ADAPTABILITY PERFORMANCE OF FEED BARLEY GENOTYPES EVALUATED UNDER NWPZ OF THE COUNTRY

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ABSTRACT

Highly significant effects of the environment (E), genotypes (G), and GxE interaction had been observed by AMMI analysis. Environment explained 63.4% whereas GxE interaction accounted for 23.4% of treatment variations in yield during first year. Harmonic Mean of Genotypic Values (HMGV) expressed higher values for PL906, KB1707, UPB1080 genotypes. Ranking of genotype as per IPCA-1 were NDB1723, NDB1709, HUB266. While IPCA-2, selected BH1023, BH1024, NDB1723 genotypes. Values of Measures ASV1 selected NDB1723, NDB1709, HUB266 and ASV identified NDB1723, NDB1709, BH1023 barley genotypes. Adaptability measures Harmonic Mean of Relative Performance of Genotypic Values (HMPRVG) pointed towards PL906, KB1707, UPB1080 and Relative Performance of Genotypic Values (RPGV) identified KB1707, PL906, RD2994 as the genotypes of performance among the locations. Biplot graphical analysis observed clustering of adaptability measures PRVG, HMPRVG, along with GM, HM in a group. During 2019-20 cropping season Environment effects accounted 61.4% whereas GxE interaction contributed for 26.9% of treatment variations in yield. HMGV expressed higher values for DWRB137, PL906. IPCA-1 scores, desired ranking of genotypes was UPB1080, PL906. While IPCA-2 pointed towards PL906, RD2994, as genotypes of choice. Analytic measures ASV and ASV1 selected PL906, UPB1080 barley genotypes. HMRPGV selected DWRB137, PL906 whereas PRVG settled for DWRB137, KB1707. Biplot analysis seen cluster of ASV, ASV1 IPC1, Mean, GM, HM along with adaptability measures PRVG, HMPRVG observed in adjacent quadrant.

Keywords: AMMI, ASV, ASV1, HMGV, GAI, HMPRVG, Biplots
Introduction

Barley (*Hordeum vulgare* L.) is frequently being described as the most cosmopolitan of the crops as it is grown over the wide environmental range than any other cereal (Kharub et al 2017; Bocianowsk et al 2019). Also known, as “poor man’s crop” due to low input requirements and better adaptability to harsh conditions (Kendel et al 2019). Traditionally the crop cultivated and used as a grain crop for human consumption as well feed for animals (Karkee et al 2020). Barley is particularly cultivated in the high-altitude areas of Himalaya as consumed by tribal people as food in the hilly areas (Kendel et al 2019). Grains consist of ample quantity of ß-glucan beneficial in decreasing the glucose level of diabetic patients and to reduce the cholesterol of heart patients (Shimizu et al. 2008). GxE interaction analysis under multi location trials carried out by AMMI analytic tools (Agahi et al 2020). Researchers gave more emphasis to identification of genotypes would express stable yield along with broad or narrow adaptation of the genotypes to environments (Bocianowsk et al 2019). Quite large number of measures for stability and adaptability of genotypes based on AMMI had observed in literature ( Tekdal & Kendal 2018). Analytic measure of adaptability as the harmonic means of the relative performance of the predicted genotypic values (MHPRVG) utilized productivity, stability, and adaptability simultaneously of genotypes (Resende & Durate 2007). Comparative performance of AMMI based measures had been studied with relatively new adaptability measures for feed barley genotypes evaluated under North Western Plains Zone of the country.

Material and methods

Parts of sub-humid Sutlej-Ganga Alluvial Plains and arid western plains, which comprises Punjab, Haryana, Delhi, Rajasthan (except Kota and Udaipur divisions), Western Uttar Pradesh (except Jhansi division and hilly areas), parts of Jammu and Kashmir (Jammu and Kathua districts) and parts of Himachal Pradesh (Paonta Valley and Una districts) categorized as the North Western Plain Zone of India. During cropping seasons of 2018-19 and 2019-20 twenty one genotypes in advanced trials evaluated at six major locations of the zone and eight genotypes at eight locations respectively. Field trials were conducted at research centers in randomized complete block designs with three replications. Recommended agronomic practices were followed to harvest good yield. Details of locations and genotype parentage were reflected in tables 1 & 2 for ready reference.

