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Research Article

Effect of terminal heat stress on stability of yield and quality parameters in bread wheat in south-west Haryana

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Abstract

A set of 42 bread wheat genotypes representing different agro climatic zones, were selected for the present study. The material was grown in four different test environment in randomized block design with three replications to identify the stable genotypes under different environments. The genotypes WH 711, DBW 17, PBW 343, UP 2338, WH 542, HD 2687, PBW 550, WH 416 and were promising for grain yield. A major portion of G×E was accounted by non-linear component for days to heading, days to maturity and biological yield per plant. However, the linear portion was higher for number of grains per spike, effective tillers per plant and protein (%). The genotypes WH 711, DBW 17, PBW 343, UP 2338, HD 2687, WH 416 and WH 283 were found stable for grain yield in all the environments, because they had above average mean, βi value equal to zero and non-significant S^2di value. It means that these were less responsive to the environmental changes and therefore, more adaptive. . The genotypes WH 1052 and WH 1053 were found stable for favourable environment as these genotypes were having high mean performance with high response and least deviation from regression.

Key words: Stability, terminal heat stress, grain yield, quality, bread wheat

1. Introduction

Wheat (*Triticum aestivum* L.em.Thell) is one of the most important cereal crops of the world. The wide spread cultivation of the crop all along the globe is largely due to high versatility of evolution, which enable its adaptation to different agro climatic conditions and the unique property of wheat flour and dough which allows its processing into a range of food products. The national wheat production accounts for 12 per cent of global wheat production that made India the 2nd largest wheat producing nation with surplus wheat as against the wheat deficient nation during 1960's. But in order to meet the challenges of temperature ahead of global warming, concerted efforts are need to evaluate, identify and develop genotypes suitable for terminal heat stressed environment (Arya *et al.*, 2012). As increased in temperature during grain filling is the main cause of low productivity. Current estimates indicate that wheat crop grown on around 13.5 mha in India is affected by heat stress (Sareen *et al*, 2012). It is also reported that the cool period for wheat crop in India is shrinking, while the threat of terminal heat stress is expanding (Joshi *et al*, 2007).

The knowledge about the nature and extent of genotype × environment interaction can help the plant breeders a great deal in formulating his/ her breeding plans in selection of varieties for location specific responses and general adaptation. Consistently good performance over a range of environments (phenotypically stable) must be one of the important criteria while evaluating any wheat genotype or variety, particularly in a country like India, where great variations occur in environmental conditions, locations and seasons. Besides this identification of phenotypical stable genotypes, it is also essential to identify genotypes suitable for specific favorable and unfavorable environment for commercial production. Thus, the identification of stable genotypes, adaptable to wide range of environments has considerable significance in bread wheat improvements.

A number of procedures to study genotype × environment interaction have been proposed. However, the joint regression analysis proposed by Perkins and Jinks (1968 a,b) bridged the gap between the statistical and genetically approaches for studying genotype environment interaction.

Keeping the above facts in view, the present study was undertaken with the objective to identify the stable genotypes under different environments.

2. Materials and method

The present investigation was carried out on 42 promising genotypes of bread wheat to generate information on stability under terminal heat stress conditions. The experiments were conducted during the winter (rabi) season of 2007-08 at two locations, Hisar (latitude 29° 10' N, longitude 75° 40' E and altitude 215.2m) and Bawal (latitude 28° 01' N,longitude 76° 05' E and altitude 266.0 m) under timely sown (21, November) and late sown (21, December) conditions in randomized block design (RBD) with three replications. Resulting 4 test environments were designated as E_1 (Hisar, timely sown), E_2 (Hisar, late sown), E_3 (Bawal, timely sown) and E_4 (Bawal, late sown).

The soil of Hisar was sandy loam, while the soil of Bawal was sandy (Type Ustrochrepts) (Soil Survey Staff, 1999). The metrological observations at weekly intervals during experimental period were recorded and depicted in Fig. 1a &b. Each entry was accommodated in a single row of 3 meter length with spacing of 30 cm between row to row and 10 cm between plant to plant in each replication. Sowing was done by dibbing method. The recommended packages of practices were followed. Five competitive plants of each genotype in each replication and in each environment were randomly selected and data were recorded on the following characters. viz., days to heading, days to maturity, plant height (cm), effective tillers per plant, number of grains per spike, 1000-grain weight (g), biological yield per plant (g), grain yield per plant (g), protein (%), sedimentation value (ml). Statistical Analysis of Data was carried out for every character under each environment as described by Panse and Sukhatme (1967). Phenotypic stability was worked out by following model given by Perkins and Jinks (1968a). Heat stability index (HSI) was calculated for each genotype according to Fisher and Maurer (1978).

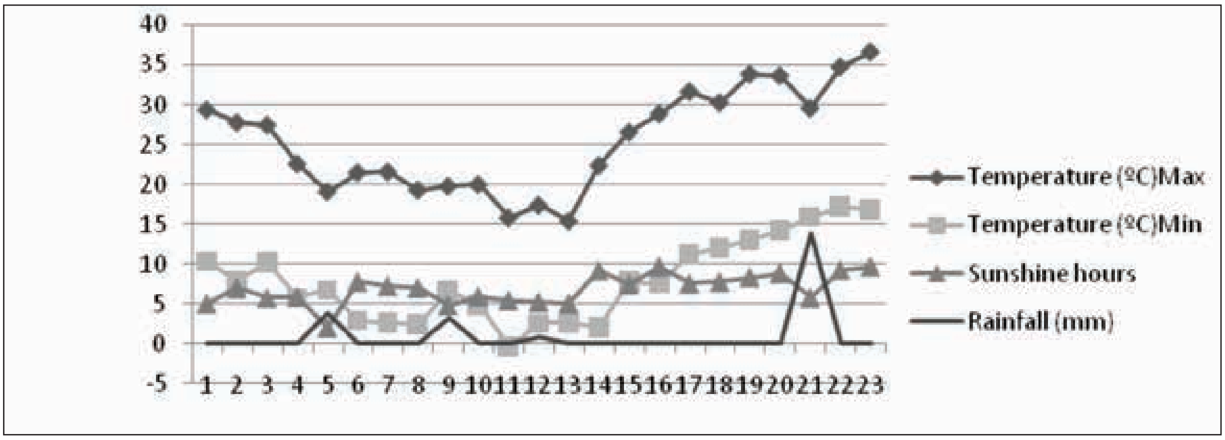

Fig 1A. Weekly meteorological data of Hisar station for the crop *rabi* season (2007-2008)

