AMMI Appended with BLUP to Assess the Superiority of Hullness Barley Genotypes Evaluated under Coordinated System of the Country

Ajay Verma1*, R. P. S. Verma1, J. Singh1, L. Kumar1 and G. P. Singh1

1ICAR-Indian Institute of Wheat and Barley Research, Karnal Haryana, India.

Authors’ contributions

This work was carried out in collaboration among all authors. Author AV performed the statistical analysis and wrote the draft of the manuscript. Author RPSV designed the study and corrected the manuscript. Authors JS and LK managed the research field data of the study. Author GPS managed the overall resources for successful completion of the study. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2021/v33i1030472
Editors:
(1) Dr. Yong In Kuk, Sunchon National University, South Korea.
(1) Mr. Habu Saleh Hamisu, National Horticultural Research Institute, Nigeria.
Reviewers:
(2) Jan Bocianowski, Poznań University of Life Sciences, Poland.
Complete Peer review History: http://www.sdiarticle4.com/review-history/68437

Received 10 March 2021
Accepted 17 May 2021
Published 20 May 2021

ABSTRACT

Highly significant effects of environments (E), G×E interaction and genotypes (G) had expressed by AMMI analysis for hulless barley genotypes under coordinated barley improvement program. Environment effects explained 69.9% and 59.7% whereas Interaction effects accounted for 17% and 20.9% during cropping seasons of 2018-19 and 2019-20, respectively. Stability measure WAASB based on all significant interaction principal components ranked suitability of DWRB204, K1149 genotypes. Superiority index while weighting 0.65 and 0.35 for mean yield & stability ranked DWRB204, Karan 16 as of stable performance with high yield barley genotypes. Ranks as per composite measures MASV1 and MASV found NDB943, KB1750 as desirable genotypes. Lower values ASTAB measure achieved by Karan 16, NDB943. Biplot graphical analysis as per 40.4% of variation of the measures exhibited MASV1 clubbed with ASTAB, EV, SIPC, Za, W6, WAASB and MASV measures. Measure IPCA1 clubbed with SI corresponding yield based. W2, W3, W4 measures observed in different group. For the second-year lower value of WAASB measure had observed for PL891, KB1843, NDB943. Ranking of genotypes as per Superiority index found Karan16, UPB1086 as of stable performance with high yield. MASV1 and MASV identified Karan16, DWRB216 genotypes of choice for these locations. Barley genotypes Karan16,
DWRB216 were selected as per values of ASTAB measure accounted AMMI analysis with BLUP of genotypes yield values. About 78.1% of variation of the measures under biplot analysis observed MASV1 grouped with ASTAB, EV, SIPC, and MASV. While Za joined together with W2, W3, W4, W5, W6, WAAASB to form separate group.

Keywords: AMMI; MASV; ASTAB; WAAASB; SSI.

1. INTRODUCTION

Hulless barley (Hordeum vulgare var. nudum L.) contains loose husk cover may be separated from the caryopsis during the process of threshing [1]. Earlier cultivated in the high-altitude Himalaya areas to supplement the food of tribal people [2]. Grains possess the ample quantity of β-glucan and therapeutic uses of β-glucan to lower the sugar level of diabetic patients and helps to reduce the serum cholesterol of heart patients received much attention [3]. Good number of statistical measures has been developed to estimate G×E interactions under multi-location trials [4]. Still AMMI analysis had been widely utilized as analysis retained most of the G×E pattern in the first interaction principal component axis (IPCA), while most of the random error had been explained by the last IPCAs [5]. BLUP proved the potential to improve the predictive accuracy of random effects [6]. BLUP and AMMI, two distinct approaches, utilized to distinguish the pattern from the random error components in G×E interactions. Taking into account the importance of AMMI and BLUP, the benefits of these two important techniques incorporated into a measure Superiority Index for stability and adaptability of genotypes [7]. The performance of Superiority measures had been compared with AMMI based measures for hulless barley genotypes evaluated under the coordinated barley improvement program of the country.

2. MATERIALS AND METHODS

Nine genotypes at thirteen locations and ten genotypes at fourteen locations were evaluated under research field trials 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.

Stability measure Weighted Average of Absolute Scores has been calculated as

\[ \text{WAASB} = \frac{\sum_{k=1}^{P} |\text{IPCA}_{ik} \times \text{EP}_{k}| / \sum_{k=1}^{P} \text{EP}_{k} \] where WAASB, 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 \( \text{EP}_{k} \) 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 \( \text{SI} = \frac{(rG_i \times \theta_G) + (rW_i \times \theta_W)}{\theta_G + \theta_W} \); where \( rG_i \) and \( rW_i \) are the rescaled values for yield and WAASB, respectively, for the \( i \)th genotype; \( \theta_G \) and \( \theta_W \) 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 \( \theta_G \times \theta_W \) are the weights for yield and stability assumed to be of order 65 and 35 respectively in this study.