Mohamadi & Amri 2008 Geometric Mean as Adaptability Index

\[ GAI = \sqrt[n]{\prod_{k=1}^{n} \frac{1}{X_k}} \]

Purchase1997 AMMI stability value

\[ ASV = \frac{\left(\frac{\text{NSP}_{1}}{\text{NSP}_{2}}\right) (PC1)^2 + (PC2)^2}{\text{NSP}_{1}^2} \]

Zali et al2012 AMMI stability value

\[ ASV1 = \frac{\left(\frac{\text{NSP}_{1}}{\text{NSP}_{2}}\right) (PC1)^2 + (PC2)^2}{\text{NSP}_{1}^2} \]

Resende 2004 Harmonic mean of Genetic

\[ \text{MHVG}_{i} = \text{Number of environments} / \sum_{i=1}^{k} \frac{1}{X_i} \]
Values

Resende & Durate 2007 Relative performance of genotypic values across environments

Resende & Durate 2007 Harmonic mean of Relative performance of genotypic values

\[ \text{MHPRVG}_i = \frac{1}{\sum_{j=1}^n \text{PRVG}_{ij}} \]

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. Simple and effective measure for adaptability is calculated as the relative performance of genetic values (PRVG) across environments and MHVG (Harmonic mean of Genetic Values), based on the harmonic mean of the genotypic values across different environments. Lower the standard deviation of genotypic performance across environments, the greater is the harmonic mean of its genotypic values.

Results and discussion

AMMI analysis of barley genotypes

First year of study 2018-19

Adaptability performance of barley genotypes studied by AMMI based measures. These measures evaluate the performance after reduction of the noise from the GxE interaction effects (Gauch 2013). Highly significant effects of the environment (E), genotypes (G), and GxE interaction had been observed by AMMI analysis (Table 3). Analysis observed the greater contribution of environments, GxE interactions, and genotypes to the total sum of squares (SS) as compared to the residual effects. Environment explained about significantly 63.4% of the total sum of squares due to treatments indicating that diverse environments caused most of the variations in genotypes yield. Genotypes explained only 9.1% of a total sum of squares, whereas GxE interaction accounted to the tune of 23.4% of treatment variations in yield. Further bifurcation of GxE interaction observed the significant four multiplicative terms most of the interaction sum of squares as compared to residual / noise (Oyekunle et al 2017).

Second year 2019-20

Analysis observed the greater contribution of environments, GxE interactions, and genotypes to the total sum of squares (SS) as compared to the residual effects. Environment explained about significantly 61.4%, GxE interaction accounted for 26.9% whereas Genotypes explained only 3.6% % of the total sum of squares due to treatments. Partitioning of GxE interaction two highly significant multiplicative terms out of six explained more of the interaction sum of squares.

Ranking of genotypes as per descriptive measures

First year of study 2018-19

An average yield of genotypes over the studied locations selected KB1707, PL906, RD2994 as higher productive genotypes (Table 4). Though this measure is simple to calculate, but failed to exploit full information contained in dataset as per the field performance. Geometric mean is used to evaluate the adaptability of genotypes. Geometric mean observed PL906, KB1707, UPB1080 were top-ranked genotypes. Harmonic Mean of Genotypic Values of yield expressed higher values for PL906, KB1707, UPB1080 genotypes. Consistent yield performance of genotypes judged by lower values of Coefficient of Variation and genotypes KB1713, DWRB205, BH1023 would be suitable for considered locations of this zone of the country. Minimum values of standard deviation of yield values
selected KB1713, DWRB205, HUB266 barley genotypes.

**Second year 2019-20**

Average yield selected DWRB137, PL906 genotypes for higher values (Table 8). Geometric mean observed DWRB137, PL906 were with top-rank. Harmonic mean of genetic values (HMGV) expressed higher values for DWRB137, PL906 genotypes. Consistent yield performance of UPB1080, DWRB137 judged by lower values of Coefficient of Variation. Minimum values of standard deviation of yield values selected UPB1080, DWRB137 barley genotypes. Analytic measures PRVG, MHVG, and MHPRVG, had showed consensus for classification of genotypes as per raking of genotypes vis-à-vis analytic measures (Table 6). Presence of significant cross over interactions has been validated by differences among ranks of genotypes vis-à-vis locations of the zone.

