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RESEARCH PAPER

Eberhart and Russell Model Based Stability Analysis for Identification of Wheat Varieties for Restricted Irrigation and Late Sown Conditions

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ABSTRACT

Forty bread wheat varieties released by various agricultural institutes in India were evaluated under timely and late sowing with normal as well as restricted irrigation conditions for two consecutive years; 2018-19 and 2019-20 in a Randomized Block Design (RBD) with three replications at Research Area of CCS Haryana Agricultural University, Hisar. Data for average grain yield per plant was collected for all varieties under all the environments and analyzed for stability using Eberhart and Russell Model. Based on this model, varieties *viz.* HI 1620, NIAW 3170, PBW 676, BRW 3806, DBW 222, WH1124, HD 3298, WH 1142 and DBW 221 were found most stable for all the environments. HD 3059 with an above average grain yield and regression value greater than one was found the most suitable variety for timely sowing and well irrigated conditions. Another variety, PBW 771 with significantly lower regression than one was recommended for areas with low water availability and late sown conditions (poor environment).

HIGHLIGHTS

- Forty wheat varieties evaluated and analyzed with stability model for late sowing and restricted irrigation.
- HI 1620, NIAW 3170, PBW 676, BRW 3806, DBW 222, WH1124, HD 3298, WH 1142 and DBW 221 found stable for all the sowing conditions.
- HD 3059 recommended for rich environment.
- PBW 771 recommended for the poor environment.

Keywords: Drought, heat, abiotic stress, stability

Wheat (*Triticum aestivum* L.) is one of the major grain crops consumed by millions of people as a staple food. The importance of this crop can be accessed by the fact that almost every country of the world is producing wheat, either for food or/and feed purposes. Global wheat production is around 793 million metric tons with China, India and Russia among the top three producers (USDA, 2025). India is the second largest producer of wheat, with a production of over 121 million metric tons in 2024-25 (USDA, 2025). In India, wheat is cultivated in different regions, including the Northern Gangetic plains of Punjab, Haryana, and Uttar Pradesh, as well as in the central and western states of Madhya Pradesh, Rajasthan, and Gujarat (Singh and Shoran, 2018). Wheat is not only a source of energy but also an excellent source of carbohydrates, protein, fiber, and various essential nutrients, including vitamins and minerals (Shewry, 2009; Saleh *et al.* 2013). In India, several research institutions, including the

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Indian Agricultural Research Institute (IARI), Indian Institute of Wheat and Barley Research (IIWBR) and various state universities under the umbrella of Indian Council of Agricultural Research (ICAR) have been working on wheat breeding programs to develop new varieties with improved traits (Singh and Huerta-Espino, 2021). Most of these newly developed varieties perform very well when the cold period prolongs along with plenty of irrigation. But in recent years, global warming has created the problem of high temperature and water scarcity which can cause a negative impact on wheat production in the coming years (Sharma and Sharma, 2017; Saroha *et al.* 2024). Various research groups have made it clear that global temperature is increasing day by day which in turn affects wheat crops negatively at various stages, from germination to maturity (Pandey and Maranville, 2012; Bheemanahalli *et al.* 2020). When the wheat varieties are planted late in the season, the flowering and seed set period coincides with slightly higher temperature. It adversely affects the photosynthetic rate and carbon assimilation in the leaves, leading to reduced grain yield (Prasad *et al.* 2011; Kumar *et al.* 2019). High temperature particularly at grain filling duration can cause up to 6% reduction in grain yield (Liu *et al.* 2016). High temperature in combination with drought stress is more severe for wheat as this reduces the availability of water and nutrients to the plant, leading to wilting and reduction in grain yield (Prasad *et al.* 2011; Farooq *et al.* 2014). Breeding of wheat varieties resistance to these stresses is the need of the hour.

