Bangladesh J. Bot. **48**(4): 1143-1151, 2019 (December)

GENOTYPE-ENVIRONMENT INTERACTION ON STABILITY OF GRAIN YIELD AND PHYSIO-BIOCHEMICAL TRAITS IN BREAD WHEAT (*TRITICUM AESTIVUM* L.)

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Keywords: Bread wheat, Terminal heat tolerance, Grain yield, Physiological traits, Protein content, Stability analysis

Abstract

To assess the stability of genotypes for grain yield and physio-biochemical traits associated with terminal heat tolerance pooled analysis of 8 genotypes of wheat of diverse origin, their 28 F_1 progeny and 2 checks were carried out in 4 different environments *i.e.* early sown (E_1), normal sown (E_2), late sown (E_3) and very late sown (E_4) conditions. The pooled analysis of variance due to environment (for proline and chlorophyll content), genotypes and genotype × environment interaction was significant for all the traits under consideration. This indicated the distinct and differential effect of the different sowing conditions (environment) and differential response of all the genotypes chosen for the study. The five stable wheat hybrids *viz.*, HI 1544 × HD 2987, Raj 4037 × HD 2987, PBW 175 × HD 2987, HD 2932 × Raj 4079 and PBW 175 × Lok 1 showed higher mean values, favourable regression coefficient and deviation from regression coefficient for grain yield and other associated characters, thus emerged as stable genotypes as per criteria of stability analysis. Similarly, some genotypes showed specific adaptations for poor or heat stress environment.

Introduction

Wheat (*Triticuma estivum* L.) (2n = 6x = 42), a self-pollinated crop of the *Poaceae* is the world's largest cereal crop (Sharma *et al.* 2019). It is the staple food for over 27 per cent of global population in more than 40 countries. It is popularly known as 'Stuff of life or King of the cereals' because of the acreage occupied, high productivity and the prominent position it holds in the international food grain trade. The main wheat growing countries include Australia, Canada, China, France, India, Russia, Turkey, Ukrain and USA. It is the second most important grain crop after rice in India and has tremendous yield potential. In India, area and production of wheat during year 2014 - 2015 was recorded 30.97 million ha and 88.94 million tonnes with an average productivity of 2872 kg/ha (DAC&FW 2015). Wheat grain contains starch (60 - 68%), protein (6 - 21%), fat (1.5 - 2.0%), cellulose (2.0 - 2.5%), minerals (1.8%) and vitamins. The uniqueness of wheat in contrast to other cereals is that wheat contains gluten protein which enables leavened dough to rise by forming minute gas cells and this property enables bakers to produce light breads.

Wheat is a thermo-sensitive crop mostly grown in temperate environment, but on account of its genetic diversity, it has extended its frontiers and has become adapted to nearly all the climates of the world. In subtropical regions it is cultivated in winter season but it exposed to high temperature (> 35ºC) stress at the end of the season i.e. during grain filling. Rise in temperature at the time of grain filling is referred to as terminal heat stress which reduces yield and decreases quality of wheat in many wheat environments around the world (Reynolds *et al.* 2001, Hays *et al.* 2007). The phenotypic performance of a genotype is not necessarily the same under diverse agro-ecological conditions (Ali *et al.* 2003).

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Breeding genotypes for heat tolerance has become an integral component of wheat improvement. To achieve this goal, growing of breeding lines over time and space has become an integral part of any plant breeding programme. The task of breeder is to screen out genotypes planted at different interval and to those genotypes which are suitable for wider range of planting. Information on phenotypic stability is useful for the selection of crop varieties as well as for breeding programs. Some genotypes may perform well in certain environment, but, fail in several others. Genotype-environment interaction is extremely important in the development and evolution of plant varieties because they reduce the genotypic-stability values under diverse environments (Herbert *et al.* 1995). Progress from selection is also reduced due to a large effect of genotypes and environment interaction as shown by Comstock and Moll (1963). Hence a study of G × E interaction can lead to successful evolution of wheat cultivars for stability in yield performance in different environments.