**Adaptability behaviour of genotypes**

**First year of study 2018-19**

The IPCA scores of a genotype in AMMI analysis indicate the stability or adaptation over environments. The greater the IPCA scores, either negative or positive (as it is a relative value), the more specifically adapted is the genotype to certain environments. The more the IPCA scores approximate zero, the more stable or adapted the genotypes. Adaptability of genotypes over locations indicated by the IPCA scores in the AMMI analysis. Ranking of genotype as per absolute IPCA-1 scores were NDB1723, NDB1709, HUB266 (Table 5). While for IPCA-2, genotypes BH1023, BH1024, NDB1723 would be of choice. Values of IPCA-3 favored NDB1709, KB1707, RD2552 barley genotypes. Lower Values of IPCA-4 settled for UPB1080, KB1707, RD2991 barley genotypes. Analytic measures of adaptability ASV and ASV1consider two significant IPCAs of the AMMI analysis for adaptability behaviour (Tekdal & Kendal 2018). Values of ASV1 selected NDB1723, NDB1709, HUB266 and ASV identified NDB1723, NDB1709, BH1023 barley genotypes. Harmonic Mean of Relative Performance of Genotypic Values (HMRPGV) method, the genotypes can be simultaneously sorted by genotypic values (yield) and stability using the harmonic means of the yield so that the smaller the standard deviation of genotypic performance among the locations. Values of HMRPGV ranked PL906, KB1707, UPB1080 as the performance of the genotypes among the locations. When considering the yield and adaptability simultaneously, the recommended approach is the relative performance of genetic values (RPGV) overcrop years. Relative Performance of Genotypic Values had settled for KB1707, PL906, RD2994 genotypes. Analytic measures PRVG, MHVG, and MHPRVG, had showed consensus for classification of genotypes as per raking of genotypes vis-à-vis analytic measures. Presence of significant cross over interactions has been validated by differences among ranks of genotypes vis-à-vis locations of the zone.

**Second year 2019-20**

UPB1080, PL906 were the top ranked genotype as per absolute IPCA-1 scores (Table 8). While for IPCA-2 identified PL906, RD2994 genotypes would be of choice. Values of IPCA-3 favoured KB1707, PL906 barley genotypes. As per IPCA-4, KB1707, DWRB137 genotypes would be of stable performance.
Minimum values of IPCA-5 settled for KB1707, RD2552 barley genotypes. Genotypes DWRB137, PL906 identified by as per IPCA-6 measure. Two significant IPCAs of the AMMI analysis considered by ASV and ASV1 for adaptability behaviour of genotypes. Both measures selected same set of PL906, UPB1080 barley genotypes. Harmonic Mean of Relative Performance of Genotypic Values (HMRPGV) values ranked DWRB137, PL906 as of stable performance among the locations. Relative Performance of Genotypic Values (RPGV) had settled for DWRB137, KB1707 genotypes.

Biplot analysis
First year of study 2018-19
Graphical analysis to understand the association if any among adaptability measures utilized the first two highly significant Interaction Principal Components of analysis. First two significant interaction principal components contribute to the tune of 39.6% & 21.8% to the total for 61.5 % of total GxE interaction sum of squares (Figure 1). Loadings of adaptability measures based on significant two interaction principal components had mentioned in table 6. Biplot observed cluster of CVs with IPC3 whereas Sdev grouped with mean, IPC1 IPC2. Cluster of ASV and ASV1 observed with IPC4 measures in one quadrant and adaptability measures PRVG, HMPRVG, along with GM, HM grouped in a separate cluster.

Second year 2019-20
First two significant interaction principal components accounted total for 52.8 % with respective share of 32.5% & 20.3% of total GxE interaction sum of squares (Figure 2). Loadings of adaptability measures based on two interaction principal components had mentioned in table 10. Measure CV clustered with Sdev, IPC4 in one quadrant of biplot analysis. ASV, ASV1 IPC1, Mean, GM, HM along with adaptability measures PRVG, HMPRVG observed in adjacent quadrant. IPC2 and IPC5 joined hands in one quadrant while IPC3 & IPC6 were grouped together in next quadrant.

Conclusions
Researchers concentrates on genotypes with high productive potential that respond to favorable environments. Often the occurrence of complex type GxE interaction leads to uncertainty in the identification of promising genotype; in this case, techniques exploit adaptability and stability can provide precise information about genotypes performance. The identification of stable and highly productive genotypes between different environments remains a constant challenge for breeders of various crop species around the world. Selection of barley genotypes by the harmonic mean of genotypic values allow to identify the stable and productive genotypes.