There are two approaches for this; either to breed new varieties exclusively for the stressed environments or evaluate already developed and released varieties under these abiotic stresses to find stable varieties. The second approach is more useful and practical because with this approach we can find suitable varieties in just one or two years and recommend it to the farmers facing this problem. Secondly, these stable genotypes can be useful resources for future wheat breeding programs. Genotypes evaluated under normal and stress environments are evaluated with various stability models as these models help in prediction of performance of genotypes across environments (Becker and Leon, 1988). Most of these stability models are either based on variance (Becker and Leon, 1988) or regression (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Perkins and Jinks, 1968; Freeman and Perkins, 1971; Shukla, 1972). Eberhart and Russell model (1966) is one such regression based approach which is used extensively by breeders because it is simple, robust and accurate. This model is based on three parameters *viz.* average yield, regression and the deviation from regression. In the present study, we have tried to identify stable wheat varieties for combined stresses of drought and heat using the Eberhart and Russell model.

MATERIALS AND METHODS

The present study was carried out at the Research Farm of Wheat and Barley Section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar located at 29.150°N and 75.705°E. Forty wheat varieties released by various institutes for cultivation in North India were used for this study (Table 1). The experiment was conducted under two sowing dates i.e., timely (November 25th) and late (December 25th) with two water regimes (irrigated vs restricted irrigation) for two consecutive years (2018-19 and 2019-20); thus making a total of eight environments (Table 2). The experiment was carried out in Randomized Block Design (RBD) with three replications in each environment. Data for grain yield was collected from randomly selected five plants per genotype and yield per plant (g/plant) was used for statistical analysis. Stability analysis was carried out using the famous Eberhart and Russell model (1966); explained by Singh and Chaudhary (1985). Eberhart and Russell stability analysis is based on regression slope and uses the following statistical model;

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

where, Y_{ij} is yield of i^{th} genotype in j^{th} environment; μ_i is average yield of i^{th} genotype across environments; β_i is the regression coefficient; I_j is the environment index (obtained by subtracting sum of mean of all genotype at j^{th} location to grand mean) and δ_{ij} is the deviation from regression of i^{th} genotype in j^{th} location. According to this model any genotype which has high average yield with unit regression ($b_i = 1$) and minimum squared deviation ($S^2_{di} = 0$) from regression is considered as a stable genotype across environments.

Table 1: List of wheat genotypes used for stability analysis study

Sl. No.	Genotype	Sl. No.	Genotype	Sl. No.	Genotype	Sl. No.	Genotype
1	BRW 3806	11	DBW 222	21	DBW 237	31	HD 1621
2	DBW 252	12	PBW 676	22	PBW 771	32	HD 3217
3	HI 1620	13	PBW 800	23	HD 3059	33	WH 730
4	HI 1623	14	PBW 801	24	WH 1021	34	PBW 757
5	HD 3237	15	HD 3226	25	WH 1124	35	PBW 797
6	NIAW 3170	16	PBW 664	26	PBW 773	36	WR 544
7	WH 1142	17	HD 2967	27	HD 3298	37	WH 1164
8	PBW 644	18	DBW 88	28	DBW 14	38	WH 1235
9	HD 3043	19	DPBW 621-50	29	DBW 71	39	WH 1202
10	DBW 221	20	WH 1105	30	DBW 278	40	C 306

Table 2: Descriptions of environments used for stability analysis of wheat varieties

Environment	Description
E1 (2018), E5 (2019)	Timely sown (November 25), irrigated condition
E2 (2018), E6 (2019)	Timely sown (November 25), restricted irrigation condition
E3 (2018), E7 (2019)	Late sown (December 25), irrigated condition
E4 (2018), E8 (2019)	Late sown (December 25), restricted irrigation condition

RESULTS AND DISCUSSION

Analysis of variance

The yield data from eight environments was analyzed separately using the traditional Randomized Block Design model. The genotype mean sum of squares was highly significant at each environment which denotes presence of genetic variability among our genotypes (table 3). Various descriptive statistics and variance components are also shown in table 3. In general, mean yield is reduced as the number of stresses are increased, while the opposite trend is noted for coefficient of variance. The increased variance clearly indicates that when any genotype faces stress, its range of performance increases (Callaghan and Holloway, 1999). Also, the heritability which ranges from 0.409 to 0.568 is affected by environment conditions in a similar pattern.