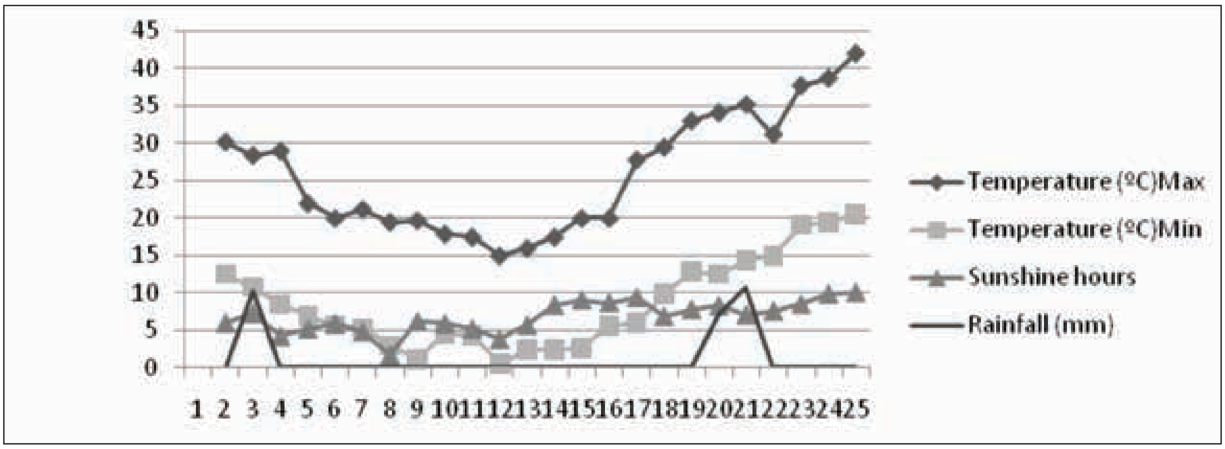

Fig 1B. Weekly meteorological data of Bawal station for the crop *rabi* season (2007-2008)

3. Results and discussions

3.1 Mean performance and heat tolerance: Considering the mean performance of genotypes for different characters studied under timely sown and and late sown (heat stress) environments in each of two locations, genotypes WH 283, WH 157, WH 291, WH 1056, UP 2425 and Raj 3765 for days to heading; WH 1046, WH 1074, WH 1053, WH 1070, WH 283, PBW 550, and WH 291 for days to maturity ; WH 416, WH 542 WH 711, DBW 17, PBW 502, WH 595 and WH 736 for plant height (cm); WH 542 PBW 343, DBW 17, PBW 502, PBW 550, WH730 and WH 1046 for effective tillers per plant; WH 1025, WH 147, WH 416, HD 2687, UP 2338, WH 542, PBW 343 and PBW 502 for number of grains per spike, UP 2425, WH 157, Sonak, PBW 343, UP 2338 and WH 283 for 1000 grain weight, Raj 3765, DBW 17, PBW 343, WH 542, WH 283, and WH 416 for biological yield per plant, WH 416, WH 283, HD 2687, UP 2338. WH 542, PBW 343, WH 711, DBW 17, PBW 502, PBW 550 and WH 730 for grain yield per plant, WH 291, WH 1022, WH 1046, WH 1053, WH 1054, WH 1055, WH 1056, and WH 1059 for protein (%), WH 712, WH 711. WH 416, and WH 147 for sedimentation value in all environments were found promising.

3.2 Joint regression analysis: The joint regression analysis of 42 wheat genotypes grown in four different environments for ten quantative characters (Table-1) revealed that the mean squares due to genotype and environment were highly significant for all the characters, indicating that there are significant differences among different genotypes as well as among different environments. This also indicates that enough genetic variability was present in the material selected for the present study. Both the heterogeneity between regression mean sum of squares (MS) and the remainder MS are significant for all the characters under study, indicating that genotype environmental interaction based on linear and non-linear component is present for all the characters except days to maturity.

The heterogeneity between regressions when tested against pooled error it was found significant for all the characters expect days to maturity. The remainder mean square when tested against pooled error, it was significant for all the characters except days to maturity. All the characters were not significant against remainders MS so this indicated both linear and non-linear components of variation were present in all the characters. The MS due to G×E interaction was highly significant when tested against pooled error.

3.3 Environmental effects: The estimates of environment additive effects (Table 2), which are expressed as deviation from grand mean showed that E_1 was the most favourable environment for all characters excepts for proteins (%) and days to heading because the additive effects and mean value for this character were maximum in E_3 followed by E_1. For effective tillers E_2, E_3 and E_4 had negative effect and for biological yield E_2 and E_4 had negative effect. For protein (%) E_1 and E_2 had negative effect, whereas, E_3 and E_4 had positive effect. In E_2 and E_4 days to heading, days

Table 1. Joint regression analysis for different characters (Perkins and Jinks, 1968a)

Source of variation	DF	Days to heading	Days to maturity	Plant height (cm)	Effective tillers per plant	Number of grains per plant	1000-grain weight (g)	Biological yield per plant (g)	Grain yield per plant (g)	Protein (%)	Sedimentation value (ml)
Genotype	41	165.67**	31.76*	249.53**	29.18**	211.68**	53.84**	380.32**	120.31**	2.08**	77.54**
Environments (joint regression)	3	1758.91**	3843.39**	712.21**	15.18**	917.67**	151.44**	612.50**	135.93**	8.84**	59.73**
Genotype x Environment	123	54.57**	23.98	60.10**	3.36**	25.14**	2.57**	23.36**	4.29**	0.62**	3.25**
Heterogeneity between regression	41	17.91**	19.21	70.37**	3.03**	28.30**	2.43**	10.95**	4.88**	0.97**	2.50**
Remainder (Pooled Deviation)	82	72.90**	26.36	54.97**	3.53**	23.56**	2.64**	29.56**	4.01**	0.44**	3.62**
Pooled Error	328	0.659	20.81	25.301	0.30	0.47	0.29	0.255	2.64	0.28	0.30

*,** significant at P> 0.05 and P>0.01,

to maturity, effective tillers per plant, number of grains per spike and 1000-grian weight showed negative effect joint regression analysis.

