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**Research Article** *Natural Resource Management*

# Combining AMMI and Mean Yield of Wheat Genotypes Evaluated under Rainfed Conditions of Northern Hills Zone for Stability Analysis

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***Data Availability Statement:*** Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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## Abstract

Highly significant effects of environment (E), GxE interaction and genotypes (G) observed by AMMI analysis during 2018-19 and 2019-20 study years. WAASB measure ranked suitability of UP 3039, VL 2035 and VL 2036 genotypes. Superiority index while weighting 0.65 and 0.35 for yield and stability found VL 2036, HS 668 and UP 3039 as of stable performance with high yield. PRVG and MHPRVG measures observed suitability of HS 668, HS 562 and HS 669 wheat genotypes. More over the average yield of genotypes ranked HS 668, VL 2036 and HS 669 as of order of choice. Mostly indirect relations of SI measure were observed with stability measures along with positive values for MHPRVG, PRVG and yield. WAASB measure exhibited significant indirect relationships with other measures except of moderate positive with SI, yield, MHPRVG and PRVG measures. For the second year of study WAASB measure ranked suitability of HS676, UP3064 and HS677 genotypes. Superiority index while weighting 0.65 and 0.35 for yield and stability found VL2041, HS675 and HS562 as of stable performance with high yield. PRVG and MHPRVG measures observed suitability of VL2041, HS675 and HPW470 wheat genotypes. More over the average yield of genotypes ranked VL2041, HS675 and HS507 as of order of choice. Mostly negative values were exhibited by SI measure with stability measures apart of direct with MHPRVG, PRVG and yield. WAASB measure exhibited direct relationships with other stability measures except of indirect relations with SI, yield, MHPRVG and PRVG.

***Keywords:*** AMMI, ASV, SIPC, Za, EV, SI, SSI, Biplots

## 1. Introduction

Wide use of AMMI model, hybrid of additive and multiplicative components, to separates the additive variance from the multiplicative variance and application of principal component analysis (PCA) to the interaction portion (Gauch, 2013; Bocianowski et al., 2019; Verma et al., 2020). This analysis has been proved to be an effective process to captures a large portion of the GxE interaction sum of squares, thereby separating main and interaction effects (Jeberson et al., 2017; Ajay et al., 2019). Multi environment trials of all crops demand an efficient estimation of main and interaction effects (Bornhofen et al., 2017). More over biased interpretation regarding the stability of the genotypes had been also reported when low proportion of the variance explained by first interaction principal component IPCA1 under AMMI analysis (Ramburan et al., 2011; Zali et al., 2012; Oyekunle et al., 2017). Stability measure i.e. Weighted Average of Absolute scores (WAASB), recommended for

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identifying productive genotypes with broad adaptation (Olivoto, 2018). The most stable genotype possessed the lower value of WAASB measure i.e. deviates minimum from the mean performance across environments (Olivoto, 2019). The superiority index (WAASBY) for the selection of promising genotypes had been assisted by simultaneous use of yield and stability by allowing variable weighting mechanism (Olivoto et al., 2019). The prime objective of the present study was to validate the type of relationships between WAASBY and other stability measures, as per AMMI model, of wheat genotypes evaluated under multi environmental trials in the Northern Hills Zone of the country in the recent past. Northern hills zone of the India 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.

## 2. Materials and Methods

Sixteen advanced wheat genotypes at eight locations and sixteen genotypes at nine locations were evaluated under field trials at of northern hills zone during 2018-19 and 2019-20 cropping seasons respectively. Field trials were conducted at research centers in randomized complete block designs with four replications. Recommended agronomic practices were followed to harvest good yield. Details of genotype parentage along with environmental conditions were reflected in Tables 1 and 2 for ready reference.

Table 1 : Parentage details of genotypes and environmental conditions 18-19

| Code | Genotype | Parentage | Environments | Latitude | Longitude | Altitude |
|---|---|---|---|---|---|---|
| G1 | HPW 462 | (VL804/PBW498) | Dhaulakuan | 28°59 N | 77°16 E | 468 |
| G2 | HPW 466 | (PASTOR/HXL7573/2*BAU/3/SOKOLL/WBLL1) | Shimla | 31°10' N | 77°17'E | 2276 |
| G3 | VL 2038 | (CHINA84-400022/PBW599) | Malan | 32°08' N | 76°35'E | 846 |
| G4 | VL 2037 | (HS485/RAJ4174//HS485-5) | Bajaura | 31°50'N | 77°9'E | 1103.85 |
| G5 | HS 507 | (KAUZ/MYNA/VUL//BUC/FLK/4/MILAN) | Wadura | | | |
| G6 | UP 3038 | (AKAW4510/AVOCET) | Khudwani | 33° 70' N | 75°10' E | 1590 |
| G7 | VL 2035 | (PRL/2*PASTOR//PBW343*2/KUKUNA/3/ROLF07/4/ BERKUT//PBW343*2/KUKUNA | Almora | 29° 35' N | 79° 39'E | 1610 |
| G8 | HS 667 | (HPW251/FLW3//HS431) | Ranichauri | 28° 43' N | 81°02' E | 2200 |
| G9 | HS 668 | (VL906/FLW13) | | | | |
| G10 | HS 669 | (VL907/VL876) | | | | |
| G11 | UP 3039 | (HUW640/LBPY06-15(SERI/DUCULA/PBW343) | | | | |
| G12 | HS 562 | (OASIS/SKUAZ//4*BCN/3/2*PASTOR) | | | | |
| G13 | VL 2036 | (SW89.5277/BORL95//SKAUZ/3/PRL/2*PASTOR/4/ HEILO/5/WHEAR/SOKOLL) | | | | |
| G14 | HPW 464 | (Raj 3765/WR 251//HW 2045/PBW 493) | | | | |
| G15 | HPW 463 | (HPW155/HW4024 (P6) | | | | |
| G16 | HD 3340 | (DPW621-50/DW1293//DW1285) | | | | |

