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Relationship between canopy temperature depression, membrane stability, relative water content and grain yield in bread wheat (*Triticum aestivum*) under heat-stress environments

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ABSTRACT

A study was conducted during winter (*rabi*) of 2006–08 at New Delhi using 49 diverse wheat (*Triticum aestivum* L. emend. Fiori & Paol) genotypes and three sowing dates (15 November, 15 December and 5 January) to assess the relationship of physiological parameters with grain yield under hot environment. From the analysis of normal, late and very late sowing date, it is evident that all the characters are showing sufficient amount of variability in all three environments among all the 49 bread wheat genotypes. All the characters expressed significant interaction with environments, indicating that all characters respond to high temperature in different ways in different genotypes. This variability gives sufficient scope for further selection of the traits under consideration. Maximum variation was observed for characters, like canopy temperature depression and membrane injury. Most of the characters had high heritability (broad sense) in pooled analysis. Traits, like canopy temperature depression (at anthesis), canopy temperature depression (10 days after anthesis), membrane injury, had high heritability estimates and can be utilized as selection criteria in stress environments. Grain yield showed positive and significant genotypic correlation coefficients canopy temperature depression at anthesis, canopy temperature depression at 10 days after anthesis and membrane injury per cent. Based on the genotypic coefficient of variation, phenotypic coefficient of variation, genetic advance and heritability, characters canopy temperature depression at anthesis, canopy temperature depression at 10 days after anthesis, membrane injury per cent and relative water content can be used as selection criteria for improving the grain yield in the hot environments.

Key words: Bread wheat, Canopy temperature depression, Grain yield, Heat stress, Membrane stability

Abiotic stress, such as drought, temperature, salinity and nutrient imbalance reduce wheat yield in many environments (Trethowan and Kazi 2008). Terminal heat stress can be a problem in up to 40% of irrigated wheat growing areas in the developing world. High temperature at the time of grain filling is one of the major constraints in increasing productivity of wheat in tropical countries like India (Rane *et al*. 2004). The effects of heat stress on wheat are dependent on the intensity, type and duration of the stress. High temperature represents a major constraint affecting wheat, particularly at the reproductive stage, in many parts of the world (Rane *et al*. 2003).

The genetic control to tolerance to abiotic stresses is complex and to a large extent poorly understood (Worland and Snape 2001). Nevertheless wheat breeders have made significant improvement in the adaptation of wheat to stress-prone environments (Trethowan *et al*. 2002, Lantican *et al*. 2003). This success has largely been achieved through field based empirical selection for stress tolerance. Selection has been conducted both in target environments under managed conditions where the intensity of single stresses can be manipulated (Trethowan *et al*. 2001).

Several heat stresses related traits have received considerable attention, in particular canopy temperature depression and membrane thermo-stability index. While a systematic understanding of the physiological basis of differences in heat tolerance of wheat cultivars are lacking, a number of physiological traits are associated with performance under heat stress and may be used to increase selection efficiency (Reynolds *et al*. 2002). Munjal and Rana (2003) have reported that cool canopy during grain-filling period in wheat is an important physiological principle for high temperature-stress tolerance.

The present study was carried out to investigate the relationship between canopy temperature depression,

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membrane thermo-stability and other physiological traits with grain yield and yield-contributing traits under heat stress environments in wheat and identification of suitable genotypes for higher production and productivity in the target environments.

MATERIALS AND METHODS

Material for the present study comprised 49 elite genotypes of bread wheat meant for different agronomic practices like timely-sown irrigated conditions, late-sown irrigated conditions and also timely-sown rainfed conditions. These lines were genetically diverse, released and pre release wheat material developed by cooperating centers of All India Wheat and Barley improvement project. The trials were conducted at the experimental farm of the Institute. Experiment was laid out during two seasons (2006–07 and 2007–08) in a 7×7 double lattice design with two replications and three dates of sowing. Sowing was done on 15 November; 15 December and 5 January. Each genotype was planted with the help of self-propelled Norwegian seed drill. The gross plot size of timely-sown experiment was 1.38 m×6.0 m with rows at 23 cm apart, whereas in the late and very late-sown experiments, the gross plot size was 1.08×6.0 m with row-to-row spacing of 18 cm. The standard cultivation practices prescribed for wheat under irrigated conditions were followed precisely. No disease incidence was noticed on the crop during growth seasons and the weed control was made manually. The field observations were recorded in crop growing season. The data were recorded from each plot for grain yield, canopy temperature depression (at anthesis and ten days after anthesis), membrane thermostability, relative water content and yield contributing traits. After the physiological maturity, plots were harvested by Hege combine/harvester.