3.4 Genotype X environment interactions: The significant of the mean square due to genotypes in the joint regression analysis indicated that a considerable genetic variability existed among the genotypes for almost all the characters (Table 1). The environment mean squares were significant for all characters. This not only revealed the amount of variability existing among the genotypes but it also reflected that the environment varied considerably. Either the heterogeneity between regression M.S., the remainder M.S. or both were significant for all the character except days to maturity, indicating the presence of G×E interaction for all the characters. Occurrence of such interaction have also been reported by several worker in wheat (Maloo *et al.*, 1993), Zalewski and Weber (2006), Hakim *et al.* (2008) and Sareen *et al.* (2012).

Table 2. Estimation of environmental additive effect (Ij) for ten characters in four environments expressed as deviation from mean.

Character	I_1	I_2	I_3	I_4	Grand mean
Days to heading	4.186	-7.203	6.591	-3.574	89.26
Days to maturity	9.108	-9.642	7.282	-6.748	123.42
Plant height	3.531	-0.718	2.712	-5.525	87.52
Effective tillers per plant	0.814	-0.067	-0.112	-0.635	10.95
Number of grains per plant	4.326	-3.510	3.725	-4.541	46.35
1000-grain weight	1.710	-0.707	1.354	-2.357	40.20
Biological yield per plant	3.852	-0.214	1.516	-5.153	65.61
Grain yield per plant	1.682	-0.795	1.267	-2.154	29.56
Protein	-0.136	-0.578	0.465	0.248	13.05
Sedimentation value (ml)	1.623	-0.002	-0.412	-1.209	36.28

The whole genotype x environment interaction was partitioned two components, namely heterogeneity between regression and remainder, the former accounting for linear component, whereas the latter for non-linear component. The significant of both heterogeneity between regression and remainder indicated that both linear and non-linear components significantly contributed to total genotype x environment interaction for all the character. However, relative magnitude of both these positions varied with the characters.

The heterogeneity between regression was found to be significant against error M.S for all characters, except days to maturity, indicating predictable type of G×E interaction, either there in no relationship or no simple relationship between the G×E interaction and the environmental values, hence no prediction can be made by the present approach. When heterogeneity between regression was tested against remainder, it was found not significant for all the characters. So this indicated that both linear and non-linear components of variation were present in all the characters.

The nature of G x E interaction is of great importance as for as predictability of performance of genotype is concerned. It has been recognized that the term 'Stability' should be used to refer to the absence or a low magnitude of unpredictable (non-linear) change in response to an environment, while the predictable (linear) component which represents definite measurable response of a genotype to environmental changes could be termed more appropriately, a measure of responsiveness of the genotype (Breese, 1969). A stable variety under this concept would be one whose performance could be predicted easily and precisely. This definition of stability would be same as Perkins and Jinks (1968a) second parameter of stability () and was used in this investigation. Thus, the genotype with smallest amount of deviation around the regression line is considered to be most stable.

In the model proposed by Perkins and Jinks (1968a), linear regression coefficient βi accounts for the linear component of genotype x environment interaction and is a convenient measure of response of a genotype to the change in the environment.

A genotype which is above average responsive has βi value significantly greater than zero. Such a genotype is useful for the better environment because any improvement in the environment will increase the performance of this genotype. On the other hand, a genotype which is below average responsive has βi value significantly less than zero. Such a genotype is useful for poor environment because the performance of the genotype does not show significant reduction with the deterioration of the environment.

A genotype which is relatively indifferent to the variation in the environment is said to be average responsible and will have βi value not significantly different from zero such a genotype is useful for average environments.

