Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2020; Sp 9(5): 295-298
Received: 01-07-2020
Accepted: 04-08-2020

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Stability analysis in wheat (*Triticum aestivum* L.)

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Abstract
The present experiment conducted with twelve genotypes of wheat by using Eberhart and Russell (1966) model for days to 50% heading, days to maturity (days), plant height (cm), spike length (cm), spikelets per spike, effective tillers per plant, grains per spike, 1000 grain weight (g), grain yield per hectare (q), biological yield per hectare (q) and harvest index in three date of sowing during Rabi- 2019-20 *viz.* 8th Nov. (normal sown), 4th Dec. (late sown) and 24th Dec. (very late sown) at All India Co-ordinated Wheat & Barley Improvement Project, B.T.C. College of Agriculture and Research Station, Bilaspur, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. The variances due to genotypes was found significant revealed the presence of genetic variability for all the characters under study. Differences due to Genotype × Environment were also found highly significant for all the study traits, indicates that genotypes interacted considerably to environmental conditions in different environments. The genotype Ratan and CG-1029 was stable for all the characters. This is revealing not only the amount of variability that existed among environments but also the presence of genetic variation among the genotypes. Only the genotype CG-1029 having high mean performance, non-significant regression coefficient deviation from unity (bi=1) and non-significant deviation from zero ($S^2d=0$) in term of grain yield per hectare. Hence, in term of grain yield per hectare CG-1029 can be considered the most stable and adopted to all environments compared to other stable genotypes.

Keywords: Wheat, stability analysis, G×E interaction

Introduction
Wheat (*Triticum aestivum* L.) (2n=6x=42 Hexaploid) is a self-pollinated crop belongs to true grass (Poaceae) family and one of the most consumed cereal crop. Wheat is a second most important stable food crop of the world after rice crop. Wheat contributes up to 20% of total food calories and protein to the people on national. It is also known as "King of cereals" for its good quality, high productivity and uses.

In India, wheat covers an area of 29.55 million ha, with total production of 101.20 million tonnes per ha and productivity 3424 kg per ha (Anonymous, 2018-19) [3]. In Chhattisgarh wheat covers an area of 101.36 ('000 ha) with 130.65 ('000 tonnes) of production and 1289 kg/ha productivity (Anonymous, 2017-18) [2]. The quality trait and yield of wheat grain is also influence by genotypes, environment and their interaction (G×E). Environment conditions such as sowing time, sowing date, temperature, humidity, soil *etc*. Many genotypes may be perform well in certain environment condition but several genotypes falls. To overcome this situation it is necessary to develop and identify of good phenotypically stable genotypes, which can significantly perform over a wide range of environment conditions. Yield is a quantitative character which are controlled by polygenic system and their expression is depend on the genotype and environment interaction and such character are greatly influence by environmental condition. The primary objective of any breeding improvement program is to increase yield stability and improve quality. The yield of the cultivar will be defined as stable when the yield of the varieties is consistent across different environments. Stability reflects the suitability of a variety for general cultivation over a wide range of environments. Stable performance of wheat genotypes in different environments is critical to the maintenance of food production. There are two possible strategies for the development of genotype with limited magnitude of genotype × environment interaction. The first is the development of a variety for a specific environmental condition and the second strategy to reduce genotype × environmental interaction with better stability across a wide range of environmental conditions. The basic variation between genotypes and in there yield is the broad occurrence of interaction between genotype and environments. The present experiment was conduct for normal sown, late sown and very late sown condition in rabi season 2019-2020. Testing the stability of genotypes and estimating the genotype × environment (G × E) interaction Eberhart and Russell (1966) [5] models were used.

Materials and Methods

Twelve genotypes of wheat were evaluated in Spilt Plot Design with 3 replications during Rabi- 2019-20 *viz.* 8th Nov. (normal sown), 4th Dec. (late sown) and 24th Dec. (very late sown) at All India Co-ordinated Wheat & Barley Improvement Project, B.T.C. College of Agriculture and Research Station, Bilaspur, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. Each genotype was grown in a plot size 1.8 X 8.0 meter keeping row to row spacing of 20 cm. for each plot in each replication. Data were recorded on 11 traits *viz.* days to 50% heading (day), days to maturity (day), plant height (cm), spike length (cm), spikelets per spike, effective tillers per plant, grains per spike, 1000 grain weight (g), grain yield per hectare (q), biological yield per hectare (q) and harvest index. Data from the three environments were subjected to stability analysis using the Eberhart and Russell (1966) [5] model. As per the model, three parameters, *viz*., mean yield over locations or seasons ($\bar{X}$), regression coefficient (bi), and deviation from regression (S^2di) were estimated.