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Conflict of interest
No conflict of interest

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Table 1: Parentage details of barley genotypes and environmental conditions (2018-19)

| Code | Genotype | Parentage | Code | Location | Latitude | Longitude | Altitude |
|------|----------|-----------|------|----------|----------|-----------|----------|
| G1   | RD2991   | RD2592 /RD2503 /RD 2715 | E1   | Karnal   | 29° 43' N | 70° 58' E | 245      |
| G2   | KB1707   | Manjula/DWRUB52 | E2   | Hisar    | 29° 10' N | 75° 46' E | 229      |
| G3   | RD2994   | RD2624 / NDB1173 | E3   | Durgapura | 26°51'N | 75° 47' E | 390      |
| G4   | RD2992   | RD2660 /3hEMBGSN-4 | E4   | Ludhiana | 30° 54' N | 75° 48' E | 247      |
| G5   | KB1713   | IBON-19 (2011-12)/RD2885 | E5   | Pantnagar| 29° 02' N | 79° 48' E | 243.8    |
| G6   | UPB1077  | AHOR1489.58/GLORIA-BAR/COPAL/3/PRO/-4/CAPUL/TOCTE/5/ICARO | E6   | Tabji    | 26°35'N | 74° 61' E | 508      |
| G7   | UPB1080  | AHOR1489.58/GLORIA-BAR/COPAL/3/PRO/-4/CAPUL/TOCTE/5/ICARO |       |          |          |           |          |
| G8   | HUB266   | DL 70 / 25TH IBYT-22-1 |       |          |          |           |          |
| G9   | PL906    | RD2503/WSA353 (H.spontaneum) |       |          |          |           |          |
| G10  | DWRB205  | CDC MANLEY/BCU2881 |       |          |          |           |          |
| G11  | NDB1709  | INBYT-HI-2 (2016) |       |          |          |           |          |
| G12  | PL909    | RD2740/BL194 |       |          |          |           |          |
| G13  | BH946    | BHMS22A/BH549/RD2552 |       |          |          |           |          |
| G14  | NDB1723  | 3rd GBSBN-35 (2016) |       |          |          |           |          |
| G15  | DWRB203  | P.STO/3/LIBRAN/UNA80/LIGNEE640/4/BLLU/S/PETUNIA 1/6/M111 |       |          |          |           |          |
| G16  | RD2552   | RD2035/DL472 |       |          |          |           |          |
| G17  | BH1023   | NBGSN-4/2011-12/RD 2552 |       |          |          |           |          |
| G18  | RD2786   | RD2634/NDB1020/K425 |       |          |          |           |          |
| G19  | DWRB137  | DWR28/DWRUB64 |       |          |          |           |          |
| G20  | BH1024   | NBGSN-12 (2011-12)/BH 393 |       |          |          |           |          |
| G21  | RD2899   | RD2592/RD2035/RD2715 |       |          |          |           |          |

Table 2: Parentage details of barley genotypes and environmental conditions (2019-20)

| Code | Genotype | Parentage | Code | Location | Latitude | Longitude | Altitude |
|------|----------|-----------|------|----------|----------|-----------|----------|
| G1   | BH946    | BHMS22A/BH549/RD2552 | E1   | Durgapura| 26°51'N | 75° 47' E | 390      |
| G2   | RD2994   | RD2624 / NDB1173 | E2   | Hisar    | 29° 10' N | 75° 46' E | 229      |
| G3   | DWRB137  | DWR28/DWRUB64 | E3   | Karnal   | 29° 43' N | 70° 58' E | 245      |
| G4   | PL906    | RD2503/WSA353 (H.spontaneum) | E4   | Ludhiana | 30° 54' N | 75° 48' E | 247      |
| G5   | BH902    | BH495/RD2552 | E5   | Modipuram| 29° 05' N | 77° 70' E | 226      |
| G6   | RD2552   | RD2035/DL472 | E6   | Pantnagar| 29° 02'N | 79° 48' E | 243.8    |
| G7   | UPB1080  | AHOR1489.58/GLORIA-BAR/COPAL/3/PRO/-4/CAPUL/TOCTE/5/ICARO | E7   | Tabji    | 26°35'N | 74° 61' E | 508      |
| G8   | KB1707   | Manjula/DWRUB52 | E8   | Udaipur  | 24° 34' N | 73° 41' E | 585      |
### Table 3: Multi environment trails analysis by AMMI of barley genotypes (2018-19)