The combined analysis of variance (ANOVA) of grain yield based on the stability model of Eberhart and Russel model is given in table 4. The variety and environment factors appeared to have a significant effect on the overall variations, as evidenced by the mean sum of squares and the associated p-value. This suggested that there were significant differences in grain yield across different varieties being tested. The significant environment factor indicated that mean yield among different varieties were also caused by environments.

Table 3: ANOVA and descriptive statistics of grain yield under different environments

Source of Variation	DF	Mean sum of square							
		E1	E2	E3	E4	E5	E6	E7	E8
Replication	2	32.110	7.659	35.785	24.660	18.512	19.794	1.759	7.030
Treatment	39	15.382**	17.608**	11.849**	9.583**	17.110**	10.751**	11.728**	9.185**
Error	78	3.349	3.768	2.522	3.118	3.906	2.174	2.615	2.269
Mean		18.034	15.441	12.442	10.319	15.575	13.749	12.448	10.175
SE		1.057	1.121	0.917	1.020	1.141	0.851	0.934	0.870
CV		10.148	12.572	12.764	17.113	12.690	10.723	12.992	14.803
CD		2.981	3.162	2.586	2.876	3.219	2.401	2.634	2.453
H^2		0.545	0.550	0.552	0.409	0.530	0.568	0.537	0.504

***Significant at p⩾0.01%.*

Genotype and environment interaction was also significant against pooled deviation and thus indicated change in performance of genotypes across environments. Our results were in line with previous study of Devi *et al.* (2021) who has reported significant genetic variability for grain yield in wheat. Similarly previous researchers have also shown that variability for yield in wheat is caused by both genotypic and environmental factors (Zaharieva *et al.* 2010; Chandrasekhar *et al.* 2017). But the presence of significant interaction components makes the situation more complicated as discussed by (Akçura *et al.* 2005).

Table 4: Analysis of variance for grain yield based on Eberhart and Russell model

Source of Variation (SV)	Degree of Freedom (DF)	Mean Sum of Squares (MSS)
Genotype (Gen)	39	12.626**
Environment (Env)	7	297.685**
Gen × Env	273	3.206*
Gen + Env × Env	280	10.568
Env (Linear)	1	2083.792
Gen × Env (Linear)	39	2.800
Pooled Deviation	240	3.191**
Pooled Error	624	2.965
Total	**319**	

**Significant at p⩾0.05%; **Significant at p⩾0.01%.*

Mean yield across environments

Mean is a direct measure of comparative analysis of phenotypic performance of various genotypes (Khan *et al.* 2008). The mean yield of each variety averaged upon eight environments is given in table 5 and Fig. 1. In our experiment grain yield ranged from 11.621 to 15.910 g/plant with a grand mean of 13.523 g/plant. The maximum grain yield was reported for variety HI1620 (15.910g) followed by NIAW3170 (15.735g), PBW676 (15.576g) and HD3059 (15.172g) whereas the variety PBW644 had the lowest mean grain yield (11.621g). Average performance of a genotype is the ultimate aim of the breeder but it can not be used directly to measure stability of a genotype due to the complex nature of grain yield (Devi *et al.* 2021). It is always suggested to take an account of genotype, environment and their interaction portion for grain yield to judge stability of a variety (Banerjee *et al.* 2006).