Stability measure Weighted Average of Absolute Scores has been calculated as

$$WAASB = \sum_{k=1}^{p} |IPCA_{ik} \times EP_k| / \sum_{k=1}^{p} EP_k$$

where $WAASB_i$ is the weighted average of absolute scores of the *i*th genotype (or environment); $IPCA_{ik}$ is the score of the *i*th genotype (or environment) in the *k*th IPCA, and $EP_k$ is the amount of the variance explained by the *k*th IPCA. Superiority index allows weighting between yield and stability measure (WAASB) to select genotypes that combine high performance and stability as $SI = (rG_i \times \theta_Y)+(rW_i \times \theta_S)/(\theta_Y+\theta_S)$; where $rG_i$ and $rW_i$ are the rescaled values for yield and WAASB, respectively, for the *i*th genotype; $G_i$ and $W_i$ are the yield and the WAASB values for *i*th genotype. SI superiority index for the *i*th genotype that weights between yield and stability, and $\theta_Y$ and $\theta_S$ are the weights for yield and stability assumed to be of order 65 and 35 respectively in this study. AMMI based measures were mentioned in Table 3.

AMMI analysis was performed using AMMISOFT version 1.0, available at https://scs.cals.cornell.edu/people/ hugh-gauch/ and SAS software version 9.3. Stability measures had been compared with recent analytic measures of adaptability calculated as the relative performance of genetic values (PRVG) and harmonic mean based measure of the relative performance of the genotypic values (MHPRVG) for the simultaneous analysis of stability, adaptability and yield

Table 2: Parentage details of genotypes and environmental conditions19-20

| Code | Genotype | Parentage | Environments | Latitude | Longitude | Altitude |
|---|---|---|---|---|---|---|
| G1 | HS507 | (KAUZ/MYNA/VUL//BUC/FLK/4/MILAN) | Dhaulakuan | 28°59 N | 77°16 E | 468 |
| G2 | SKW356 | (SEL-VL968) | Shimla | 31°10 ' N | 77°17'E | 2276 |
| G3 | VL2042 | (TX71A983.4/TX69D4812//PYN/3/VPM/MOS83.11.4-8//PEW/HSB3177(Yr15+Yr24)/6*Avocet//2*BAXTER/FLW13 | Malan | 32°08 ' N | 76°35'E | 846 |
| G4 | HPW471 | (HPW236/VL900) | Bajaura | 31°50’N | 77°9'E | 1103.85 |
| G5 | HS675 | (HS240*2FLW20//HS240*2/FLW13) | Wadura | 21° 18' N | 77° 41' E | 508 |
| G6 | HPW472 | (HPW155/HD29) | Khudwani | 33° 70' N | 75°10' E | 1590 |
| G7 | VL2039 | (RL6043/4*NAC//PASTOR/3/BABAX/VL892) | Almora | 29° 35 ' N | 79° 39 'E | 1610 |
| G8 | HS677 | (ID8900994W/VEE/3/CHEN/AES/HD2932) | Ranichauri | 28° 43' N | 81°02' E | 2200 |
| G9 | HS676 | (VL907/DL460) | Umiam | | | |
| G10 | UP3064 | (RAJ3765/HD3121) | | | | |
| G11 | HS678 | (VL907/HD2997) | | | | |
| G12 | HS562 | (OASIS/SKUAZ//4*BCN/3/2*PASTOR) | | | | |
| G13 | HPW470 | (NAC/TH.AC//3*MIRLO/BUC/4PASTOR) | | | | |
| G14 | HPW469 | (HPW89/VL867) | | | | |
| G15 | VL2041 | (NESSER/SAULSKU32/MACS6240//HS507) | | | | |
| G16 | VL2040 | (17thDSBWYT99(SERI.1B//KAUZ/HEVO/3/AMAD/4/PYN/BAU//MILAN/5/ OPATA/ RAYON//KAUZ) | | | | |

Table 3: Stability measures as per AMMI model

| | | |
|---|---|---|
| Zobel, 1998 | Averages of the squared eigenvector values | $EV=\sum_{n=1}^{N}\lambda_{in}^{2}/n$ |
| Sneller et al., 1997 | Sums of the absolute value of the IPC scores | $SIPC=\sum_{n=1}^{N}\lambda_{n}^{0.5}\gamma_{in}$ |
| Purchase, 2000 | AMMI stability Value | $ASV=[(\frac{SSIPC\,1}{SSIPC\,2}PCI)^2+PC2)^2]^{1/2}$ |
| Rao and Prabhakaran, 2005 | AMMI based stability parameter | $ASTAB=\sum_{n=1}^{n}\lambda_n\gamma_{ni}^{2}$ |
| Zali et al., 2012 | ASV1 | $ASV1=[(\frac{SSIPC\,1}{SSIPC\,2}PCI)^2+PC2)^2]^{1/2}$ |
| Zali et al., 2012 | Modified AMMI stability Value | $MASV=\sqrt{(\sum_{n-1}^{N-1}\frac{SSIPC_n}{SSIPC_{n+1}}PC_n)^2+PC_{n+1})^2}$ |
| Zali et al., 2012 | Absolute value of the relative contribution of IPCs to the interaction | $Z_a=\sum_{n=1}^{N}\lvert\lambda_n\gamma_{in}$ |
| Ajay et al., 2019 | MASV1 | $MASV1=\sqrt{(\sum_{n-1}^{N-1}\frac{SSIPC_n}{SSIPC_{n+1}}PC_n)^2+PC_{n+1})^2}$ |
| Resende and Durate, 2007 | Relative performance of genotypic values across environments | $PRVG_{ij}=VG_{ij}/VG_i$ |
| Resende and Durate, 2007 | Harmonic mean of Relative performance of genotypic values | MHPRVGi.= Number of environment / $\sum_{j=1}^{k}\frac{1}{PRVG_{ij}}$ |
| Olivato et al., 2019 | Superiority Index | $SI=\frac{(rG_i\times\theta_Y)+(rW_i\times\theta_S)}{(\theta_Y+\theta_S)}$ |

(Resende and Durate, 2007).