| Source          | Degree of freedom | Mean Sum of Squares | Significance level       | % contributions of factors |
|-----------------|-------------------|---------------------|--------------------------|----------------------------|
| Treatments      | 125               | 638.79              | .0000000 ***             | 95.94                      |
| Genotypes (G)   | 20                | 378.02              | .0000000 ***             | 9.08                       |
| Environments (E)| 5                 | 10555.55            | .0000000 ***             | 63.42                      |
| Interactions (GxE) | 100             | 195.11              | .0000000 ***             | 23.44                      |
| IPC1            | 24                | 305.44              | .0000000 ***             |                            |
| IPC2            | 22                | 228.62              | .0000000 ***             |                            |
| IPC3            | 20                | 186.59              | .0000000 ***             |                            |
| IPC4            | 18                | 116.28              | .0000000 ***             |                            |
| Residual        | 16                | 82.85               | .0000000 ***             |                            |
| Error           | 252               |                     |                          |                            |
| Total           | 377               | 220.75              |                          |                            |

### Table 4: Ranking of barley genotypes as per descriptive measures (2018-19)

| Genotype | Karnal | Hisar | Durgapura | Ludhiana | Panipat | Tabji | MEAN | Rk | GM | Rk | HM | Rk | CV | Rk | Sdev | Rk |
|----------|--------|-------|-----------|----------|---------|-------|------|----|----|----|----|----|----|----|------|----|
| RD2991   | 40.74  | 40.58 | 25.94     | 40.41    | 43.26   | 39.45 | 41.22| 20 | 38.56| 20 | 35.96| 20 | 0.4016| 14  |
| KB1707   | 89.78  | 47.99 | 76.81     | 51.26    | 39.81   | 34.22 | 56.65| 1  | 53.37| 2  | 50.49| 2  | 0.3863| 19  |
| RD2994   | 78.75  | 34.38 | 66.43     | 52.34    | 39.85   | 52.74 | 54.08| 3  | 52.01| 4  | 50.00| 4  | 0.3045| 15  |
| RD2992   | 62.24  | 30.28 | 53.96     | 17.17    | 29.55   | 39.45 | 38.76| 21 | 35.59| 21 | 32.42| 21 | 0.4321| 16  |
| KB1713   | 44.77  | 43.72 | 62.56     | 44.69    | 41.97   | 44.28 | 47.00| 14 | 46.55| 12 | 48.84| 17 | 0.4060| 10  |
| UPB1077  | 53.62  | 39.05 | 70.29     | 29.79    | 48.49   | 38.24 | 46.58| 17 | 43.22| 16 | 43.11| 14 | 0.3421| 10  |
| UPB1080  | 79.79  | 43.08 | 66.18     | 41.87    | 37.12   | 56.36 | 54.07| 4  | 52.07| 3  | 50.24| 3  | 0.3062| 13  |
| PRGV1    | 57.76  | 44.36 | 78.26     | 49.38    | 32.76   | 55.15 | 55.95| 2  | 53.51| 1  | 51.10| 1  | 0.3203| 16  |
| DWRB205  | 49.60  | 39.85 | 55.79     | 40.26    | 33.11   | 61.59 | 46.70| 16 | 46.65| 14 | 44.63| 14 | 0.2318| 2   |
| NDB1709  | 61.35  | 33.57 | 64.73     | 37.57    | 39.60   | 44.69 | 46.92| 15 | 45.49| 16 | 44.19| 15 | 0.2778| 7   |
| PL909    | 74.40  | 44.12 | 64.73     | 39.18    | 34.23   | 52.74 | 51.57| 7  | 49.68| 7  | 47.90| 7  | 0.3011| 10  |
| BH496    | 69.56  | 51.45 | 71.02     | 25.76    | 37.29   | 37.04 | 48.69| 11 | 45.64| 15 | 42.70| 17 | 0.3824| 18  |
| DWRB203  | 57.89  | 39.13 | 60.63     | 36.23    | 29.95   | 42.27 | 44.35| 19 | 42.98| 19 | 41.68| 18 | 0.2676| 6   |
| RD2552   | 65.14  | 38.41 | 67.15     | 48.04    | 44.07   | 32.21 | 49.17| 10 | 47.48| 10 | 45.86| 11 | 0.2889| 9   |
| BH1023   | 58.70  | 43.24 | 70.53     | 38.49    | 32.21   | 55.96 | 49.85| 8  | 48.12| 9  | 46.42| 9  | 0.2875| 8   |
| RD2786   | 60.47  | 41.55 | 66.67     | 33.55    | 48.09   | 47.50 | 49.64| 9  | 48.39| 8  | 47.15| 8  | 0.2449| 3   |
| DWRB137  | 76.73  | 52.98 | 67.87     | 47.23    | 32.98   | 37.04 | 52.47| 6  | 50.16| 6  | 47.95| 6  | 0.3269| 17  |
| BH1024   | 62.32  | 36.47 | 79.95     | 45.62    | 36.50   | 56.76 | 52.94| 5  | 50.80| 5  | 48.82| 5  | 0.3192| 15  |
| RD2899   | 50.81  | 52.01 | 66.91     | 50.46    | 32.46   | 33.82 | 47.74| 13 | 46.25| 13 | 44.76| 13 | 0.2698| 5   |

