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Analytic Measures of Adaptability for Wheat Genotypes Evaluated under Northern Hills Zone of India for Restricted Irrigated Late Sown Conditions: Comparative Study

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ABSTRACT: Adaptability of wheat genotypes while considering their random effects had been studied by recent analytic measures. High yield and better adaptability of VL892, VL3010 & HS627 wheat genotypes identified during 2015-16. HPW433 had specific adaptations to Kalimpong, Shimla and Dhaulakuan whereas HS626 for Imphal and Bajura, while HS625 identified for Malan in biplot analysis exploiting 80.6 % of total GxE interaction sum of squares. BLUE based measures identified VL892, VL3010 & HS627 for high yield and better adaptability. Biplot analysis based on 78.9 % reflected HPW433 and HS626 had specific adaptations to Bajura, Imphal, Dhaulakuan locations. Second year (2017-18) expressed better adaptability along high yield of HS490, HS660 and VL 3017 wheat genotypes. Genotypes VL3018, VL3016 and VL892 had exhibited specific adaptations to locations of Una, Almora and Dhaulakuan. Adaptability measures as per BLUE exhibited better adaptability and high yield of HS490, HS660 and VL 3017 wheat genotypes. Specific adaptations of VL3018, VL3016 and VL892 observed for Una and Dhaulakuan while HS490, VL3017 and HS660 for Imphal, Malan, Almora and Bajaura locations. Genotypes stratification by measures based on BLUP was more efficient. Biplot analysis exhibited that more of GxE interactions sum of squares was explained by first two significant principal components based on BLUP. Adaptability of genotypes based on BLUP would be more precise as compared to earlier measures.

Keywords: MET, BLUP, BLUE, GAI, HMGV, RPGV, HMRPGV, Biplot analysis

INTRODUCTION

Breeding programs for the wheat improvement aim to select new genotypes with local or broad adaptation to sustain high yields over the coming years to ensure food security (Crespo *et al.* 2017). The promising genotypes are evaluated at research field trials at number of locations and known multi environment trials (MET). MET are characterized by testing and estimation of genotype x environment interactions. The cross over GxE interaction may change the relative ranking of genotypes across locations and complicate the identification of superior genotypes (Gogel *et al.* 2018). MET is to recommend the better performing genotypes and to estimate random effects of genotypes, BLUP of wheat genotypes will be better options (Friesen *et al.* 2016). Correlation between the realized values and true values had been maximized by BLUP's as quoted by Piepho *et al.* (2008). Use of Factor analytic (FA) model with sufficient multiplicative terms had been proved as robust from computation point of view by Resende and Thompson 2004 and superiority of the FA model in a breeding program had been demonstrated by Nuvunga *et al.* (2018).

MATERIALS AND METHODS

Northern hills zone of the India comprises J&K (except Jammu and Kathua distt.); Himachal Pradesh (except Una and Paonta Valley); Uttarakhand (except Tarai area); Sikkim, hills of West Bengal and North Eastern states. Advanced wheat genotypes were evaluated in field trials at major locations of the zone during cropping season's viz. 2015-16 and 2017-18 as details are reflected in Tables 1 & 2 for ready reference. Randomized block design with three replications were used for research field trials and recommended agronomical practices had followed to harvest good crop. More over yield were further analysed as per recent analytic adaptability measures.

The relative performance of genetic values across environments is considered to define simple and effective measure (PRVG). Based the yield & stability simultaneous MHVG method (harmonic mean of genetic values) described and based on the harmonic mean of the genotypic values. The lower the standard deviation of genotypic performance across environments, the greater is the harmonic mean of genotypes.

Table 1: Parentage and location details under multi environmental trials (2015-16).

