Genotype x Environment Interaction and Stability Studies in Late Sown Bread Wheat (*Triticum aestivum* L. em Thell)

Mahesh S Khumkar, S Chandrashekaran and HB Chaudhary
Division of Genetics, Indian Agricultural Research Institute, Pusa, New Delhi-110 012

Forty nine genotypes of wheat were evaluated in three different environments for number of seeds/spike, 1000-grain weight, number of productive tillers/m^2 and grain yield/plot. Mean performances between genotypes and environments were significant indicating substantial variability among genotypes and environments for all the characters except number of productive tiller/m^2. Highly significant variance due to environment + (GxE) revealed that genotypes interacted considerably with environmental conditions. Though both linear and non-linear components of GxE interaction played important role in the expression of number of seeds/spike and 1000-grain weight, the linear component was larger in magnitude. Number of productive tiller/m^2 and grain yield/plot showed highly significant variance due to non-linear component. Considering the three parameters of stability for each character, the genotypes namely PS 461, DW 1104, DL 97-8, DW 1106 and HP 1744 were found to be stable across the environments for yield as well as component traits.

Key words: GxE Interaction, Stability, Wheat

Late sown wheat is frequently affected by heat stress in early vegetative stage and during grain filling. With this background, breeders continually strive to broaden the genetic base of crop species to prevent their vulnerability to changing environments. Understanding the genetic basis of differential responses to environments and broadening the genetic base for such traits are extremely important in crop breeding programmes. Differential genotypic responses to different environments are collectively called 'Genotype x Environment (GxE) Interaction'. Besides, stability reflects the suitability of a genotype for cultivation over a range of environments. The breeder's objective should be to produce genotypes that are better adapted over a range of environments. Hence, studies of GxE interaction and stability analysis of grain yield and its component characters are important.

Materials and Methods

The experimental material consisted of 49 genotypes of wheat suited for late sowing contributed by different breeders of Indian Agricultural Research Institute (IARI), New Delhi and its regional research stations alongwith four check varieties. They were evaluated in a randomised block design with three replications in three different environments during *rabi* seasons of 1997-98 and 1998-99 at IARI, New Delhi under late sown irrigated conditions. The three different environments were artificially created by changing the dates of sowing, irrigation and fertilizer levels. Each genotype was planted in a plot having a gross area of 6mx1.08 m, with 6 rows at 18 cm spacing. The recommended cultural and agronomic practices for late sown irrigated condition were followed to raise the crop. Five random plants/plot/replication were labelled and observations were recorded for four characters *viz.* number of seeds/spike, 1000-grain weight, number of productive tillers/m^2 and grain yield/plot. The data were subjected to analysis of stability as per the method proposed by Eberhart and Russell (1966).

Results and Discussion

For estimating GxE interaction, multi-location and multi-year testing of genotypes are essential. However, the difficulty in handling the material at different locations with the required precision imposes a restriction on the number of locations. A possible way to overcome this bottleneck is to create artificial environments at the same location by changing the agronomic treatments such as levels of fertility and irrigation, fertilizer doses, sowing dates etc. The reliability of unilocational testing of genotypes by creating artificial environments as mentioned earlier has been reported by Gupta (1971) and Luthra *et al.,* (1974).

The pooled analysis of variance over environments is presented in Table 1. The differences among the genotypes and environments were significant in respect of all the characters namely number of seeds/spike, 1000-grain weight and grain yield/plot except number of productive tillers/m^2. This indicated that number of productive tillers/m^2 exhibited less GxE interaction as compared to the other characters. Since the formation of tillers in short duration genotypes follows a rapid vegetative phase, there is possibility that most of the

Table 1. Pooled analysis of variance for 4 characters

Source	d.f.	Mean sum of squares for different characters			
		No. of productive tillers/m^2	No. of seeds/ spike	1000-grain weight	Grain yield/ plot
Genotypes	48	149.33**	28.71**	20.35**	0.18**
Environments	2	725.46**	3840.01*	94.94**	1.42**
GxE	96	122.97	16.11**	6.93**	0.09**
Pooled error	288	113.94	12.52	2.41	1.35

*Significant at 1%, ** Significant at 5%

genotypes which represent early maturity strains, have responded uniformly under different environments.