Table 5: Average grain yield, regression and squared deviation of wheat varieties

Variety	Mean	Regression (b_i)	Stability parameter (S^2_{di})
BRW 3806	14.911	1.458	2.643
DBW 252	14.937	1.297	3.592*
HI 1620	15.910	1.363	0.379
HI 1623	13.669	1.165	5.128*
HD 3237	14.792	1.186	4.366*
NIAW 3170	15.735	1.234	0.042
WH 1142	14.365	0.886	0.167
PBW 644	11.621	1.281	3.214*
HD 3043	13.798	0.886	4.419*
DBW 221	14.293	1.153	1.516
DBW 222	14.845	0.811	1.881
PBW 676	15.576	0.668	3.921*
PBW 800	13.047	0.928	2.824
PBW 801	11.664	1.153	5.361*
HD 3226	13.866	0.923	0.517
PBW 664	12.761	0.722	1.481
HD 2967	12.673	0.806	-0.409
DBW 88	13.115	1.033	0.092
DPBW 621-50	12.940	0.906	0.279
WH 1105	13.087	1.025	3.822*
DBW 237	14.071	0.926	16.272*
PBW 771	11.839	0.384*	-0.183
HD 3059	15.172	1.512*	3.915*
WH 1021	12.064	0.967	1.480
WH 1124	14.753	1.151	0.817
PBW 773	12.928	0.840	1.043
HD 3298	14.545	0.838	0.042
DBW 14	11.909	0.904	-0.003
DBW 71	13.480	1.180	0.443
DBW 278	13.140	0.615	1.824
HD 1621	14.173	1.154	3.094*
HD 3217	15.118	1.008	6.031*
WH 730	12.679	0.871	3.528*
PBW 757	12.177	0.721	0.241
PBW 797	11.985	1.065	-0.047
WR 544	11.708	1.082	1.994
WH 1164	13.133	1.188	0.274
WH 1235	12.529	0.982	0.108
WH 1202	13.966	0.837	0.650
C 306	11.938	0.890	1.360
Mean	13.523	1.000	
SE	**0.680**	**0.248**	
LSD	**1.134**	**0.489**	

