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Grain growth rate and heat susceptibility index: Traits for breeding genotypes tolerant to terminal high temperature stress in bread wheat (*Triticum aestivum* L)

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Abstract

High temperature stress has an adverse effect on wheat productivity. To generate information on the effect of high temperature on various morpho-physiological yield attributes, which would help in developing high temperature stress tolerant genotypes, an experiment was conducted on a set of 15 diverse cultivars, recommended for different sowing conditions. The experiment was planted on three sowing dates to subject the material to different temperature regimes in the cropping period. The results revealed that early maturing genotypes like HD2285, HD2307, Sonalika UP2338, Lok1 and C306, showed better performance under high temperature stress conditions with less reduction in grain yield and have relatively higher grain growth rates with more tolerance to heat stress for most of the yield attributing characters (low HSI values). The characters GGR and HSI could be taken as important criteria for breeding genotypes acclimatised to late planting conditions.

Key words : Wheat, grain growth rate (GGR), heat susceptibility index (HSI), high temperature stress.

Introduction

Crop yield is determined by the interaction of genotype, management and environment. Water availability and temperature are the major environmental variables affecting crop yield. Howard [1] while analysing the factor controlling wheat production remarked that "wheat production in India is a gamble in temperature". This statement is valid even today. The cultivation of wheat is limited by temperature at both ends of the cropping season. The present day rice-wheat cropping system, keeping in view monsoonal irregularities, has compelled wheat crop to be subjected to rapidly ascending temperatures coupled with hot dry winds during the post anthesis stage, especially during grain development. These unfavourable environments terminate grain growth prematurely and reduces yield considerably. It has already been established that high temperature stress can be a significant factor in reducing yield and quality of wheat [2]. Wardlaw [3], also reported that mean temperature greater than 15-18°C following anthesis can result in decrease in grain weight at maturity. Breeding for heat tolerance is an integral component of wheat breeding programmes at both national and international level [4]. These programmes will not only help in spreading wheat cultivation to non-traditional warm areas besides, optimising wheat yield in more tropical environments under the present situation of multiple-cropping system. Breeding for thermo-tolerance in wheat cultivars requires understanding of the physiological responses of wheat crop to heat stress which will help in identifying traits, to be used as selection criteria. The present study was attempted to understand the responses of wheat genotypes to terminal high temperature stress under field conditions and select the traits that are to be considered for breeding cultivars suitable for the stress environments.

Materials and methods

The experiment was carried out in the experimental farm of Indian Agricultural Research Institute, New Delhi, during the *rabi* season of 1996-97, with 15 genetically diverse wheat genotypes adapted to different environmental conditions, laid out in Randomized block design with three replications on three sowing dates, viz. 30th Nov. 1996 (timely sown), 16th Dec. 1996 (late sown) and 14th Jan. 1997 (very late sown) under high fertility conditions. The recommended cultural and agronomical practices were followed to raise a good crop under all three conditions. Observations were recorded on 15 morpho-physiological characters, viz. days to 50% anthesis, days to maturity, flag leaf area, flag leaf dry weight, ion leakage to measure membrane thermostability, grain growth rate, plant height, effective tillers/m^2, peduncle length, ear length, spikelets/ear, grains/ear, 1000-grain weight, biological yield, grain yield

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and harvest index. Procedures used for recording ion leakage to measure membrane thermostability to high temperature were the same as those described by Sullivan [5] for sorghum, and modified by Blum and Ebercon [6]. The formula used was: Ion Leakage = EC at 45°C $[C_1]$/EC at 100°C $[C_2]$, where, EC = Conductivity in mhos. The grain growth rate was calculated by computing the data with the formula suggested by Gardner *et al.* [7]. GGR = $\ln G_2 - \ln G_1/T_2-T_1$, where, G_2-G_1 = increase in weight of grain; T_2-T_1 = time interval taken (7 days interval in the present study). Heat Susceptibility Index (HSI) was calculated for grain yield and other attributes over high temperature stress and non-stress environments by using the formula as presented by Fischer and Maurer [8]: HSI = $[1 - Y_D/Y_P]$ /D, where, Y_D = mean of the genotype in high temperature stress environment, Y_p = mean of genotype under non-stress environment; D = Heat Intensity = 1 - [mean Y_D of all genotypes/mean Y_p of all genotypes]. The HSI values were used to characterise the relative tolerance of genotypes based on minimisation of yield losses based under normal environmental condition. The difference between genotypes for different characters were tested for significance by using standard techniques for analyses of variance.