Genotypes that proved to be stable for most stability analysis or at least for the yield then selected as the best. According to this model, a regression coefficient (bi) of approximately one coupled with a deviation from regression coefficient (S^2d) least/zero, it implies average stability over different environments.

Result and Discussion

Stability analysis as per Eberhart and Russell (1966) [5] model showed highly significant differences among twelve genotypes for all the 11 characters *viz.* 50% heading, days to maturity (days), plant height (cm), spike length (cm), spikelets per spike, effective tillers per plant, grains per spike, 1000 grain weight (g), grain yield per hectare (q), biological yield per hectare (q) and harvest index. The studies on estimate of parameters of stability revealed that two genotypes Ratan and CG 1029 was stable for all the characters. This is revealing not only the amount of variability that existed among environments but also the presence of genetic variation among the genotypes. It was emphasized that both linear (bi) and non-linear (S^2di) components of G×E interactions are necessary for judging the stability of a genotype. A regression coefficient (bi) of approximately one coupled with a deviation from regression coefficient (S^2d) least/zero, it implies average stability. The value of regression coefficient more than one identify genotype with greater sensitivity to changing environments (below average stability) and higher specificity of adaptability to high yielding environments. A value of regression coefficient less than one contribute a measurement of higher resistance to environmental chances (above average stability) and thus increases the specificity of adaptability to low yielding environments.

The analysis of variance as per the Eberhart and Russell (1966) [5] model showed a very significant differences between the 12 variety for all characters. The variances due to environment were also found highly significant for all the studied characters, indicating that the presence of wide variation among environmental conditions used for the evaluation of the materials. Thakur *et al.*, 2019 [18], Krupal *et al*., 2018 [10], Mut *et al*., 2010 [12] and Singh *et al.*, 2018 [17] had observed similar results. Differences due to Genotypes × Environment (G× E) were also found highly significant for all the traits. Present results are in agreement with those of earlier reports of Patel *et al*., 2014 [14], Amin *et al*., 2005 [1], Verman *et al*., 2015 [19].

Components analysis of the Environment + (Genotype × Environment) interaction (E+ (G× E) was found to be highly significant for all the characters except for spike length and harvest index. Similar results was reported for grain yield by Singh *et al*., 2018 [17], Mekuria *et al*., 2018 [11], Kabir *et al*., 2009 [9], Gulzar *et al*., 2015. Genotype × Environment (linear) variances was significant for days to maturity, plant height, spikelets per spike, number of grains per spike, grain yield (q). per hectare and biological yield per hectare (q). Mean square due to pooled deviation was found significant for days to 50% heading, spike length and biological yield per hectare, indicating greater role of non-predictable components in genotypes × environment interaction. Thus, both linear and non-linear components were useful for determining the stability in the current study. Similar results reported for days to 50% heading and spike length by Thakur *et al*., 2019 [18]; Pansuriya *et al*., 2014 [13]; Verman *et al*., 2015 [19] and Gulzar *et al*., 2015 [6].

The regression coefficients ranging from -0.22 (Ratan) to 1.71 (HD 2932) for grain yield. This large variation in regression coefficients indicates different responses of genotypes to environmental conditions.

Table 1: Combined Analysis of variance for stability in wheat under three different environments.

Source	DF	Mean Sum of Square					
		Days to 50% heading	Days to maturity	Plant height (cm)	Spike length (cm)	Spikelets per spike	Number of effective tillers per plant
Genotypes	11	49.76**	46.47**	279.53**	1.30**	5.82**	2.54**
Environments	2	916.75**	3329.59**	20.71**	1.5236**	19.61**	11.13**
Genotypes ×Environment	22	20.32**	14.18**	2.78**	0.60**	2.03**	0.14*
Env.(Gen.× Env.)	24	31.67**	96.82**	1.42*	0.22	1.16**	0.35**
Environment (linear)	1	611.16**	2219.72**	13.80**	1.01*	13.07**	7.42**
Genotypes × Env. (linear)	11	9.63	8.66**	1.39*	0.23	1.09**	0.0450
Pooled deviation	12	3.58**	0.72	0.42	0.14*	0.24	0.0454
Pooled error	72	0.60	3.01	3.75	0.06	0.53	0.09
Total	35	37.36	81.00	88.83	0.56	2.63	1.04