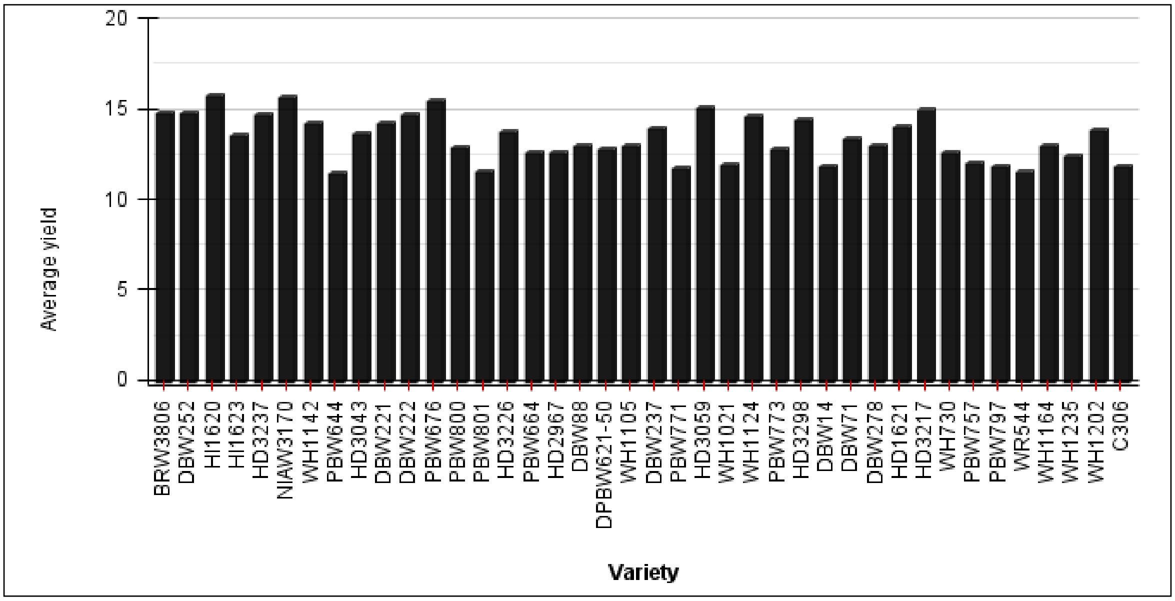

Fig. 1: Mean of grain yield of wheat genotypes averaged upon environments

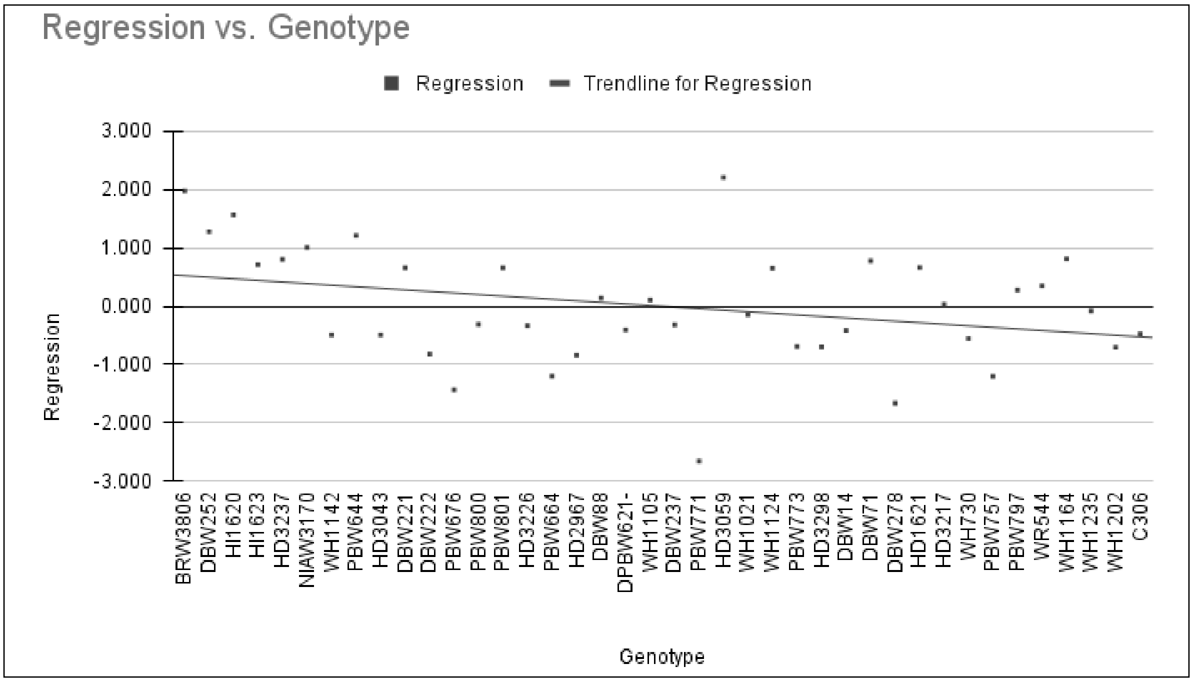

Fig. 2: Graph representing regression of wheat varieties on regression slope

Regression (b_i) and deviation from regression (S^2_{di})

According to Eberhart and Russell (1966), a stable genotype has average performance along with unit regression. Similarly a genotype with regression greater than unit performs well only in favorable environments, while genotypes with above average yield and regression less than one are perfect for poor environments. In our experiment only one genotype; HD 3059 had a regression coefficient greater than unit (1.512) along with above average yield (15.172g), thus making it a perfect choice for a favorable environment i.e. timely sown and well irrigated conditions (Table 5, Fig. 2). Similarly, PBW 771 had a regression coefficient significantly lower than one (0.384). The importance of linear regression has been shown by Tuteja (2006) in stability analysis of cotton genotypes also. Thus if a farmer has to choose a variety for late sown, restricted irrigation

