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GENETICS AND PLANT BREEDING

Adaptability Measures for Wheat Genotypes Evaluated under Northern Hills Zone of Country for Irrigated Timely Sown Conditions

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ABSTRACT

Wheat genotypes were evaluated under multi environment trials for Northern Hills Zone of India to study the adaptability performance. Genotypes HS612, HS507 and HPW430 were of high yield and better adaptability by analytic measures of adaptability based on BLUP values during 2015-16. Two interaction principal components, accounted for 89.9 % of total GxE interaction sum of squares in biplot analysis. HPW428, HS613, VL2020, VL2024 had specific adaptations to Almora and Malan while HS616, HPW423, HPW430, VL2021, HPW426 expressed for Shimla and Khudwani locations. Wheat genotypes HS612, HS507 and HPW430 were cited by analytic measures as per BLUE values. HPW429, HS613, VL2020, VL2024 had specific adaptations to Almora and Malan while HS616, HS618, HPW425, HPW426, HPW430, VL2023, VL2021, HPW426 observed for Shimla and Khudwani. Second year (2017-18) had seen high yield and better adaptability of HS631, HS632, VL2030, VL2025 genotypes as per BLUP values. Biplot analysis expressed specific adaptations of HPW429, HS613, VL2020, VL2024 to Almora and Malan locations. BLUE values based measures showed high yield and better adaptability of HS631, HS632, VL2030, VL2025 genotypes. Biplot analysis while utilizing 79.5 % of total GxE interaction sum of squares exhibited specific adaptations of HPW446, VL907, HS632, VL2025, VL2030 to Almora and Shimla. Stratification of wheat genotypes as per BLUP values was more efficient than that by BLUE. Biplot analysis exhibited more of GxE interactions sum of squares by first two significant principal components based on BLUP as compared to BLUE values.

Highlights

⊙ Adaptability of wheat genotypes were studied by analytic measures based on random and fixed effects of genotypes. Further clustering pattern were studied among measures based on biplot analysis.

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

Wheat improvement programs conduct multi environment trials (MET) for estimation of main of genotypes, environments and genotype x environment interactions (Crespo *et al.* 2017). The cross over GxE interactions hampers the real yield potential and stable performance of genotypes as relative ranking of genotypes change across locations (Elesandro *et al.* 2017). Though, analysis of variance (ANOVA) technique estimates the influence of the different factors underlying phenotypic variation (Gogel *et al.* 2018). More over all factors are considered as of fixed effects along with homogeneity of variance and the same covariance for all pairs of genotypes. These assumptions are often inappropriate and unreliable (Friesen *et al.* 2016). The mixed model method considers fixed and random effects in commonly used experimental designs and correctly estimates

genotype effect (G) and genotype × environment (G × E) interaction effects using an appropriate variance–covariance structure (Nuvunga *et al.* 2018). The procedures based on restricted maximum likelihood/best linear unbiased prediction (REML/ BLUP) have proven to be effective in assessing genotypic performance (Santos *et al.* 2015). The statistical approach based on restricted maximum likelihood (REML) provides efficient estimates of variance components and genetic parameters (Smith and Cullis, 2018). Methods of mixed models have been gaining more and more space in the statistical evaluation of genotypes in plant-breeding trials, for crops, such as maize (Mendes *et al.* 2012; Baretta *et al.* 2016), corn (Oliveira *et al.* 2017), and cotton (Moiana *et al.* 2014) and cowpea (Torres *et al.* 2015). Prime objective of the study was to compare the adaptability performance of wheat genotypes as per their BLUP and BLUE values by analytic measures.

MATERIALS AND METHODS

Northern hills zone encompasses the hilly terrain of Northern region extending from Jammu & Kashmir to North Eastern States. NHZ 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.

Simple and effective measure for adaptability is based on the relative performance of genetic values (PRVG) across environments. MHVG method (harmonic mean of genetic values) as based on the harmonic mean of the genotypic values considered the yield & stability. The lower the standard deviation of genotypic performance across environments, the greater is the harmonic mean of genotypes. For the use of mixed models, 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 (Resende and Duarte, 2007).

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

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

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

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 package. Mohammadi & Amri, 2008 defined geometric adaptability index (GAI) to evaluate the adaptability of genotypes as GAI =

$$\sqrt[n]{\prod_{k=1}^{n} \overline{X}_k}$$

in which $\overline{X}_1$, $\overline{X}_2$, $\overline{X}_3$, … *m* are the mean yields of the first, second and *m*th genotype across environments and *n* is number of environments. Genotypes with higher values of GAI are desirable.

RESULTS AND DISCUSSION

First year (2015-16) based on BLUP

Analytic measures

Average yield of genotypes as per BLUP values identified HS612, HS507 and HPW430 as of high yield with better adaptations while HS615 & UP2952 expressed low yield. Harmonic mean ranked genotypes as HS612, HPW430 and VL2024 for better adaptation at the same time pointed out suitability of HS615 & HS617 for specific adaptations (Table 3). Least values of standard error reflected the consistent performance of VL2019, UP2952, VL907 for considered location of this zone. Higher values of Geometric Adaptability Index selected HS612, HPW430,VL2023 as suitable wheat genotypes. PRVG

as well as PRVG*GM pointed towards HS612, HS507 and HPW430 for the better adaptable behavior and HS615 & HS617 of low adaptability under irrigated timely sown conditions for Northern Hills Zone. Most cited analytic measures HMPRVG and HMPRVG*GM marked HS612, HS507 and HPW430 as of high yield and better adaptability across major locations of this zone while HS615 & HS617 for low degree of adaptation. An overall agreement has been observed among analytic measures PRVG, MHVG, MHPRVG, GAI and average yield for the classification of wheat genotypes (Table 3) (de Pelegrin *et al.* 2017). Variations among ranks of genotypes as per analytic adaptability measures observed as per various locations to highlight presence of cross over interactions effects for studied genotypes (Table 4).
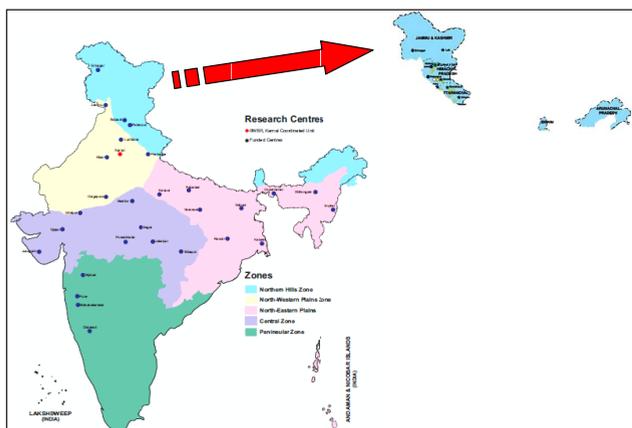