Results and discussion

The results obtained from the analysis of variance studies showed highly significant variation for all characters and all genotypes, which explains the fact that the characters are highly influenced by temperature differences. Similarly, all traits expressed significant interaction with the environments which supports that all characters respond to high temperature in different ways in different genotypes. The increase in productivity under late sown condition depends on the biomass attained by a genotype at the time of anthesis [9]. As the duration from anthesis to maturity is relatively shortened, so the stem reserves play an important role in supply of assimilate to the developing sink. The increase in yield is possible either through increase in grain number per m^2 or 1000-grain weight [10]. The balance between these two important yield parameters determine the yield potential of a genotype and its suitability to stress environment. The grain number is well decided during the early phases of growth and development. So, increase in 1000- grain weight remains an unexploited parameter for increasing productivity under high temperature stress environments. Zhong-Hu and Rajaram [11], emphasised that the grain filling rate was more temperature sensitive than days to anthesis and duration of grain filling. Further, Whan *et al.* [12] suggested that the rate of grain growth is more important than the duration as a selection criteria to improve kernel weight and ultimately, grain yield. In the present investigation, the results of the grain growth rate studies (Table 1 and 2) clearly revealed that the genotypes which are generally grown under irrigated conditions possessed medium to high grain growth rates under normal planting and resulting into low GGRs under very late planting conditions. On the contrary, the genotypes which are normally recommended for late planting (HD 2285, HD2307, HD2402, Sonalika, UP2338, Lok1 and C306) showed low to medium GGRs under normal condition and resulted into medium to high GGRs under high temperature stress condition. It was further observed that the genotypes generally recommended for rainfed conditions showed not much change in grain growth rates. It was also noticed that the susceptible genotypes possessed relatively high grain number per ear as compared to tolerant types,

Table 1. Grain growth rate in 15 wheat genotypes under normal, late and very late planting conditions

Genotypes	Normal Planting				Late Planting				Very Late Planting			
	7-14 Days	14-21 Days	21-28 Days	Mean	7-14 Days	14-21 Days	21-28 Days	Mean	6-12 Days	12-18 Days	18-24 Days	Mean
HD 2329	0.1724	0.0771	0.1745	0.1420	0.1791	0.1246	0.0201	0.1079	0.1239	0.0977	0.0251	0.0822
HD 2189	0.1136	0.0781	0.0675	0.0864	0.1742	0.0544	0.0117	0.0801	0.1147	0.0573	0.0331	0.0684
PBW 343	0.0666	0.0508	0.1852	0.1009	0.1821	0.0594	0.0093	0.0836	0.1272	0.0932	0.0284	0.0829
WL 711	0.0958	0.0673	0.0706	0.0779	0.1100	0.1186	0.0204	0.0830	0.1287	0.0570	0.0230	0.0696
WH 147	0.1465	0.0551	0.1683	0.1233	0.1438	0.1249	0.0094	0.0927	0.1338	0.0849	0.0307	0.0831
HD 2285	0.1505	0.0596	0.1344	0.1145	0.2279	0.1543	0.0229	0.1350	0.2944	0.1246	0.0577	0.1589
HD 2307	0.0860	0.1230	0.0850	0.0980	0.3990	0.2562	0.0448	0.2333	0.3693	0.1436	0.0442	0.1857
HD 2402	0.1790	0.0607	0.0682	0.1026	0.2332	0.1280	0.0269	0.1294	0.1700	0.1442	0.0371	0.1171
Sonalika	0.1815	0.1253	0.0351	0.1140	0.2846	0.1303	0.0399	0.1516	0.3769	0.0994	0.0324	0.1696
UP 2338	0.1014	0.1252	0.0721	0.0996	0.2420	0.1252	0.0186	0.1286	0.2831	0.1441	0.0171	0.1481
LOK 1	0.1852	0.1228	0.0595	0.1225	0.2747	0.1256	0.0361	0.1455	0.3146	0.0895	0.0363	0.1468
C-306	0.1523	0.0888	0.0509	0.0973	0.1709	0.0612	0.0154	0.0825	0.1943	0.0999	0.0519	0.1154
Kundan	0.1133	0.0753	0.0503	0.0796	0.1025	0.0854	0.0252	0.0710	0.1379	0.1437	0.0592	0.1136
HDR 77	0.1554	0.0374	0.1084	0.1004	0.0659	0.0241	0.0101	0.0304	0.0357	0.1440	0.0422	0.0740
Raj 1777	0.1118	0.0909	0.0170	0.0732	0.0810	0.1285	0.0222	0.0732	0.0895	0.1438	0.0415	0.0916
CD at 5%	0.0438	0.0277	0.0936		0.0763	0.1013	0.0165		0.0492	0.0279	0.0129	