In the present study, the approach suggested by Eberhart and Russell (1966) has been employed to understand the differential G × E interaction of parents and their hybrids to access the stability of individual genotypes. An understanding of environmental and genotypic causes leading to G × E interactions are important at all stages of plant breeding including ideotype design, parental selection, selection based on traits and selection based on yield (Jackson *et al*. 1996, Yan and Hunt 1998). This understanding can be used to establish breeding objectives, identify ideal test conditions and formulate recommendations for areas of optimal cultivar adaptation. Thus, this study was undertaken to evaluate wheat genotypes for their yield stability under diverse temperature regimes.

Materials and Methods

Eight diverse wheat genotypes (Table 1) selected on the basis of broad range of genetic diversity for major yield components, geographical origin, heat tolerance and their suitability for different yield traits, were crossed in half diallel fashion resulting in 28 F_1s at Research Farm, Rajasthan College of Agriculture, Udaipur (Rajasthan) during the year 2014-15. These eight parents and their 28 F_1s were grown in a randomized block design with three replications under early (E_1), normal (E_2), late (E_3) and very late (E_4) sown conditions. The environments were created by four different date of sowings (Table 2). Row-to-row and plant-to-plant distances were 30 and 10 cm, respectively in each environment. Recommended plant protection procedures were followed for raising the crop in all the environments.

Table 1. Particulars of wheat parent material used.

Sl. No.	Name of cultivar	Pedigree
1.	HD 2932(PUSA WHEAT 111)	KAUZ/STAR//HD 2643
2.	GW 366	DL 802-3/GW 232
3.	Raj 4037	DL 788-2 / RAJ 3717
4.	PBW 175	HD 2160 /WG 1025
5.	HI 1544 (PURNA)	HINDI 62/BOBWHITE/ CPAN 2099
6.	Raj 4079	UP 2363/WH 595
7.	HD 2987(PUSA BAHAR)	HI1011/HD2348//MENDOS//IWP 72/DL 153-2
8.	LOK 1	S-308 / S 331,

Table 2. The details of the four environments.

Environment	Date of sowing
E_1 (Early sown)	October 27, 2015
E_2 (Normal sown)	November 17, 2015
E_3 (Late sown)	December 07, 2015
E_4 (Very late sown)	December 27, 2015

The observations were recorded on randomly selected competitive plants from each plot in each replication in case of parents, F_1 progeny and checks in all the four environments separately on seven distinct characters. The data on grain yield per plant, leaf canopy temperature, proline content, chlorophyll content, chlorophyll stability index, heat injury and total protein content were recorded for statistical analysis.

A combined analysis of variance was undertaken across the test environments. The phenotypic stability of genotype for different characters was estimated according to model proposed by Eberhart and Russell (1966).

The statistical model of the analysis was as follows:

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$$

where,

Y_{ij} = Mean performance of i^{th} genotype in j^{th} environment

μ_i = Mean of i^{th} genotype over all the environments

β_i = The regression coefficient of i^{th} genotype

δ_{ij} = Deviation from regression of the i^{th} genotype

I_j = The environmental index for j^{th} environment

Two parameters of stability *viz.* regression coefficient (b_i) and mean square deviation from linear regression (S^2d_i) were estimated as follows (Sing and Chaudhary 1979).

$$b_i = \frac{\sum_{j=1}^{l} Y_{ij} \times I_j}{\sum_{j=1}^{l} I_j^2}$$

The mean squares deviation from regression (S^2d_i) was estimated as:

$$S_{di}^2 = \left(\frac{\sum_{j=1}^{l} \hat{\delta}_{ij}^2}{l-2} \right) - \frac{S_e^2}{r}$$

where, S^2_e = Estimate of pooled error mean square and

$$\sum_{j}^{l} \hat{\delta}_{ij}^2 = \left(\sum_{j=1}^{i} Y_{ij}^2 - \frac{Y_i^2}{l} \right) - \frac{\left(\sum_{j=1}^{i} Y_{ij}^2 . I_j \right)^2}{\sum_{j=1}^{i} I_j^2}$$

The linear regression coefficient (b_i) of the relationship between yield for genotype at each location and the yield for mean location is the measure of the linear responses to environmental change. The mean square for deviation from the regression (S^2d_i) measures the consistency of this response: in other words, it is a measure of heterogeneity.

