (L) sown plants and control (C) and elevated temperature (ET) grown plants were analysed for yield components at maturity. The data was analysed statistically to determine CD values (Panse and Sukhatme 1967). From the date of anthesis to date at which grains attained maximum dry weight (derived from grain weight samples taken at regular intervals) was taken as grain growth duration (GGD). Heat degree days [HDDs = $\sum$ (mean daily temperature-base temperature)] were calculated using base temperature of 7.5ºC for grain growth duration. Heat susceptibility index (S) was calculated for grain weight as described by Fischer and Maurer (1978).

$$S = (1 - Y/Yp)/(1 - X/Xp)$$

Where Y = mean grain weight of a genotype in a stress environment, Yp = mean grain weight of a genotype in a stress free environment, X = mean Y of all genotype, Xp = mean Yp of all genotypes. S is the relative heat stress tolerance of wheat varieties ($S \leq 0.5$ stress tolerant, $S > 0.5 \leq 1.0$ moderately stress tolerant and $S > 1.0$ susceptible).

The grain growth rate (GGR) was calculated using the formula: $GGR = (W_2 - W_1) / (T_2 - T_1)$, where W_1 =

initial grain weight, W_2 = final grain weight and T_2 - T_1 duration of grain growth (days or HDDs).

RESULTS

In the present study, grain growth under both late sowing and in heated OTC experiment occurred under moderately higher temperature compared to respective controls. The mean minimum temperature during grain growth duration of wheat cultivars at normal sowing was between 14.2 and 15.7°C and mean maximum temperature between 30.5 and 33.1°C. Under late sowing, mean minimum temperature was between 17 and 17.8ºC and mean maximum temperature between 34.1 and 34.8ºC. Under late sowing, wheat cultivars were therefore, exposed to mean maximum temperatures of upto 3.6ºC and mean minimum temperatures of upto 2.8ºC higher during grain growth duration compared to normal sowing. In heated OTCs, wheat cultivars were exposed to mean maximum temperature of 3.2ºC higher than control OTCs during grain growth period.

The grain yield was decreased under late sowing in all the four cultivars of wheat (Table 1). The decrease in grain yield by late sowing was 30.29% in DL 153-2 and 33.83% in C306. IN HD2329 and WH542, the decrease in grain yield was 42.81% and 38.82% respectively. In DL 153-2, the decrease in grain yield was due to a decrease in ear number per pot, whereas, no significant effect was observed in grain number per ear and 1000 grain weight. C306, however, showed no significant effect of late sowing on ear number per pot. In WH 542, no significant effect of late sowing on grain number per ear was observed, whereas, in HD2329, ear

Table 1. Yield components of wheat cultivars under normal and late sown conditions

Cultivar	Sowing	Grain yield (g/pot)	Ear number per pot	Grain number per ear	1000 grain weight (g)	Total dry matter (g/pot)	Harvest index (%)
DL 153-2	Normal	63.01	30.33	38.16	50.66	137.72	46.65
	Late	43.92	21.00	42.33	49.40	101.17	43.41
	CD at 5% P	7.10	1.81	NS	NS	2.71	2.18
	% decrease	30.29	30.76	NS	NS	26.53	7.46
C 306	Normal	66.94	33.00	48.12	42.37	135.66	49.31
	Late	44.29	32.33	36.40	38.09	101.73	43.51
	CD at 5% P	7.10	NS	6.09	2.19	8.19	4.06
	% decrease	33.83	NS	24.35	10.10	25.01	11.76
HD 2329	Normal	87.21	42.66	48.06	42.62	167.34	52.11
	Late	49.87	35.66	40.00	34.98	106.18	46.94
	CD at 5% P	5.35	4.21	9.07	4.98	3.07	4.11
	% decrease	42.81	16.40	16.77	17.92	36.54	10.76
WH 542	Normal	55.38	31.33	51.46	34.58	127.84	43.78
	late	33.88	25.33	47.36	29.82	90.53	39.46
	CD at 5% P	3.69	4.38	NS	1.76	2.18	7.04
	% decrease	38.82	19.15	NS	13.76	29.18	9.86