Fig. 1: Agro climatics zones for wheat cultivation in country

Biplot analysis

First two highly significant Interaction Principal Components expressed stable yield of HS618, UP2953, HS613, HPW431 and HPW428 genotypes in Biplot analysis. HS612, VL2019 and HS615 would be good for specific adaptations. Two interaction principal components, accounted for 89.9 % of total G×E interaction sum of squares (Fig. 2). Shimla would be suitable environment for stable yield of genotypes. Environments Khudwani and Almora observed as larger contributor to the G × E interactions, because as positioned relatively away from the origin. Biplot presentations were considered more stable; however, the greater the distance from the source the lower the stability related to the grain yield character; these effects are due to the nature of the G × E interaction (Yan

and Kang 2003). Genotypes and environments placed in proximity have positive associations as these observations would enable to identify specific adaptations of the genotypes. HPW428, HS613, VL2020, VL2024 had specific adaptations to Almora and Malan while HS616, HPW423, HPW430, VL2021, HPW426 for Shimla and Khudwani. Location Almora with Malan, Khudwani with Shimla would show similar performance of genotypes as acute angles expressed among rays connecting these environments. Almora had an obtuse angle with Khudwani this would express opposite performance of genotypes i.e. HPW426 & HPW428 will not be of choice for Almora. Standard error had been observed at distant from others analytic measures.
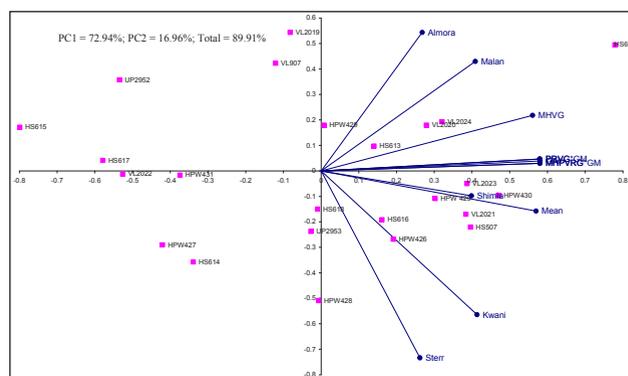
Fig. 2: Biplot analysis of genotypes *vis-à-vis* environments based on BLUP (2015-16)

First year (2015-16) based on BLUE

Analytic measures

Mean yield of wheat genotypes based on BLUE values selected HS612, HPW430 and HS507 as of high yield with better adaptations while HS615 & UP2952 achieved low yield. Ranking of genotypes based on harmonic mean selected HS612, HPW430 and VL2024 as better adapted genotypes along with suitability of HS615 & HS617 for specific adaptations (Table 5). Lower values of standard error associated with the consistent performance of VL2019, UP2952, VL907 for considered locations of this zone. Higher values of Geometric Adaptability Index pointed towards HS612, HPW430, VL2023 as suitable wheat genotypes. PRVG as well as PRVG*GM pointed towards HS612, HS507 and HPW430 for the better adaptable behavior and HS615 & HS617 of low adaptability under irrigated timely sown

Table 1: Parentage details and environmental conditions (2015-16)

Genotype	Parentage	Locations	Latitude	Longitude	Altitude
HPW 425	(VL832/WH423)	Almora	29° 35 ' N	79° 39 'E	1610
VL2022	(EC635640)	Khudwani	33° 70' N	75°10' E	1590
VL2019	(RWP2002-2/SW89.3218//AGRI/NAC//VL905)	Malan	32°08 ' N	76°35'E	846
HPW431	(HPW42/HPW236)	Shimla	31°10 ' N	77°17'E	2276
HPW430	(HPW249/HPW211)	Bajaura	31°50'N	77°9'E	1103.85
UP2953	(WBLL1/KUKUNA//TACUPETO F2001/3/KIRITATI)	Wadura	21° 18' N	77° 41' E	508
VL2024	(W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/5/MUNAL)				
VL2023	(ATTILA/3/WEAVER*2/TSC//WEAVER/4/ATTILA/PASTOR)				
HPW427	(VL616/FLW3)				
HS616	(SOKOLL/3/PASTOR//HXL7573/2*BAU)				
HS612	(SERI.1B*2/3KAUZ*2/BOW//KAUZ*2/5/CNO79/PF70354/ MUS/3/PASTOR/4/BAV92)				
HPW429	(ESWYT(2008)115/HPW211)				
HPW426	(HPW155/HD29)				
UP2952	(MILAN/S87230//BAV92*2/3/AKURI)				
HS615	(BERKUT/HTG)				
HPW428	(HPW155/HD29)				
HS613	(WBM1587/VL824)				
HS614	(HPW155/CHINESE LINE 14)				
HS617	(PASTOR/3/CROC-1/AE.SQUARROSA(224)//OPATA/4/ BERKUT)				
VL2020	(KLEIBER/2*FL80/DONSK.POLL/AKAW4006)				
VL2021	(KLEIBER/2*FL80/DONSK.POLL/GW2000-18)				
HS618	(BERKUT/HTG)				
HS507	(KAUZ/MYNA/VUL//BUC/FLK/4/MILAN)				
VL907	(DYBR 1982-83/842 ABVD 50/VW 9365//PBW 343)				