Results and Discussion

The analysis of variance representing the mean squares due to different sources of variation for different characters is presented in Table 3. The variance due to environment was significant for proline and chlorophyll content indicating the distinct and differential effect of the different sowing conditions. The pooled analysis of variance for stability revealed that genotypes were found to be highly significant for all the characters when tested against pooled error as well as pooled deviation indicating thereby differential response of all the genotypes selected for the study. The variance due to G × E (L) have shown significant interaction for all the characters showing differential response to the genotypes to the all these environmental conditions. Highly significant G × E interactions for many wheat traits were previously reported by Hamam and Khaled (2009) and Tripura *et al.* (2011).

Significant mean squares due to E + (G × E) for all the characters revealed that the genotypes interacted considerably with environmental conditions that existed under different conditions of sowing. The significant variances due to pooled deviation components to the proline content, chlorophyll content and heat injury suggested that the genotypes differed significantly with respect to their stability for this characters. Similar results for one or more characters in wheat were also reported by Arya *et al.* (2004), Amin *et al.* (2005), Meena *et al.* (2014).

Table 3. Analysis of variance over the environment (Eberhart and Russell 1966).

Sl. No.	Characters	Genotype [37]	E + (G × E) [114]	E (L) [1]	G × E (L) [37]	Pool dev. [76]	Pool error [296]
1.	Grain yield/plant (g)	18.13**	11.19**	0.82	33.78**	0.33	0.54
2.	Leaf canopy temp. (^{0}C)	1.43**	7.86**	0.61	23.94**	0.12	0.17
3.	Proline content (µg)	34.10**	63.43**	4.86**	192.92**	1.16**	0.16
4.	Chlorophyll content (mg/g)	0.42**	0.05**	0.004*	0.15**	0.002**	0.00
5.	Chlorophyll stability index	31.02**	5.03**	0.34	15.03**	0.22	0.19
6.	Heat injury (%)	110.87**	20.19**	1.45	59.60**	1.24**	0.72
7.	Total protein content (%)	1.20**	0.11**	0.008	0.32**	0.01	0.02

*, ** Significant at 5 and 1 per cent level, respectively. Degree of freedom indicated within third bracket [ ].

The estimates of stability parameters like mean performance of the genotypes, regression coefficient (b_i) and deviation from the regression (S^2d_i) for seven different characters are presented in Table 4. In the present study, linear regression is regarded as measure of responsiveness and deviation from regression as measure of stability of a particular genotype. The genotypes with higher *per se* performance with non-significant S^2d_i were classified on the basis of regression coefficient (b_i). The genotypes with $b_i < 1$ (significantly less than 1) were identified for adverse environmental conditions, $b_i > 1$ (significantly higher than 1) for favourable environmental conditions and $b_i = 1$ for unknown or unpredictable environmental conditions. A genotype is considered to be stable in performance if it has high mean performance, unit regression coefficient ($b_i = 1$) and least deviation from regression ($S^2d_i = 0$).

Table 4. Stability parameters for different characters.