A perusal of Table 2 for analysis of variance for stability revealed highly significant variance due to environment + (GxE) which indicated that genotypes interacted differentially with environmental conditions that existed in different seasons for all the four characters. Highly significant pooled deviations suggested that the genotypes differed considerably with respect to their stability for all the four characters. The GxE interaction was further partitioned into linear and non-linear components. Since linear and non-linear components were significant for the two characters namely number of seeds/spike and 1000-grain weight, practical usefulness of prediction would depend on relative magnitudes of two variances. The other two characters namely number of productive tillers/m^2 and grain yield/plot revealed non-significant variance due to linear component and highly significant variance due to non-linear component indicating the unpredictable performance of genotypes across the environments for number of productive tillers/m^2 and grain yield/plot. In case of number of seeds/spike and 1000-grain weight, linear component played an important role in the expression of these characters because the linear component was 1.76 and 3.88 times higher than the non-linear component for these characters, respectively indicating that the performance of genotypes may be predicted across the environments for these characters. In prediction of performance, the non-linear component may have a role since it is also significant.

Different measures of stability have been used by various workers. Earlier Finlay and Wilkinson (1963) considered linear regression slope as a measure of stability. Eberhart and Russel (1966) emphasized the need of considering both the linear and non-linear components of GxE Interation in judging the stability of genotypes. According to Eberhart and Russell (1966), a variety with unit regression coefficient (b=1) and the deviation not significantly different from zero ($S^2_{di}=0$) and high mean ($\bar{x}$) is said to be stable. All the three parameters of stability for number of seeds/spike, 1000-grain weight, number of productive tillers/m^2 and grain yield/plot are presented in Table 3.

In case of number of productive tillers/m^2, out of 49 genotypes, 37 were significant for linear component and 12 were significant for non-linear component of GxE interaction, indicating thereby that for most of the genotypes, GxE was linear in nature suggesting that the prediction can be possible for number of productive tillers/m^2 across the environments. These findings are in agreement with Singh and Chatrath (1995), Menon *et al.* (1997) and Deswal *et al.* (1996). Considering the individual parameters of stability, it is evident that the genotypes *viz.* PS 465, DL 97-11, DW 1123, PS 467,

Table 2. Analysis of variance for stability

Source	d.f.	Mean sum of squares for different characters			
		No. of productive tillers/m^2	No. of seeds/ spike	1000-grain weight	Grain yield/ plot
Genotypes	48	149.33	28.71	20.35**	0.18*
Environment + (GxE)	98	135.07**	94.15**	8.72**	0.12**
Env. (Linear)	1	1450.67**	7680.10**	189.99**	2.85**
Genotype x Env. (Linear)	48	128.86	20.41	10.97**	0.06
Pooled deviation	49	114.30**	11.57**	2.83**	0.12**
Pooled error	288	37.98	4.17	0.80	0.0045

*Significant at 1%, ** significant at 5%

Table 3. Estimation of stability parameters - mean ($\bar{X}$), regression coefficient (bi) and deviation from regression (S^{-2}_{di}) for 4 characters