Table 2: Parentage details and environmental conditions (2016-17)

Genotype	Parentage	Locations	Latitude	Longitude	Altitude
HPW 441	(NAC/TH.AC//3*MIRLO/BUC/4/PASTOR)	Almora	29° 35 ' N	79° 39 'E	1610
HPW442	(LONG291*2/PASTOR)	Khudwani	33° 70' N	75°10' E	1590
HPW443	(PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1)	Malan	32°08 ' N	76°35'E	846
HPW444	(AZAR2/4/CROC_1/AE.SQUARROSA (205)// BORL95/3/2*MILAN/5/BERKUT)	Shimla	31°10 ' N	77°17'E	2276
HPW445	(PBW575/HPW251)				
HPW446	(BOW/URES//KEA/3/SITE)				
HPW447	(HPW266/HPW249)				
UP2991	(SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL/WBLL1)				
HS631	(WHEAR/VIVITSI//WHEAR)				
HS636	(PASTOR//KAUZ/6/CNDO/R143//ENTE/MEX1-2/3/ AEGILOPSSQUARROSA(TAUS)/4/WEAVER/5/2*KAUZ)				
HS635	(PFAU/MILAN/5/CHEN/AE.SQUARROSA(TAUS)//BCN/3/ VEE#7/BOW/4/PASTOR)				
HS632	(HS240*2/FLW20(LR19)//HS240*2/FLW13(YR15)				
HS633	(HS240*2/FLW20(LR19)//HS240*2/FLW13(YR15)				
HS634	(PBW343*2/KUKUNA/5/CNO79/PF73054/MUS/3/PASTOR/4/ BAV92)				
HS637	(PRL/2*PASTOR)				
UP2990	(UP2744/WL711//PBW644)				
VL 2026	(GW366/KS82W428/SWM75740//UP2739)				
VL 2027	(RAJ4083/SKAUZ/HATUSA//VL900)				
VL 2025	(LBPY04-1/RAJ4132//HS490)				
VL 2029	(MUNAL#1/FRANCOLIN#1)				
VL 2028	(FRANCOLIN#1*2/MUU)				
VL2030	(KA/NAC//TRCH/3/DANPHE#1)				
VL 907	(DYBR1982-8384ABVD50/VW9365//PBW343)				
HS 507	(KAUZ/MYNA/VUL//BUC/FLK/4/MILAN)				

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

	Almora	Kwani	Malan	Shimla	Mean	Sterr	GAI	PRVG	PRVG*GM	MHPVRG	MHPVRG*GM	MHVG
HPW 425	17.87	42.85	23.49	24.68	27.22	6.25	25.81	1.07	26.90	1.06	26.56	24.63
VL2022	18.49	30.81	15.69	21.64	21.66	3.79	20.97	0.87	21.76	0.87	21.68	20.36
VL2019	21.93	26.10	23.29	23.71	23.76	1.00	23.71	1.00	25.03	0.96	24.05	23.67
HPW431	18.92	31.56	15.79	23.98	22.56	3.97	21.81	0.90	22.65	0.90	22.52	21.10
HPW430	20.31	43.89	20.82	27.63	28.16	6.35	26.76	1.11	27.76	1.10	27.68	25.60
UP2953	21.80	43.84	15.12	22.21	25.74	7.22	23.80	1.00	25.02	0.97	24.28	22.24
VL2024	19.43	35.09	23.98	27.72	26.56	3.82	25.95	1.08	27.00	1.07	26.75	25.36
VL2023	20.33	44.16	22.33	24.11	27.73	6.38	26.37	1.09	27.41	1.09	27.21	25.30
HPW427	13.29	33.81	18.46	25.12	22.67	5.12	21.37	0.89	22.37	0.87	21.87	20.12
HS616	18.52	39.83	17.98	28.62	26.24	5.95	24.82	1.03	25.81	1.02	25.60	23.58
HS612	24.66	37.95	26.90	27.41	29.23	3.43	28.82	1.20	30.04	1.18	29.66	28.46
HPW429	19.27	31.62	20.98	26.40	24.57	3.23	24.10	1.00	25.06	0.99	24.87	23.66
HS507	20.46	48.55	20.78	23.31	28.28	7.84	26.34	1.10	27.50	1.08	27.07	24.93
HPW426	17.53	42.59	19.16	27.34	26.66	6.62	25.01	1.04	26.03	1.03	25.77	23.63
UP2952	20.16	24.22	18.86	21.19	21.11	1.32	21.02	0.88	22.08	0.86	21.44	20.93
HS615	18.89	22.23	14.93	22.15	19.55	1.99	19.30	0.81	20.30	0.79	19.67	19.04
HPW428	15.02	45.63	18.41	25.14	26.05	7.92	23.73	1.00	24.94	0.97	24.23	21.91
HS613	20.08	36.93	21.14	24.68	25.71	4.47	24.94	1.03	25.85	1.03	25.82	24.29
HS614	16.02	39.40	16.10	22.67	23.55	6.36	21.91	0.91	22.83	0.90	22.56	20.62
HS617	19.23	28.38	14.73	22.51	21.21	3.32	20.62	0.86	21.49	0.85	21.23	20.04
VL907	20.75	27.11	22.25	24.15	23.56	1.58	23.45	0.98	24.60	0.96	23.95	23.33
VL2020	21.64	37.94	22.03	24.53	26.54	4.45	25.81	1.07	26.77	1.07	26.69	25.20
VL2021	21.96	43.72	16.79	28.99	27.86	6.75	26.14	1.09	27.30	1.07	26.83	24.62
HS618	19.15	38.42	16.92	26.17	25.16	5.59	23.89	0.99	24.82	0.98	24.67	22.78

Table 4: Rank of wheat genotypes as per adaptability measures based on BLUP (2015-16)