Sl. No.	Genotype	Grain yield per plant (g)			Leaf canopy temperature (^{0}C)			Proline content (µg)			Proline content (µg)		
		μ_i	b_i	S^2d_i	μ_i	b_i	S^2d_i	μ_i	b_i	S^2d_i	μ_i	b_i	S^2d_i
1	HD 2932	13.74	1.00*	0.177	25.50	1.13**	0.023	21.61	0.90*	1.74**	1.67	1.54*	0.007**
2	GW 366	13.32	1.00**	–0.470	24.74	1.04**	–0.135	16.48	1.00**	-0.08	1.14	0.92**	–0.001
3	Raj 4037	10.16	0.60*+	–0.407	25.22	1.23**	–0.004	23.20	0.88*	3.15**	1.65	1.67**+	0.002*
4	PBW 175	11.79	0.88*	0.325	24.86	1.05**	–0.022	17.08	0.85**	0.71**	1.34	0.85**	–0.001
5	HI 1544	15.37	1.31**++	–0.521	26.16	1.00**	–0.133	16.32	1.15*	4.36**	0.96	0.68**+	–0.001
6	Raj 4079	11.15	0.66	0.218	24.29	1.08**	–0.041	21.11	0.81*	1.50**	1.60	1.65*	0.004**
7	HD 2987	13.31	1.03**	–0.457	24.68	1.04**	0.047	18.03	0.90**+	–0.09	1.32	1.29*	0.005**
8	Lok1	13.98	1.14**	–0.495	26.22	0.92**+	–0.164	17.33	0.92**	0.24	1.49	1.51*	0.010**
9	HD 2932 × GW 366	14.05	1.06**	–0.236	25.49	0.93**	–0.043	22.10	0.92**	0.36*	1.22	0.74*	0.000
10	HD 2932 × Raj 4037	14.33	0.79*	–0.122	25.17	0.97**	0.028	26.25	1.16**	0.42*	1.70	0.99**	–0.001
11	HD 2932 × PBW 175	13.41	1.27**	–0.398	25.86	1.00**	–0.072	19.73	0.91**	0.60**	1.43	1.22**+	–0.001
12	HD 2932 × HI 1544	11.74	0.99*	0.169	26.29	1.00**	–0.149	18.42	0.89**	0.32*	1.10	0.92**	–0.001
13	HD 2932 × Raj 4079	16.37	0.84*	–0.116	24.59	1.00*	0.374*	23.29	1.10**	0.37*	1.85	0.95**	–0.001
14	HD 2932 × HD 2987	12.89	1.13**	–0.481	24.60	1.05**	–0.150	24.82	0.95**	0.42*	2.10	0.95*	0.001
15	HD 2932 × Lok1	11.65	0.68*	–0.297	24.33	1.05**	0.026	21.94	0.90**	1.16**	1.31	0.85**	–0.000
16	GW 366 × Raj 4037	14.08	1.32*	0.720	26.35	1.00**	–0.036	21.40	0.95**	0.33*	1.07	1.04**	–0.001
17	GW 366 × PBW 175	13.48	1.12*	0.910	24.04	1.16*	0.180	17.98	1.00**	-0.13	0.98	0.95**	–0.001
18	GW 366 × HI 1544	10.54	0.80**+	–0.499	24.99	0.94**	–0.142	16.06	1.07**	0.13	1.04	0.87**	–0.001
19	GW 366 × Raj 4079	9.74	0.74**+	–0.489	25.90	1.03**	–0.109	20.04	0.90**	0.26	1.10	0.88**+	–0.001