Source	DF	Mean Sum of Square				
		Number of grains per spike	1000 grain weight	Grain yield per hectare (q)	Biological yield per hectare (q)	Harvest index
Genotypes	11	94.40**	22.03**	71.17**	172.81**	74.19**
Environments	2	56.86**	74.42**	461.67**	1606.25**	98.35**
Genotypes × Environment	22	20.83**	1.08**	17.54 **	187.51**	32.61*

Env.(Gen.× Env.)	24	7.94*	2.3989**	18.18**	101.91*	12.69
Environment (linear)	1	37.90**	49.60**	307.78**	1070.83**	65.56*
Genotypes × Env. (linear)	11	10.63*	0.36	8.51*	95.17*	11.05
Pooled deviation	12	2.98	0.33	2.9181	27.35*	9.80
Pooled error	72	1.89	0.91	3.2878	12.39	5.21
Total	35	35.11	8.56	34.840	124.19	32.02

* and ** indicates significant at 5% and 1% against pooled deviation respectively.

Table 2: Estimation of stability parameters for different observation included in the present studies

Genotypes	Days to 50% heading			Days to maturity			Plant height (cm)			Spike length (cm)			Spikelets per spike			Effective tillers per plant		
	$\bar{X}$	bi	S^2d	$\bar{X}$	bi	S^2d	$\bar{X}$	bi	S^2d	$\bar{X}$	bi	S^2d	$\bar{X}$	bi	S^2d	$\bar{X}$	bi	S^2d
HD-2864	54.0	1.18	−0.38	108.4	1.12	−1.69	72.2	0.51	−3.71	7.2	0.93	−0.01	17.1	0.09	−0.14	7.68	0.92	−0.09
Chhattisgarh Genhu 3	64.7	0.28	2.54*	111.4	1.26*	−3.01	83.6	0.269	−1.51	7.9	1.70	−0.02	17.7	−0.02	−0.47	7.24	1.20	−0.09
Chhattisgarh Genhu 4	53.2	1.11	7.15**	100.1	0.95	−3.00	76.4	0.45	−3.73	7.6	1.45	−0.05	16.2	0.40	−0.12	6.90	1.17	−0.03
Chhattisgarh Amber wheat	60.8	0.77	0.77	113.7	1.29*	−2.96	83.0	1.27	−3.13	8.7	1.24	0.39**	16.9	−0.02	0.05	7.30	0.93	−0.02
Chhattisgarh Hansa wheat	64.2	0.10	13.37**	104.0	1.02	−2.12	102.6	0.267	−3.58	7.9	−1.60	0.16	18.4	0.73	−0.35	5.95	0.91	−0.09
Ratan	57.3	1.08	1.49	110.0	1.06	−0.57	76.3	2.96	−3.54	7.9	3.68	−0.04	16.3	−0.24	−0.50	6.23	0.82	−0.07
Raj 4238	60.7	0.82	2.19*	112.2	1.23	−2.37	66.6	1.38	−3.17	6.6	0.94	−0.06	13.0	0.66	−0.39	6.45	1.69	0.00
CG 1029	58.5	1.22	−0.29	108.6	0.86	−0.68	78.7	−0.64	−3.67	8.1	2.97	0.03	14.9	2.11	−0.32	8.88	0.78	0.03
HI 1634	58.2	1.31	0.87	104.5	0.95	−2.36	74.5	−0.04	−3.31	7.5	−1.78	0.72**	15.4	2.33	0.18	5.75	0.66	−0.04
MP 4010	54.0	1.20	5.74**	106.6	0.88	−2.99	72.2	2.85	−3.21	6.3	−0.53	−0.05	15.9	2.26	−0.35	6.10	0.81	−0.07
HD 2932	61.2	1.26	1.87*	106.0	0.78	−2.65	74.5	1.64	−3.730	7.3	2.36	−0.06	16.1	1.92	−0.52	5.95	1.08	−0.07
MP 3336	53.7	1.60	0.42	105.0	0.55	−3.01	66.2	1.07	−3.64	7.1	0.61	0.03	15.8	1.75	−0.52	7.35	0.98	−0.02

Table 2: To be contd.