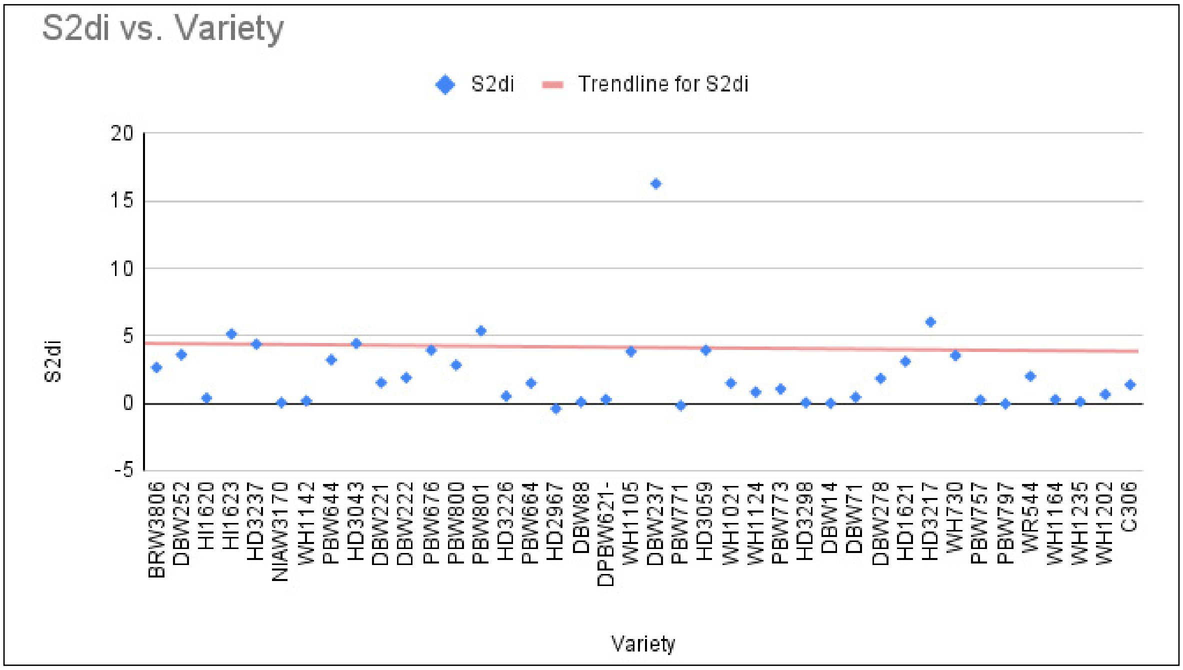

Fig. 3: Graph representing stability parameter (S^2_{di})