### Table 5: Adaptability measures of barley genotypes evaluated under MET (2018-19)

| Genotype | IPC1 | IPC2 | IPC3 | IPC4 | ASV1 | RASV1 | ASV  | RASV | PRVG | HPVRG | Rp. | Rk | Sdev | Rk |
|----------|------|------|------|------|------|-------|------|------|------|-------|-----|----|------|----|
| RD2991   | -2.715 | -1.048 | 1.823 | -0.336 | 4.09 | 20   | 3.44 | 19   | 0.8366| 20   | 0.7815| 20  |
| KB1707   | 3.630 | -1.478 | 0.196 | 0.189 | 5.49 | 21   | 4.62 | 21   | 1.1423| 1    | 0.1090| 2   |
| Genotype   | IPC1 | IPC2 | IPC3 | IPC4 | ASV1 | RASV1 | ASV  | RASV | PRVG | RPRVG | HMPRVG | RHMPRVG |
|------------|-----|-----|-----|-----|-----|-------|------|------|------|-------|--------|---------|
| RD2994     | 1.721 | 1.634 | -1.214 | 1.752 | 2.99 | 16 | 2.64 | 16 | 1.1069 | 3 | 1.0784 | 4 |
| RD2992     | 0.549 | 1.261 | 2.211 | 0.363 | 1.49 | 5 | 1.42 | 4 | 0.7707 | 21 | 0.7208 | 21 |
| KB1713     | -2.133 | -0.959 | -1.670 | 0.392 | 3.25 | 17 | 2.75 | 17 | 0.9901 | 12 | 0.9652 | 12 |
| UPB1077    | -1.399 | -1.434 | 1.485 | 1.691 | 2.49 | 13 | 2.22 | 13 | 0.9577 | 17 | 0.9287 | 17 |
| UPB1080    | -1.359 | 1.965 | 0.433 | 0.087 | 2.79 | 15 | 2.56 | 15 | 1.1003 | 4 | 1.0885 | 3 |
| HUB266     | -0.204 | -1.450 | -1.220 | 0.627 | 1.48 | 3 | 1.47 | 7 | 0.9876 | 13 | 0.9747 | 11 |
| PL906      | 1.063 | 1.193 | -0.613 | -0.861 | 1.96 | 9 | 1.75 | 9 | 1.1325 | 2 | 1.1160 | 1 |
| DWRB205    | -2.100 | 2.366 | -1.506 | -0.534 | 3.87 | 19 | 3.47 | 20 | 0.9764 | 15 | 0.9447 | 15 |
| NDB1709    | -0.111 | 0.427 | 0.016 | 1.466 | 0.46 | 2 | 0.45 | 2 | 0.9597 | 16 | 0.9524 | 14 |
| PL909      | 1.011 | 1.498 | 0.406 | -0.656 | 2.10 | 11 | 1.93 | 11 | 1.0487 | 7 | 1.0394 | 7 |
| BH 946     | 0.685 | -1.187 | 2.692 | -1.399 | 1.55 | 6 | 1.45 | 5 | 0.9790 | 14 | 0.9379 | 16 |
| NDB1723    | -0.021 | 0.299 | -0.415 | -0.562 | 0.30 | 1 | 0.30 | 1 | 0.9044 | 19 | 0.9020 | 18 |
| DWRB203    | 0.964 | -1.801 | -0.942 | 1.873 | 2.28 | 12 | 2.14 | 12 | 1.0130 | 10 | 0.9816 | 10 |
| RD2552     | -1.037 | 1.298 | -0.199 | -1.137 | 1.99 | 10 | 1.80 | 10 | 1.0179 | 9 | 1.0051 | 9 |
| BH1023     | -1.021 | -0.091 | 1.159 | 1.337 | 1.49 | 4 | 1.24 | 3 | 1.0253 | 8 | 1.0091 | 8 |
| RD2786     | 2.209 | -1.139 | -0.403 | -1.588 | 3.41 | 18 | 2.90 | 18 | 1.0682 | 6 | 1.0398 | 6 |
| DWRB137    | -0.732 | 1.227 | -0.681 | 0.430 | 1.63 | 7 | 1.51 | 8 | 1.0765 | 5 | 1.0585 | 5 |
| BH1024     | -1.204 | -0.185 | 0.728 | -1.274 | 1.76 | 8 | 1.47 | 6 | 0.9135 | 18 | 0.9013 | 19 |
| RD2899     | -0.514 | -2.396 | -2.286 | -1.687 | 2.51 | 14 | 2.48 | 14 | 0.9926 | 11 | 0.9526 | 13 |
Table 6: Loadings of adaptability measures as per Principal Components (2018-19)