20	GW 366 × HD 2987	13.01	1.09**	–0.211	24.71	0.91**	–0.053	20.12	0.92*	3.16**	0.89	0.89**+	–0.001
21	GW 366 × Lok1	14.56	1.25**+	–0.446	25.73	1.00**	–0.111	16.00	1.19**	1.59**	0.92	0.84**+	–0.001
22	Raj 4037 × PBW 175	13.28	1.14**+	–0.520	24.99	1.08**	–0.121	20.65	0.94*	2.28**	1.16	0.74**+	–0.001
23	Raj 4037 × HI 1544	14.26	1.19*	0.476	25.61	1.14*	0.329	21.33	1.01**	0.58**	0.92	0.88**	–0.000
24	Raj 4037 × Raj 4079	11.27	0.49*+	–0.357	25.15	0.95**	–0.155	24.31	1.05**	0.57**	2.05	0.93**	–0.000
25	Raj 4037 × HD 2987	17.69	0.81**+	–0.494	24.63	0.89**+	–0.163	24.96	1.15**	0.83**	1.93	0.87	0.008**
26	Raj 4037 × Lok1	12.49	1.09**	–0.377	25.79	0.92**	–0.070	21.21	1.04**	1.21**	1.73	1.14**	–0.001
27	PBW 175 × HI 1544	8.27	0.56**++ -	0.508	25.29	0.87*	0.062	18.96	0.90**	0.48*	1.34	0.99**	–0.000
28	PBW 175 × Raj 4079	14.37	1.13*	0.175	25.05	1.06**	–0.090	19.14	0.94**	0.67**	1.32	0.92**	–0.000
29	PBW 175 × HD 2987	16.74	1.48**++ -	0.475	25.34	1.08**	–0.028	18.25	1.19**	2.05**	1.25	1.17**	–0.000
30	PBW 175 × Lok1	15.69	1.36**+	–0.353	25.92	0.97**	–0.134	18.31	1.35*	3.45**	1.13	0.94**+	–0.001
31	HI 1544 × Raj 4079	15.63	1.41**	–0.009	25.57	1.00**	–0.110	20.12	0.97**	0.60**	1.30	0.73**+	–0.001
32	HI 1544 × HD 2987	18.57	1.00*	0.090	25.21	0.99*	0.122	18.40	0.87**	0.25	0.93	0.95**	–0.000
33	HI 1544 × Lok1	15.16	0.79**+	–0.478	24.93	0.93**	–0.156	13.88	1.04**	0.35*	1.29	1.01*	0.002
34	Raj 4079 × HD 2987	13.54	1.16**+	–0.501	25.61	0.93*	0.040	23.77	1.36**	2.94**	1.31	0.68**+	–0.000
35	Raj 4079 × Lok1	14.02	1.22**+	–0.483	24.21	0.84**++	–0.165	20.26	1.11**	–0.001	1.02	0.96**	–0.001
36	HD 2987 × Lok1	14.44	0.99**	–0.337	25.14	0.95**	–0.069	14.95	1.10**	0.68**	1.07	0.95*	0.001
37	HI 1563	12.18	0.68**+	–0.486	25.20	0.91**	–0.157	20.11	0.86**	0.37*	1.25	0.81	0.005**
38	HD 2967	13.67	0.80*	–0.210	25.25	0.94**	–0.153	20.30	0.88**	0.35*	1.22	1.15*	0.003*