## 3. Results and Discussion

### 3.1. First year of study (2018-19)

#### 3.1.1. AMMI analysis of MET

The AMMI model is comprised of additive main effects of genotype and environment, and the multiplicative effect of GxE interaction, and thus can explain more information compared to other methods (Gauch, 2013). AMMI analysis as such does not make provision for a quantitative stability measure that is deemed useful to quantify the ranking of studied genotypes according to their yield stability. AMMI stability parameters permit to evaluate yield stability after reduction of the noise from the GxE interaction effects (Zhang et al., 1998). Highly significant effects of environment (E), GxE interaction and genotypes (G) had been observed by AMMI analysis. Environment explained about significantly 53% of the total sum of squares due to treatments indicating that diverse environments caused most of the variations in genotypes yield (Table 4). Significant proportion of GxE interaction deserves the stability estimation of genotypes over environments (Veenstra et al., 2019). Genotypes explained only 5.4% of total sum of squares, whereas GxE interaction accounted for 30.5% of treatment variations in yield. More of GxE interaction sum of squares as compared to genotypes indicated the presence of genotypic differences across environments and complex GxE interaction for wheat yield. Partitioning of GxE interaction revealed that the first six multiplicative terms (IPCA1, IPCA2, IPCA3, IPCA4, IPCA5 and IPCA6) of AMMI were significant and explained 38.4%, 22.5%, 17.4%, 9.8%, 6.4% and 4.2% of interaction sum of squares, respectively. Total of significant components were 98.8% and remaining 1.2% was the residual or noise that discarded (Adjebeng et al., 2017).

Table 4: AMMI analysis of wheat genotypes evaluated under MET (2018-19)

| Source | Degree of freedom | Mean Sum of Squares | Level of significance | Proportional contribution of factors | GxE interaction Sum of Squares (% ) | Cumulative Sum of Squares (% ) by IPCA's |
|---|---|---|---|---|---|---|
| Treatments | 127 | 242.41 | *** | 88.87 | | |
| Genotype (G) | 15 | 124.66 | *** | 5.40 | | |
| Environment ( E ) | 7 | 2623.83 | *** | 53.02 | | |
| GxE interaction | 105 | 100.47 | *** | 30.45 | | |
| IPC1 | 21 | 192.74 | *** | | 38.37 | 38.37 |
| IPC2 | 19 | 125.04 | *** | | 22.52 | 60.89 |
| IPC3 | 17 | 108.06 | *** | | 17.41 | 78.30 |
| IPC4 | 15 | 69.20 | *** | | 9.84 | 88.14 |
| IPC5 | 13 | 51.74 | *** | | 6.38 | 94.51 |
| IPC6 | 11 | 40.62 | *** | | 4.24 | 98.75 |
| Residual | 9 | 14.67 | 0.16 | | | |
| Error | 384 | 10.05 | | | | |
| Total | 511 | 67.80 | | | | |

#### 3.1.2. Stability measures of yield

Least value of absolute IPCA1 expressed by G13, G11, G9 and higher value achieved by G3 (Table 5). Low values of (EV) associated with stable genotype accordingly, the genotype G7 followed by G11, G16 and maximum value by genotype G4. Measure SIPC identified G11 followed by G7, G13 as the stable genotypes, whereas G2 would be of least stable behaviour. Za measure considered absolute value of the relative contribution of IPCs to the interaction revealed G11, G7 and G13 as genotypes with descending order of stability, whereas G2 genotype with the least stability. ASTAB measure observed genotypes G7 G11 and G9 as stable and G5 was least stable in this study (Rao and Prabhakaran, 2005). ASV measure showed that genotypes G11, G13 G7 possessed lower values would express stable performance and G3 be of least stable type. Values of ASV1 selected G11, G13, G7 for their stable behaviour whereas G3 would express unstable performance. Measures MASV and MASV1 consider all significant IPCAs. Values of MASV showed that the genotypes G7, G11 and G16 were most stable and G7, G11 and G9 would be stable by MASV1measure respectively (Ajay et al., 2019). The lower values of WAASB associated with stable nature of genotypes as G7, G13 G9 for considered locations of the zone at the same time maximum value obtained by G15, that is, the one that deviates maximum from the average performance across environments. MHPRVG identified G7, G6, G2 and PRVG measures G7, G6, G8 and G15 of least stable yield. Maximum average yield expressed by G15 followed by G5 and G1 as moderate yield variation observed from 22.5 to 31.2 q ha$^{-1}$ among genotypes.

Table 5: Measures of stability for wheat genotypes as per AMMI analysis (2018-19)