\[ \text{EV} = \sum_{n=1}^{N} \lambda_{in}^2 / n \]

\[ \text{SIPC} = \sum_{n=1}^{N} \lambda_{n}^{0.5} Y_{im} \]

\[ \text{ASTAB} = \sum_{i=1}^{n} \lambda_{n} Y_{ni}^2 \]

\[ \text{MASV} = \frac{\sum_{i=1}^{k} \text{SSIPC}_{	ext{MASV}} (P_{C_{i}})^2 + (P_{C_{v}})}{\sum_{i=1}^{k} \text{SSIPC}_{	ext{MASV}} \sum_{i=1}^{k} (P_{C_{i}})^2 + (P_{C_{v}})} \]

\[ \text{Za} = \sum_{i=1}^{N} |\lambda_{n} Y_{ni}| \]

\[ \text{MASV1} = \frac{\sum_{i=1}^{k} \text{SSIPC}_{	ext{MASV}} (P_{C_{i}})^2 + (P_{C_{v}})}{\sum_{i=1}^{k} \text{SSIPC}_{	ext{MASV}} \sum_{i=1}^{k} (P_{C_{i}})^2 + (P_{C_{v}})} \]

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.
3. RESULTS AND DISCUSSION

3.1 AMMI Analysis of Barley Genotypes

3.1.1 First year of study 2018-19

Highly significant effects of environment (E), G×E interaction and genotypes (G) had been observed AMMI analysis. Environment explained 69.9% of the total sum of squares due to treatments indicating that diverse environments caused most of the variations in yield of evaluated genotypes (Table 3). Significant proportion of G×E interaction deserves the stability estimation of genotypes over environments [4]. Genotypes explained only 2.8% of total sum of squares, whereas G×E interaction accounted for 17% of treatment variations in yield. More of G×E interaction sum of squares as compared to genotypes indicated the presence of genotypic differences across environments and complex G×E interaction for yield. Significant seven multiplicative terms of G×E interaction contributed about 28.2%, 23.9%, 17.5%, 11.2%, 8.5%, 5.9% and 3.9% of interaction sum of squares. Total of the components were to the tune of 99.1% and remaining 0.9% was the residual or noise that discarded [13].

3.1.2 Second year of study 2019-20

Highly significant effects of environment (E), G×E interaction and genotypes (G) had contributed 59.7%, 20.9% and 13.8%, respectively of the total sum of squares due to treatments indicated the diversity of environments caused most of the variations in yield of evaluated genotypes (Table 7). Seven multiplicative terms of G×E interaction explained significantly 33.4%, 24.3%, 12.6%, 10%, 8.3%, 5.9% and 3.1% of interaction sum of squares. Total 97.6% of significant components and residual was only 2.4% that discarded.

3.2 Ranking of Barley Genotypes as per AMMI Based Stability Measures

3.2.1 First year of study 2018-19

Least value of absolute IPCA1 expressed by PL891, DWRB188 and higher value achieved by DWRB206 (Table 4). Low values of (EV) associated with stable behaviour, the genotypes KB1757 followed by DWRB206 expressed lower values and maximum value possessed by K1149 genotype. Measure SIPC identified KB1757 followed by DWRB206 as of stable nature, whereas DWRB204 would be of least stable type. Za measure considered absolute value of the relative contribution of IPCs to the interaction revealed KB1757 and DWRB206 as genotypes with descending order of stability, whereas UPB1077, DWRB204 genotype with the least stability. ASTAB measure observed genotypes KB1757 and PL891 as stable and DWRB204 was least stable in this study [10]. All significant IPCAs had been considered by MASV1 and MASV measures. Values of MASV1 showed that the genotypes, KB1757 and DWRB206 were most stable and KB1757 and DWRB206 would be stable by MASV measure respectively [12]. Measure W1 favoured DWRB188 and NDB943 while as per W2, genotypes identified were DWRB188 and NDB943, while W3 favoured DWRB204 and DWRB188 whereas values of measure W4 settled for DWRB204 and KB1750. Genotypes DWRB204 and K1149 had pointed out by W5 and W6 measures. Finally lower values of WAASB associated with stable nature of DWRB204 and K1149 genotypes as for considered locations of the zone at the same time maximum deviation from the average performance across environments obtained by KB1757 (Oliveto et al. 2019), [7].

3.2.2 Second year of study 2019-20

Least value of absolute IPCA1 expressed by UPB1086, Karan16, DWRB217 and higher value achieved by PL891 (Table 8). Stable behaviour of the genotypes DWRB217 followed by DWRB204, Karan16 as per low values of EV and maximum value possessed by PL891 genotype. SIPC ranked DWRB216, followed by Karan16, KB1848 as of stable nature, whereas PL891, would be of least stable type. Za measure revealed the preferences for DWRB217, DWRB204, and Karan16 as genotypes with descending order of stability, whereas PL891 genotype with the least stability. ASTAB values ranked DWRB216, Karan16 and KB1848 as stable genotypes and PL891 was least stable in this study. MASV1 and MASV measures showed the desirability for genotypes, DWRB216, Karan16 and KB1848 as stable genotypes and PL891 was least stable in this study. MASV1 and MASV measures showed the desirability for genotypes, DWRB216, Karan16 and KB1848. W1 favoured PL891, KB1843 and K1149 while as per W2, identified genotypes were PL891, K1149 and KB1843, while W3 favoured PL891, NDB943 and K1149 whereas values of measure W4 settled for PL891, NDB943 and KB1843. Genotypes PL891, KB1843 and NDB943 had pointed out by W5 and W6 measures. Finally values of WAASB selected PL891, KB1843 and NDB943 genotypes as for considered locations of the zone at the same time maximum deviation from the average performance across environments obtained by DWRB216.
3.3 Superiority Indexes as per AMMI and BLUP: Barley Genotypes