Strain	No. of productive tillers/m²			No. of seeds/spike		
	$\bar{X}$	bi	S^{-2}_{di}	$\bar{X}$	bi	S^{-2}_{di}
PS 458	74.22	-3.86*	-30.14	29.56	0.62	18.25*
Ind 98-35	90.89	2.42	902.99**	31.78	1.19	0.97
DW 1105	81.44	2.14	-19.38	33.33	0.80	14.86
PS 470	70.67	0.09	-37.98	36.44	1.52	13.29
DL 97-9	86.87	1.06	363.60**	239.56	0.85	21.88*
NIAW 34	68.56	0.78	-26.05	36.56	0.85	21.88*
Ind 98-33	76.78	0.55	21.73	32.89	1.34	1.81
DW 1093	90.67	-1.57	309.88**	37.11	1.12	24.94*
DW 1120	76.22	1.45	74.39	40.11	1.82**	1.30
PS 461	71.89	1.12	14.97	39.33	0.93	3.44
DW 1114	80.44	-0.22	314.89**	33.56	1.32	22.45*
HW 2045	72.11	-0.08	45.01	35.11	1.33	14.14
PS 465	85.00	0.83	-37.98	40.33	1.08	27.48*
DW 1102	87.44	2.20	278.89**	34.56	1.12	0.00
DL 97-11	89.11	-0.48	-24.84	39.00	0.34*	2.38
DW 1123	91.44	1.45	34.32	33.89	0.90	25.45*
PS 467	81.67	-2.61	-37.64	37.89	1.67*	1.27
Ind 98-36	73.78	2.03	18.41	38.00	1.29	2.90
DW 1092	75.67	-0.41	-36.85	33.89	0.93	27.03*
PS 462	79.56	3.02	-12.51	39.56	0.89	3.61
DL 97-10	83.33	2.12	101.96	43.56	0.81	35.64**
DW 1104	80.78	1.82	-0.99	41.22	1.38	-4.13
DL 97-8	83.44	0.56	-27.54	37.33	0.49	-3.96
PBW 373	82.56	2.32	244.20*	41.00	0.86	13.21
PS 456	80.33	-0.94	29.52	34.78	0.43*	-3.12
DW 1097	75.11	-1.23	157.00*	38.33	1.27	-2.26
PS 463	71.11	-2.29	36.25	34.67	0.96	15.81
WR 821	78.22	-0.63	29.31	36.78	1.47	0.75
PS 469	70.78	2.82	59.61	32.89	0.87	-3.11
DL 97-12	79.44	1.52	-37.98	38.89	0.68	-0.34
DW 1106	74.11	0.35	48.24	35.89	1.44	49.08**
GW 173	92.00	1.67	159.66*	34.67	0.44*	3.55
DW 1119	65.67	0.99	243.46*	38.44	1.32	-3.12
PS 460	80.56	2.48	-24.81	33.78	0.66	22.78
DW 1117	78.11	1.90	-37.74	39.00	1.34	6.37
PS 468	70.22	-1.83	228.15*	39.44	0.68	31.39**
PS 459	96.44	2.11	-97.00	35.11	0.85	-0.95
DW 1111	82.56	1.59	-10.74	37.78	0.95	-3.49
PS 464	70.67	5.54*	-19.50	44.11	0.83	6.69
HP 1744	74.11	0.44	-37.97	40.67	1.35	20.15*
PS 457	70.56	-0.52	435.55**	34.33	0.28**	1.18
PS 466	83.44	-1.63	-34.25	33.44	0.78	-1.47
Ind 98-32	76.33	0.29	-36.17	34.11	1.09	-3.21
DW 1115	83.56	3.82	-28.66	35.11	0.77	-4.01
PS 455	83.78	3.71	16.21	35.44	0.80	-3.66
DW 1122	79.89	4.61	207.10*	36.56	0.83	-2.53
Ind 98.37	69.78	-1.69	1.52	32.89	1.45	15.45

Population mean = 79.295 SE(Mean)=7.56 Population mean = 36.58 SE(Mean) = 2.40
Mean of bi = 1.0001 SE of bi = 1.96 Mean of bi = 1.000 SE of bi = 0.27

Strain	1000 grain weight			Grain yield/plot		
	$\bar{X}$	bi	S^{-2}_{di}	$\bar{X}$	bi	S^{-2}_{di}
PS458	37.84	2.07	2.26	1.63	-1.58	2.06**
Ind 98-35	38.29	0.53	0.69	1.68	1.98	0.10**
DW 1105	42.06	5.80**	5.74**	1.89	2.47	0.00
PS 470	40.35	2.10	3.01	1.97	0.58	0.07**
DL 97-9	38.47	-0.56	-0.36	2.02	2.63	0.05**
NIAW 34	42.34	2.42	-0.07	1.85	1.81	0.19**
Ind 98-33	35.48	-1.92**	12.51**	1.56	0.87	0.00
DW 1093	34.62	0.28	-0.37	1.88	1.35	0.00
DW 1120	26.02	1.64	-0.74	1.88	2.27	0.03
PS 461	36.82	0.17	0.84	2.25	0.88	0.00
DW 1114	37.83	5.47**	5.53**	1.65	3.41	0.04**
HW 2045	42.83	0.13	-0.19	2.15	2.88	0.37**
PS 465	39.66	1.71	-0.14	2.17	0.49	0.52**
DW 1102	41.09	2.10	-0.38	2.08	1.68	0.09**
DL97-11	37.44	1.36	6.91**	2.18	0.58	0.08
DW 1123	40.43	-1.00*	9.10**	1.81	-0.09	0.36**
PS 467	42.25	-0.47	1.93	2.14	1.44	0.25**
Ind 98-36	42.28	-1.60**				
DW 1092	38.78	1.35	-0.31	1.76	1.72	0.02*
PS 462	43.94	-0.09	-0.70	2.39	0.81	0.12**
DL 97-10	37.59	3.84**	13.26**	2.27	0.95	0.03*
DW 1104	38.69	2.36	0.00	2.62	0.75	0.01
DL 97-8	38.32	0.30	1.84	2.06	0.28	0.00
PBW 373	36.01	0.82	0.26	2.29	0.14	0.02
PS 456	44.45	0.54	-0.71	2.01	-0.64	0.16**
DW 1097	38.56	0.83	1.61	1.71	1.17	0.07**
PS 463	40.66	-1.67**	2.38	1.57	0.15	0.18**
WR 821	39.20	1.27	-0.72	2.34	-0.03	0.11**
PS 469	40.90	2.52	6.82**	2.19	1.80	0.10**
DL 97-12	37.62	1.33	-0.67	2.44	1.51	0.10**
DW 1106	37.56	1.94	-0.39	2.15	1.92	0.00
GW 173	43.39	0.53	-0.01	2.22	1.24	0.06**
DW 1119	40.14	-0.23	3.54*	1.94	0.43	0.15**
PS 460	38.02	1.87	-0.17	0.05	1.13	0.02*
DW 1117	37.27	2.31	-0.80	1.71	1.13	0.34**
PS 468	42.11	1.69	-0.33	2.34	1.00	0.00
PS 459	41.23	0.67	-0.80	1.98	-0.84	0.31*
DW 1111	39.85	0.06	0.79	2.16	-0.13	0.21**
Ind 98-34	39.004	-0.01	-0.80	1.98	-0.84	0.02*
DW 1118	38.37	2.77*	4.41*	2.17	1.87	0.03
PS 464	42.72	-1.88*	1.23	1.97	1.81	0.03
HP 1744	40.55	1.14	0.07	2.07	1.39	0.00
PS 457	44.44	-1.99*	-0.06	2.15	0.74	0.07**
PS 466	42.72	2.52	0.72	2.12	1.97	0.01**
Ind 98-32	40.55	0.98	-0.34	1.97	0.08	0.00
DW 1115	39.81	-0.15	2.36	2.20	-0.43	0.47**
PS 455	42.63	-0.65	0.54	2.10	-0.56	0.05**
DW 1122	45.95	3.04*	4.03*	2.52	0.89	0.09**
Ind 98-37	43.31	0.74	-0.79	1.77	3.16	0.40**