| Genotype | IPCA1 | MASV1 | MASV | ASV1 | ASV | Za | EV | SIPC | ASTAB | WAASB | SI | MHPRVG | PRVG | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G1 | 2.03 | 5.28 | 4.27 | 3.46 | 2.66 | 17.40 | 0.031 | 5.98 | 58.79 | 1.212 | 21.65 | 0.914 | 0.944 | 29.92 |
| G2 | 1.35 | 5.56 | 4.76 | 2.81 | 2.39 | 18.90 | 0.040 | 6.79 | 63.63 | 1.282 | 34.32 | 0.944 | 0.977 | 31.43 |
| G3 | 2.51 | 5.37 | 4.36 | 4.33 | 3.35 | 17.73 | 0.038 | 6.05 | 69.47 | 1.255 | 54.50 | 1.004 | 1.033 | 33.31 |
| G4 | 0.38 | 5.45 | 4.82 | 1.34 | 1.27 | 14.32 | 0.060 | 6.53 | 54.58 | 0.864 | 69.12 | 1.020 | 1.043 | 33.26 |
| G5 | 1.25 | 5.25 | 4.72 | 3.51 | 3.23 | 17.09 | 0.037 | 5.75 | 72.03 | 1.198 | 29.99 | 0.905 | 0.955 | 30.68 |
| G6 | 0.91 | 5.25 | 4.45 | 2.03 | 1.77 | 17.47 | 0.034 | 6.54 | 52.97 | 1.158 | 44.69 | 0.987 | 1.009 | 31.98 |
| G7 | 0.48 | 2.37 | 2.07 | 1.02 | 0.87 | 8.37 | 0.012 | 3.39 | 12.55 | 0.540 | 77.82 | 1.033 | 1.039 | 32.89 |
| G8 | 1.66 | 4.63 | 3.99 | 3.50 | 2.99 | 16.23 | 0.025 | 5.13 | 55.30 | 1.168 | 32.65 | 0.927 | 0.962 | 30.83 |
| G9 | 0.33 | 3.61 | 3.20 | 1.13 | 1.07 | 12.17 | 0.030 | 5.26 | 29.19 | 0.754 | 86.70 | 1.085 | 1.102 | 34.57 |
| G10 | 1.09 | 4.69 | 3.98 | 1.97 | 1.56 | 15.56 | 0.045 | 6.04 | 50.21 | 1.023 | 70.68 | 1.048 | 1.064 | 34.02 |
| G11 | 0.05 | 2.61 | 2.26 | 0.29 | 0.29 | 6.83 | 0.014 | 3.08 | 13.90 | 0.408 | 77.95 | 1.002 | 1.008 | 32.41 |
| G12 | 1.14 | 3.91 | 3.31 | 2.04 | 1.62 | 11.97 | 0.021 | 4.37 | 30.62 | 0.813 | 77.32 | 1.051 | 1.065 | 33.87 |
| G13 | 0.03 | 5.06 | 4.18 | 0.30 | 0.30 | 9.57 | 0.029 | 3.84 | 42.95 | 0.602 | 86.99 | 1.029 | 1.050 | 34.03 |
| G14 | 1.29 | 4.65 | 3.99 | 2.78 | 2.39 | 16.68 | 0.026 | 5.75 | 48.01 | 1.153 | 9.16 | 0.851 | 0.883 | 28.47 |
| G15 | 2.20 | 5.74 | 4.73 | 3.80 | 2.94 | 18.87 | 0.041 | 6.48 | 71.55 | 1.317 | 27.82 | 0.944 | 0.982 | 30.92 |
| G16 | 2.23 | 4.06 | 3.19 | 3.85 | 2.98 | 13.47 | 0.017 | 4.03 | 44.49 | 1.000 | 12.20 | 0.849 | 0.884 | 28.19 |

*3.1.3. Ranking of genotypes as per AMMI measures and yield*

Stability alone is not a desirable selection criterion as stable genotypes may not be a high yielders, simultaneous use of yield and stability in a single measure is essential (Kang, 1993; Farshadfar, 2008). Simultaneous Selection Index also referred to as genotype stability index (GSI) or yield stability index (YSI) (Farshadfar et al., 2011) was computed by adding the ranks of stability measure and average yield of genotypes. Least ranks for IPCA1 measure exhibited by VL 2038, HS 669 and HS 562 were considered as stable with high yield, whereas high values suggested as least stable yield for UP 3039 genotype (Table 6). EV measure identified HS 669, VL 2037 and VL 2038 by whereas SPIC favoured HS 669, VL 2037 and VL 2038 genotypes. Genotypes VL 2038, HPW 466 and HS 669 possessed lower value of Za measure. WAASB measure ranked suitability of UP 3039, VL 2035 and VL 2036 genotypes. Superiority index while weighting 0.65 and 0.35 for yield and stability found VL 2036, HS 668 and UP 3039 as of stable performance with high yield. Composite measure MASV found VL 2037, VL 2036, VL 2038 and as per MASV1 ranks VL 2038, VL 2037, VL 2036 genotypes would be of choice for these locations of the zone. Values of least magnitude of ASV VL 2038 HS 668 HS 669 and ASV1 pointed towards VL 2038, HS 668 and HPW 463 wheat genotypes (Oyekunle et al., 2017). PRVG and MHPRVG measures observed suitability of HS 668, HS 562 and HS 669 wheat genotypes. More over the average yield of genotypes ranked HS 668, VL 2036 and HS 669 as of order of choice. In the present study, all measures identified genotypes VL 2038 HS 668 and HS 669 as stable and high yielders.

*3.1.4. Clustering pattern of measures*

Loadings of stability measures as per first two significant principal components were reflected in Table 7 and Figure 1. Graphical clustering considered two PCAs accounted as 86.3% of variation of the ranks of stability measures (Rad et al., 2013). Studied measures grouped into two major clusters. MASV1 clubbed with ASTAB, IPCA1, ASV, ASV1, SIPC, Za and MASV measures. Yield clubbed with SI, PRVG and MHPRVG measures. Measure EV, and WAASB maintained distance from stability measures and observed as outliers in different quadrants.

*3.1.5. Association analysis among measures*

Correlation values were computed for each pair of measures to have an idea about association analysis among measures. Average yield of genotypes expressed only significant positive correlations with SI, MHPRVG&PRVG (Table 8). Similar behaviours of MHPRVG&PRVG were observed with other measures. Mostly indirect relations of SI measure were observed with stability measures along with positive values for MHPRVG, PRVG and yield. WAASB measure exhibited significant indirect relationships with other measures except of moderate positive with SI, yield, MHPRVG and PRVG measures. AMMI based measures Za, SIPC, EV, SV, ASV1, MASV1, MASV and ASTAB expressed only positive correlation values among themselves and with others (Ajay et al., 2019). ASTAB had indirect relation with SI, PRVG, MHPRVG and yield..