3.3.1 First year of study 2018-19

Mean yield of genotypes based on BLUP values favoured DWRB204 and NDB943 where DWRB204 and NDB943 selected by Geometric adaptability index while Harmonic mean of genotypic values pointed for DWRB204 and NDB943 as suitable genotypes as far as considered locations are concerned (Table 5). 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 [14,15]. Simultaneous Selection Index also referred to as genotype stability index (GSI) or yield stability index (YSI) [16] was computed by adding the ranks of stability measure and mean yield of genotypes. Least ranks for IPCA1 measure exhibited by DWRB204 and DWRB188 were considered as stable with high yield, whereas high values suggested as least stable yield for DWRB206 genotype (Table 9). EV measure identified DWRB204 and KB1750 whereas SPIC favoured NDB943 and DWRB206 genotypes. Genotypes NDB943 and Karan16 possessed lower value of Za measure. ASTAB measure achieved the desirable lower values for Karan16 and NDB943. Composite measure MASV1 found NDB943 and KB1750 and as per MASV ranks NDB943 and KB1750 genotypes would be of choice for these locations of the zone.

Superiority index assigned 0.65 and 0.35 weights for average yield and stability found DWRB204 and Karan16 as of stable performance with high yield. Least magnitude of Sigm ranked DWRB204 and Karan16 as desirable genotypes while values of SLhm measure favoured DWRB204 and Karan16 barley genotypes.

3.3.2 Second year of study 2019-20

Average yield as per BLUP values of genotypes favoured UPB1086 and Karan16 where Geometric adaptability index pointed for UPB1086 and Karan16 selected by while Harmonic mean of genotypic values pointed for UPB1086 and Karan16 as suitable genotypes as far as considered locations. Least ranks for Simultaneous Selection Index for IPCA1 measure exhibited by UPB1086 and Karan16 were considered as stable with high yield, whereas high values suggested as least stable yield for PL891 and DWRB206 genotype (Table 7). EV measure identified Karan16 and DWRB216 whereas SPIC favoured UPB1086 and Karan16. Genotypes Karan16 and UPB1086 possessed lower value of Za measure. Desirable lower values ASTAB measure achieved by Karan16 and DWRB216. Ranks of composite measure MASV1 and MASV found Karan16, DWRB216 genotypes would be of choice for these locations.

Superiority index with assigned weights for yield and stability found Karan16 and UPB1086 as of stable performance with high yield. Least magnitude of Sigm ranked Karan16 and UPB1086 as desirable genotypes while values of SLhm measure favoured Karan16 and DWRB204 barley genotypes.

3.4 Biplot Graphical Analysis

3.4.1 First year of study 2018-19

Biplot graphical analysis considered two significant PCAs as for 40.4 % of variation of the measures had been accounted [17]. Loadings of studied measures as per first two significant principal components were reflected in Table 9. Stability measures of barley genotypes grouped into three major clusters. MASV1 clubbed with ASTAB, EV, SIPC, Za, W6, WAA SB and MASV measures. Measure IPCA1 clubbed with SI corresponding to yield based measures. W2, W3 and W4 measures observed in different group. Angles among the measures depict the degree of association as acute angles depict strong relationships for W2, W3 and W4. Right angles between group of AMMI based and Superiority index measures show no relationship.

3.4.2 Second year of study 2019-20

Loadings of stability, adaptability measures as per first two significant principal components were reflected in Table 10. Biplot graphical analysis based two significant PCAs accounted for 78.1% of variation of the studied measures observed three clusters of stability measures of barley genotypes. MASV1 grouped with ASTAB, EV, SIPC and MASV measures. Za measure joined with W2, W3, W4, W5, W6 and WAA SB. Average yield clustered with superiority indexes as per GAI and HMGV. Measures W1 and IPCA1 observed as outliers. Angles among the measures depict the degree of association as acute angles depict strong relationships for W2, W3, W4, W5 and Za measures. Right angles between group of AMMI based and Superiority index measures show no relationship.
Table 1. Parentage details of barley genotypes and locations of the country 2018-19