Table 2. Relative classification of 15 wheat genotypes on the basis of grain growth rate

Genotypes	Normal planting			Mean	Late planting			Mean	Very late planting			Mean
	7-14 Days	14-21 Days	21-28 Days		7-14 Days	14-21 Days	21-28 Days		6-12 Days	12-18 Days	18-24 Days	
HD 2329	M	M	H	M	M	M	L	M	L	M	L	L
HD 2189	M	M	M	L	M	L	L	L	L	L	M	L
PBW 343	L	L	H	M	M	L	L	L	L	M	M	L
WL 711	L	M	M	L	L	M	L	L	L	L	L	L
WH 147	M	L	H	M	L	M	L	L	L	L	M	L
HD 2285	M	L	H	M	H	H	M	H	H	M	H	M
HD 2307	L	H	M	M	H	H	H	H	H	H	H	H
HD 2402	H	L	M	M	H	H	M	H	M	H	M	M
Sonalika	H	H	L	M	H	H	H	H	H	M	M	M
UP 2338	L	H	M	M	H	M	L	H	H	H	L	M
LOK 1	H	H	L	M	H	H	H	H	H	M	M	M
C-306	M	M	L	M	M	L	L	L	M	M	H	M
Kundan	M	M	L	L	L	L	M	L	L	H	H	M
HDR 77	M	L	M	M	L	L	L	L	L	H	H	L
Raj 1777	M	M	L	L	L	M	M	L	L	H	H	L

L = Low; M = Medium; H = High

while the 1000-grain weight was relatively high in the tolerant ones. It could be visualised that the high 1000-grain weight obtained in most of the tolerant types was likely because they could maintain high GGRs under high temperature stress condition. Slafer *et al.* [13], suggested that the number of grains per m^2 is negatively related to individual grain weight, which supports the results of the present study. It can be strongly concluded that the grain growth rate parameter should be taken as an important criteria for breeding cultivars acclimatised to late planting condition.

The heat susceptibility index (HSI) was calculated for various parameters as presented in Table 3, indicate that yield under delayed planting condition was determined by the biomass produced by an individual cultivar where it was observed that genotypes WH147, HD2285, HD2307, UP2338, Lok1 and Raj1777 showed tolerance in biomass weight and also yield per m^2 (values of HSI below unity). Blum *et al.* [14] concluded that biomass of large plants under stress were always better than their smaller counterparts, which support the results of the present investigation. They also emphasised that selection for high biomass yield should bring about positive improvement in grain yield, effective tiller number and number of kernels per spike. Thus selection for biomass yield is one of the ways to

Table 3. Heat susceptibility index for different parameters in 15 wheat genotypes

Characters/ Genotypes	Spikelet No./ear	Grain no./ar	1000-grain weight	Yield/ m^2	Biomass/ m^2	Harvest index	Flag leaf area	Flag leaf dry wt.	Ion leakage
HD2329	0.902	0.996	–0.530	1.608	1.315	0.000	1.093	1.334	15.291
HD2189	0.333	1.867	0.024	1.244	1.335	1.670	0.952	1.192	4.882
PBW343	0.456	0.620	–1.459	1.714	1.459	1.050	0.894	0.329	4.211
WL711	0.948	1.148	5.241	0.772	1.003	1.588	1.065	1.192	3.556
WH147	1.464	1.435	4.650	0.639	0.688	0.644	0.831	1.061	7.568
HD2285	0.971	1.300	–0.105	0.656	0.910	1.608	1.035	1.268	–14.815
HD2307	0.417	1.762	2.372	0.434	0.807	1.736	1.350	1.335	–12.000
HD 2402	0.949	1.493	1.285	0.721	1.008	1.817	1.108	1.012	3.158
Sonalika	1.387	1.749	0.739	1.044	1.057	1.127	0.893	0.739	13.793
UP2338	0.672	0.619	–1.078	0.793	0.960	1.386	0.742	0.960	8.649
LOK1	1.674	2.877	4.161	0.715	0.904	1.530	0.881	0.906	–17.600
C-306	0.706	0.203	0.767	0.707	1.129	0.193	1.148	0.909	–2.353
kundan	0.915	–2.206	1.343	1.264	1.335	0.030	1.341	0.850	5.000
HDR77	1.230	0.237	0.352	1.104	0.856	–0.206	0.673	0.804	17.931
RAJ1777	1.800	0.346	–0.606	0.347	0.674	1.409	0.868	0.781	34.286
D-Value	0.100	0.156	–0.058	0.324	0.395	–0.150	0.451	0.380	–0.025