Table 6: Simultaneous ranks of genotypes as per AMMI measures and mean yield (2018-19)

| Genotype | IPCA1 | MASV1 | MASV | ASV1 | ASV | Za | EV | SIPC | ASTAB | WAASB | SI | MHPRVG | PRVG | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HPW 462 | 18 | 19 | 21 | 20 | 20 | 19 | 22 | 21 | 19 | 13 | 14 | 13 | 14 | 14 |
| HPW 466 | 16 | 12 | 12 | 17 | 18 | 11 | 14 | 11 | 14 | 15 | 10 | 10 | 11 | 10 |
| VL 2038 | 6 | 9 | 11 | 6 | 6 | 8 | 10 | 10 | 8 | 14 | 8 | 7 | 7 | 5 |
| VL 2037 | 19 | 9 | 7 | 18 | 18 | 16 | 7 | 9 | 13 | 6 | 7 | 6 | 5 | 6 |
| HS 507 | 21 | 19 | 17 | 17 | 15 | 19 | 19 | 22 | 14 | 12 | 12 | 14 | 13 | 13 |
| UP 3038 | 20 | 16 | 14 | 19 | 18 | 13 | 16 | 11 | 17 | 10 | 9 | 9 | 8 | 9 |
| VL 2035 | 19 | 23 | 23 | 21 | 21 | 22 | 23 | 22 | 23 | 2 | 4 | 4 | 6 | 7 |
| HS 667 | 17 | 23 | 21 | 17 | 15 | 20 | 24 | 23 | 18 | 11 | 11 | 12 | 12 | 12 |
| HS 668 | 15 | 15 | 14 | 14 | 14 | 13 | 10 | 11 | 15 | 4 | 2 | 1 | 1 | 1 |
| HS 669 | 13 | 12 | 14 | 14 | 14 | 12 | 5 | 9 | 12 | 8 | 6 | 3 | 3 | 3 |
| UP 3039 | 23 | 23 | 23 | 24 | 24 | 24 | 23 | 24 | 23 | 1 | 3 | 8 | 9 | 8 |
| HS 562 | 13 | 17 | 16 | 13 | 14 | 17 | 17 | 16 | 17 | 5 | 5 | 2 | 2 | 4 |
| VL 2036 | 18 | 10 | 10 | 17 | 17 | 16 | 12 | 16 | 14 | 3 | 1 | 5 | 4 | 2 |
| HPW 464 | 22 | 25 | 25 | 23 | 22 | 22 | 26 | 23 | 25 | 9 | 16 | 15 | 16 | 15 |
| HPW 463 | 14 | 12 | 14 | 14 | 16 | 13 | 14 | 15 | 13 | 16 | 13 | 11 | 10 | 11 |
| HD 3340 | 18 | 28 | 30 | 18 | 20 | 27 | 30 | 29 | 27 | 7 | 15 | 16 | 15 | 16 |

Table 7: Loadings of stability measures as per first two PC's (2018-19)

| Measure | PC1 | PC2 |
|---|---|---|
| IPCA1 | 0.241 | -0.203 |
| MASV1 | 0.308 | -0.082 |
| MASV | 0.302 | -0.039 |
| ASV1 | 0.258 | -0.222 |
| ASV | 0.254 | -0.225 |
| Za | 0.301 | -0.184 |
| EV | 0.318 | 0.010 |
| SIPC | 0.307 | -0.039 |
| ASTAB | 0.304 | -0.181 |
| WAASB | -0.031 | 0.533 |
| SI | 0.190 | 0.431 |
| MHPRVG | 0.248 | 0.346 |
| PRVG | 0.267 | 0.318 |
| Yield | 0.278 | 0.303 |
| % variance | 62.79 | 23.49 |

Same pattern of negative correlations had displayed by IPCA1, ASV1, MASV1, ASV, MASV, EV, Za, SIPC also.

*3.2. Second year of study (2019-20)*

*3.2.1. AMMI analysis of MET*

Highly significant effects of environment (E), genotypes (G) and GxE interaction had been observed by AMMI analysis.

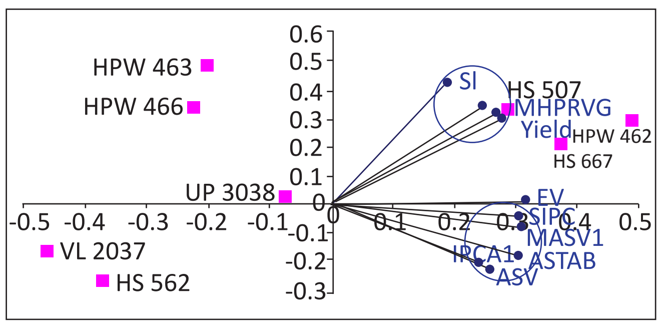


Figure 1: Biplot graphical analysis of stability measures for evaluated wheat genotypes under MET 18-19

Environment explained about significantly 48.7% of the total sum of squares due to treatments indicating that diverse environments caused most of the variations in genotypes yield (Table 9). Significant proportion of GxE interaction deserves the stability estimation of genotypes over environments (Veenstra et al., 2019). Genotypes explained only 7.8% of total sum of squares, whereas GxE interaction accounted for 31.4% of treatment variations in yield. Further division of GxE interaction revealed that the seven multiplicative terms (IPCA1, IPCA2, IPCA3, IPCA4, IPCA5 and IPCA7) explained 33.4%, 29.4%, 16.8%, 11%, 4.1% , 2.9% and 2.1 % of interaction sum of squares, respectively. Total of significant components were 99.8% and remaining was merely 0.2% thus discarded (Adjebeng et al., 2017).

*3.2.2. Stability measures of yield*

Least value of absolute IPCA1 expressed by G14, G10, G6 and higher value achieved by G4 (Table 10). Low values of (EV) associated with stable genotype accordingly G9 G10