| Component   | PC1   | PC2   |
|-------------|-------|-------|
| IPC1        | 0.2345| -0.1821|
| IPC2        | 0.0289| -0.1778|
| IPC3        | -0.1527| -0.0527|
| IPC4        | 0.0263| 0.3791|
| ASV1        | 0.0878| 0.4457|
| ASV         | 0.0878| 0.4457|
| PRVG        | 0.3623| -0.0057|
| MHPRVG      | 0.3589| -0.0009|
| Karnal      | 0.2649| -0.1735|
| Hisar       | 0.1338| -0.1404|
| Durgapura   | 0.2135| -0.0113|
| Ludhiana    | 0.3031| 0.0291|
| Pantnagar   | 0.0878| 0.4457|
| Tabji       | 0.0924| -0.0994|
| MEAN        | 0.3607| -0.0470|
| CV          | -0.0694| -0.2535|
| Sdev        | 0.1270| -0.2530|
| GM          | 0.3617| -0.0041|
| HM          | 0.3544| 0.0379|

% variation 39.65 21.83

Figure 1: Biplot analysis of adaptability measures for barley genotypes (2018-19)
Table 7: Multi environment trails analysis by AMMI of barley genotypes (2019-20)

| Source                  | Degree of Freedom | Mean Sum of Squares | Significance level | % contributions of factors |
|-------------------------|-------------------|---------------------|--------------------|---------------------------|
| Treatments              | 6                  | 425.98              | ***                | 91.93                     |
| Genotypes (G)           | 7                  | 150.36              | ***                | 3.61                      |
| Environments (E)        | 7                  | 259.33              | ***                | 61.37                     |
| Interactions (GxE)      | 49                 | 160.59              | ***                | 26.95                     |
| IPC1                    | 13                 | 237.81              | ***                |                           |
| IPC2                    | 11                 | 198.94              | **                 |                           |
| IPC3                    | 9                  | 126.06              |                    |                           |
| IPC4                    | 7                  | 130.13              |                    |                           |
| IPC5                    | 5                  | 68.54               |                    |                           |
| IPC6                    | 3                  | 63.48               |                    |                           |
| Residual                |                    |                     |                    |                           |
| Error                   | 128                | 10.58               |                    |                           |
| Total                   | 191                | 152.85              |                    |                           |

Table 8: Ranking of barley genotypes as per descriptive measures (2019-20)

| Genotype   | Durgapura | Hisar | Karnal | Ludhiana | Modipuram | Pantnagar | Tabiji | Udaipur | MEAN | Rk | GM | Rk | HM | Rk | CV | Rk | Sdev | Rk |
|------------|-----------|-------|--------|----------|-----------|-----------|--------|---------|------|----|----|----|----|----|----|----|-----|----|
| BH946      | 50.48     | 53.49 | 38.09  | 48.31    | 60.14     | 28.82     | 60.03  | 57.41   | 49.60| 3  |    | 46.82| 5  | 22.38| 3  | 11.10| 3   |
| RD2994     | 65.30     | 40.74 | 43.07  | 50.72    | 48.71     | 33.38     | 72.46  | 42.75   | 48.54| 5  | 47.55| 4  | 46.93| 4  | 26.00| 6   |
| DWRB137    | 48.16     | 47.47 | 45.41  | 46.38    | 64.21     | 36.24     | 69.42  | 53.95   | 50.95| 1  | 49.64| 1  | 49.53| 1  | 21.14| 2   |
| PL906      | 50.31     | 54.3  | 33.96  | 51.45    | 57.37     | 36.40     | 72.22  | 44.12   | 50.38| 2  | 49.31| 2  | 47.45| 2  | 24.26| 4   |
| BH902      | 49.80     | 46.21 | 29.51  | 50.24    | 52.90     | 31.05     | 77.07  | 34.1    | 48.78| 4  | 47.54| 5  | 42.35| 7  | 31.77| 8   |
| RD2552     | 54.86     | 35.14 | 21.08  | 43.12    | 48.19     | 39.20     | 72.14  | 44.2    | 46.89| 7  | 45.28| 7  | 39.99| 8  | 31.74| 7   |
| UPB1080    | 50.40     | 46.02 | 37.59  | 49.76    | 50.64     | 42.56     | 54.92  | 35.43   | 45.57| 8  | 44.31| 8  | 44.96| 6  | 1.0504| 1   |
| KB1707     | 39.47     | 52.05 | 26.60  | 55.68    | 50.60     | 54.63     | 67.28  | 60.03   | 47.45| 6  | 46.30| 6  | 47.14| 3  | 0.2655| 5   |