| Code | Genotype | Parentage | Code | Location | Latitude | Longitude | Altitude |
|------|----------|-----------|------|----------|----------|-----------|----------|
| G1   | DWRB188  | PENCO/CHEVRON-BAR/3/LEGACY//PENCO/CHEVRON-BAR | E1   | Gwalior  | 26° 13' N | 78° 10' E | 213      |
| G2   | DWRB206  | ZIGZIG/4/TOCTE//HIGO/LINO/3/PETUNIA1 | E2   | Hisar    | 29° 10' N | 75° 46' E | 229      |
| G3   | DWRB204  | ALELI/4/Egypt/7/TERAN78//P.STO/3/QUINA | E3   | Durgapur  | 26°51'N   | 75° 47' E | 390      |
| G4   | K1149    | K12/K572-10/EB410 | E4   | Faizabad  | 26°46' N  | 82° 9' E  | 97       |
| G5   | KB1750   |Sel. INBYT-HI-11 (2016-17) | E5   | Varanasi  | 25° 19' N  | 82° 59' E | 81       |
| G6   | KB1757   | CHAMICO/TOCTE//CONGONA/3/PETUNIA2/4/PENCO/CHEVRON-BAR | E6   | Morena    | 26° 30' N  | 78° 00' E | 177      |
| G7   | NDB943   | K 1178/Karan 748 | E7   | Udaipur   | 29° 02'N  | 79° 48' E | 243.8    |
| G8   | PL891    | IBON 343/12th HSBN-176 | E8   | Vijapur   | 23°33' N  | 72° 45' E | 129.4    |
| G9   | Karan 16 | AZAM (DWARF)1/EB7576 | E9   | Pantnagar  | 29° 02'N  | 79° 48' E | 243.8    |
| G10  | DWRB217  | PETUNIA2/M112 | E10  | Ludhiana  | 30° 54' N  | 75° 48' E | 247      |
| G11  | K1149    | K12/K572-10/EB410 | E11  | Kanpur    | 26° 26' N  | 80° 19' E | 126      |
| G12  | NDB943   | K 1178/Karan 748 | E12  | Sabour    | 25°23' N   | 87°04' E  | 46       |
| G13  | PL891    | IBON 343/12th HSBN-176 | E13  | Kamal     | 29° 43' N  | 70° 58' E | 245      |

Table 2. Parentage details of barley genotypes and locations of the country 2019-20

| Code | Genotype | Parentage | Code | Location | Latitude | Longitude | Altitude |
|------|----------|-----------|------|----------|----------|-----------|----------|
| G1   | UPB1086  | MSEL//LIMON/BICHY2000 | E1   | Durgapur  | 26° 51'N  | 75° 47' E | 390      |
| G2   | DWRB204  | ALELI/4/Egypt/7/TERAN78//P.STO/3/QUINA | E2   | Faizabad  | 26° 46' N  | 82° 9' E  | 97       |
| G3   | KB1843   | LACEY/9/MOLA//BERMEJO/5/CM67-B//RYE//CAM-B/3/ROW906.73/4//GLORIA-BAR//COME//LINO/7//P/7/PETUNIA1 | E3   | Gwalior   | 26° 13' N  | 78° 10' E | 213      |
| G4   | PL891    | IBON 343/12th HSBN-176 | E4   | HAU Hisar | 29° 10' N  | 75° 46' E | 229      |
| G5   | Karan16  | AZAM (DWARF)1/EB7576 | E5   | Jhansi    | 29° 10' N  | 75° 46' E | 229      |
| G6   | DWRB216  | BLLU/5/PETUNIA1/6/LEGACY//PENCO/CHEVRON-BAR | E6   | Kanpur    | 26° 26' N  | 80° 19' E | 126      |
| G7   | K1149    | K12/K572-10/EB410 | E7   | Karnal    | 29° 43' N  | 70° 58' E | 245      |
| G8   | KB1848   | ICNB93-369/IRAN(Kordistan) | E8   | Ludhiana  | 30° 54' N  | 75° 48' E | 247      |
| G9   | NDB943   | K 1178/Karan 748 | E9   | Modipuram | 29° 05' N  | 77° 70' E | 226      |
| G10  | DWRB217  | PETUNIA2/M112 | E10  | Pantnagar  | 29° 02'N  | 79° 48' E | 243.8    |
| G11  | K1149    | K12/K572-10/EB410 | E11  | Tikamgarh | 24° 45' N  | 78° 50' E | 349      |
| G12  | NDB943   | K 1178/Karan 748 | E12  | Udaipur   | 24° 34' N  | 73° 41' E | 585      |
| G13  | PL891    | IBON 343/12th HSBN-176 | E13  | Varanasi  | 25° 19' N  | 82° 59' E | 81       |
| G14  | K1149    | K12/K572-10/EB410 | E14  | Vijapur   | 23°33' N   | 72° 45' E | 129.4    |
Table 3. AMMI analysis and percentage contribution of significant interaction principal components (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            | 116               | 438.02              | ***                   | 89.74                                |                                   |                                        |
| Genotype (G)          | 8                 | 199.97              | ***                   | 2.83                                 |                                   |                                        |
| Environment (E)       | 12                | 3298.26             | ***                   | 69.90                                |                                   |                                        |
| GxE interactions      | 96                | 100.33              | ***                   | 17.01                                |                                   |                                        |
| IPC1                  | 19                | 142.89              | ***                   | 28.19                                | 28.19                             |                                        |
| IPC2                  | 17                | 135.86              | ***                   | 23.98                                | 52.17                             |                                        |
| IPC3                  | 15                | 112.65              | ***                   | 17.54                                | 69.71                             |                                        |
| IPC4                  | 13                | 82.73               | ***                   | 11.17                                | 80.88                             |                                        |
| IPC5                  | 11                | 74.13               | ***                   | 8.47                                 | 89.34                             |                                        |
| IPC6                  | 9                 | 63.18               | ***                   | 5.90                                 | 95.24                             |                                        |
| IPC7                  | 7                 | 52.91               | **                    | 3.85                                 | 99.09                             |                                        |
| Residual              | 5                 | 17.54               |                       |                                      |                                   |                                        |
| Error                 | 351               | 16.55               |                       |                                      |                                   |                                        |
| Total                 | 467               | 121.24              |                       |                                      |                                   |                                        |