Table 8: Association analysis of SI with other measures (2018-19)

| Measure | MASV1 | MASV | ASV1 | ASV | Za | EV | SIPC | ASTAB | WAASB | SI | MHPRVG | PRVG | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IPCA1 | 0.468 | 0.374 | 0.963 | 0.916 | 0.712 | 0.095 | 0.411 | 0.654 | 0.799 | -0.735 | -0.585 | -0.540 | -0.559 |
| MASV1 | | 0.986 | 0.539 | 0.556 | 0.836 | 0.771 | 0.831 | 0.936 | 0.792 | -0.458 | -0.305 | -0.212 | -0.187 |
| MASV | | | 0.480 | 0.518 | 0.825 | 0.818 | 0.857 | 0.923 | 0.767 | -0.417 | -0.268 | -0.170 | -0.145 |
| ASV1 | | | | 0.990 | 0.792 | 0.174 | 0.497 | 0.751 | 0.872 | -0.801 | -0.658 | -0.595 | -0.609 |
| ASV | | | | | 0.813 | 0.203 | 0.527 | 0.775 | 0.887 | -0.816 | -0.679 | -0.609 | -0.620 |
| Za | | | | | | 0.590 | 0.902 | 0.906 | 0.987 | -0.699 | -0.474 | -0.392 | -0.407 |
| EV | | | | | | | 0.824 | 0.682 | 0.476 | -0.035 | 0.126 | 0.207 | 0.215 |
| SIPC | | | | | | | | 0.808 | 0.821 | -0.416 | -0.171 | -0.093 | -0.114 |
| ASTAB | | | | | | | | | 0.898 | -0.604 | -0.447 | -0.345 | -0.326 |
| WAASB | | | | | | | | | | -0.768 | -0.560 | -0.481 | -0.494 |
| SI | | | | | | | | | | | 0.948 | 0.923 | 0.936 |
| MHPRVG | | | | | | | | | | | | 0.992 | 0.980 |
| PRVG | | | | | | | | | | | | | 0.989 |

Table 9: AMMI analysis of wheat genotypes evaluated under MET (2019-20)

| Source | Degree of freedom | Mean Sum of Squares | Level of significance | Proportional contribution of factors | GxE interaction Sum of Squares (% ) | Cumulative Sum of Squares (% ) by IPCA's |
|---|---|---|---|---|---|---|
| Treatments | 143 | 218.91 | *** | 87.87 | | |
| Genotype (G) | 15 | 185.53 | *** | 7.81 | | |
| Environment ( E ) | 8 | 2167.13 | *** | 48.66 | | |
| GxE interaction | 120 | 93.21 | *** | 31.39 | | |
| IPC1 | 22 | 169.69 | *** | | 33.38 | 33.38 |
| IPC2 | 20 | 164.26 | *** | | 29.37 | 62.75 |
| IPC3 | 18 | 104.59 | *** | | 16.83 | 79.58 |
| IPC4 | 16 | 77.15 | *** | | 11.04 | 90.62 |
| IPC5 | 14 | 33.00 | *** | | 4.13 | 94.75 |
| IPC6 | 12 | 27.24 | ** | | 2.92 | 97.67 |
| IPC7 | 10 | 23.61 | 0.10 | | 2.11 | 99.79 |
| Residual | 8 | 3.00 | 0.96 | | | |
| Error | 432 | 10.01 | | | | |
| Total | 575 | 61.96 | | | | |

followed by G14 and maximum value had by G13 genotype. SIPC measure identified G9 G10 followed by G11 for the lower value, whereas G13 would be of least stable behaviour. Za measure revealed G9 G10 and G8 genotypes in descending order of stability, whereas G1 genotype with the least stability. ASTAB measure observed genotypes G9, G10 and G16 as most stable and genotype G1 was least stable in this study (Rao and Prabhakaran, 2005). ASV measure showed that genotypes G9, G8, G10 possessed lower values would express stable performance and G3 be of least stable type. Values of ASV1 selected G9, G10, G8 for their stable behaviour whereas G3 would express unstable performance. G10, G9, G5 genotypes were of choice by of MASV and MASV1measure observed G10, G5, G2 as the stable genotypes while G13 would be unstable (Ajay et al., 2019). Lower value of Superiority index had observed for G14, G16 and G1 whereas large value by G13. Genotypes G16, G14and G1 were identified for their more stable yield performance by MHPRVG and PRVG measure settled for G14, G16, G1 along with least stable yield of G9. Maximum yield expressed by G9, G13 followed by G10 and good variation had been observed from 28.1 to 34.6 q $ha^{-1}$ among genotypes. Stable nature of G9, G10, G8 genotypes

Table 10: Measures of stability for wheat genotypes as per AMMI analysis (2019-20)

| Geno-type | IPCA1 | MASV1 | MASV | ASV1 | ASV | Za | EV | SIPC | ASTAB | WAASB | SI | MHPRVG | PRVG | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G1 | 2.62 | 8.86 | 6.25 | 4.57 | 3.46 | 21.03 | 0.050 | 7.76 | 108.38 | 1.459 | 56.44 | 1.024 | 1.080 | 30.10 |
| G2 | 2.15 | 5.51 | 3.76 | 3.76 | 2.85 | 12.42 | 0.031 | 5.35 | 48.50 | 0.856 | 50.05 | 0.901 | 0.940 | 26.64 |
| G3 | 2.46 | 8.83 | 5.28 | 4.72 | 3.80 | 20.04 | 0.033 | 6.93 | 84.22 | 1.457 | 32.52 | 0.921 | 0.969 | 26.88 |
| G4 | 2.55 | 6.32 | 4.31 | 4.57 | 3.53 | 17.16 | 0.029 | 6.11 | 67.31 | 1.239 | 61.01 | 1.051 | 1.076 | 29.76 |
| G5 | 0.90 | 4.69 | 3.81 | 2.15 | 1.89 | 14.88 | 0.030 | 5.85 | 41.57 | 1.018 | 71.16 | 1.080 | 1.104 | 30.17 |
| G6 | 0.50 | 5.61 | 4.30 | 2.38 | 2.31 | 13.87 | 0.025 | 5.22 | 48.86 | 0.971 | 32.99 | 0.866 | 0.896 | 24.85 |
| G7 | 0.85 | 10.77 | 5.83 | 2.89 | 2.72 | 19.12 | 0.036 | 7.19 | 72.92 | 1.330 | 4.13 | 0.756 | 0.803 | 22.52 |
| G8 | 0.72 | 7.66 | 4.33 | 1.27 | 0.97 | 10.50 | 0.028 | 4.83 | 38.60 | 0.665 | 50.67 | 0.911 | 0.928 | 25.90 |
| G9 | 0.29 | 8.60 | 3.14 | 0.69 | 0.60 | 5.99 | 0.012 | 3.18 | 9.02 | 0.370 | 67.14 | 0.970 | 0.973 | 26.84 |
| G10 | 0.08 | 3.72 | 2.77 | 1.01 | 1.01 | 8.51 | 0.021 | 4.20 | 19.18 | 0.539 | 61.37 | 0.960 | 0.968 | 26.79 |
| G11 | 0.80 | 8.29 | 5.25 | 1.43 | 1.10 | 12.63 | 0.026 | 4.92 | 51.48 | 0.852 | 56.82 | 0.970 | 0.995 | 27.53 |
| G12 | 0.83 | 12.25 | 5.21 | 1.80 | 1.53 | 13.68 | 0.027 | 5.75 | 37.27 | 0.920 | 69.12 | 1.049 | 1.071 | 29.47 |
| G13 | 1.39 | 16.20 | 6.71 | 2.78 | 2.28 | 18.94 | 0.051 | 8.04 | 65.50 | 1.266 | 59.47 | 1.057 | 1.082 | 29.67 |
| G14 | 0.06 | 6.73 | 4.57 | 1.39 | 1.38 | 13.68 | 0.024 | 5.51 | 44.80 | 0.908 | 55.90 | 0.978 | 0.994 | 27.65 |
| G15 | 0.63 | 6.75 | 4.88 | 1.86 | 1.72 | 13.52 | 0.047 | 5.94 | 51.09 | 0.904 | 82.85 | 1.120 | 1.141 | 31.24 |
| G16 | 0.72 | 14.94 | 5.60 | 1.85 | 1.66 | 12.57 | 0.029 | 5.54 | 32.48 | 0.840 | 56.74 | 0.963 | 0.980 | 27.47 |