The canopy temperature depression (CTD) was measured at anthesis and 10 days after anthesis of the unirrigated crop using a portable infrared thermometer (Model AG-42, Teletemp Corporation, Fullerton, CA) with a view of 2.5° at late morning to early afternoon in cloudless period. The data for each plot were the mean of 10 readings taken at an angle of 45°. The measurements were taken at the time of anthesis and 10 days after anthesis. Relative water content was determined following the method described by Weatherley (1950). Membrane thermal stability was estimated using procedures as described by Blum and Ebercon (1981). The statistical analysis was carried out using software MSTAT C (1989).

RESULTS AND DISCUSSION

All the characters studied showed significant variation in respect of the genotypes under the present investigation. This was apparent from the significant to highly significant mean squares (MS) values under timely-sown irrigated conditions, late-sown irrigated condition, very late-sown irrigated conditions and pooled analysis of variance over the three dates of sowings (Table 1). From the analysis of variance of first, second and third sowing dates, it is evident that all the characters are showing sufficient amount of variability in all

Table 1 Analysis of variance (ANOVA) pooled over three dates of sowing

Source of variance	d.f.	Mean square				
		Grain yield	CTD (at anthesis)	CTD (10 days after anthesis)	Membrane injury (%)	Relative water content
Location (L)	2	5224.04	7.18	3.04	270.81	1457.62
Replication (R)	1	15.53	0.44	0.0069	16.56	0.12
L×R	2	8.80	58.59	0.0018	9.53	0.19
Treatment (T)	48	131.33**	11.15**	9.48**	24.46**	165.30**
L×T	96	18.48	0.027	0.081	8.19	32.97
Error	144	7.83	0.0073	0.017	3.03	2.49

* *P*=0.05, ** *P*=0.01

Table 2 Merit-wise performance of the selected wheat genotypes for five characters pooled over three dates of sowing

Grain yield	Canopy temperature depression (at anthesis)	Canopy temperature depression (10 days after anthesis)	Membrane injury (%)	Relative water content
‘DBW 17’	‘DBW 14’	‘DBW 14’	‘CBW 12’	‘URJA’
‘HD 2922’	‘CBW 14’	‘DBW 16’	‘NIAW 845’	‘RS 950’
‘CBW 17’	‘DBW 16’	‘CBW 17’	‘NW 1014’	‘CBW 12’
‘DBW 16’	‘RS 950’	‘CBW 14’	‘DBW 16’	‘CBW 25’
‘CBW 25’	‘URJA’	‘CBW 23’	‘CBW 14’	‘DBW 28’

three environments. One of the reasons for this may be due to the fact that all the genotypes differ greatly with respect to their parentage for which the material has been chosen very carefully. Therefore there is scope for selection. This variability may be because all the genotypes selected in the present experiment were genetically different with more genetic variability for the traits under consideration. The results obtained from present study reveals that the test genotypes behave differently for the studied characters under high temperature.

In order to estimate heritable portion of variability, heritability and expected genetic advance were worked out from the genotypic and phenotypic coefficients of variation (GCV and PCV). The values of GCV, PCV, heritability and expected genetic advance are presented in Table 3.

A perusal of Table 3 shows that higher coefficient of variation were observed at phenotypic level for all the characters when compared with GCV in three dates of sowing and pooled analysis. The highest phenotypic coefficient was observed for the character canopy temperature depression (10 days after anthesis) pooled over the three dates of sowing, followed by membrane injury percentage, canopy temperature depression (at anthesis), relative water content, and grain yield. It was observed that the phenotypic coefficient of variability was lowest in the optimum sowing conditions which increased in the stress environments. The maximum genotypic coefficient of variability was observed for the character canopy temperature depression (10 days after anthesis), followed by membrane injury percentage, canopy temperature depression (at anthesis), relative water content and grain yield.