(Contd.)

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Sl. No.	Genotype	Chlorophyll stability index			Heat injury (%)			Total protein content in grain (%)		
		μ_i	b_i	S^2d_i	μ_i	b_i	S^2d_i	μ_i	b_i	S^2d_i
1	HD 2932	15.48	1.10*	–0.03	37.35	0.80**	–0.431	11.01	1.18**	–0.019
2	GW 366	15.23	0.67*	0.02	45.49	0.68**++	–0.693	11.50	0.91**	–0.021
3	Raj 4037	12.00	0.88*	0.26	36.14	0.53	0.990	10.92	1.15*	–0.009
4	PBW 175	9.24	0.46**++	–0.17	47.20	1.20**	0.073	11.95	0.64*	–0.019
5	HI 1544	9.62	0.54**++	–0.19	47.12	0.79*	0.306	11.58	1.34*	–0.011
6	Raj 4079	14.80	0.59**++	–0.19	38.26	0.80**	–0.454	10.68	1.29**	–0.019
7	HD 2987	15.24	0.84**	–0.17	45.72	0.70**+	–0.549	11.45	1.23**	–0.018
8	Lok1	12.11	0.44	0.27	42.26	0.80**	–0.392	11.57	1.18*	–0.016
9	HD 2932 × GW 366	7.16	0.39**++	–0.18	38.65	1.04*	1.551*	11.67	0.78**++	–0.021
10	HD 2932 × Raj 4037	8.62	0.71*	0.01	34.61	1.25*	2.323*	10.79	1.32*	–0.012
11	HD 2932 × PBW 175	15.82	1.11*	0.21	42.17	1.11**	–0.416	12.31	1.20**	–0.017
12	HD 2932 × HI 1544	15.09	1.37**+	–0.15	46.70	1.23**	–0.274	12.22	1.18**	–0.018
13	HD 2932 × Raj 4079	16.44	0.90**	–0.14	32.45	0.76*	–0.285	10.85	1.02**	–0.018
14	HD 2932 × HD 2987	14.80	1.74**++	–0.18	36.44	1.47**	0.428	12.25	1.70*	0.005
15	HD 2932 × Lok1	17.23	0.99**	–0.13	34.07	0.65*+	–0.460	10.59	0.83**++	–0.021
16	GW 366 × Raj 4037	17.09	1.10*	0.28	45.72	1.21*	0.842	11.11	1.19*	–0.016
17	GW 366 × PBW 175	14.87	1.33**	–0.08	44.38	0.85*	0.323	12.10	1.28*	–0.014
18	GW 366 × HI 1544	15.07	1.25*	0.09	48.19	1.04**	–0.129	11.17	0.86**++	–0.021
19	GW 366 × Raj 4079	15.68	1.26*	0.07	47.32	1.17	3.391**	11.64	0.68**+	–0.020
20	GW 366 × HD 2987	14.73	1.64*	0.35	46.84	1.39*	0.578	11.53	0.58*+	–0.020
21	GW 366 × Lok1	14.49	1.05**	–0.11	45.55	1.14**	-0.478	12.15	0.61**+	–0.020
22	Raj 4037 × PBW 175	8.95	0.36+	–0.10	36.81	1.25*	0.166	11.51	1.18*	–0.017
23	Raj 4037 × HI 1544	17.26	1.58*	0.40*	35.38	1.12	4.042**	10.91	1.09**	–0.018
24	Raj 4037 × Raj 4079	17.38	1.06**	–0.09	31.99	1.14**	–0.229	10.99	0.94**	–0.021
25	Raj 4037 × HD 2987	18.61	0.97**	–0.08	32.81	0.85**	–0.335	10.96	1.02**	–0.019
26	Raj 4037 × Lok1	10.46	0.71*	0.04	40.19	0.88*	–0.061	12.72	0.91**++	–0.021
27	PBW 175 × HI 1544	16.07	0.84*	–0.08	46.91	0.85*	0.196	11.56	0.89**++	–0.021
28	PBW 175 × Raj 4079	15.91	1.35**+	–0.13	45.12	1.41	5.586**	11.26	0.42	–0.014
29	PBW 175 × HD 2987	14.89	1.52*	1.09**	48.21	1.01*	0.161	11.10	0.99**	–0.020
30	PBW 175 × Lok1	13.34	1.08*	0.09	46.49	1.07**+	–0.706	10.77	0.73**+	–0.021
31	HI 1544 × Raj 4079	15.97	1.22**	–0.07	47.34	0.90**	–0.382	11.12	0.50	–0.017
32	HI 1544 × HD 2987	17.40	1.04*	0.04	48.85	1.08**	–0.262	12.20	0.89**++	–0.021
33	HI 1544 × Lok1	11.56	0.83*	0.24	49.10	0.86**	–0.616	12.50	0.73*	–0.016
34	Raj 4079 × HD 2987	13.22	0.96*	–0.04	41.51	1.47*	1.322	11.22	0.89**+	–0.021
35	Raj 4079 × Lok1	16.45	1.17**	–0.03	43.99	0.79**+	-0.614	11.65	1.13*	–0.015
36	HD 2987 × Lok1	14.03	0.91**	–0.09	41.66	0.72**+	-0.545	11.34	1.19*	–0.016
37	HI 1563	15.56	1.04**	–0.05	41.17	1.03	3.069**	11.19	1.11*	–0.013
38	HD 2967	15.33	1.00*	0.05	42.02	0.94	3.041**	11.10	1.23	0.144**

*, ** Significant at 5 and 1 per cent level, respectively. +, ++ Significant deviation of bi from unity at 5 and 1 per cent level, respectively.