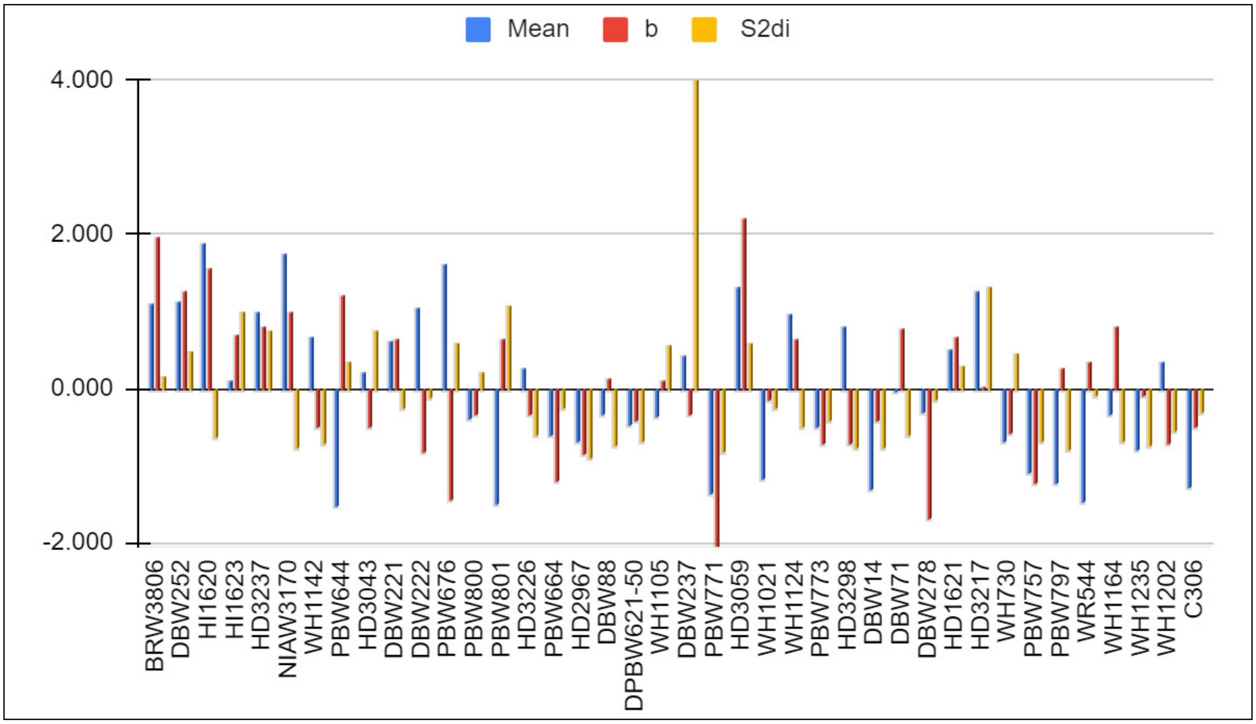

Fig. 4: Relative stability of wheat varieties based on mean, regression and stability parameter

conditions then PBW 771 will be the perfect choice. Most present day varieties are the result of selections from some common parents which are the major cause of their narrow adaptability (Tiwari *et al.* 2010). The narrow adaptation and low stability are terms generally used interchangeably. In Eberhart and Russell model consistency of a genotype is measured in terms of square deviation from the regression (S^2_{di}) which is an indirect measure of heterogeneity (Akçura *et al.* 2005). The values of the stability parameter in our case ranged from -0.409 (HD 2967) to 16.272 (DBW 237) as depicted in table 4 and Fig. 3. Thirteen varieties had a significant squared deviation from regression and thus did not qualify to be in the group of stable genotypes. As per Eberhart and Russell any genotype with significant deviation from regression has a narrow adaptability.

Stable genotypes

Stability is a complex phenomenon and requires multiple parameters to define. In the Eberhart and Russell model, regression measures the stability but its prediction depends on squared deviation from regression. Accordingly, a genotype with higher yield, unit regression and non-significant S^2_{di} is considered as stable (Eberahrt and Russell, 1966; Khan *et al.* 2008). For easy and comparative analysis, a combined standardized depiction of mean, regression and deviation from regression is shown in Fig. 4. Out of the forty genotypes, thirteen varieties (HI 1620, NIAW 3170, PBW 676, HD 3059, HD 3217, DBW 252, BRW 3806, DBW 222, HD 3237, WH 1124, HD 3298, WH 1142, DBW 221) had mean yield higher than the grand mean. But 5 varieties namely PBW 676, HD 3059, HD 3217, DBW 252 and HD 3237 had significant squared deviation. Further HD3059 had a regression value of greater than 1. Thus HI 1620 was the most stable variety among all the forty varieties followed by NIAW 3170, PBW 676, BRW 3806, DBW 222, WH 1124, HD 3298, WH 1142 and DBW 221. The beauty of the Eberhart and Russell model is that it takes in consideration three parameters including performance of genotype, linear component (bi) and non-linear component (S^2_{di}) to call a genotype stable (Tuteja, 2006).

CONCLUSION

Five varieties namely HI 1620, NIAW 3170, BRW 3806, DBW 222, WH 1124, HD 3298, WH 1142, DBW 221 with above average grain yield, unit regression and zero deviations are the most stable varieties for timely as well as late sown conditions along with varying water availability. While HD 3059 is the most suitable variety for high input situations. PBW 771 can be a perfect variety for areas with low water availability and high temperature.

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