Once the variability patterns are clear, it becomes imperative to a plant breeder to assess the extent of variability for the characters under investigation. The results obtained from pooled analysis disclose the fact that all the traits were highly significant. This observation clearly explains the high level influence of high temperature on different characters studied. All characters expressed significant interaction with environments, indicating that all characters respond to high temperature in different ways in different genotypes. Selection is more important part of breeding programme .The success of selection mainly depends on variability present in the base population. In the present study, the estimates of PCV listed in Table 3 were higher than GCV for all the characters studied. Phenotypic coefficient of variation was higher in all cases because it includes both genotypic and environmental variability.

Maximum variation was observed for characters like canopy temperature depression, membrane injury. For the remaining traits, there was moderate variation. The GCV for most of the characters suggests that major portion of PCV of these traits were due to genetic causes and environmental influence was negligible. The results are in conformation with Shukla *et al*. (2001).

The heritability can be expressed as the proportion of total variance that can be attributable to genetic cause and this is

Table 3 Heritability (%), genetic advance, genetic advance as percent of mean, genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) for grain yield and physiological traits in normal, late and very late sowing.

Character	Date of sowing	Heritability (%)	Genetic advance	GA per cent mean	GCV	PCV
Grain yield	I	58.80	7.15	15.61	9.89	12.90
	II	93.60	10.08	26.23	13.93	15.23
	III	87.00	9.26	29.68	15.45	16.57
	P	70.60	7.51	19.52	11.27	13.41
Canopy temperature depression at anthesis	I	97.20	2.78	61.78	30.45	30.88
	II	98.20	2.79	64.29	31.45	31.74
	III	93.80	2.82	71.03	35.65	36.81
	P	96.10	2.72	63.73	31.55	32.19
Canopy temperature depression (10 days after anthesis)	I	98.70	2.77	110.36	53.77	54.12
	II	99.20	2.60	108.79	53.22	53.43
	III	99.00	2.39	110.14	53.87	54.15
	P	98.90	2.56	108.78	53.17	53.45
Membrane injury (%)	I	99.40	40.62	78.12	38.03	38.15
	II	99.30	41.46	80.18	39.06	39.21
	III	99.20	42.43	77.53	37.79	37.95
	P	99.30	41.38	78.35	38.17	38.31
Relative water content	I	97.90	7.95	10.05	4.93	4.99
	II	90.30	13.52	18.13	9.26	9.74
	III	96.00	14.12	19.77	9.80	10.00
	P	89.90	9.17	12.22	6.26	6.60

I, 15 November sowing; II, 15 December sowing; III, 15 January sowing; P, pooled the factor which determines the degree of resemblance for the characters between parents and offspring's. It also expresses the reliability of the phenotypic value as a guide to the breeding value. Heritability in broad sense is the proportion of genotypic variance to phenotypic variance. It also indicates the relative success of selection. However, it is worth to mention that the estimates of heritability are not constant and are more valid for the population from which they are estimated. From the results obtained for heritability which is shown in Table 3, it is evident that most of the characters studied had high heritability in pooled analysis.

Genetic advance indicates the possible gains which can be expected from the character under investigation over the three environments. The expected genetic advance is defined as the difference between mean of the progeny of selected individuals and base population which is expressed as percentage of mean in the present study. It indicates the gain which can be obtained for the character. Under timely-sown irrigated conditions, the maximum value for the expected genetic advance was observed for canopy temperature depression (at anthesis), followed by membrane injury per cent canopy temperature depression (at 10 days after anthesis). Under stress environments (late and very late sowings), the similar trend of expected genetic advance over per cent of mean was observed. The characters which showed the maximum genetic advance as per cent of mean was canopy temperature depression (at anthesis), followed by membrane injury per cent and canopy temperature depression (at 10 days after anthesis). The amount of expected genetic advance in the very late sowing was higher than the other stress environment which is late sowing. Generally high heritability percentage is related with higher genetic advance. But there is deviation also from the above mentioned traits. The genetic advance expected from selection can be best explained if the estimates of heritability and genotypic coefficient of variation were considered together. These characters which gave high GCV coupled with high to moderate heritability and genetic gain support the fact that there is scope of improvement for these traits, particularly under high temperature stress conditions.