	Almora	Khudwani	Malan	Shimla	Mean	Sterr	GAI	PRVG	PRVG*GM	MHPVRG	MHPVRG*GM	MHVG
HPW 425	20	7	3	12	6	16	7	7	7	8	8	7
VL2022	19	19	21	23	21	8	22	22	22	21	21	21
VL2019	3	22	4	17	16	1	16	13	13	16	16	10
HPW431	16	18	20	16	20	10	19	19	19	19	19	18
HPW430	9	4	10	4	3	17	2	2	2	2	2	2
UP2953	4	5	22	21	12	22	14	14	14	14	14	16
VL2024	12	15	2	3	8	9	6	6	6	6	6	3
VL2023	8	3	5	15	5	19	3	4	4	3	3	4
HPW427	24	16	14	10	19	13	20	20	20	20	20	22
HS616	18	9	16	2	10	15	11	11	11	11	11	13
HS612	1	12	1	5	1	7	1	1	1	1	1	1
HPW429	13	17	9	7	15	5	12	12	12	12	12	11
HS507	7	1	11	18	2	23	4	3	3	4	4	6
HPW426	21	8	12	6	7	20	9	9	9	10	10	12
UP2952	10	23	13	24	23	2	21	21	21	22	22	19
HS615	17	24	23	22	24	4	24	24	24	24	24	24
HPW428	23	2	15	9	11	24	15	15	15	15	15	17
HS613	11	14	8	11	13	12	10	10	10	9	9	9
HS614	22	10	19	19	18	18	18	18	18	18	18	20
HS617	14	20	24	20	22	6	23	23	23	23	23	23
VL907	6	21	6	14	17	3	17	17	17	17	17	14
VL2020	5	13	7	13	9	11	8	8	8	7	7	5
VL2021	2	6	18	1	4	21	5	5	5	5	5	8
HS618	15	11	17	8	14	14	13	16	16	13	13	15

conditions for Northern Hills Zone. HS612, HS507 and HPW430 genotypes cited by analytic measures HMPRVG and HMPRVG*GM for high yield and better adaptability whereas HS615 & HS617 for low of adaptation. An agreement has been maintained by analytic measures PRVG, MHVG, MHPRVG, GAI and average yield for the classification of wheat genotypes (Table 5). Differences among ranks of genotypes as per various locations highlighted cross over interactions effects for studied genotypes (Table 6).

Biplot Analysis

Two interaction principal components, accounted for 87.9 % of total GxE interaction sum of squares in biplot analysis (Fig. 3). Stable performance of HS618, UP2953, HPW429, HS613, HPW431 and VL2022 genotypes would be as compared to HS612, VL2019, HPW428 and HS615 by virtue of their positions with respect to origin of biplot. Shimla location would be conducive for yield of genotypes vis-à-vis to Khudwani and Almora as positioned away from the origin. HPW429, HS613, VL2020, VL2024 had specific adaptations to Almora and Malan while HS616, HS618, HPW425, HPW426, HPW430, VL2023, VL2021, HPW426 for Shimla and Khudwani. Almora with Malan and Khudwani with Shimla expressed acute angles among rays therefore similar performance of genotypes would be expected. More over Almora had an obtuse angle with Khudwani i.e. HPW429 & HS613 would not be suitable for Almora. Analytic measure standard error had maintained distance from others adaptability measures (Fig. 3).

Second year (2017-18) based on BLUP

Analytic measures

HPW447, HS631, HS632, VL2030 wheat genotypes were selected by average yield based on the BLUP values for possessing high yield with better adaptation and HS635, HS637 & VL2028 for low yield & specific adaptation. Harmonic mean identified HS631, HS632, VL2030, VL2025 for better adaptation along with suitability of HS635, VL2028 & HPW444 for specific adaptations (Table 7). Least values of standard error associated with HPW446, HPW441, HS637 and VL907 genotypes for their consistent performance. HS631, HS632 VL2030,

HPW447 exhibited higher values of Geometric Adaptability Index while lower values by HS635, VL2028 & HPW444. PRVG and PRVG*GM pointed towards HS631, HS632, HPW447, VL2030 for their better adaptation whereas HS635, VL2028 & HPW444 for low adaptability. Analytic measures HMPRVG and HMPRVG*GM marked HS631, HS632, VL2030, VL2025 as of high yield and better adaptability as compared to HS635, VL2028 & HPW444 wheat genotypes. An agreement had been observed among analytic measures PRVG, MHVG, MHPRVG, GAI and average yield for the classification of wheat genotypes (Table 7). Variations among ranks of genotypes as per various locations observed by adaptability measures to highlight presence of cross over interactions effects (Table 8).
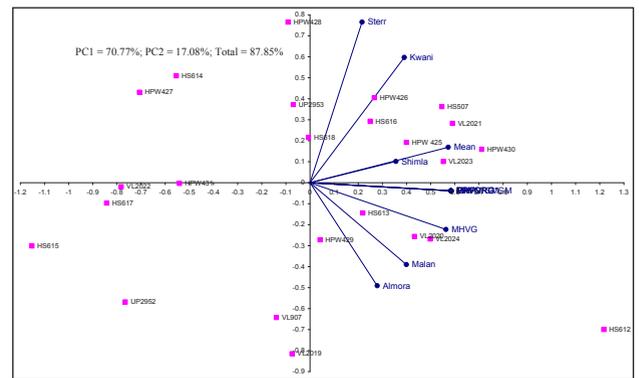
Fig. 3: Biplot analysis of genotypes *vis-à-vis* environments based on BLUE (2015-16)

Biplot Analysis

Total of 87.8 % of G×E interaction sum of squares was explained by first two significant interaction principal components in biplot analysis (Fig. 4). Stable performance of HS618, UP2953, HPW429, HS613, HPW431 and VL2022 wheat genotypes were observed as compared to HS612, VL2019, HPW428 and HS615 by virtue of their positions with respect to origin of biplot. Shimla location would be conducive for yield of genotypes *vis-à-vis* to Khudwani and Almora as positioned away from the origin. HPW429, HS613, VL2020, VL2024 had specific adaptations to Almora and Malan while HS616, HS618, HPW425, HPW426, HPW430, VL2023, VL2021, HPW426 for Shimla and Khudwani. Acute angles among rays of Almora with Malan and Khudwani with Shimla expressed similar performance of genotypes. More over