Population mean = 40.01 SE (Mean) = 1.19 Population mean = 2.047 SE (Mean) = 0.24
Mean of bi = 0.99 SE of bi = 0.85 Mean of bi = 0.0001 SE of bi = 1.41

PS 462, DL 97-10, DW 1104, DL 97-8, DL 97-12, PS 460, PS 459, DW 1111, Ind 98-34, PS 466, DW 1115 and PS 455 were specifically adapted to unfavourable (poor) environments for number of productive tillers/m^2 while the genotype DW 1118 was found to be specifically adapted to favourable (rich) environments for this character.

In case of number of seeds/spike, 38 genotypes were significant for linear components and 11 genotypes were significant for non-linear components indicating thereby the predominance of linear GxE interaction for this character. The present results are in consonance with Singh and Chatrath (1995). On examination of individual parameters of stability, it reveals that the genotypes DL 97-9, DW 1114, Ind 98-36, PS 462, DW 1104, DL 97-8, DW 1097, WR 821, DL 97-12, DW 1117, DW 1111 and PS 464 were specifically adaptable to unfavourable environments for number of seeds/spike and the genotypes DW 1120, DL 97-11 and PS 467 were specifically adaptable to favourable environments for this character.

In case of 1000-grain weight, 38 genotypes were significant for linear component and 11 genotypes were significant for non-linear GxE component, indicating thereby the preponderance of linear GxE interaction. Similar findings have been reported by Thete *et al.* (1987), Patil *et al.* (1992), Singh and Chatrath (1995) and Deswal *et al.* (1996). On consideration of individual parameters of stability, the genotypes namely PS 470, NIAW 34, HW 2045, DW 1102, PS 467, PS 462, PS 456, GW 173, PS 468, PS 459, HP 1744, PS 466, Ind 98-32 and PS 455 were found to be specifically adapted to unfavourable environments while the genotypes PS 464 and PS 457 were specifically suited to favourable environments for 1000-grain weight.

In case of grain yield/plot, 13 genotypes were significant for linear component while 36 genotypes were significant for non-linear GxE component, indicating the predominance of non-linear GxE interaction. This indicated that variation among genotypes for yield was largely unexplained by regression slopes and performance across the environments was mostly governed by unpredictable component. These results are in consonance with Maloo *et al.* (1993). On examination of individual parameters of stability, the genotypes *viz.* PS 461, PS 467, DW 1104, DL 97-8, DW 1106, PS 468, HP 1744 and PS 466 were found to be specifically adaptable to unfavourable environment in case of grain yield/plot.

From the ongoing discussion, it can be concluded that out of 49 genotypes, the genotypes namely PS 461, DW 1104, DL 97-8, DW 1106 and HP 1744 were found to be stable across the environments for yield as well as its component traits.

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