Genotype	Parentage	Locations	Latitude	Longitude	Altitude
HS 625	(CM H82A.1294/2*KAUZ/MUNIA/CHTO/3/MILAN)	Bajaura	31°50'N	77°9 'E	1103.85
HPW 433	(VL832/PBW498)	Dhaulakuan	28°59 N	77°16 E	468
HS 627	(69-1 776/663//2*BCN/3/7*BCN/4/PARUS/PASTOR)	Imphal	24°81' N	93°93' E	786
HPW 432	(HS295/FLW2-1)	Kalimpong	27° 4' N	88° 28' E	1121
VL 3010	(RAJ4083/NESSER/SAULES:KU32)	Malan	32°08' N	76°35'E	846
VL 892	(WH542/PBW226)	Shimla	31°10' N	77°17'E	2276
HS 626	(CHEN/AE.SQUARROSA(TAUS)/BCN/3/BAV92/4/BERKUT)				
VL 3012	(RAJ4132/SW89.3218//AGRI/NAC//VL900)				
UP 2955	(RAJ 4132 / HPW 155/TAS T/S PRW//TL176.73 /7 /SOTY)				
HS 490	(HS364/HPW 114 //HS240//HS346)				
VL 3011	(RAJ4132/SW89.3218//AGRI/NAC/ /VL900)				

Table 2: Parentage and location details under multi environmental trials (2017-18).

Genotype	Parentage	Locations	Latitude	Longitude	Altitude
VL 3017	(RWP2008-31/VL895)	Almora	29° 35' N	79° 39'E	1610
UP 3017	(FRANCOLIN#1/BAJ#1)	Bajaura	31°50'N	77°9'E	1103.85
VL 3016	(KA/NAC//TRCH/3/DANPHE)	Dhaulakuan	28°59 N	77°16 E	468
HS 662	(SERI.1B*2/3/KAUZ*2/BOW//KAUZ*2/5/CNO79//PF70353/MUS/3/PASTOR/4/BAV92)	Gangtok	27° 20' N	88° 36' E	1509
HS 490	(HS364/HPW114//HS240//HS346)	Imphal	24°81° N	93°93 E	786
VL 892	(WH542/PBW226)	Kalimpong	27° 4 ' N	88° 28' E	1121
HS 661	(HS295*2/FLW20//HS295*2/FLW13)	Majhera	29° 16' N	80° 5' E	1532
HS 660	(PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1)	Malan	32°08' N	76°35'E	846
VL 3018	(FRNCLN/NIINI#1//FRANCOLIN#1)	Ranichauri	28° 43' N	81°02' E	2200
HPW 459	(HPW249/HPW211)	Shimla	31°10' N	77°17'E	2276
		Una	31°46' N	76°27° E	369

For the mixed models approach, Resende & Duarte (2007) proposed the simultaneous analysis of stability, adaptability and yield based on the harmonic mean of the relative performance of the genotypic values (MHPRVG). The MHPRVG combines the methods PRVG and MHVG, simultaneously. Consequently, the selection for higher values of the harmonic mean results in selection for both yield and stability.

$PRVG_{ij} = VG_{ij} / VG_i$

$MHVG_i$ = Number of environments / $\sum_{i=1}^{k} \frac{1}{X_i}$

$MHPRVG_{i.}$= Number of environments / $\sum_{j=1}^{k} \frac{1}{PRVG_{ij}}$

VG_{ij} is the genotypic value of the *i* genotype, in the *j* environment, expressed as a proportion of the average in this environment. PRVG and MHPRVG values were multiplied by the general mean (GM) to have results in the same magnitude as of the average wheat yield in order to facilitate interpretation (Verardi *et al.* 2009). Estimation of the variance components were carried out by using residual maximum likelihood (REML) along with estimation / prediction of the fixed as well as random effects by ASReml-R (Smith and Cullis, 2018). Geometric adaptability index (GAI) (Mohammadi & Amri, 2008) was used to evaluate the adaptability of genotypes and calculated as Geometric Adaptability Index (GAI) $= \sqrt[n]{\prod_{k=1}^{n} \bar{X}_k}$

in which $\bar{X}_1, \bar{X}_2, \bar{X}_3, \ldots \bar{X}_m$ are the mean yields of the first, second and mth genotype across environments and n is number of environments. Genotypes with higher values of GAI are desirable.

RESULTS AND DISCUSSION

Average yield of genotypes, as per BLUPs during 2015-16 cropping season, identified VL892, HS627 and VL3010 as of high yield with better adaptations while VL3011 & HPW432 expressed low yield. Harmonic mean of genotypes selected VL892, VL3010 & HS627 as better adapted genotypes at the same time pointed out suitability of VL3011 & VL3012 for specific adaptations (Table 3). Least values of standard error reflected the consistent performance of UP2955, HS625, HPW432 for considered location of this zone. Higher values of Geometric Adaptability Index selected VL892, VL3010, HS627 as suitable wheat genotypes. Genotypes VL892, VL3010 & HS627 were pointed out by PRVG as well as by PRVG*GM for the better adaptable behavior and VL3011 & VL3012 of low adaptability under restricted irrigated late sown conditions for Northern Hills Zone. Most cited analytic measures HMPRVG and HMPRVG*GM marked VL892, VL3010 & HS627 as of high yield and better adaptability across major locations of this zone while VL3011 & VL3012 for low degree of adaptation. Consensus has been observed among analytic measures PRVG, MHVG, MHPRVG, GAI and average yield for the classification of wheat genotypes (Table 3) (Silveira *et al*. 2018).