4 plants/pot

number per pot, grain number per ear and 1000 grain weight were decreased by late sowing. There was a decrease in harvest index (HI) by late sowing in all the cultivars, indicating that grain mass was more affected than biomass under late sowing. Late sowing decreased the days to anthesis (Table 2). There was also a decrease in grain growth duration (GGD) by late sowing in all the four cultivars of wheat. The grain growth rate expressed on per day basis was 31-38% higher under late sowing in wheat cultivars except WH 542. When GGR was expressed on per HDD basis, the increase was only 8-14%. WH 542 showed a decrease in GGR HDD^{-1} by late sowing.

High temperature treatment given after anthesis in heated OTCs decreased grain yield only by 16.53% in HD2329 and 17.10% in WH 542 compared to control chambers. DL 153-2 and HD 2285 showed no significant decrease in grain yield by ET (Table 3). The decrease in grain yield under ET in HD 2329 and WH 542 appeared to be mainly due to a decrease in thousand grain weight. The heat susceptibility index for grain growth and yield for late sown and OTCs experiment is shown in Table 4. Apart from differences in the magnitude of susceptibility, the varietal pattern was more or less same in both the experiments. DL 153-2, C 306 and HD 2285 were found to be relatively heat stress tolerant for grain growth and yield compared to HD 2329 and WH 542.

DISCUSSION

In the present study, in spite of more or less similar increase in temperature during grain growth period by late sowing and in OTCs experiment, the magnitude of responses were different. All the cultivars showed a decrease in yield by late sowing and decrease was greater than OTCs experiment wherein the significant decrease in yield under elevated temperature (ET) was observed only in two cultivars. The main effect of high temperature in OTCs appeared to be on grain size, whereas, in late sowing experiment, different yield components including grain growth rate were differentially affected in different cultivars. Nonetheless, the varietal pattern of susceptibility remained more or less same in late sowing and OTCs experiments. DL 153-2, C 306 and HD 2285 were relatively heat stress tolerant for grain growth and yield compared to HD 2329 and WH 542.

The greater decrease in grain yield under late sowing compared to high temperature exposure after anthesis in OTCs could be because change in sowing date modifies temperature not only during the grain filling

Table 2. Grain growth duration (GGD) and grain growth rate (GGR) of wheat cultivars under normal (N) and late (L) sowing

Cultivar	Sowing	Days to anthesis	GGD		GGR	
			Days	HDDs	mg day^{-1}	µg HDD^{-1}
DL 153-2	Normal	94	30	446	1.80	121.18
	Late	80	20	362	2.37	131.07
	L/N	0.85	0.66	0.81	1.31	1.08
C 306	Normal	94	30	446	1.48	99.37
	Late	80	20	362	2.00	111.02
	L/N	0.85	0.66	0.81	1.35	1.11
HD 2329	Normal	94	30	446	1.47	99.37
	Late	79	20	362	2.04	113.00
	L/N	0.84	0.66	0.81	1.38	1.14
WH 542	Normal	105	26	443	1.42	83.90
	Late	86	20	377	1.50	79.70
	L/N	0.82	0.76	0.85	1.05	0.94

Table 3. Yield components of wheat cultivars under control (C) and elevated temperature (ET) in open top chambers

Cultivar	Treatment	Grain yield (g/pot)	Ear number per pot	Grain number per ear	1000 grain weight (g)	Total dry matter (g/pot)	Harvest index (%)
DL 153-2	C	57.86	38.50	30.64	49.04	144.92	39.92
	ET	56.22	31.00	37.07	48.92	142.48	39.65
	CD at 5% P	NS	5.92	NS	NS	NS	NS
	% decrease	NS	19.48	NS	NS	NS	NS
HD 2285	C	60.29	37.00	34.56	47.14	147.74	40.80
	ET	59.69	41.00	27.68	46.43	146.83	40.65
	CD at 5% P	NS	NS	NS	NS	NS	NS
	% decrease	NS	NS	NS	NS	NS	NS
HD 2329	C	66.63	39.33	38.75	43.51	135.94	48.79
	ET	55.36	38.00	36.34	40.08	122.07	45.35
	CD at 5% P	8.34	NS	NS	2.87	NS	3.00
	% decrease	16.53	NS	NS	7.88	NS	7.05
WH 542	C	70.97	39.00	47.90	37.98	145.53	48.76
	ET	58.83	43.67	45.70	29.47	132.31	44.46
	CD at 5% P	6.94	NS	1.32	1.72	NS	4.40
	% decrease	17.10	NS	4.59	22.40	NS	8.81