Table 3. Estimates of stability parameters for 8 traits in wheat

	Days to maturity			Plant height (cm)			Effective tillers per plant			Number of grains per spike		
Genotypes	$\bar{x}$	bi	S^2di	$\bar{x}$	bi	S^2di	$\bar{x}$	bi	S^2di	$\bar{x}$	bi	S^2di
C 306	127.49	-0.125*	-6.048	113.58	1.833*	17.263	7.89	0.224	0.686	51.42	0.570	12.479**
WH 533	127.24	-0.171	-0.906	79.74	-0.866**	-7.940	7.66	0.432	0.632	64.24	-0.433	7.053**
WH 1025	127.33	-0.245	48.491	82.00	0.275	20.022**	13.31	-0.007	1.927**	40.32	-0.751*	6.188**
WH 147	126.16	-0.037*	-6.840	85.24	-0.691**	-5.693	8.74	1.544	0.704	53.66	0.390*	1.969**
WH 416	122.41	-0.310	1.365	73.91	-0.621	1.548	8.50	0.073	4.744**	54.92	0.442**	0.474
WH 157	126.58	-0.011	-6.281	83.66	-0.353	15.975	7.99	-0.519	0.765	48.33	-0.174	8.527**
WH 283	124.91	0.064**	-6.796	77.08	-0.918	67.794**	8.99	0.551*	-0.019	51.50	-0.642**	0.717
HD 2687	126.74	-0.164*	-5.718	84.41	-0.040	-3.203	13.08	1.895	3.944**	59.80	-0.949**	3.801**
UP 2338	126.24	0.079	-5.916	86.83	-0.722	24.086	11.81	1.246	1.034*	52.41	-1.556**	1.549*
WH 542	125.16	-0.217**	-5.869	82.06	0.597**	-8.410	16.58	3.204	12.134**	60.73	-0.780	11.498**
PBW 343	127.16	-0.139	-4.266	85.24	-0.282	-4.097	15.47	3.240	4.307**	57.33	-0.704**	-0.029
WH 711	126.99	-0.294**	-6.705	74.99	-0.754	1.770	14.98	1.606	0.632	53.00	-0.121	24.872**
DBW 17	125.75	-1.040	54.432**	73.50	-0.434*	-6.459	16.10	0.254	1.406**	43.58	-0.655	38.781**
PBW 502	125.50	0.090	-5.513	81.50	0.171	-5.489	15.00	2.124	6.535**	51.17	-0.801**	2.924**
PBW 550	123.41	0.432	10.679	86.21	1.334	36.087	15.54	0.074	-0.034	43.06	-0.093	0.510
WH 712	126.16	-0.126	-5.691	78.83	-0.775	11.080	8.41	1.207	1.423**	51.16	-0.014	8.573**
WH 595	125.99	-0.198**	-6.284	80.49	-0.403	40.669	8.41	0.207	0.279	49.75	-0.146	10.479**
WH 730	125.25	0.064	-5.431	89.75	0.508	47.256	9.98	-2.145	10.110**	44.06	-1.083**	1.806**
WH 291	122.50	-0.148	1.159	87.49	-0.594	55.668	6.83	0.140	0.187	52.58	0.323	2.232**
SONAK	124.41	-0.242**	-5.645	88.07	1.143	15.695*	6.83	-0.847	0.919*	49.00	0.852**	8.971**
DBW 16	127.00	0.077	19.246	96.10	0.993	57.823*	10.89	-0.297	2.061**	46.97	0.421**	2.335**
UP 2425	126.24	0.030	-6.544	83.74	-1.220*	3.271	6.18	-1.464	1.242*	45.66	-0.434**	0.797
PBW 373	125.66	-0.112**	-6.528	93.90	-0.118	41.754	8.08	0.796*	0.040	49.75	-0.768**	0.629
WH 1021	126.25	0.330	15.365	106.33	-0.237	47.062	11.14	-0.324	0.298	38.81	1.028	84.128**
RAJ 3765	125.33	-0.025	-3.390	91.08	0.096	78.007*	8.20	-2.771**	0.217	43.98	1.381	64.968**
WH 1022	127.00	0.187	11.229	91.32	0.661	9.727	7.20	0.284	2.828**	39.39	0.542	50.290**
WH 1046	117.50	-0.177	77.729**	85.00	-0.151	10.939	12.16	-0.564	1.332*	48.40	-0.008	82.016**
WH 1051	125.25	0.091	-3.989	85.75	-0.319**	-8.298	9.76	1.008	14.669**	39.12	-0.568**	2.122**
WH 1052	124.00	0.214	-1.210	91.00	-0.140	12.355	11.04	0.773	4.079**	48.84	-0.306**	0.425
WH 1053	122.25	0.057	-3.343	85.25	-0.543	80.743*	10.18	2.185	24.007**	40.65	-0.447**	1.765*
WH 1054	123.75	-0.057	2.653	94.00	-0.203	23.297	10.93	-0.243	2.757**	41.30	0.360	4.505**
WH 1055	127.50	0.083	-5.529	78.50	-0.373	61.185**	11.95	1.411	0.688	48.49	0.782**	-0.133
WH 1056	124.00	-0.032	9.828	75.50	-2.114*	25.366	10.03	0.046	2.556**	36.16	-0.087	1.749*
WH 1059	122.50	-0.007	0.822	76.75	-3.298**	67.162	10.53	-1.931	7.951**	37.62	0.044	31.242**
WH 1061	125.41	0.257	13.679	99.78	0.430	11.446	7.44	-2.090	3.117**	33.07	0.564	18.697**
WH 1062	126.25	0.255	16.824	104.47	1.160	48.010	7.36	-2.695	2.022**	32.90	0.571	9.129**
WH 1069	128.91	0.267**	-4.643	83.02	0.142	-5.669	7.54	-3.194	10.001**	47.48	0.195	23.890**
WH 1070	124.08	0.309	22.418	91.29	2.645	33.479**	8.09	-4.853*	3.603**	45.57	0.565	79.187**
WH 1071	129.08	0.345**	-3.304	94.19	3.413	81.178**	10.24	-0.859	0.180	47.10	0.250	10.170**
WH 1073	129.33	0.277**	-4.509	94.93	0.927	93.020*	9.80	0.460	2.558**	40.67	0.890*	10.772**
WH 1074	122.33	0.524	17.738	94.34	1.218*	9.558	9.48	-1.041	2.108**	37.52	0.851**	2.938**
WH 736	126.24	-0.152**	-6.607	83.66	-0.373	1.725	8.41	0.857**	-0.041	45.83	0.368	15.283**
Population mean	125.46	0.000	-	87.01	0.00	-	10.21	0.000	-	46.84	0.00	-
S.E. (m)	0.292	0.306		0.422	1.027		0.107	1.782		0.276	0.592	

Contd..

Table 3 Contd..