Biplot analysis based on first two highly significant Interaction Principal Components expressed stable yield of HS625, HS490 and HPW433 genotypes. VL3010 and VL3011 would be good for specific adaptations. These two significant interaction principal components, accounted for 80.6 % of total GxE interaction sum of squares (Fig. 1). Kalimpong and Dhaulakuan, would be suitable environments for stable yield of genotypes. Mean yield of wheat genotypes, during 2015-16 cropping season, based on BLUE values selected VL892, HS627 and VL3010 as of better adaptations along with UP2955 & HPW432 for specific adaptation. Environments Malan, Imphal and Bajura observed as larger contributor to the G x E interactions, because as positioned relatively away from the origin. HPW433 had specific adaptations to Kalimpong, Shimla and

Dhaulakuan while HS626 for Imphal and Bajura, whereas HS625 identified for Malan location. Genotypes or environments located near the origin of the coordinate system in the A genotype is considered adapted to a particular environment when it is situated in the same quadrant of the environment (Yan and Kang, 2003). Bajura with Imphal, Kalimpong with Dhaulakuan, Shimla with Kalimpong would show similar performance of genotypes as expressed acute angles among rays connecting these environments. Malan had an obtuse angle with Imphal this would express opposite performance of genotypes i.e. HS626 will not be of choice for Malan.

Table 3: Adaptability measures of wheat genotypes as per BLUP (2015-16).

15-16	Bajaura	Dhaulakuan	Imphal	Kalimpong	Malan	Shimla	Mean	Sterr	GAI	PRVG	PRVG*GM	HPVRG	HPVRG*GM	MHVG
HS 625	35.44	27.15	16.97	15.82	29.89	21.92	24.53	3.43	23.52	0.99	24.66	0.99	24.64	22.54
HPW 433	37.72	28.17	16.75	15.52	33.46	22.33	25.66	4.03	24.31	1.02	25.50	1.02	25.46	23.01
HS 627	39.23	31.08	19.67	14.74	31.00	21.52	26.21	4.06	24.86	1.05	26.10	1.04	26.01	23.52
HPW 432	36.41	23.63	15.20	16.41	27.10	21.03	23.29	3.49	22.28	0.94	23.44	0.93	23.26	21.35
VL 3010	39.01	31.23	22.89	17.98	26.70	19.32	26.19	3.55	25.24	1.07	26.73	1.05	26.19	24.37
VL 892	34.68	34.08	16.43	19.76	32.54	24.84	27.05	3.51	26.02	1.10	27.44	1.09	27.10	24.93
HS 626	40.16	30.00	20.20	13.94	25.97	21.61	25.32	4.06	23.99	1.01	25.30	1.00	24.98	22.71
VL 3012	33.31	27.08	13.80	12.38	34.84	21.39	23.80	4.29	22.05	0.93	23.29	0.92	22.94	20.30
UP 2955	30.95	27.09	15.12	16.34	31.02	20.17	23.45	3.21	22.50	0.95	23.65	0.94	23.51	21.55
HS 490	38.70	28.60	20.13	13.36	32.52	21.29	25.77	4.13	24.31	1.02	25.58	1.02	25.37	22.81
VL 3011	34.75	24.67	13.33	13.80	33.15	20.00	23.28	4.15	21.70	0.92	22.87	0.91	22.63	20.20

Table 4: Adaptability measures of wheat genotypes as per BLUE (2015-16).