identified by lower values WAASB for the considered locations of the zone whereas maximum deviation from the average performance across environments value expressed by G1. Superiority index had observed lower value expressed by G7, G3, G6 and large value by G15.

*3.2.3. Ranking of genotypes as per AMMI measures and yield*

Ranks for IPCA1 measure favoured VL2041, HPW469 & HS675 as per the least values, whereas large values of VL2039 SKW356 suggested unstable high yield (Table 11). EV measure settled for HPW469, HS676 and HPW471 wheat

Table 11: Simultaneous ranks of genotypes as per AMMI measures and mean yield (2019-20)

| Genotype | IPCA1 | MASV1 | MASV | ASV1 | ASV | Za | EV | SIPC | ASTAB | WAASB | SI | MHPRVG | PRVG | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HS507 | 19 | 15 | 18 | 17 | 17 | 19 | 18 | 18 | 19 | 16 | 10 | 6 | 4 | 3 |
| SKW356 | 26 | 16 | 16 | 26 | 26 | 17 | 24 | 19 | 21 | 6 | 13 | 14 | 13 | 13 |
| VL2042 | 24 | 21 | 22 | 26 | 26 | 25 | 22 | 23 | 25 | 15 | 15 | 12 | 11 | 10 |
| HPW471 | 19 | 9 | 10 | 19 | 19 | 16 | 12 | 16 | 17 | 12 | 6 | 4 | 5 | 4 |
| HS675 | 13 | 4 | 6 | 11 | 11 | 13 | 12 | 12 | 8 | 11 | 2 | 2 | 2 | 2 |
| HPW472 | 19 | 19 | 20 | 25 | 26 | 25 | 19 | 20 | 24 | 10 | 14 | 15 | 15 | 15 |
| VL2039 | 26 | 29 | 30 | 28 | 28 | 30 | 29 | 30 | 30 | 14 | 16 | 16 | 16 | 16 |
| HS677 | 20 | 22 | 21 | 17 | 16 | 17 | 21 | 17 | 19 | 3 | 12 | 13 | 14 | 14 |
| HS676 | 14 | 21 | 13 | 12 | 12 | 12 | 12 | 12 | 12 | 1 | 4 | 8 | 10 | 11 |
| UP3064 | 14 | 13 | 13 | 14 | 15 | 14 | 14 | 14 | 14 | 2 | 5 | 11 | 12 | 12 |
| HS678 | 16 | 17 | 19 | 13 | 12 | 14 | 13 | 12 | 19 | 5 | 8 | 9 | 7 | 8 |
| HS562 | 15 | 20 | 16 | 12 | 12 | 14 | 12 | 15 | 10 | 9 | 3 | 5 | 6 | 6 |
| HPW470 | 17 | 21 | 21 | 16 | 15 | 18 | 21 | 21 | 17 | 13 | 7 | 3 | 3 | 5 |
| HPW469 | 8 | 13 | 15 | 11 | 12 | 16 | 10 | 14 | 14 | 8 | 11 | 7 | 8 | 7 |
| VL2041 | 6 | 8 | 10 | 9 | 9 | 8 | 15 | 12 | 11 | 7 | 1 | 1 | 1 | 1 |
| VL2040 | 16 | 24 | 22 | 16 | 16 | 14 | 18 | 17 | 12 | 4 | 9 | 10 | 9 | 9 |

genotypes. Minimum ranks of SPIC favoured HS675, HS676 and VL2041 genotypes. Lower value of Za measure possessed by VL2041, HS676 and HS675 genotypes for stable higher yield as compared to others genotypes. Values of least magnitude of ASV and ASV1 pointed towards VL2041, HS675 and HS676 wheat genotypes (Oyekunle et al., 2017). Composite measure MASV selected HS675 VL2041 HPW471 while HS675 VL2041 HPW471 identified by MASV1 asgenotypes of choice for these locations of the zone. WAASB measure ranked suitability of HS676, UP3064 and HS677 genotypes. Superiority index while weighting 0.65 and 0.35 for yield and stability found VL2041, HS675 and HS562 as of stable performance with high yield. PRVG and MHPRVG measures observed suitability of VL2041, HS675 and HPW470 wheat genotypes. More over the average yield of genotypes ranked VL2041, HS675 and HS507 as of order of choice. In the present study, all measures identified genotypes VL2041, HS675 and HS562 as stable and high yielders.