	1000-grain weight (g)			Grain yield per plant (g)			Protein (%)			Sedimentation value (ml)		
Genotypes	$\bar{x}$	bi	S^2di	$\bar{x}$	bi	S^2di	$\bar{x}$	bi	S^2di	$\bar{x}$	bi	S^2di
C 306	40.71	-0.193	0.124	20.12	0.137	6.848	12.59	0.223	0.079	38.21	0.553	2.278**
WH 533	38.82	0.517	3.619**	28.61	-1.280	30.195**	12.32	0.636	-0.023	38.85	0.106	0.673
WH 1025	27.44	-0.159	0.227	25.41	1.057	4.253	12.24	-1.000	0.775**	35.62	-0.368	0.224
WH 147	42.41	-0.473	1.111*	27.66	-0.247	-0.126	11.46	-0.119	0.423**	39.28	-0.165	0.149
WH 416	40.08	-0.580**	0.106	35.99	-0.017	0.538	12.71	2.153	1.689**	39.18	-0.194	0.099
WH 157	46.48	0.358	0.765	26.73	-0.308	-0.192	12.34	0.751	1.142**	38.29	-0.137	0.295
WH 283	43.33	-0.371*	0.255	35.50	-0.402	0.960	12.56	-0.019	-0.096	39.81	-0.748*	0.472
HD 2687	41.75	-0.184	1.903**	36.98	-0.253	0.965	12.82	0.271	1.046**	37.81	-0.298	0.385
UP 2338	42.49	-0.061	2.318**	37.82	-0.624	0.593	13.23	0.043	0.180	30.58	-0.360	11.049**
WH 542	39.66	-0.228	2.456**	37.49	-0.103	8.682*	12.76	2.933**	0.114	37.98	-0.747	2.199**
PBW 343	43.99	-0.258**	-0.081	39.09	-0.046	0.804	12.34	0.918	1.175**	36.31	-0.181	1.844*
WH 711	42.74	0.675	7.104**	40.35	-0.306	0.436	13.09	2.126**	0.089	39.74	0.016	1.411*
DBW 17	38.26	0.143	0.110	40.16	-0.234	1.691	12.85	-2.411**	0.46	34.08	1.085	2.332**
PBW 502	38.43	0.008	2.097**	33.45	0.324	6.493*	12.89	-0.241	0.838*	33.00	0.074	0.325
PBW 550	38.60	0.535	6.514**	36.72	0.061	17.023**	12.15	-0.793	0.409**	38.15	-0.207	0.155
WH 712	42.08	0.875	13.830**	25.75	-0.362	0.144	12.68	1.245	0.173	58.33	1.399	3.718**
WH 595	38.41	-0.722	3.515**	28.35	-0.268	0.187	13.40	1.084	0.176	37.07	0.015	2.169**
WH 730	41.01	0.159	2.079**	32.23	-1.054**	0.021	13.65	-0.126	0.019	36.08	-0.683**	0.060
WH 291	39.83	-0.591**	0.376	26.63	-0.202	0.909	13.98	0.206	0.011	38.16	-0.271**	-0.066
SONAK	44.74	0.029	-0.064	29.20	-0.066	-0.665	12.40	-0.204	0.733*	34.15	1.331**	0.457
DBW 16	38.39	-1.569	7.709**	31.85	-0.352	6.937*	11.51	1.095	1.140**	31.98	-0.679	9.721**
UP 2425	41.99	-0.335	10.306**	17.56	0.010	4.507	12.94	-0.562	0.122	30.08	2.141	13.847**
PBW 373	42.07	0.067	4.790**	26.02	-0.466	1.511	12.65	0.448	0.001	31.30	-0.025	3.461**
WH 1021	34.99	-0.588**	-0.058	26.72	-1.070*	1.755	12.49	1.179**	0.048	33.25	0.012	0.091
RAJ 3765	39.57	-0.319	0.193	26.02	-1.065**	0.236	12.69	-0.418	0.183	30.98	-1.815	34.645**
WH 1022	40.11	0.005	0.284	26.32	-0.140	0.906	13.61	0.413	0.259	35.08	-0.683**	0.060
WH 1046	33.76	-0.264	9.433**	24.31	1.349**	1.227	13.92	-0.491	0.010	36.16	-0.777**	0.071
WH 1051	40.72	-0.105	0.391	32.78	0.979	-6.485*	12.60	-1.189	0.187	31.58	-0.400	0.839
WH 1052	37.10	-0.079	-0.064	33.15	1.129**	-0.723	13.39	0.013	0.143	32.50	-0.247	26.713**
WH 1053	42.40	-0.133	0.153	32.33	0.987**	0.117	13.46	-1.337**	-0.075	36.25	-0.685	1.618*
WH 1054	40.42	0.515	1.136*	31.01	1.209	3.176*	13.59	-1.389**	-0.096	33.98	-1.533	3.332**
WH 1055	37.09	0.487**	-0.037	32.45	1.267	7.465*	14.40	-1.132**	-0.040	40.33	0.643	0.471
WH 1056	40.57	0.550	2.191**	28.79	1.102	4.507	14.95	-0.634**	-0.092	33.90	-0.140	2.379**
WH 1059	40.71	0.646**	0.791	31.51	0.733	10.369*	13.63	-1.006**	-0.088	34.91	1.435*	1.287*
WH 1061	34.77	0.472**	0.046	25.21	0.484	1.691	13.30	-1.662**	0.438**	37.42	0.901**	0.563
WH 1062	35.41	0.491	0.844	26.15	0.360	5.372	12.95	0.625	0.183	33.37	0.268	5.023**
WH 1069	33.43	0.743	7.222**	24.77	-1.447**	0.002	12.60	2.334	0.940**	32.10	-0.393	3.377**
WH 1070	41.45	0.071	1.072*	26.25	-0.180	5.198	12.73	0.263	0.209	36.00	0.455	1.269*
WH 1071	31.48	-0.300**	0.042	23.78	-0.072	2.655	11.63	0.261**	-0.095	39.00	0.455	1.269*
WH 1073	38.28	-0.028	0.863	26.09	0.103	1.461	11.61	-3.388**	1.308**	34.42	0.328	0.510
WH 1074	40.86	0.118	6.116**	23.49	-0.074	0.572	12.75	-1.196	0.482**	30.66	0.200	0.267
WH 736	39.16	0.081	2.757**	25.93	-0.650*	0.048	12.85	0.098	0.023	34.91	0.323	3.538**
Population mean	39.43	0.00	-	29.68	0.00	-		12.87	0.00	35.97	0.00	
S.E. (m)	0.928	0.488		0.114	0.632		0.380	0.829		0.108	0.910	

3.5 Stability parameters: The estimates of the stability parameters of 42 genotypes with non – significant values for βi, $s^{-2}d_i$ for ten characters in present study are given in Table 4.

3.6 Phenological stability: The data on days to heading indicated that three genotypes recorded significant positive regression coefficient (βi) estimate showing that linear response alone accounted for G x E interaction. And two genotypes were recorded significant positive regression coefficient (βi) and $s^{-2}d_i$ value that linear and non-linear response accounted for G x E interaction one genotype recorded non-significant $s^{-2}d_i$ value, indicated that the absence of non-linear component of G x E interaction variety C 306 was most desirable and stable genotype for this character. Since this entire had below average mean, βi value near zero and $s^{-2}d_i$ value equal to zero. WH416, WH542 and WH711 were suited to poor environment, βi value less than zero and non-significant $s^{-2}d_i$ value. None of the genotypic was found for suitable for favorable environment. For days to maturity variety WH283 was found suitable for favorable environment, since they had, βi value more than zero and $s^{-2}d_i$ non-significant varieties Sonak and PBW373 had average mean βi value below zero and $s^{-2}d_i$ value non-significant are suitable for poor environment. Varieties WH 416, UP 2338, PBW 502, PBW 550, WH 712, WH 730, WH 291, DBW 16, WH 1021, Raj 3765, WH 1022, WH 1052, WH 1053, WH 1054, WH 1056, WH 1059, WH 1061, WH 1062, WH 1070 and WH1074 had average mean, zero regression and $s^{-2}d_i$ value equal to zero hence more responsive for this character. Twenty seven genotypes had both βi and $s^{-2}d_i$ non-significant indicating the absence of G x E interaction none of the genotypes was found to have both βi and $s^{-2}i$ significant indicating the absence of simultaneously presence of linear and non-linear components of G x E interaction. Thirteen genotypes were found to have only linear component of G x E interaction as only βi value were significant, while only two genotypes had only $s^{-2}d_i$ value significant i.e. only non-linear component of G x E interaction was present in these genotypes.