	Bajaura	Dkuan	Imphal	Kmpong	Malan	Shimla	Mean	Sterr	GAI	PRVG	PRVG*GM	HPVRG	HPVRG*GM	MHVG
HS 625	35.16	26.77	17.26	16.11	29.80	22.42	24.59	3.31	23.65	0.99	24.81	0.99	24.77	22.73
HPW 433	38.28	27.92	16.78	15.56	33.80	22.80	25.86	4.10	24.48	1.03	25.68	1.03	25.63	23.14
HS 627	39.67	31.39	19.58	14.21	31.13	21.38	26.23	4.21	24.77	1.04	26.02	1.04	25.89	23.31
HPW 432	36.72	23.00	14.95	17.31	26.62	21.53	23.36	3.46	22.37	0.95	23.60	0.93	23.30	21.48
VL 3010	38.54	31.39	23.34	18.70	26.56	18.46	26.17	3.49	25.25	1.07	26.82	1.05	26.11	24.40
VL 892	34.64	34.58	16.01	20.51	32.41	25.35	27.25	3.52	26.19	1.11	27.69	1.09	27.22	25.07
HS 626	40.71	30.24	19.87	13.29	25.52	21.85	25.25	4.23	23.79	1.01	25.12	0.99	24.74	22.37
VL 3012	33.16	27.34	13.60	11.34	35.13	21.12	23.62	4.45	21.68	0.92	22.97	0.90	22.48	19.72
UP 2955	29.69	27.20	15.34	16.76	30.90	19.44	23.22	3.06	22.35	0.94	23.53	0.93	23.33	21.50
HS 490	38.72	28.21	20.93	12.69	33.04	21.64	25.87	4.19	24.33	1.03	25.67	1.01	25.32	22.70
VL 3011	35.07	24.74	12.83	13.56	33.28	19.42	23.15	4.29	21.45	0.91	22.63	0.90	22.34	19.86

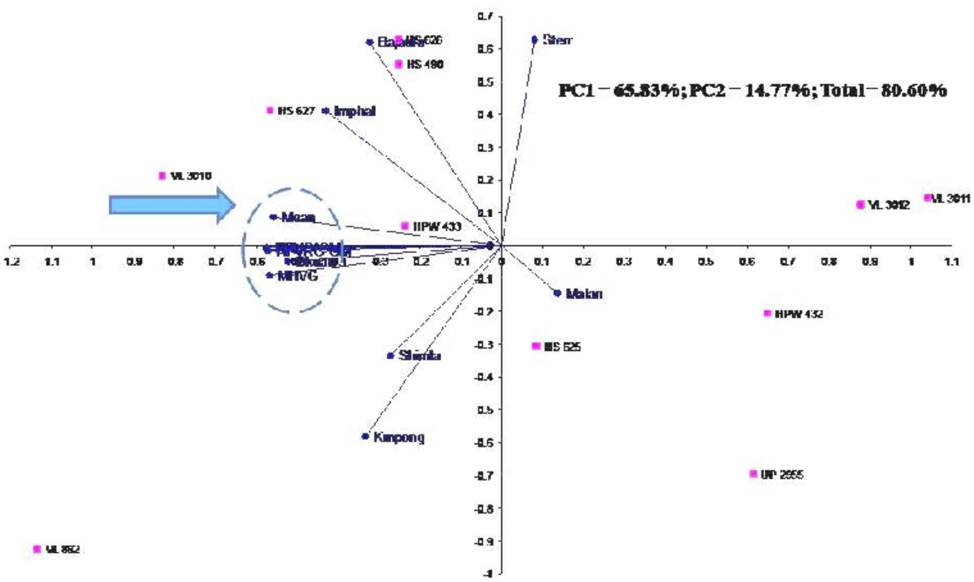

Fig. 1. Biplot analysis of genotypes vis-à-vis environments based on BLUP (2015-16).

Minimum values of standard error observed for UP2955, HS625, HPW432 genotypes for their consistent performance at considered locations of this zone. Maximum values of Geometric Adaptability Index identified VL892, VL3010, HS627 as suitable wheat genotypes for this zone. Harmonic mean of genotypes showed VL892, VL3010 & HS627 would express better adaptations and VL3011 & VL3012 for specific adaptations (Table 5). Genotypes VL892, VL3010 & HS627 were pointed out by PRVG as well as by PRVG*GM for the better adaptable behavior and VL3011 & VL3012 of low adaptability under restricted irrigated late sown conditions for Northern Hills Zone. Recent analytic measures HMPRVG and HMPRVG*GM pointed towards VL892, VL3010 & HS627 as wheat genotypes of high yield and better adaptability across major locations of this zone while VL3011 & VL3012 for low degree of adaptation. Consensus has been observed among analytic measures PRVG, MHVG, MHPRVG, GAI and average yield for the classification of wheat genotypes (Table 4) (Kleinknecht *et al.,* 2013).