Yield is a complex and highly variable character and is a result of cumulative effect of its component characters, so it is not effective to go for direct selection as such for yield, particularly under stress conditions like drought and terminal heat stress. The yield components are not independent in their action and are inter-linked and may also bring simultaneous change for other characters at phenotypic and genotypic level. One of the major objectives of this investigation was to study the association of grain yield with other morpho-physiological and quality traits in stress as well as in normal environments. The phenotypic correlation is the association between two traits that can be visualized directly and its estimation is done by simple correlation. The genotypic correlation in true sense may be interpreted as the correlation

Table 4 Genotypic correlation coefficient among grain yield and physiological traits pooled over three dates of sowing

Character	Grain yield			
	Date of sowing			
	Timely sown	Late sown	Very late sown	Pooled correlation
Canopy temperature depression (at anthesis)	0.232	0.487*	0.688**	0.514**
Canopy temperature depression (10 days after anthesis)	0.257	0.468*	0.662**	0.562**
Membrane injury (%)	–0.192	0.442*	–0.598**	–0.456*
Relative water content	–0.412*	0.254	–0.691**	–0.292

* *P*=0.05, ** *P*=0.01

Table 5 Genotypic path coefficient among grain yield and physiological traits pooled over three dates of sowing

Character	Direct effect on grain yield			
	Timely sown	Late sown	Very late sown	Pooled over three dates of sowing
Canopy temperature depression (at anthesis)	0.459	0.573	0.336	0.398
Canopy temperature depression (10 days after anthesis)	0.333	0.223	0.353	1.171
Membrane injury (%)	0.175	–0.156	–0.214	0.144
Relative water content	–0.228	–0.227	–0.217	–1.177
Residual effects	0.147	0.424	0.118	0.000

of breeding value. The phenotypic and genotypic correlation coefficients among all the characters under study are presented in Table 4. A perusal of the Table shows that under stress environment (late and very late sowing), the grain yield significant positive correlation with canopy temperature depression at anthesis, canopy temperature depression at 10 days after anthesis and negative correlation with membrane injury per cent. Therefore, these traits can be utilized as selection criteria under terminal heat stress for selecting genotypes with better yield potential. Similar results were also obtained by Balota *et al.* (2007), Kumari *et al.* (2007), Reynolds *et al*. (2007) and Bahar *et al*. (2008). The plant breeders argue that selection for yield component is more efficient than the selection for yield *per se*. So it can be concluded that significant positive correlation with grain yield could be better with improvement of components under normal and stress environments (late and very late sowing).

Path coefficient analysis is a standardized partial regression coefficient, which splits the correlation into direct and indirect effects on independent variables on the dependent variable. It reveals whether the association of these characters with yield is due to their direct effect on yield or it is a consequence of their indirect effect via some other character, if the correlation between yields with other character is due to direct effect of that character. It reflects the true relationship between them and hence, it makes easy to improve grain yield. But if character is due to indirect effect through another component trait, then selection is difficult and it has to be made for the later character through which the indirect effect can be extended.

The genotypic path analysis for the normal-sown irrigated condition shows that maximum direct effect on grain yield was due to canopy temperature depression at anthesis (0.459). Negative direct effect was realized for the characters relative water content (–0.228).

The genotypic path analysis for the late-sown irrigated condition is presented in Table 5 which shows that positive and maximum direct effect on grain yield was due to canopy temperature depression at anthesis (0.573).

Thus, it appears that the present set of materials in the form of test entries for the normal late and very late sowing has enough variability in association or combination of traits where from genotypes with proper combination can be identified for suitability for their cultivation under different environmental conditions where change of any environmental component will be taken care by combinations of traits in the genotypes. Through their direct or indirect effects, under such conditions of abiotic stress of high temperature, such type of combinations with direct or indirect effects can be selected for their suitability to high temperature stress.

It can be concluded in the present investigation that grain yield showed positive and significant genotypic correlation coefficients under timely-sown condition with days to relative water content. Under stress environment (late and very late sowing), the grain yield significant positive correlation with canopy temperature depression at anthesis, canopy temperature depression at 10 days after athesis, membrane injury per cent and negative correlation with membrane injury per cent. Therefore, these traits can be utilized as selection criteria under terminal heat stress for selecting genotypes with better yield potential. Based on GCV, PCV, genetic advance and heritability, the characters, canopy temperature depression at anthesis, canopy temperature depression at 10 days after anthesis, membrane injury per cent and relative water content can be used as selection criteria for improving the grain yield in the stress environments.

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