Table 4. AMMI measures and Weighted average of absolute scores for barley genotypes 2018-19

| Genotype           | IPCA1 | EV  | SIPC | Za  | ASTAB | MASV1 | MASV  | W1   | W2   | W3   | W4   | W5   | W6   | WAAASB |
|--------------------|-------|-----|------|-----|-------|-------|-------|------|------|------|------|------|------|---------|
| DWRB188            | 0.760 | 0.059 | 8.209 | 20.601 | 101.292 | 6.657 | 6.001 | 0.7600 | 1.9953 | 1.6201 | 1.3682 | 1.3036 | 1.3222 | 1.2896 |
| DWRB206            | 2.593 | 0.056 | 7.552 | 18.024 | 82.194 | 4.860 | 4.481 | 2.5934 | 1.3770 | 1.0799 | 1.1352 | 1.1701 | 1.0625 | 1.1051 |
| DWRB204            | 1.920 | 0.059 | 9.179 | 23.499 | 104.163 | 6.883 | 5.940 | 1.9200 | 1.7125 | 1.9018 | 1.8915 | 1.7055 | 1.6358 | 1.5059 |
| K1149              | 0.840 | 0.062 | 9.094 | 22.391 | 94.253 | 6.756 | 6.034 | 0.8401 | 1.4715 | 1.5252 | 1.4429 | 1.5750 | 1.4656 | 1.3863 |
| KB1750             | 2.316 | 0.056 | 8.704 | 21.291 | 87.446 | 5.727 | 5.121 | 2.3157 | 1.4473 | 1.5215 | 1.5174 | 1.3334 | 1.3470 | 1.3217 |
| KB1757             | 1.627 | 0.027 | 5.318 | 13.679 | 52.546 | 4.680 | 4.091 | 1.6265 | 0.8621 | 1.2339 | 1.0381 | 0.9847 | 0.9330 | 0.8778 |
| NDB943             | 2.336 | 0.061 | 7.978 | 19.455 | 84.788 | 5.877 | 5.229 | 2.3359 | 1.7709 | 1.3400 | 1.1297 | 1.1449 | 1.2641 | 1.2045 |
| PL891              | 0.176 | 0.057 | 7.656 | 18.195 | 72.197 | 5.426 | 4.956 | 0.1764 | 1.1456 | 1.1511 | 1.2186 | 1.0728 | 1.0238 | 0.9194 |
| Karan 16           | 0.928 | 0.062 | 8.457 | 19.311 | 78.177 | 6.123 | 5.507 | 0.9281 | 0.5316 | 0.8437 | 1.0970 | 1.1989 | 1.1360 | 1.1302 |
**Table 5. Superiority index measures and corresponding ranking of genotypes 2018-19**

| Genotype  | IPCA1 | EV | SIPC | Za  | ASTAB | MASV1 | MASV | MEAN | RkSlam | RkGM | RkStlm | RkHM | RkSIam | RkSIgm | RkGM | RkStlm | RkHM | RkSIam | RkSIgm | RkGM | RkStlm | RkHM |
|-----------|-------|----|------|-----|-------|-------|------|------|--------|------|--------|------|--------|--------|------|--------|------|--------|--------|------|--------|------|
| DWRB188   | 7     | 11 | 10   | 11  | 13    | 12    | 13   | 36.01| 5      | 35.83| 5      | 30.90| 6      | 32.74  | 5    | 25.59  | 7    |
| DWRB206   | 16    | 9  | 9    | 9   | 11    | 9     | 9    | 34.33| 7      | 24.47| 8      | 33.24| 7      | 26.34  | 8    | 28.67  | 6    |
| DWRB204   | 7     | 6  | 10   | 10  | 10    | 9     | 8    | 39.19| 1      | 65.00| 1      | 37.77| 1      | 65.00  | 1    | 65.00  | 1    |
| K1149     | 11    | 17 | 16   | 15  | 17    | 17    | 34.21| 8      | 7.28  | 9    | 32.94  | 6    | 6.66   | 9      | 6.66 | 9      |
| KB1750    | 11    | 7  | 11   | 10  | 8     | 8     | 36.20| 4      | 36.54| 4    | 34.34  | 4    | 29.11  | 7      | 32.40| 6      | 19.04| 8      |
| KB1757    | 14    | 10 | 10   | 10  | 10    | 10    | 34.17| 9      | 35.00| 6    | 33.03  | 8    | 36.13  | 4      | 32.02| 8      | 38.58| 5      |
| NDB943    | 10    | 9  | 6    | 7   | 7     | 7     | 7    | 36.71| 2      | 49.71| 3      | 35.43| 2      | 50.22  | 3    | 34.05  | 2    | 48.48  | 3    |
| PL891     | 7     | 10 | 9    | 9   | 9     | 9     | 9    | 34.73| 6      | 30.37| 7      | 33.78| 6      | 34.32  | 5    | 32.89  | 4    | 38.78  | 4    |
| Karan 16  | 7     | 11 | 9    | 7   | 6     | 9     | 9    | 36.43| 3      | 50.14| 2      | 35.14| 3      | 50.56  | 2    | 34.02  | 3    | 52.17  | 2    |