First two significant interaction principal components, accounted for 78.9 % of total GxE interaction sum of squares by biplot analysis (Fig. 2). Biplot analysis expressed stable performance of HS625, HS626 and HPW433 genotypes and unstable behavior of VL3012, VL892 and VL3011. Imphal, Milan and Shimla locations would be conducive for stable yield of genotypes. HPW433 and HS626 had specific adaptations to Bajura, Imphal, Dhaulakuan and Shimla while VL3010 and VL892 for Kalimpong. Acute angles among rays connecting Imphal with Bajura, Dhaulakuan, Shimla with Kalimpong would show similar performance of genotypes. Malan had right angle with Kalimpong this would express opposite performance of genotypes VL3012 and VL3011 for Kalimpong location.

Average genotypes yield during the year of study (2017-18) as per BLUP values identified HS490, VL3017 and HS660 with high yield and better adaptations at the same time low realization of yield expressed for UP3017, HS661. Minimum values of standard error related to consistent performance of wheat genotypes HS662, HS661, and UP3017 for major locations. Larger value of Geometric Adaptability Index favored HS490, HS660, HS662 wheat genotypes. Harmonic mean of genotypes yield selected HS490, HS662 and HS660 for their better adaptations whereas specific adaptability of VL892, UP3017 (Table 5). PRVG and by PRVG*GM pointed out HS490, HS662 and HS660 for better adaptation along with lower adaptability of UP3017 & VL892. Analytic measures HMPRVG and HMPRVG*GM marked HS490, HS660 and VL 3017 wheat genotypes for better adaptability along high yield and VL892, UP3017 expressed low adaptation. PRVG, MHVG, MHPRVG, GAI measures had classified productive wheat genotypes.

Table 5. Adaptability measures of wheat genotypes as per BLUP (2017-18).

	Almora	Bajaura	Dkuan	Gangtok	Imphal	Kalimpong	Majhera	Malan	Ranichauri	Shimla	Una	Mean	Sterr	GAI	PRVG	PRVG*GM	HPVRG	HPVRG*GM	MHVG
VL 3017	11.03	29.88	37.99	25.64	20.75	19.59	9.97	26.35	7.61	8.03	32.22	20.82	3.34	18.08	1.024	20.23	0.991	19.58	15.41
UP 3017	10.58	23.33	33.31	17.21	16.84	17.99	9.13	23.09	8.79	8.89	26.68	17.80	2.58	16.10	0.904	17.87	0.892	17.62	14.53
VL 3016	10.88	26.38	36.37	24.14	17.69	21.72	9.90	26.48	7.97	7.33	29.01	19.81	3.08	17.35	0.985	19.46	0.948	18.73	14.94
HS 662	10.27	28.06	29.68	22.70	19.20	20.55	10.37	16.77	8.88	22.67	25.21	19.49	2.28	18.08	1.035	20.45	0.988	19.52	16.57
HS 490	10.33	32.82	30.12	26.39	26.18	19.99	10.90	28.51	8.70	21.37	25.48	21.89	2.67	20.02	1.137	22.46	1.099	21.72	17.90
VL 892	11.05	32.06	39.00	4.95	21.98	18.52	6.63	20.55	8.94	14.24	35.78	19.43	3.74	15.98	0.954	18.85	0.785	15.51	12.82
HS 661	10.35	28.56	30.50	22.11	22.31	22.38	10.19	13.84	8.97	14.81	23.03	18.82	2.38	17.35	0.982	19.40	0.951	18.80	15.89
HS 660	10.66	28.28	34.00	21.11	26.23	22.56	9.67	26.24	8.45	9.60	30.78	20.69	2.99	18.38	1.032	20.39	1.019	20.13	16.06
VL 3018	10.97	30.06	37.81	12.63	29.68	20.58	7.95	23.50	8.51	10.31	26.99	19.91	3.29	17.34	0.983	19.43	0.950	18.78	15.02
HPW 459	10.62	20.86	33.55	21.13	19.30	22.88	9.72	23.16	8.57	10.13	28.45	18.94	2.62	17.18	0.965	19.07	0.952	18.80	15.46