Table 5: Adaptability measures of wheat genotypes as per BLUE(2015-16)

	Almora	Kwani	Malan	Shimla	Mean	Sterr	GAI	PRVG	PRVG*GM	MHPVRG	MHPVRG*GM	MHVG
HPW 425	17.15	43.07	24.34	24.06	27.15	6.42	25.65	1.07	26.83	1.05	26.30	24.36
VL2022	18.46	30.73	15.31	20.98	21.37	3.84	20.66	0.86	21.45	0.85	21.35	20.03
VL2019	22.28	25.76	23.91	23.48	23.85	0.83	23.82	1.01	25.23	0.96	24.09	23.79
HPW431	19.02	31.41	15.23	24.14	22.45	4.04	21.65	0.90	22.52	0.89	22.33	20.89
HPW430	20.53	44.06	20.78	28.24	28.40	6.37	26.99	1.12	28.00	1.11	27.92	25.82
UP2953	22.91	44.27	14.30	21.25	25.68	7.47	23.56	1.00	24.95	0.95	23.85	21.83
VL2024	19.08	34.90	24.61	28.52	26.77	3.84	26.14	1.09	27.26	1.07	26.90	25.51
VL2023	20.43	44.48	22.81	23.32	27.76	6.48	26.37	1.10	27.45	1.08	27.17	25.29
HPW427	11.55	33.65	18.75	25.39	22.33	5.44	20.74	0.88	21.94	0.84	20.96	19.13
HS616	18.41	39.79	17.50	29.96	26.41	6.10	24.89	1.04	25.96	1.02	25.61	23.53
HS612	25.64	37.92	27.66	27.77	29.75	3.19	29.40	1.22	30.69	1.21	30.21	29.08
HPW429	19.07	31.35	21.17	27.07	24.67	3.23	24.20	1.00	25.18	1.00	24.94	23.74
HS507	20.77	49.09	21.02	22.15	28.25	8.03	26.25	1.10	27.47	1.07	26.90	24.80
HPW426	17.05	42.71	19.06	28.01	26.71	6.75	24.97	1.04	26.03	1.03	25.69	23.50
UP2952	20.33	23.91	18.98	20.43	20.91	1.21	20.84	0.88	21.93	0.85	21.22	20.76
HS615	18.97	21.80	14.38	22.11	19.31	2.07	19.04	0.80	20.07	0.77	19.36	18.74
HPW428	13.89	45.94	18.52	24.92	25.82	8.17	23.29	0.98	24.61	0.94	23.64	21.29
HS613	20.15	36.95	21.41	24.49	25.75	4.44	25.00	1.03	25.91	1.03	25.87	24.35
HS614	15.30	39.58	15.90	21.99	23.19	6.54	21.45	0.89	22.39	0.88	22.06	20.10
HS617	19.48	28.18	14.06	22.34	21.01	3.40	20.38	0.85	21.28	0.84	20.93	19.73
VL907	20.84	26.77	22.73	24.10	23.61	1.44	23.51	0.99	24.72	0.96	23.97	23.42
VL2020	22.10	38.02	22.34	24.18	26.66	4.40	25.96	1.08	26.95	1.07	26.82	25.37
VL2021	22.98	43.85	15.78	30.39	28.25	6.92	26.37	1.11	27.69	1.07	26.89	24.60
HS618	19.29	38.44	16.37	26.76	25.21	5.68	23.87	0.99	24.84	0.98	24.61	22.68

Table 6: Rank of wheat genotypes as per adaptability measures based on BLUE(2015-16)

	Almora	Kwani	Malan	Shimla	Mean	Sterr	GAI	PRVG	PRVG*GM	MHPVRG	MHPVRG*GM	MHVG
HPW 425	20	7	3	15	6	17	8	8	8	8	8	8
VL2022	18	19	20	23	21	8	22	22	22	20	20	21
VL2019	4	22	4	16	16	1	14	12	12	14	14	10
HPW431	16	17	21	13	19	10	18	18	18	18	18	18
HPW430	8	5	11	4	2	16	2	2	2	2	2	2
UP2953	3	4	23	22	13	22	15	14	14	16	16	16
VL2024	14	15	2	3	7	9	6	6	6	4	4	3
VL2023	9	3	5	17	5	18	3	5	5	3	3	5
HPW427	24	16	14	9	20	13	21	20	20	22	22	23
HS616	19	9	16	2	10	15	11	10	10	11	11	12
HS612	1	13	1	6	1	5	1	1	1	1	1	1
HPW429	15	18	9	7	15	6	12	13	13	12	12	11
HS507	7	1	10	19	3	23	5	4	4	5	5	6
HPW426	21	8	12	5	8	20	10	9	9	10	10	13
UP2952	10	23	13	24	23	2	20	21	21	21	21	19
HS615	17	24	22	20	24	4	24	24	24	24	24	24
HPW428	23	2	15	10	11	24	17	17	17	17	17	17
HS613	11	14	8	11	12	12	9	11	11	9	9	9
HS614	22	10	18	21	18	19	19	19	19	19	19	20
HS617	12	20	24	18	22	7	23	23	23	23	23	22
VL907	6	21	6	14	17	3	16	16	16	15	15	14
VL2020	5	12	7	12	9	11	7	7	7	7	7	4
VL2021	2	6	19	1	4	21	4	3	3	6	6	7
HS618	13	11	17	8	14	14	13	15	15	13	13	15