4 plants/pot

Table 4. Heat susceptibility index (S) for grain growth and yield of wheat cultivars for normal and late sown and control and elevated temperature (in OTC) grown plants

Cultivar	S for grain growth (1000 grain weight)	S for grain yield (grain yield pot^{-1})
	Normal and late sowing experiment	
DL 153-2	0.235***	0.818**
C 306	0.962**	0.916**
HD 2329	1.698*	1.159*
WH 542	1.301*	1.051*
	Control and elevated temperature (in OTC) experiment	
DL 153-2	0.041***	0.287***
HD 2285	0.222***	0.099***
HD 2329	1.097*	1.683*
WH 542	3.125*	1.702*

*susceptible, **moderately stress tolerant, ***stress tolerant period but also before anthesis. Late sowing in the present study decreased the days to anthesis. The reduction in days to anthesis under late sowing indicated that the duration of phenological phases before anthesis was decreased. It has been reported that early heat (emergence to double ridge) has a negative effect on spike number (Rawson 1986, Shpiler and Blum 1986). The phase from double ridge to anthesis was reported to be the most thermosensitive stage and was related to spikelets number and grains per spike (Shpiler and Blum 1986, 1991, Slafer *et al.* 1996). The pre-anthesis high temperature may also affect grain weight potential through its effect on growth of the ovaries which may in turn impose an upper limit for potential grain weight (Calderini *et al.* 1999). Thus all phenological phases of wheat are sensitive to temperature. Genotypes, however, differed in their response. The late sowing, therefore, influenced the pre-anthesis phenology of wheat and depending on varietal response the grain number and spike number per plant would be influenced as observed in the present study. On the other hand, in OTCs experiment high temperature exposure was given only after anthesis, hence, main effect was on the grain growth. Effect on other yield components if any could be due to differential realization of the potential.

Grain growth takes place entirely during post anthesis period and is determined by the rate and duration of grain filling (McMaster 1997). The duration of grain filling in wheat is decreased by high temperature (Wiegand and Cueller 1981, Alkhatib and Paulsen 1984, Shpiler and Blum 1986, 1991, Slafer *et al.* 1996). An increase in the rate of grain filling in wheat with a rise in temperature above 20ºC is commonly observed (Wardlaw *et al.* 1989, Hunt *et al.* 1991, Zahedi *et al.* 2003). In the present study also late sowing decreased the grain growth duration and increased the grain growth rate. On per HDD basis increase in GGR was only marginal. WH 542, however, showed no significant increase in GGR per day whereas GGR per HDD was decreased by late sowing. Furthermore, the reduction in the duration of grain filling by late sowing in this study was more or less similar in most of the wheat cultivars, so the difference in the responses between cultivars was due to the response of the rate of grain filling to high temperature. It may be mentioned that under late sowing, only grain growth is not affected. Depending upon cultivar, other components of yield were also affected. Hence, effect of late sowing was not exclusively on thousand grain weight because of compensation phenomenon among yield components (Slafer *et al.* 1996).

The present study further emphasized that late sowing of wheat by end of December can bring down the grain yield by 30-40% compared to November sowing. The late sowing of wheat being generally practiced because of prevalence of rice-wheat cropping system could therefore, be one of the reasons for overall decline in wheat productivity. It appears that from late sowing experiment one may not be able to analyse precisely the effect of high temperature experienced exclusively during port-anthesis period. By late sowing, pre-anthesis phenological events determining potential yield components would also be affected which were then carried over to grain growth phase and influenced the grain growth and yield.

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