*AMu, GMu, HMu = Arithmetic, Geometric, Harmonic Mean for BLUP values; SI au, SI gu, SI hu = Superiority index as per Arithmetic, Geometric, Harmonic Mean; RPGVu, MHRPGVu = Relative performance and Harmonic mean of Relative Performance as per BLUP of genotypes; Rk = Rank of genotypes*

**Table 6. Loadings of measures as per two Principal Components 2018-19**

| Measure | PC1     | PC2     |
|---------|---------|---------|
| IPCA1   | 0.0135  | -0.2131 |
| MASV1   | 0.2464  | 0.1348  |
| MASV    | 0.2444  | 0.1481  |
| Za      | 0.2685  | 0.1124  |
| EV      | 0.1924  | 0.1378  |
| SIPC    | 0.2485  | 0.1344  |
| ASTAB   | 0.2558  | 0.0762  |
| W1      | 0.0135  | -0.2131 |
| W2      | 0.1677  | 0.0067  |
| W3      | 0.2061  | -0.0105 |
| W4      | 0.2406  | -0.0014 |
| W5      | 0.2483  | 0.1091  |
| W6      | 0.2709  | 0.0538  |
| WAASB   | 0.2723  | 0.0850  |
| Gwallor | 0.0942  | -0.2925 |
| Hisar   | 0.0003  | -0.1948 |
| Durgapura | 0.0897  | -0.0604 |
Table 7. AMMI analysis and percentage contribution of significant interaction principal components (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              | 139               | 569.56              | ***                   | 94.42                                |                                   |                                         |
| Genotype (G)            | 9                 | 1284.74             | ***                   | 13.79                                |                                   |                                         |
| Environment (E)         | 13                | 3847.56             | ***                   | 59.65                                |                                   |                                         |
| GxE interactions        | 117               | 150.33              | ***                   | 20.98                                |                                   |                                         |
| IPC1                    | 21                | 279.92              | ***                   | 33.42                                | 33.42                             |                                         |
| IPC2                    | 19                | 224.55              | ***                   | 24.26                                | 57.68                             |                                         |
| IPC3                    | 17                | 130.33              | ***                   | 12.60                                | 70.28                             |                                         |
| IPC4                    | 15                | 117.60              | ***                   | 10.03                                | 80.31                             |                                         |
| IPC5                    | 13                | 112.55              | ***                   | 8.32                                 | 88.62                             |                                         |
| IPC6                    | 11                | 93.82               | ***                   | 5.87                                 | 94.49                             |                                         |
| IPC7                    | 9                 | 60.72               | ***                   | 3.11                                 | 97.60                             |                                         |
| Residual                | 12                | 35.21               | ***                   |                                      |                                   |                                         |
| Error                   | 420               | 11.14               |                       |                                      |                                   |                                         |
| Total                   | 559               | 150.00              |                       |                                      |                                   |                                         |
Table 8. AMMI measures and Weighted average of absolute scores of barley genotypes 2019-20

| Genotype | IPCA1 | EV  | SIPC | Za   | ASTAB | MASV1 | MASV | W1  | W2  | W3  | W4  | W5  | W6  | WAASB |
|----------|-------|-----|------|------|-------|-------|------|-----|-----|-----|-----|-----|-----|-------|
| UPB1086  | 0.122 | 0.052 | 7.922 | 17.415 | 149.665 | 9.402 | 7.473 | 0.1216 | 1.8309 | 1.5562 | 1.3462 | 1.2818 | 1.3085 | 1.2739 |
| DWRB204  | 0.590 | 0.062 | 9.592 | 18.170 | 117.906 | 6.987 | 6.393 | 0.5898 | 0.6000 | 0.9979 | 1.1789 | 1.3229 | 1.2603 | 1.2285 |
| KB1843   | 2.219 | 0.049 | 9.292 | 20.618 | 119.200 | 6.894 | 5.953 | 2.2191 | 1.8963 | 1.5366 | 1.6361 | 1.6444 | 1.6067 | 1.5290 |
| PL891    | 4.974 | 0.063 | 9.519 | 25.413 | 260.899 | 8.460 | 7.115 | 4.9745 | 3.6011 | 2.9546 | 2.5303 | 2.3825 | 2.2011 | 2.0724 |
| Karan16  | 0.497 | 0.040 | 7.253 | 13.607 | 65.927 | 5.042 | 4.600 | 0.4972 | 0.6659 | 0.8227 | 1.0291 | 0.9053 | 0.8907 | 0.9254 |
| DWRB216  | 0.653 | 0.026 | 6.595 | 13.089 | 47.994 | 4.658 | 4.034 | 0.6532 | 0.8812 | 0.8779 | 0.9912 | 0.8960 | 0.9114 | 0.9164 |
| K1149    | 1.640 | 0.047 | 7.998 | 17.668 | 98.423 | 6.360 | 5.266 | 1.6405 | 2.0075 | 1.7047 | 1.5139 | 1.3824 | 1.2799 | 1.3250 |
| KB1848   | 1.607 | 0.043 | 8.252 | 16.631 | 73.887 | 5.471 | 4.725 | 1.6068 | 1.2450 | 1.1114 | 1.0300 | 1.1307 | 1.1510 | 1.1732 |
| NDB943   | 1.446 | 0.058 | 9.680 | 20.317 | 132.201 | 7.446 | 6.586 | 1.4459 | 1.3790 | 1.7773 | 1.6765 | 1.5517 | 1.5476 | 1.4709 |
| DWRB217  | 0.515 | 0.061 | 9.407 | 17.209 | 96.921 | 7.217 | 6.202 | 0.5151 | 0.5202 | 0.7166 | 0.8518 | 1.0092 | 1.1389 | 1.1253 |