*3.2.4. Clustering pattern of measures*

Biplot graphical analysis based on two significant principal component analysis (PCA) of the simultaneous ranks of measures (Figure 2). More over the loadings of the measures as per first two PC's were reflected in Table 12. Nearly 85.6% of variation of the ranks of stability measures accounted by two PCAs (Rad et al., 2013). Three major groups of stability measures depicted in Figure 2. Yield clubbed PRVG & MHPRVG measures. MASV1 grouped with SI and MASV. Larger group comprises of SIPC, Za, ASTAB ASV, IPCA1, ASV1. Measure

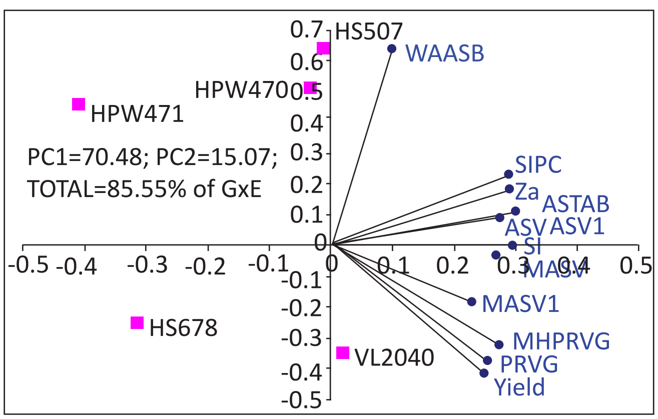


Figure 2: Biplot graphical analysis of stability measures of wheat genotypes evaluated under MET 19-20

Table 12: Loadings of stability measures as per first two PC's (2019-20)

| Measure | PC1 | PC2 |
|---|---|---|
| IPCA1 | 0.275 | 0.093 |
| MASV1 | 0.231 | -0.188 |
| MASV | 0.267 | -0.026 |
| ASV1 | 0.297 | 0.117 |
| ASV | 0.293 | 0.107 |
| Za | 0.290 | 0.190 |
| EV | 0.275 | 0.101 |
| SIPC | 0.286 | 0.226 |
| ASTAB | 0.294 | 0.111 |
| WAASB | 0.098 | 0.639 |
| SI | 0.292 | 0.004 |
| MHPRVG | 0.274 | -0.317 |
| PRVG | 0.255 | -0.380 |
| Yield | 0.249 | -0.409 |
| % variance | 70.48 | 15.07 |

WAASB maintained distance from other stability measures and observed as outliers in graphical analysis.

*3.2.5. Association analysis among measures*

All direct relations were displayed by yield with all considered stability measures. Though significant values of positive correlations observed with SI, MHPRVG and PRVG (Table 13). Same pattern of positive correlations were maintained by PRVG measure. Negative values of MHPRG with ASV, ASV1, ASTAB and WAASB only rest were direct relations had exhibited by MHPRVG. Mostly negative values were exhibited by SI measure with stability measures apart of direct with MHPRVG, PRVG &yield. WAASB measure exhibited direct relationships with other stability measures except of indirect relations with SI, yield, MHPRVG and PRVG. Stability measures considering AMMI analysis i.e. Za, SIPC, SV,ASV1, MASV1, MASV and ASTAB achieved only positive correlation values with others and among themselves (Ajay et al., 2019). Indirect relations of ASTAB had seen with SI, PRVG, MHPRVG and yield. Small positive correlation value of EZ with SI also observed. Negative correlations of ASV & ASV1 with SI and MHPRVG need mention yield were of low magnitude.

Table 13: Association analysis of SI with other measures (2019-20)

| Measure | MASV1 | MASV | ASV1 | ASV | Za | EV | SIPC | ASTAB | WAASB | SI | MHPRVG | PRVG | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IPCA1 | 0.070 | 0.359 | 0.945 | 0.878 | 0.680 | 0.488 | 0.597 | 0.764 | 0.711 | -0.144 | 0.096 | 0.220 | 0.265 |
| MASV1 | | 0.763 | 0.034 | 0.035 | 0.313 | 0.368 | 0.455 | 0.159 | 0.272 | -0.099 | 0.035 | 0.050 | 0.053 |
| MASV | | | 0.398 | 0.414 | 0.760 | 0.746 | 0.831 | 0.693 | 0.721 | -0.256 | 0.043 | 0.137 | 0.148 |
| ASV1 | | | | 0.986 | 0.803 | 0.522 | 0.700 | 0.840 | 0.838 | -0.331 | -0.037 | 0.098 | 0.136 |
| ASV | | | | | 0.838 | 0.527 | 0.732 | 0.842 | 0.874 | -0.412 | -0.097 | 0.038 | 0.069 |

Table 13: Continue...

| Measure | MASV1 | MASV | ASV1 | ASV | Za | EV | SIPC | ASTAB | WAASB | SI | MHPRVG | PRVG | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Za | | | | | | 0.743 | 0.957 | 0.932 | 0.996 | -0.397 | 0.009 | 0.146 | 0.157 |
| EV | | | | | | | 0.865 | 0.737 | 0.701 | 0.004 | 0.296 | 0.405 | 0.420 |
| SIPC | | | | | | | | 0.863 | 0.932 | -0.294 | 0.093 | 0.220 | 0.232 |
| ASTAB | | | | | | | | | 0.933 | -0.384 | -0.037 | 0.110 | 0.135 |
| WAASB | | | | | | | | | | -0.417 | -0.012 | 0.127 | 0.138 |
| SI | | | | | | | | | | | 0.905 | 0.845 | 0.843 |
| MHPRVG | | | | | | | | | | | | 0.988 | 0.979 |
| PRVG | | | | | | | | | | | | | 0.996 |

## 4. Conclusion

GxE interaction in multi-environment yield trials had been studied effectively by AMMI model. Recent stability measures use AMMI model and yield of genotypes simultaneous for more meaning interpretation as compared to measures consider either the AMMI or yield of genotypes only. Measures WAAB and SI would be effective to identify stable high-yielding genotypes.

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