Under late sown condition the increase in temperature is responsible for advancement in the main phonological stages, shorting of the growing season which resulted in severe yield reduction. Above finding were supported by Moriondo *et al* (2011). Heat stress is an important production constraint of wheat during grain-fill period in India and in other parts of the world where the temperature become high during anthesis to maturity stage of plant growth (Arya *et al.*, 2012).

3.7 Morphological stability: For Plant height (cm), none of the genotype had both βi and $s^{-2}d_i$ significant values indicating the presence of G×E interaction with linear and non-linear response. Ten genotypes were found to have only linear response of G×E interaction as only βi value have significant. The significant of $s^{-2}d_i$ for non-linear response was recorded for eight genotypes. Varieties WH 730, PBW 373, WH 1021, WH 1022, WH 1052, WH 1054 WH 1061, and WH 1062 were stable, which had high mean, βi value equal to zero and non-significant $s^{-2}d_i$ value. Genotypes C 306 and WH 1074 also had high $s^{-2}d_i$ value equal to zero with βi value more than zero and therefore, were more suitable for favourable environment.

A critical examination of the results on effective tillers per plant showed eleven genotypes having non-significant βi and $s^{-2}d_i$ values indicating thereby the absence of G×E interaction only one genotype (WH 1070) had both βi and $s^{-2}d_i$ significant value indicating the presence of varying environmental conditions. The presence of linear response was recorded for 4 genotypes i.e. these genotypes have only significant βi value. Twenty six genotypes showed significant of $s^{-2}d_i$ for non-significant linear component of G×E interaction. Varieties WH 711, PBW 550, WH 1021 and WH 1055 were stable which had high mean, βi value equal to zero and non-significant $s^{-2}d_i$ value. For number of grains per spike, seven genotypes recorded only significant βi values reflecting the presence of linear response, one genotype PBW 550 showed both $s^{-2}d_i$ and βi values non significant indicating absence of GxE interaction. Varieties WH 283, PBW 343, PBW 373 and WH 1052 found for poor environment, since they had high mean, βi value less than zero and non-significant S^2 di suitable for poor environment. The data for 1000- grain Weight (g) indicated that 12 genotypes had both βi and $s^{-2}d_i$ non-significant thereby indicating absence of G×E interaction. None of the genotype was found to have both βi and $s^{-2}d_i$ significant indicating the absence of simultaneously presence of linear non-linear components of G×E interaction. Nine genotypes were showed linear component of G×E interaction as only βi value were significant while twenty one genotypes had only $s^{-2}d_i$ value significant i.e. only non-linear component of G×E interaction was present in these genotypes. Genotypes WH 157, Sonak and WH 1053 were stable which had high mean, βi value equal to zero and non-significant $s^{-2}d_i$ were suitable for all environments. Genotypes WH 283 and PBW 343 were stable for poor environment since they possessed high mean, βi value less than zero and non-significant .

Aruna *et al.* (1989) reported that varieties differed in environmental responses affecting tillers per plant, grains per spike and test weight. The changes in frequency of extreme climatic events during the more sensitive growth stages (i.e. tillering, spike development, anthesis and grain filling) have been recognized as a major yield stabilizing factors. Above findings are supported by Easterling and Apps (2005). Therefore, under late sown (heat stress) conditions plant height, effective tillers per plant, number of grain per spikes and 1000 grain yield were reduced drastically responsible for yield instability.

3.8 Yield Stability: The data presented for biological yield per plant (g) indicated that two genotypes had both βi and value $s^{-2}d_i$ non-significant indicating the absence of G×E interaction. Three genotypes had both βi value and $s^{-2}d_i$ significant indicated that the presence of linear and non-linear component of G×E interaction. Genotypes WH 283 and HD 2687 were stable for all environment since they possessed high mean, βi value equal to zero and non-significant.

A critical examination of the results on grain yield per plant (g) revealed that 30 genotypes out of the 42 both βi and $s^{-2}d_i$ non-significant indicating the absence of G×E interaction. None of the genotype was found to have both βi and $s^{-2}d_i$ significant indicating the absence of simultaneous presence of linear & non-linear components of G×E interaction. Eight genotypes were found to have only linear portion of G×E interaction as only βi value were significant while only non-linear component of G×E in was present in these genotypes. The genotypes WH 711, DBW 17, PBW 343, UP 2338, HD 2687, WH 416 and WH 283 were found stable for all environments for grain yield because of highest grain yield βi value mean to zero and $s^{-2}d_i$ non-significant moreover, WH 730 was stable for poor environment since it had high mean, βi value less than zero, non-significant $s^{-2}d_i$ value. Genotypes WH 1052 and WH 1053 were found sable for formable environment as they had above average mean, βi value more than zero and $s^{-2}d_i$ value equal to zero.

The pattern of genotypic response was not similar at all the four environments, due to inter and entra location

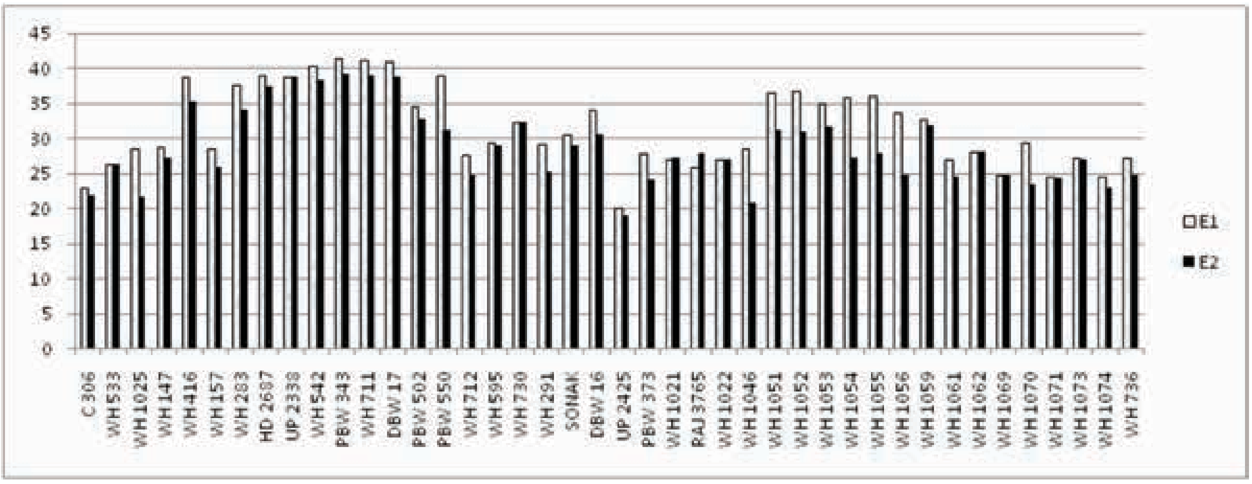

Fig 2a. Grain yield (g/plant) of different genotypes at Hisar location under timely sown (E_3) and late sown (E_4) environments