Almora had an obtuse angle with Khudwani i.e. HPW429 & HS613 would not be suitable for Almora. Analytic measure standard error had maintained distance from others adaptability measures as observed from (Fig. 3).
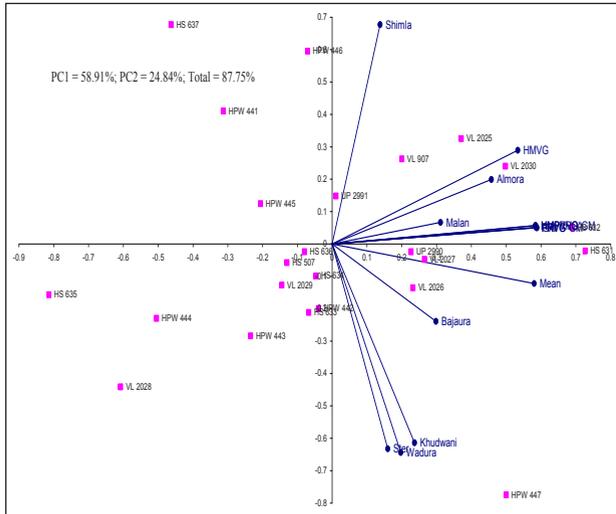

Fig. 4: Biplot analysis of genotypes *vis-à-vis* environments based on BLUP (2016-17)

Second year (2017-18) based on BLUE

Analytic measures

Wheat genotypes HS631, HPW447, HS632, VL2030 were identified by mean yield as per their BLUE values for high yield and better adaptation at the same time low yield & specific adaptation of HS635, HS637 & HPW444. Harmonic mean of genotypes values selected HS631, HS632, VL2030, VL2025 for better adaptation and specific adaptations of HS635, HPW444, VL2028 (Table 9). Consistent performance of HPW446, HPW445, VL907, HPW441 wheat genotypes would be judged by minimum values of standard error. Higher values of Geometric Adaptability Index exhibited by HS631, HS632 VL2030, HPW447 wheat genotypes for better adaptability and specific adaptations by HS635, HPW444 &VL2028. PRVG and PRVG*GM measures expressed better adaptations of HS631, HS632, VL2030, HPW447 for locations of this zone. Analytic measures HMPRVG and HMPRVG*GM marked HS631, HS632, VL2030, VL2025 as of high yield and better adaptability as compared to HS635, VL2028 & HPW444 wheat genotypes. Analytic measures of adaptability PRVG, MHVG, MHPRVG, GAI and average yield had maintained an agreement

for the classification of wheat genotypes (Table 7). Differences among ranks of genotypes, as per various locations, observed by adaptability measures to highlight the presence of cross over interactions effects (Table 10). The ranking of genotypes through HMRPGV*GY was ideal and should be considered for the final recommendation of the best genotypes. This criterion of selection simultaneously considers stability, adaptability and grain yield of the genotypes grown in the experimental net environments.

Biplot Analysis

First two significant interaction principal components expressed 79.5 % of total G×E interaction sum of squares in biplot analysis (Fig. 5). HS636, UP2991, HPW445, HS507, HPW442, HS634, HPW443 and VL2029 wheat genotypes observed near to origin as compared to HS635, HPW447 and HS637 genotypes in biplot presentations. Malan and Almora location would be conducive for yield of genotypes vis-à-vis to Shimla, Wadura and Khudwani as positioned away from the origin. HPW446, VL907, HS632, VL2025, VL2030 had specific adaptations to Almora and Shimla while HPW447, UP2990, HS631, HS633, VL2026, VL2027 for Wadura, Malan, Bajura and Khudwani. Acute angles between rays of Almora with Shimla and Khudwani with Wadura and Malan with Bajura expressed similar performance of genotypes. More over Shimla had an obtuse angle with Wadura i.e. VL907, HPW446, VL2025, VL2030 would not be suitable for Wadura location. Analytic measure standard error along with average yield observed in other quadrant with respect to others adaptability measures as seen from Fig. 5.
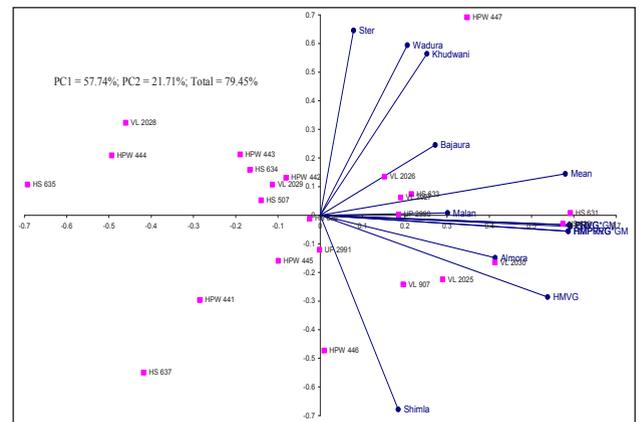

Fig. 5: Biplot analysis of genotypes *vis-à-vis* environments based on BLUE (2016-17)

Table 7: Adaptability measures of wheat genotypes as per BLUP(2016-17)