For grain yield per plant, all the parents and hybrids depicted non-significant deviation from regression (S^2d_i), were stable and predictable for this trait. Out of these eight parents, parent HD 2932 and HD 2987 had regression coefficient around unity (b_i = 1) with high mean value than population mean, indicated its suitability and stability of performance under varied environments. Parents HI 1544 and Lok 1 showed regression coefficient greater than unity (b_i > 1) with high average value than population mean indicating its stability under favorable environments. Among hybrids, hybrid HD 2932 × Raj 4037, HD 2932 × Raj 4079, Raj 4037 × HD 2987 and HI 1544 × Lok 1 exhibited regression coefficient less than unity (b_i < 1) with high mean value than population mean, indicating its stability under unfavorable environments. Hybrids HD 2932 × GW 366, HI 1544 × HD 2987 and HD 2987 × Lok 1 exhibited regression coefficient around unity (bi=1) with high mean value than population mean, indicating its suitability and stability of performance under different environments. Hybrids GW 366 × Raj 4037, GW 366 × Lok 1, Raj 4037 × HI 1544, PBW 175 × Raj 4079, PBW 175 × HD 2987, HI 1544 × Raj 4079, Raj 4079 × HD 2987 and Raj 4079 × Lok 1 had regression coefficient greater than unity (b_i > 1) with high mean value than population mean, indicating its suitability and stability under favorable environments.

Parents HD 2932, HI 1544, HD 2987 and Lok 1 also showed stable performance for leaf canopy temperature. In addition to this characters, parent HD 2932 also exhibited stable performance for heat injury, while for chlorophyll stability index parents HD 2987 and Lok 1; for total protein content parents HI 1544 and Lok 1, showed stable performance. For proline content and chlorophyll content none of genotypes showed the stable performance.

Comparative study of five stable hybrids *viz.*, HI 1544 × HD 2987, Raj 4037 × HD 2987, PBW 175 × HD 2987, HD 2932 × Raj 4079 and PBW 175 × Lok 1 resulted showed that the hybrids were stable for grain yield per plant and also depict stability in respect of its one or more physio-biochemical traits like leaf canopy temperature, proline content, chlorophyll content, chlorophyll stability index, heat injury and total protein content (Table 5). The results indicate that the stability of various traits might be responsible for the observed stability of different hybrids for grain yield per plant. Sixteen hybrids had above average mean value for grain yield per plant and non-significant deviation from regression (S^2d_i) with high, low or unit regression values therefore, categorized as stable, better for good environment and poor environment. The stability of genotypes revealed that none of the parents and hybrids were ideal for better as well as poor environment for all the characters. The chances for selection of stable hybrids could be strengthened by selection in favour of stability in individual environment. Similar trends for adaptability of genotypes were also observed by Gowda *et al.* (2010), Ameen (2012), Meena *et al.* (2014) and Mohtasham *et al.* (2014).

Table 5. Stable hybrids identified on the basis of high mean for grain yield per plant along with stability of component traits.

Sl. No.	Hybrids	Grain yield/plant (g)	Stable for component traits
1.	HI 1544 × HD 2987	18.57	TP^{++}
2.	Raj 4037 × HD 2987	17.69	LCT^{++}, H^{++}
3.	PBW 175 × HD 2987	16.74	GY^{+}
4.	HD 2932 × Raj 4079	16.37	GY^{++}, CSI^{++}, H^{++}
5.	PBW 175 × Lok 1	15.69	-

+, ++ Better for favourable and unfavourable environment. GY: Grain yield/plant. H: Heat injury.
TP: Total protein content. LCT: Leaf canopy temperature. CSI: Chlorophyll stability index.

According to Eberhart and Russell (1966), a genotype having high mean performance with b_i equal to unity and S^2d_i equal to zero will be well adapted to all the environments. Accordingly, the above mentioned genotypes, which showed desirable performance not only for grain yield but also for associated characters, emerged as potential genotypes. These genotypes could be used to develop new genotypes with combination of stable characters. Similar findings were also reported by Madariya *et al.* (2001) and Tripura *et al.* (2011).

Acknowledgements

The first author (VS) expresses thanks the Department of Science and Technology, Government of India for providing Inspire Fellowship for Ph.D. research work and to Dr. Jagdish Choudhary, Department of Agronomy, Rajasthan College of Agriculture, Udaipur for providing seed materials, untiring help and assistance during the field experiments.

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(Manuscript received on 13 May, 2018; revised on 5 February, 2019)