Table 9. Superiority index measures and corresponding ranking of genotypes 2019-20

| Genotype | IPCA1 | EV  | SIPC | Za   | ASTAB | MASV1 | MASV | Mean | R_g | GM  | R_g | HM  | R_g | Slam | R_g | Slgm | R_g | Slhm | R_g |
|----------|-------|-----|------|------|-------|-------|------|------|-----|-----|-----|-----|-----|------|-----|------|-----|------|-----|
| UPB1086  | 2     | 7   | 4    | 6    | 10    | 11    | 11   | 40.18 | 1   | 38.34 | 1   | 36.63 | 3   | 89.18 | 2   | 89.18 | 2   | 89.11 | 3   |
| DWRB204  | 7     | 12  | 12   | 10   | 9     | 9     | 9    | 38.60 | 3   | 37.64 | 3   | 36.65 | 1   | 83.29 | 3   | 87.55 | 3   | 90.55 | 2   |
| KB1843   | 18    | 14  | 15   | 18   | 16    | 14    | 14   | 28.78 | 9   | 27.00 | 9   | 25.49 | 9   | 29.02 | 9   | 33.38 | 9   | 39.75 | 9   |
| PL891    | 20    | 20  | 18   | 20   | 19    | 19    | 19   | 26.05 | 10  | 23.01 | 10  | 19.26 | 10  | 20.00 | 10  | 0.00  | 10  | 0.00  | 10  |
| Karan16  | 6     | 4   | 4    | 4    | 4     | 4     | 4    | 39.55 | 2   | 38.09 | 2   | 36.64 | 2   | 96.86 | 1   | 98.00 | 1   | 99.66 | 1   |
| DWRB216  | 11    | 7   | 7    | 7    | 7     | 7     | 7    | 34.06 | 6   | 32.88 | 5   | 31.65 | 5   | 71.85 | 5   | 76.84 | 4   | 81.29 | 4   |
| K1149    | 16    | 12  | 12   | 14   | 13    | 12    | 12   | 32.06 | 8   | 30.45 | 9   | 29.00 | 7   | 50.29 | 8   | 54.18 | 8   | 59.02 | 8   |
| KB1848   | 14    | 10  | 6    | 10   | 10    | 10    | 10   | 33.10 | 7   | 30.89 | 7   | 28.61 | 8   | 59.65 | 6   | 60.65 | 6   | 62.18 | 6   |
| NDB943   | 11    | 12  | 15   | 13   | 13    | 13    | 13   | 34.78 | 5   | 32.84 | 6   | 30.96 | 6   | 58.40 | 7   | 59.90 | 7   | 61.94 | 7   |
| DWRB217  | 7     | 12  | 11   | 8    | 11    | 10    | 10   | 35.75 | 4   | 34.01 | 4   | 32.32 | 4   | 73.29 | 4   | 75.31 | 5   | 77.47 | 5   |

Verma et al.; IJPSS, 33(10): 48-61, 2021; Article no.IJPSS 68437
| Measure  | PC1   |       | PC2   |
|---------|-------|-------|-------|
| IPCA1   | -0.2227 |       | -0.0624 |
| MASV1   | -0.1119 |       | 0.3109 |
| MASV    | -0.1118 |       | 0.3283 |
| Za      | -0.2176 |       | 0.1261 |
| EV      | -0.1087 |       | 0.2747 |
| SIPC    | -0.1299 |       | 0.1858 |
| ASTAB   | -0.1950 |       | 0.1906 |
| W1      | -0.2227 |       | -0.0624 |
| W2      | -0.2106 |       | 0.0160 |
| W3      | -0.2134 |       | 0.0694 |
| W4      | -0.2171 |       | 0.0655 |
| W5      | -0.2241 |       | 0.0869 |
| W6      | -0.2245 |       | 0.1058 |
| WAASB   | -0.2264 |       | 0.0931 |
| Durgapura | 0.1705 |       | 0.2032 |
| Faizabad | 0.1204 |       | -0.1791 |
| Gwalior  | 0.0395  |       | -0.2371 |
| HAU     | 0.2214  |       | 0.0883 |
| Jhansi  | 0.1366  |       | 0.2019 |
| Kanpur  | 0.1021  |       | 0.2553 |
| Kamal   | 0.0350  |       | 0.2484 |
| Ludhiana| -0.0053 |       | 0.2438 |
| Modipuram| 0.1023 |       | 0.2233 |
| Pantnagar| 0.1729 |       | 0.1039 |
| Tikamgarh| 0.1683 |       | 0.0179 |
| Udaipur | 0.1353  |       | 0.2606 |
| Varanasi| 0.1576  |       | 0.1651 |
| Vijapur | 0.1973  |       | -0.1196 |
| Mean    | 0.2047  |       | 0.1795 |
| Siam    | 0.2258  |       | 0.0965 |
| Sigm    | 0.2280  |       | 0.0837 |
| Sihm    | 0.2296  |       | 0.0681 |
| 78.09   | 57.05   |       | 21.04  |
Fig. 1. Biplot analysis of superiority index & other measures of barley genotypes 2018-19
Fig. 2. Biplot analysis of stability & adaptability measures of barley genotypes 2019-20
4. CONCLUSION