	Almora	Bajaura	Khudwani	Malan	Shimla	Wadura	Mean	Ster	GAI	PRVG	PRVG*GM	HMPRVG	HMPVRG*GM	HMVG
HS 631	35.76	44.98	29.17	29.44	19.54	30.83	31.62	3.76	30.67	1.08	31.55	1.08	31.45	29.69
HS 632	36.19	44.72	28.43	29.00	20.10	30.31	31.46	3.71	30.55	1.08	31.45	1.07	31.31	29.65
HS 633	33.85	38.21	30.22	23.70	16.67	31.75	29.07	3.45	28.08	0.99	28.93	0.98	28.75	26.97
HS 634	34.01	39.48	27.18	29.10	15.54	29.90	29.20	3.58	28.11	0.99	28.91	0.99	28.83	26.82
HS 635	29.90	38.22	26.33	20.08	16.18	29.31	26.67	3.49	25.68	0.91	26.53	0.90	26.20	24.66
HS 636	34.29	37.34	29.07	23.64	18.12	30.89	28.89	3.15	28.10	0.99	28.93	0.98	28.78	27.25
HS 637	32.85	35.86	20.81	27.48	22.82	25.22	27.50	2.61	27.00	0.96	28.17	0.93	27.32	26.52
HPW 441	33.88	30.45	24.96	31.53	18.67	28.23	27.95	2.44	27.45	0.97	28.37	0.96	28.02	26.89
HPW 442	34.83	36.27	30.32	25.81	15.78	31.89	29.15	3.36	28.15	0.99	28.98	0.99	28.85	26.94
HPW 443	29.32	36.86	29.22	31.56	14.11	31.33	28.73	3.44	27.58	0.97	28.51	0.96	28.15	26.09
HPW 444	30.37	38.53	27.20	26.25	14.31	30.03	27.78	3.53	26.66	0.94	27.45	0.93	27.31	25.32
HPW 445	31.67	36.81	27.68	25.64	18.66	29.96	28.41	2.73	27.81	0.98	28.60	0.98	28.53	27.17
HPW 446	36.27	34.08	24.80	26.06	23.00	27.75	28.66	2.38	28.26	1.00	29.34	0.98	28.76	27.89
HPW 447	37.61	39.15	35.37	29.97	12.29	35.41	31.63	4.46	29.65	1.06	30.93	1.02	29.89	26.86
VL 2025	35.30	37.92	26.19	33.62	19.83	28.91	30.29	2.98	29.62	1.04	30.55	1.04	30.30	28.89
VL 2026	32.80	42.17	28.23	30.59	16.52	30.49	30.13	3.69	29.06	1.02	29.90	1.02	29.79	27.82
VL 2027	35.84	33.66	30.13	33.03	16.18	31.74	30.10	3.17	29.17	1.03	30.09	1.02	29.84	27.99
VL 2028	26.93	36.08	29.60	28.60	12.88	31.68	27.63	3.53	26.36	0.93	27.33	0.92	26.81	24.71
VL 2029	32.29	36.88	28.85	28.27	15.63	30.97	28.81	3.20	27.88	0.98	28.67	0.98	28.61	26.74
VL 2030	36.07	39.29	27.43	32.09	19.72	29.71	30.72	3.08	30.01	1.06	30.88	1.05	30.76	29.24
UP 2990	35.62	36.97	29.81	28.22	17.37	31.43	29.90	3.13	29.08	1.02	29.88	1.02	29.86	28.10
UP 2991	34.84	35.50	27.76	28.55	17.94	30.07	29.11	2.84	28.44	1.00	29.22	1.00	29.19	27.66
VL 907	37.03	34.21	28.60	27.45	19.94	30.44	29.61	2.65	29.07	1.02	29.94	1.02	29.78	28.48
HS 507	35.24	36.82	28.60	24.24	16.99	30.69	28.76	3.28	27.88	0.98	28.68	0.98	28.58	26.88

Table 8: Ranks of wheat genotypes as per adaptability measures based on BLUP (2016-17)

	Almora	Bajaura	Khudwani	Malan	Shimla	Wadura	Mean	Ster	GAI	PRVG	PRVG*GM	HMPRVG	HMPVRG*GM	HMVG
HS 631	7	1	8	8	7	10	2	23	1	1	1	1	1	1
HS 632	4	2	13	10	3	14	3	22	2	2	2	2	2	2
HS 633	16	9	3	22	14	3	13	16	15	14	14	15	15	13
HS 634	14	4	19	9	20	18	10	20	13	15	15	12	12	18
HS 635	22	8	20	24	17	20	24	17	24	24	24	24	24	24
HS 636	13	11	9	23	10	9	14	10	14	13	13	13	13	11
HS 637	17	19	24	15	2	24	23	3	21	21	21	21	21	20
HPW 441	15	24	22	5	8	22	20	2	20	20	20	20	20	15
HPW 442	12	17	2	19	18	2	11	14	12	12	12	11	11	14
HPW 443	23	14	7	4	22	7	17	15	19	19	19	19	19	21
HPW 444	21	7	18	17	21	16	21	19	22	22	22	22	22	22
HPW 445	20	16	16	20	9	17	19	5	18	18	18	18	18	12
HPW 446	3	22	23	18	1	23	18	1	11	10	10	14	14	8
HPW 447	1	6	1	7	24	1	1	24	4	3	3	5	5	17
VL 2025	9	10	21	1	5	21	5	7	5	5	5	4	4	4

VL 2026	18	3	14	6	15	12	6	21	9	8	8	8	8	9
VL 2027	6	23	4	2	16	4	7	11	6	6	6	7	7	7
VL 2028	24	18	6	11	23	5	22	18	23	23	23	23	23	23
VL 2029	19	13	10	13	19	8	15	12	16	17	17	16	16	19
VL 2030	5	5	17	3	6	19	4	8	3	4	4	3	3	3
UP 2990	8	12	5	14	12	6	8	9	7	9	9	6	6	6
UP 2991	11	20	15	12	11	15	12	6	10	11	11	10	10	10
VL 907	2	21	12	16	4	13	9	4	8	7	7	9	9	5
HS 507	10	15	11	21	13	11	16	13	17	16	16	17	17	16

Table 9: Adaptability measures of wheat genotypes as per BLUE(2016-17)