Genotypes	Grains per spike			1000 grain weight			Grain yield per hectare (q)			Biological yield per hectare (q)			Harvest index		
	$\bar{X}$	bi	S^2d	$\bar{X}$	bi	S^2d	$\bar{X}$	bi	S^2d	$\bar{X}$	bi	S^2d	$\bar{X}$	bi	S^2d
HD-2864	33.3	−0.58	2.26	43.61	1.07	−0.75	32.00	0.96	0.082	80.08	1.42	67.65*	40.62	0.13	−4.26
Chhattisgarh Genhu 3	41.7	−2.33	−1.79	42.31	0.83	−0.91	33.42	0.66	1.21	71.75	0.52	19.10	46.51	1.10	−1.88
Chhattisgarh Genhu 4	30.6	0.29	3.70	47.03	1.05	−0.85	30.51	0.74	−2.86	73.83	0.43	−11.79	41.29	1.03	−1.99
Chhattisgarh Amber wheat	41.0	4.22	5.65*	46.48	1.48	−0.45	31.07	1.09	−2.91	71.13	0.18	−10.36	43.66	0.94	35.25**
Chhattisgarh Hansa wheat	45.8	−0.88	0.38	42.23	0.76	−0.89	32.51	1.04	11.25*	86.03	0.49	116.59**	38.16	4.83*	−4.69
Ratan	33.9	−0.20	−1.75	43.27	0.43	−0.72	24.92	−0.22	−2.19	60.72	−0.87	−5.09	41.33	1.66	2.37
Raj 4238	26.9	1.22	−1.72	47.14	1.12	−0.84	28.14	0.27	−2.31	69.05	0.05	−1.03	40.87	0.79	−0.98
CG 1029	29.5	1.06	−0.83	43.12	1.08	−0.90	41.51	1.46	−1.26	86.09	2.29	25.72	48.55	−0.98	6.67
HI 1634	30.8	3.00	5.69*	42.37	1.37	0.16	38.39	1.08	−3.28	76.48	1.03	−5.87	50.22	0.42	−5.19
MP 4010	34.0	2.10*	3.05	39.57	1.16	0.36	37.53	1.50	1.28	73.97	2.06	−7.37	50.99	0.73	7.10
HD 2932	32.5	1.99*	−1.88	41.16	0.97	−0.28	39.53	1.71	−1.53	77.87	2.35	1.56	50.61	−0.26	1.60
MP 3336	32.0	2.08*	0.39	38.72	0.62	−0.89	34.00	1.66	−1.89	65.50	2.01	−9.58	52.26	1.58	20.99*
							33.62	0.64							

* and ** indicates significant at 5% and 1% deviation from unity respectively

When the genotypes were grouped according to stability parameters as Eberhart and Russell model (1966) [5], it was found that all genotypes except Chhattisgarh Hansa wheat were found to have stable performance under three dates of sowing conditions in term of grain yield per hectare. Whereas genotype Chhattisgarh Genhu 3 and Chhattisgarh Amber wheat for days to maturity, genotype MP 4010, HD 2932 and MP 3336 for number of grains per spike and genotype Chhattisgarh Hansa wheat for harvest index was found stable and specially adopted to favourable environments. Value of regression coefficient (bi) ranged from -0.64 (CG 1029) to 2.96 (Ratan) and all the varieties have non-significant linear regressions for plant height. Only HI 1634 (0.72**) and Chhattisgarh Amber wheat (0.39**) have significant deviation for regression indicating that the spike length can varies with variable environments. Chhattisgarh Amber wheat (0.05) have near to zero value for deviation from regression (S^2d), so said to be highly stable variety for number of spikelets per spike under varying environment. CG 1029 (1.06) recorded near to one bi value indicate its average response over the varying environment for grains per spike. Similar results were obtained by Pujer *et al*., 2020 [16], Haydar *et al*., 2018 [7], Singh *et al*., 2018 [17], Jhinjer *et al*., 2017 [8], Polat *et al*., 2016 [15], Verman *et al*., 2015 [19].

Conclusion

Only the genotype CG 1029 having high mean performance, non-significant regression coefficient deviation from unity (bi=1) and non-significant deviation from zero (S^2d=0) in term of grain yield per hectare. Hence, in term of grain yield per hectare CG 1029 can be considered the most stable and adopted to all environments compared to other stable genotypes. Therefore, it could be included in the hybridization program to converge the stability characteristics of grain yield for the development of stable cultivar adapted to a wide range of environments.

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