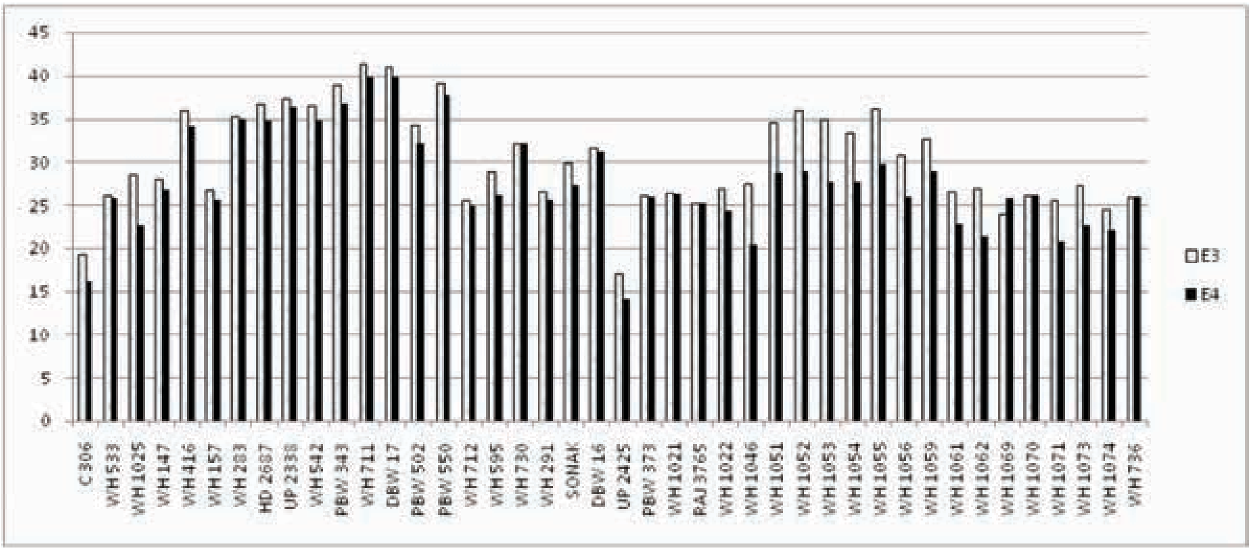

Fig 2b. Grain yield (g/plant) of different genotypes at Bawal location under timely sown (E_3) and late sown (E_4) environments

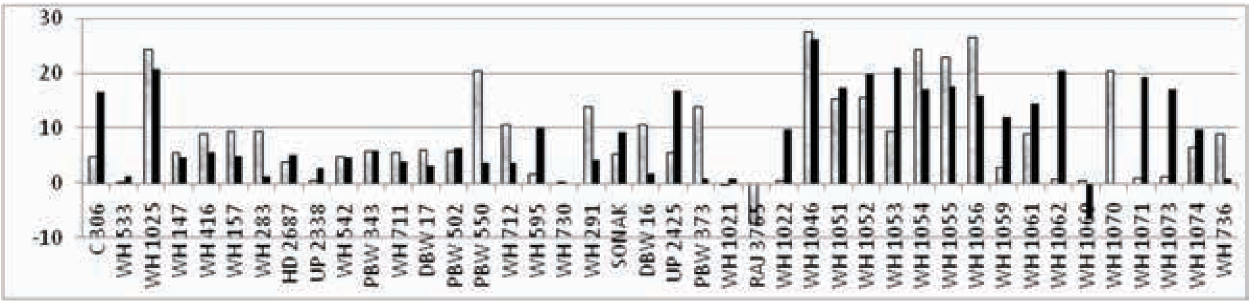

Fig 2c. Reduction (%) in grain yield of different genotypes at Hisar and Bawal location due to heat stress under late sown environments

variations in genotypic response over the dates of sowing (Fig. 2a,b &c). Similar finding were also reported by Rana *et al* (2007).They also reported that Raj 3765 and Raj 4027 were more stable across all the environments. This was due to their adaptability to high temperature environments and hence, these genotypes being proposed as promising genotypes (sources) for late sown and/or warmer environments.

3.9 Heat stability index: Heat stability index (HSI) was used to measure terminal heat stress tolerance in term of minizing the reduction in yield caused by unfavourable vs favourable environments. In the present study the genotypes viz. WH 730, WH 533, WH 1069, WH 1021 WH 595, HD 2967, UP 2338, RAJ 3765 exhibited HSI values less than 0.5, which indicated that these genotypes are highly tolerant to terminal heat stress. Thus, these may be cultivated under terminal heat stress conditions for high grain yield production. Moreover, above all the genotypes may be utilized in breeding program to develop high yielding heat tolerant/resistance cultivars. Above finding were also supported by Verma *et al.* (2006).

3.10 Grain quality stability: The data for protein percentage indicated that eighteen genotypes showed non-significant βi and values indicating thereby the absence of genotype environment interaction. Only two genotypes have both βi and $s^{-2}d_i$ values significant indicating the presence of G×E interaction with linear and non-linear response of genotypes to the varying environment condition. Ten genotypes showed presence of linear response. The significance of value for non-linear response was recorded for twelve genotypes. Genotypes WH 291, WH 1022 and WH 1046 were stable for all environments since these genotypes had above average mean, βi value to zero, and non-significant $s^{-2}d_i$ values (Verma *et al.*, 2006). Genotypes WH 1053, WH 1055 and WH 1056 were stable for poor environment since these genotypes had above average mean, βi value less than zero, and non-significant values.

A critical examination of the results on sedimentation value (ml) revealed that thirteen genotypes out of the 42 had both βi and $s^{-2}d_i$ non-significant indicating the absence of G×E interaction. Only one of the genotype (WH1059) was found to have βi and $s^{-2}d_i$ significant indicating the absence of simultaneously presence of linear & non – linear components of G×E interaction.