	Almora	Bajaura	Khudwani	Malan	Shimla	Wadura	Mean	Ster	GAI	PRVG	PRVG*GM	HMPRVG	HMPVRG*GM	HMVG
HS 631	35.53	46.07	30.47	29.60	20.36	29.69	31.95	3.79	31.03	1.09	31.96	1.09	31.78	30.11
HS 632	36.17	45.80	28.64	29.11	20.89	30.42	31.84	3.76	30.94	1.09	31.88	1.08	31.68	30.08
HS 633	33.49	38.21	30.96	29.20	17.23	32.07	30.19	3.15	29.35	1.03	30.17	1.03	30.12	28.33
HS 634	35.00	39.91	25.59	29.29	13.75	29.70	28.87	4.00	27.45	0.97	28.33	0.96	28.04	25.72
HS 635	29.26	38.48	25.96	18.93	15.89	29.17	26.28	3.62	25.21	0.89	26.11	0.88	25.64	24.12
HS 636	33.97	37.23	29.53	22.95	18.93	31.49	29.02	3.08	28.27	1.00	29.16	0.99	28.90	27.48
HS 637	32.82	35.89	20.40	27.46	22.86	23.37	27.13	2.74	26.58	0.95	27.81	0.92	26.81	26.05
HPW 441	34.43	29.46	23.98	32.10	18.04	28.14	27.69	2.65	27.10	0.96	28.05	0.94	27.62	26.45
HPW 442	35.15	35.98	31.86	25.45	15.36	30.07	28.98	3.43	27.92	0.98	28.78	0.98	28.57	26.63
HPW 443	28.27	36.79	29.82	32.10	14.02	31.01	28.67	3.46	27.50	0.97	28.46	0.96	28.03	25.99
HPW 444	30.29	38.84	26.24	26.03	13.04	29.81	27.37	3.77	26.05	0.92	26.89	0.91	26.61	24.44
HPW 445	30.51	36.70	28.50	25.27	20.00	30.28	28.54	2.51	28.06	0.99	28.92	0.98	28.72	27.56
HPW 446	36.40	33.57	23.78	25.76	24.29	29.49	28.88	2.33	28.50	1.01	29.70	0.99	28.89	28.14
HPW 447	38.73	39.11	35.16	30.18	11.34	36.92	31.91	4.73	29.60	1.06	31.07	1.01	29.60	26.29
VL 2025	35.67	38.04	25.47	34.46	19.82	29.04	30.42	3.10	29.69	1.05	30.65	1.04	30.35	28.92
VL 2026	32.66	42.95	27.93	30.98	16.16	30.30	30.16	3.85	28.99	1.02	29.86	1.01	29.70	27.67
VL 2027	36.49	32.95	30.41	33.75	15.71	31.59	30.15	3.30	29.14	1.03	30.10	1.02	29.76	27.83
VL 2028	25.21	35.89	30.23	28.71	13.13	32.01	27.53	3.53	26.29	0.93	27.30	0.91	26.68	24.70
VL 2029	32.05	36.79	28.33	28.30	15.45	31.89	28.80	3.24	27.84	0.98	28.63	0.97	28.55	26.65
VL 2030	36.43	39.55	26.80	32.68	20.00	30.36	30.97	3.13	30.25	1.06	31.14	1.06	30.99	29.47
UP 2990	35.88	36.79	30.51	28.21	17.50	31.10	30.00	3.11	29.19	1.02	29.99	1.02	29.96	28.22
UP 2991	35.19	35.18	27.63	28.62	17.77	30.00	29.06	2.87	28.37	1.00	29.15	0.99	29.12	27.57
VL 907	37.35	33.57	29.42	27.32	20.71	30.32	29.78	2.53	29.30	1.03	30.22	1.02	29.97	28.79
HS 507	35.82	36.70	28.34	23.66	16.52	30.71	28.63	3.42	27.65	0.97	28.48	0.97	28.32	26.57

Table 10: Rank of wheat genotypes as per adaptability measures based on BLUE (2016-17)

	Almora	Bajaura	Khudwani	Malan	Shimla	Wadura	Mean	Ster	GAI	PRVG	PRVG*GM	HMPRVG	HMPVRG*GM	HMVG
HS 631	10	1	5	8	5	19	1	21	1	1	1	1	1	1
HS 632	6	2	11	11	3	10	3	19	2	2	2	2	2	2
HS 633	16	9	3	10	13	2	6	11	6	7	7	5	5	6
HS 634	13	4	20	9	21	18	15	23	19	19	19	18	18	21
HS 635	22	8	19	24	16	21	24	18	24	24	24	24	24	24

HS 636	15	11	9	23	9	6	12	7	13	12	12	12	12	13
HS 637	17	18	24	16	2	24	23	5	21	21	21	21	21	19
HPW 441	14	24	22	4	10	23	20	4	20	20	20	20	20	17
HPW 442	12	17	2	20	19	15	13	15	15	15	15	15	15	15
HPW 443	23	13	8	4	20	8	17	16	18	18	18	19	19	20
HPW 444	21	7	18	18	23	17	22	20	23	23	23	23	23	23
HPW 445	20	15	12	21	6	14	19	2	14	14	14	14	14	12
HPW 446	5	21	23	19	1	20	14	1	11	11	11	13	13	8
HPW 447	1	6	1	7	24	1	2	24	5	4	4	10	10	18
VL 2025	9	10	21	1	8	22	5	8	4	5	5	4	4	4
VL 2026	18	3	15	6	15	13	7	22	10	10	10	9	9	10
VL 2027	3	23	6	2	17	5	8	13	9	8	8	8	8	9
VL 2028	24	18	7	12	22	3	21	17	22	22	22	22	22	22
VL 2029	19	13	14	14	18	4	16	12	16	16	16	16	16	14
VL 2030	4	5	17	3	6	11	4	10	3	3	3	3	3	3
UP 2990	7	12	4	15	12	7	9	9	8	9	9	7	7	7
UP 2991	11	20	16	13	11	16	11	6	12	13	13	11	11	11
VL 907	2	21	10	17	4	12	10	3	7	6	6	6	6	5
HS 507	8	15	13	22	14	9	18	14	17	17	17	17	17	16

CONCLUSION

Classification of wheat genotypes as per their adaptability by analytic measures based on BLUP by exploiting REML procedure was more efficient than that by BLUE (Smith and Cullis 2018). Biplot analysis showed that more of G×E interactions sum of squares was explained by first two principal components as compared to accounted by BLUE. There was no overall difference between analytic measures as far as adaptability of genotypes is concerned either based on Harmonic or Geometric means as compared to usual mean yield of genotypes. Genotype classifications by BLUP/ REML were superior to that of by BLUE for both years, despite the presence of cross over genotype × environment interactions (Kleinknecht *et al.* 2011).

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