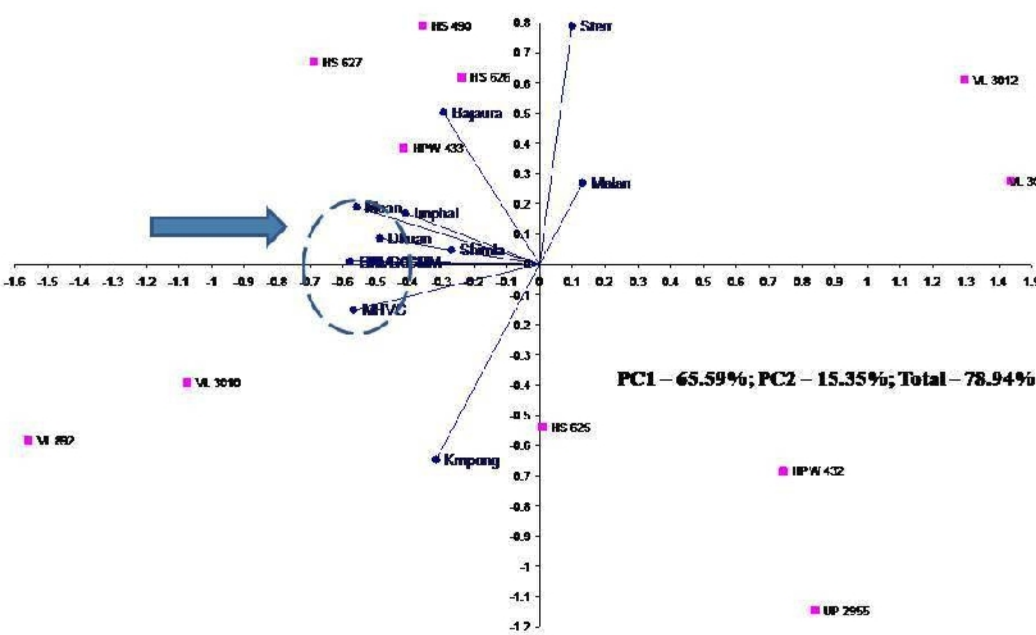

Fig. 2. Biplot analysis of genotypes vis-à-vis environments based on BLUE (2015-16).

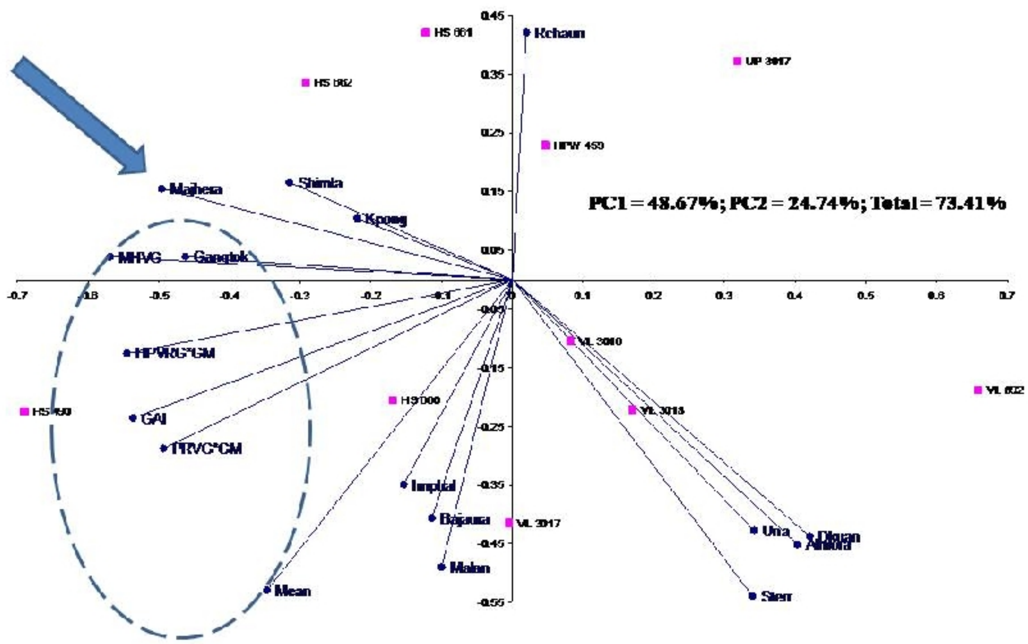

Fig. 3. Biplot anlaysis of genotypes vis-à-vis environments based on BLUP (2017-18).