Seven genotypes were found to have only linear component of G×E interaction as only $s^{-2}d_i$ values were significant, while twenty one genotypes has only value significant i.e. only non-linear component of G×E interaction was present in these genotypes. The genotypes WH 533, WH 147, WH 416, WH 157, HD 2687 , PBW 550 and WH 1055 were stable for all environments because of height mean, βi value equal to zero and non-significant. Genotypes WH 283 and WH 291 were found for poor environment since they have high mean, βi value less than zero and non-significant $s^{-2}d_i$ values.

The stability in quality standards for marketing of value added products is must. But, the grain quality is highly influenced by environmental factors and no positive significant association was observed between yield and quality parameters. However, some research workers reported negative association between yield and quality measures (Arya *et al.*, 2010).

3.11 Stability analysis implications: The present study helped to identify some genotypes which could be suitable for different kinds of environment conditions. The selected genotypes are likely to give predicted response of grain yield in a given environment According to Perkins and Jinks (1968a) a desirable variety should have high mean ($\bar{x}$) with βi and values approaching to zero. Out of 42 genotypes, none of the genotype was found to be stable for all the ten characters studied. However, PBW550 and WH1022 were stable for three characters out of ten as βi and were non- significant. Considering the above three parameters of stability together, the maximum number of desirable genotypes was 20 for days to maturity , followed by 7 for grain yield per plant , 9 for plant height, 7 for sedimentation value, 4 for effective tillers per plant therefore, emphasis should be placed on these characters while breeding for stability.

Stability analysis for individual genotypes which revealed that none was found stable for all the characters. However, the genotypes WH 711, DBW 17, PBW 343, UP 2338, HD 2687, WH 416 and WH 283 were found stable for grain yield all the environments because they had above average mean, βi value equal to zero and non-significant value. It means that these were less responsive to the environmental changes and therefore, more adaptive. Moreover, WH 730 was stable for poor environment since it had high mean, βi value less than zero, non-significant value. Genotypes WH 1052 and WH 1053 were found sable for formable environment as they had above average mean, βi value more than zero and value equal to zero.

Hence WH 711, DBW 17, PBW 343, UP 2383, HD 2687, WH 416 and WH 283 were found stable having above average mean performance, regression coefficient near to zero and deviation from regression almost zero. Therefore, emphasis should be laid on above said genotypes while breeding for stability.

It may be concluded that the genotypes viz. WH 730, WH 1021, WH 533 and UP 2338 exhibited the least reduction under terminal heat stress condition, as well as low ($<$ 0.5) HSI values. Moreover, the genotype UP 2338 was found stable and high yielder along with the resistance against terminal heat stress. It may be cultivated under terminal heat stress conditions. However, above all the genotypes may be utilized in breeding program to develop high yielding heat tolerant/resistance cultivars.

References

1. Arya RK, HP Yadav, AK Yadav and MK Singh. 2010. Effect of environment on yield and its contributed traits in pearl millet. *Forage Research* **36**(4):176-180.
2. Arya RK, Renu Munjal and SS Dhanda. 2012. Evaluation of bread, durum and synthetic wheats and triticale for physiological traits under heat stress conditions. In: *National seminar on sustainable agriculture and food security: challenges in changing climate*, March, 27-28, 2012 at CCSHAU, Hisar.
3. Breese EL. 1969. The measurement and significance of genotype-environment interaction in grasses. *Heredity* **24**:26-44.
4. Din, Riaz-ud, GM Subhani, Naeem-Ahmad, Makhdoom-Hussain and Aziz-ur-Rehman. 2010. Effect of temperature on development and grain formation in spring wheat. *Pakistan Journal of Botany* **42**(2):899-906.
5. Easterling W and M Apps. 2005. Assessing the consequences of climate change for good and forest resources: a view from the IPCC. *Climate change* **70**: 165-189.
6. Fisher RA and R Maure. 1978. Drought resistance in spring wheat cultivars. *Australian Journal of Agricultural Research* **29**:897-912.
7. Hakim MA, NCD Barma, MM Akhter, MB Banu and MQI Matin. 2008. Yield stability of some promising bread wheat genotypes. *International-Journal-of-Sustainable-Agricultural-Technology* **4**(1): 66-69.
8. Joshi AK, B Mishra, R Chatrath, G Ortiz Ferrara and RP Singh. 2007. Wheat improvement in India: present status, emerging challenges and future prospects. *Euphytica* **157**:431-446.
9. Moriondo M, C Giannakopoulos and M Bindi. 2010. Climate change impact assessment: the role of climate extremes in crop yield simulation. *Climate change.* **104**: 679-701.
10. Panse VG and PV Sukhatme. 1967. *Statistical Methods for Agricultural Workers*, ICAR, New Delhi Pub.
11. Perkins JM and JL Jinks. 1968a. Environmental and genotype environmental components of variability. VI. Diallel sets of crosses. *Heredity* **23**: 339-356.
12. Perkins JM and JL Jinks. 1968b. Environmental and genotype environmental components of variability. VI. Diallel sets of crosses. *Heredity.* **23**: 525-535.
13. Rane J, RK Pannu, VS Sohu, RS Saini, B Mishra, J Shoran, J Crossa, M Vargas and AK Joshi. 2007. Performance of yield and stability of advanced wheat genotypes under heat stress environments of the Indo-Gangetic plains. *Crop-Science.* **47**(4):1561-1573.
14. Sareen S, R Munjal, NB Singh, BN Singh, RS Varma, BK Meena, J Shoran, AK Sarial and SS Singh. 2012. Genotype X environment interaction and AMMI analysis for heat tolerance in wheat. *Cereal Research Communications.* **40**(2): 267-276.
15. Soil Survey Staff. 1999. Soil Taxonomy, USDA, Washington, DC.
16. Verma RS, CS Panday, Sandeep Kumar and Ombir Singh. 2006. Screening of heat tolerant wheat genotypes for late sown conditions. *Indian Journal of Agricultural Sciences* 2(1):157-159.
17. Zalewski D and R Weber. 2006. Evaluation of genotype-environment interaction and yield stability of winter wheat varieties. *Biuletyn Instytutu-Hodowli-i-Aklimatyzacji Roslin.* **24**(2):33-43.