G×E interaction study in multi-environment trials had been carried out by a well-established AMMI model. The simultaneous consideration of stability measures and yield would be more appropriate to recommend high-yielding stable genotypes. In the present study, the main advantages of AMMI and BLUP had been combined to increase the reliability of multi-locations trials analysis. An additional advantage was provided by Superiority Indexes to assign variable weights to the yield and stability performance. Depending upon the goal of crop breeding trials, the researchers may prioritize the productivity of a genotype rather than its stability (and vice-versa). The stability index of genotype performance has the potential to provide reliable estimates of stability in future studies along with a joint interpretation of performance and stability in biplots while considering the number of significant IPCA’s.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

ACKNOWLEDGEMENTS

The barley genotypes were evaluated at research fields at coordinated centers of AICW&BIP across the country. The first author sincerely acknowledges the hard work of all the staff for field evaluation and data recording of genotypes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Karkee A, Ghimire KH, Joshi BK. Evaluation on naked barley landraces for agro-morphological traits. Journal of Nepal Agricultural Research Council. 2020;6:34-43.
2. Kendel M, Dhami NB, Shrestha J. Performance evaluation of barley (Hordeum vulgare L.) genotypes in Dolakha, Nepal: From yielding perspective. Journal of Agriculture and Natural Resources. 2019;2(1):322-337.
3. Shimizu C, Kihara M, Aoe S, Araki A, Ito K, Hayashi K, Watari J, Sakata Y, Ikegami S. Effect of high ß-glucan barley on serum cholesterol concentrations and visceral fat area in Japanese men- A randomized, double-blinded, placebo-controlled trial. Plant Food Human Nutrition. 2008;63:21-25.
4. Agahi K, Ahmadi J, Oghan HA, Fotokian MH, Orang SF. Analysis of genotype × environment interaction for seed yield in spring oilseed rape using the AMMI model. Crop Breeding and Applied Biotechnology. 2020; 20(1):e26502012.
5. Gauch HG. A simple protocol for AMMI analysis of yield trials. Crop Sci. 2013; 53:1860–1869.
6. Piepho HP, Mo’hring J, Melchinger AE, Bu’chse A. BLUP for phenotypic selection in plant breeding and variety testing. Euphytica. 2008;161(1):209–228.
7. Olivoto T, Lucia A Dal’Col, Gonzalez, Silva JA da, Marchioro VS. Mean performance and stability in multi-environment trials I: Combining features of AMMI and BLUP techniques. Agron J. 2019;111:1–12.
8. Zobel RW, Wright MJ, Gauch HG. Statistical analysis of yield trial. Agronomy Journal. 1988;80:388-393.
9. Sneller CH, Norquest L K, Dombek D. Repeatability of yield stability statistics in soybean. Crop Sci. 1997;37:383–390.
10. Rao AR , Prabhakaran VT. Use of AMMI in simultaneous selection of genotypes for yield and stability. Journal of the Indian Society of Agricultural Statistics. 2005;59:76-82.
11. Zali H, Farshadfar E, Sabaghpour SH, Karimizadeh R. Evaluation of genotype × environment interaction in chickpea using measures of stability from AMMI model. Ann Biol Res. 2012;3:3126–3136.
12. Ajay BC, Bera SK, Singh AL, Kumar N, Gangadhar K, Kona P. Evaluation of Genotype × Environment Interaction and Yield Stability Analysis in Peanut Under Phosphorus Stress Condition Using Stability Parameters of AMMI Model. Agric Res. 2020;9:477-486.
13. Oyekunle M, Menkiri A, Mani H, Olaoye G, Usman IS, Ado S. Stability analysis of maize cultivars adapted to tropical
environments using AMMI analysis. Cereal Res Commun. 2017;45:336–345.

14. Kang MS. Simultaneous selection for yield and stability in crop performance trials: Consequences for growers. Agronomy Journal. 1993;85:754-757.

15. Farshadfar E. Incorporation of AMMI stability value and grain yield in a single non-parametric index (GSI) in bread wheat. Pak J Biol Sci. 2008;11:1791–1796.

16. Farshadfar E, Mahmodi N, Yaghotipoor A. AMMI stability value and simultaneous estimation of yield and yield stability in bread wheat (*Triticum aestivum* L.). Aust J Crop Sci. 2011;5:1837–1844.

17. Bocianowski J, Niemann J, Nowosad K. Genotype-by environment interaction for seed quality traits in interspecific cross-derived Brassica lines using additive main effects and multiplicative interaction model. Euphytica. 2019;215(7):1–13.

© 2021 Verma et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

**Peer-review history:**
The peer review history for this paper can be accessed here: http://www.sdiarticle4.com/review-history/68437