Biplot analysis based first two highly significant Interaction principal components, accounted for 73.4 % of total GxE interaction sum of squares, expressed stable performance of HPW495, VL3016, Vl3018 and HS660 genotypes evident by placement near the origin (Fig. 3). Genotypes positioned far from origin HS490, HS661, VL892 and UP3017 would be of unstable nature. Environments Imphal, Shimla, Kalimpong and Gangtok would be conducive for yield performance of genotypes. Ranichauri, Almora, and Dhaulakuan contributed maximum to the G x E interactions. VL3018, VL3016 and VL892 had exhibited specific adaptations to Una, Almora and Dhaulakuan while HS490 and HS660 would be for Imphal, Malan and Bajaura whereas UP3017 and HPW459 for Ranichauri location. Genotypes HS662 and HS 661 identified for Shimla, Majhera, Gangtok and Kalimpong conditions. Environments Una with Almora and Dhaulakuan, Bajura with Imphal and Malan, Shimla with Majhera, Gangtok and Kalimpong would show similar performance of genotypes as acute angles observed among these environments. Ranichauri had an obtuse angle with Imphal, Bajura and Malan this would express opposite performance of genotypes i.e. VL3017 and HPW459 for these locations.

Mean values of genotypes yield, for second year 2017-18, based on BLUEs selected HS490, HS660 and VL3017 with yield and better adaptations and low yield realization by UP3017, HPW459. Least values of standard error expressed consistent performance of HS661, HS662, and HPW459 at major locations of this zone (Table 6). More value of Geometric Adaptability Index identified HS490, HS660, VL3017 wheat genotypes. Harmonic mean of genotypes yield selected HS490, HS661 and HS660 for their better adaptations whereas specific adaptability of VL892, UP3017. PRVG and PRVG*GM pointed out HS490, HS662 and VL3017 for better adaptation and lower adaptability of UP3017 & VL892. Analytic measures HMPRVG and HMPRVG*GM marked HS490, HS660 and VL 3017 wheat genotypes for better adaptability along high yield and VL892, UP3017 expressed low adaptation. First two highly significant Interaction principal components accounted for 66.8 % of total GxE interaction sum of squares in biplot analysis. HPW495, VL3016, VL3017, Vl3018 and HS660 genotypes placed near to the origin and HS490, HS662, VL892 & UP3017 positioned far from origin (Fig. 4).

Table 6: Adaptability measures of wheat genotypes as per BLUE (2017-18).

	Almora	Bajaura	Dkuan	Gangtok	Imphal	Kpong	Majhera	Malan	Rchauri	Shimla	Una	Mean	Sterr	GAI	PRVG	PRVG*GM	HPVRG	HPVRG*GM	MHVG
VL 3017	9.97	30.03	38.76	26.12	20.71	18.85	9.88	26.19	7.20	8.13	32.44	20.75	3.44	17.84	1.012	19.99	0.977	19.30	15.05
UP 3017	10.26	22.95	32.41	16.99	16.49	16.79	8.18	23.25	7.72	8.49	26.49	17.27	2.61	15.43	0.867	17.13	0.855	16.90	13.73
VL 3016	11.62	26.26	36.71	24.36	17.45	22.07	9.49	26.49	8.28	7.22	28.87	19.89	3.08	17.45	0.991	19.59	0.951	18.79	15.02
HS 662	8.82	28.11	29.60	22.92	19.05	20.28	9.26	16.50	7.20	23.02	25.30	19.10	2.47	17.30	0.995	19.66	0.943	18.63	15.31
HS 490	10.94	33.27	29.93	26.41	26.49	19.27	11.81	29.00	9.77	21.74	25.60	22.20	2.60	20.53	1.166	23.05	1.126	22.25	18.68
VL 892	10.67	32.28	39.19	4.66	21.88	18.25	7.33	20.54	9.77	14.49	36.31	19.58	3.75	16.15	0.968	19.12	0.782	15.45	12.95
HS 661	10.86	28.64	30.92	22.22	22.34	23.03	10.65	13.31	10.55	14.67	22.62	19.07	2.33	17.73	1.008	19.92	0.967	19.10	16.45
HS 660	10.78	28.31	33.23	20.75	26.51	23.41	11.03	26.47	7.82	9.38	31.25	20.81	2.98	18.51	1.041	20.58	1.023	20.21	16.13
VL 3018	11.73	30.16	38.36	12.57	30.12	20.93	7.10	23.54	7.92	10.32	26.19	19.90	3.35	17.18	0.978	19.32	0.938	18.54	14.67
HPW 459	11.07	20.30	33.23	21.01	19.13	23.88	9.72	23.18	9.16	9.91	28.57	19.02	2.59	17.31	0.975	19.26	0.956	18.90	15.66