Table 9: Adaptability measures of barley genotypes evaluated under MET (2019-20)

| Genotype   | IPC1  | IPC2  | IPC3  | IPC4  | IPC5  | IPC6  | ASV1  | RASV  | ASV  | RASV  | PRVG  | RPRVG  | HMPRVG  | R_HMPRVG  |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|------|-------|-------|-------|--------|----------|
| BH946      | 0.829 | 3.135 | -0.977| 0.639 | -1.867| 0.452 | 3.35  | 6     | 3.29 | 6     | 1.025 | 3     | 1.0034  | 4        |
| RD2994     | -3.041| -0.291| 0.781 | 1.734 | -0.516| -1.639| 4.31  | 7     | 3.63 | 7     | 1.024 | 5     | 1.0025  | 5        |
| DWRB137    | 0.194 | 2.298 | -0.954| 0.507 | 2.561 | -0.121| 2.31  | 3     | 2.31 | 3     | 1.067 | 1     | 1.0522  | 1        |
| PL906      | -0.111| 0.109 | -0.550| -1.921| -0.538| 0.251 | 0.19  | 1     | 0.17 | 1     | 1.025 | 4     | 1.0212  | 2        |
| BH902      | -1.673 | -1.236 | -1.096 | -2.524 | 0.098 | -0.363 | 2.67  | 4     | 2.34 | 4     | 0.937 | 7     | 0.9216  | 7        |
| RD2552     | -0.515 | -2.700 | -1.185 | 1.831 | 0.088 | 1.625 | 2.80  | 5     | 2.77 | 5     | 0.905 | 8     | 0.8762  | 8        |
| UPB1080    | -0.047 | 0.371 | 3.743 | -0.524 | 0.256 | 0.948 | 0.38  | 2     | 0.37 | 2     | 0.962 | 6     | 0.9464  | 6        |
| KB1707     | 4.365 | -1.686 | 0.238 | 0.258 | -0.082| -1.153| 6.39  | 6     | 5.45 | 6     | 1.055 | 2     | 1.0092  | 3        |
Table 10: Loadings of adaptability measures as per Principal Components (2019-20)

| Component | PC1   | PC2   |
|-----------|-------|-------|
| IPC1      | 0.1254| -0.2042|
| IPC2      | 0.2938| 0.1883 |
| IPC3      | -0.0183| 0.2418 |
| IPC4      | -0.0369| -0.0909|
| IPC5      | 0.0459| 0.0505 |
| IPC6      | -0.1364| 0.2567 |
| ASV1      | 0.0086| -0.4061|
| ASV       | 0.0103| -0.4005|
| Durgapur  | -0.1177| 0.1340 |
| Hisar     | 0.2628| -0.0319|
| Kamal     | 0.2558| 0.1946 |
| Ludhiana  | 0.1265| -0.1820|
| Modipuram | 0.2913| 0.0837 |
| Pantnagar | -0.0185| -0.1742|
| Tabiji    | -0.1020| -0.2308|
| Udaipur   | 0.2205| -0.2598|
| Average   | 0.2442| -0.0626|
| GM        | 0.2623| -0.0604|
| HM        | 0.3491| -0.0132|
| CV        | -0.2054| -0.3063|
| Sdev      | -0.1671| -0.3057|
| PRVG      | 0.3370| -0.1278|
| HMPRVG    | 0.3492| -0.0554|

% variation 32.52 20.31

Figure 2: Biplot analysis of adaptability measures for barley genotypes (2019-20)