D-Value = Heat Intensity = $1 - \left[\frac{\text{mean } Y_D \text{ of all genotypes}}{\text{mean } Y_P \text{ of all genotypes}}\right]$; Y_D = mean of genotype in high temperature stress environment; Y_P = mean of genotype in non-stress environment improve the productivity in bread wheat. In the present investigation, apart from biomass yield, other important yield attributing traits like 1000 grain weight and grain number per ear showed either below unity or negative HSI values for the more tolerant genotypes like UP2338, C306, Raj 1777 and HD2285, with a few exceptions observed for cultivars like HD 2329 and PBW343. On the other hand traits like flag leaf area, flag leaf dry weight and ion leakage also indicate positive response in terms of tolerance (low HSI values) particularly in the cultivars which are normally recommended for the planting condition (UP2338, Lok1, Raj1777, HDR77 and Sonalika). It is visualised that the higher flag leaf dry weight and flag leaf area are the suitable parameters to be considered for breeding cultivars suitable to late late planting condition. As under late planting the assimilate supply becomes a limiting factor because of increase in temperature during grain development due to rapid senescence of the assimilatory surface. It may be emphatically felt that to allow proper assimilate supply a significant amount of biomass production, with high to medium grain growth rate and having low HSI values, are the significant features of a high yielding genotype under high temperature stress condition and this should be given utmost consideration in the breeding programme for the selection of cultivars tolerant to the stress environment.

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References

1. **Howard A.** 1924. Crop production in India: A critical survey of its problems. Oxford University Press, Oxford, U.K. p156.
2. **Stone P. J. and Nicolas M. E.** 1995. Effect of timing of heat stress during grain filling on two wheat varieties differing in heat tolerance. I. Grain growth. Aust. J. Plant Physiol., **22**: 927-934.
3. **Wardlaw I. F.** 1994. The effect of high temperature on kernel development in wheat: Variability related to pre-heading and post-anthesis conditions. Aust. J. Plant Physiol., **21**: 731-739.
4. **Acevedo E., Nachit M and Ortiz G.** 1990. Effect of heat stress on wheat and possible selection tools for the use in breeding for tolerance. Wheat for the non-traditional warm areas. *In*: Proc. Intern. Conf., July, 29-3, Aug., Mexico (ed. D. A. Saunders): 401-402.
5. **Sullivan C. Y.** 1972. Mechanism of heat and drought resistance in grain sorghum and methods of measurement. *In*: Sorghum in the seventies. N. G. P. Rao and L. R. House (ed.). Oxford & IBH Publishing Co., New Delhi.
6. **Blum A and Ebercon A.** 1981. Cell membrane stability as a measure of draught and heat tolerance in wheat. Crop Sci., **21**: 43-47.
7. **Gardner F. P., Pearce R. B. and Mitchell R. L.** 1985. Physiology of crop plants. The Iowa State University Press, Iowa, USA: 202.
8. **Fischer R. A. and Maurer R.** 1978. Draught resistance in spring wheat cultivars. I. Grain yield responses. Aust. J. Agri. Res., **29**: 897-907.
9. **Sharma R. C.** 1993. Selection for biomass yield in wheat. Euphytica, **70**: 35-42.
10. **Reynolds M. P., Rajaram M. P. and McNab A.** 1996. Increasing yield potential in wheat: Breaking the barriers. *In*: Proc. of a workshop held in Mexico: pp 101-133.
11. **Zhong-Hu H. and Rajaram S.** 1994. Differential responses of bread wheat characters to high temperature. Euphytica, **72**: 197-203.
12. **Whan B. R., Carton G. P. and Anderson W. K.** 1996. Potential for increasing rate of grain growth in spring wheat. I. Identification of genetic improvement. Aust. J. Plant Physiol., **47**: 17-31.
13. **Slafer G. A., Calderini D. F. and Miralles D. J.** 1996. Yield components and compensation in wheat: *In*: Opportunities for further increasing yield potential in wheat: Breaking the barriers. M. P. Reynolds, S. Rajaram and A. McNab (ed.). CIMMYT, Mexico.
14. **Blum A, Sullivan C. Y. and Nguyen H. T.** 1997. The effect of plant size of wheat response to drought stress. II. Water deficit, heat and ABA. Aust. J. Plant Physiol., **24**: 43-48.