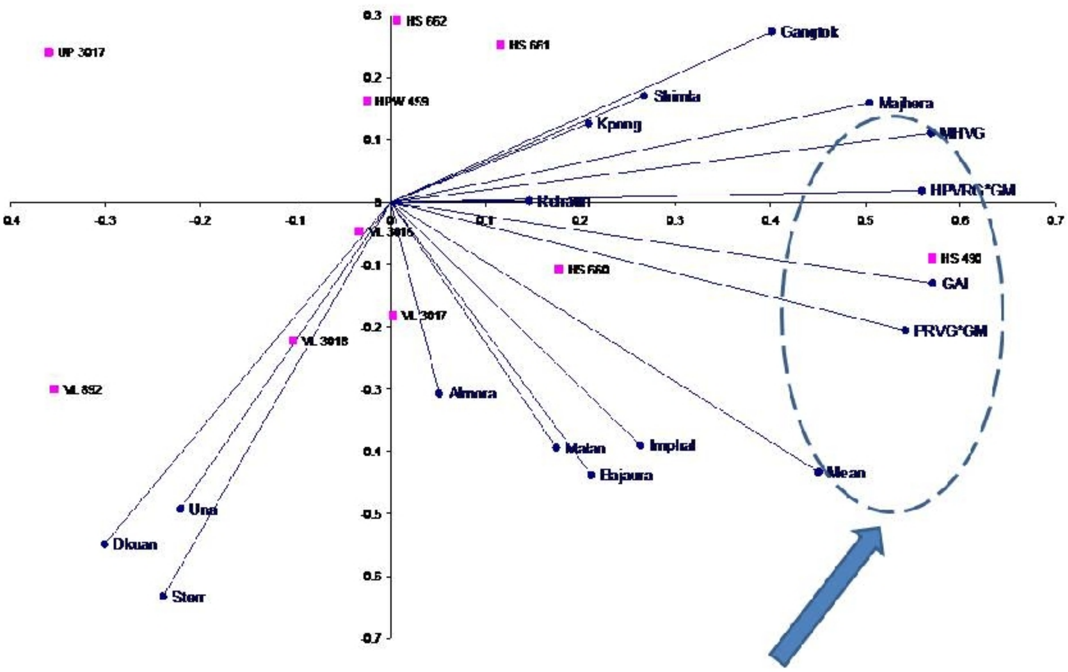

Fig. 4. Biplot analysis of genotypes vis-à-vis environments based on BLUE (2017-18).

Ranichauri, Kalimpong, Shimla, Almora and Malan would be conducive for stable performance of genotypes. Gangtok, Una and Dhaulakuan contributed maximum to the G x E interactions. Specific adaptations of VL3018, VL3016 and VL892 observed for Una and Dhaulakuan while HS490, VL3017 and HS660 for Imphal, Malan, Almora and Bajaura locations. Genotypes HS662 and HS 661 identified for Shimla, Majhera, Gangtok and Kalimpong conditions. Acute angles among environments Una with Dhaulakuan, Bajaura with Imphal, Almora and Malan, Kalimpong with Shimla, Majhera and Gangtok would show similar performance of genotypes. Gangtok had an obtuse angle with Dhaulakuan and Una this would express opposite performance of genotypes i.e. HS661 and HS662 for these locations.

Wheat genotypes stratification by analytic measures of adaptability based on BLUP was more efficient as compared to values of analytic measures while considering BLUE of genotypes. Biplot analysis exhibited that more of GxE interactions sum of squares was explained by first two significant principal components based on BLUP as compared to accounted by BLUE. Random effects of genotypes would provide more efficient estimates of yield.

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