Original Research Article

Yield Stability of Newly-Released Wheat Varieties Evaluated in Multi-Environment Trials in Bangladesh

ABSTRACT

One thousand six trials were conducted in the farmers' fields with four wheat varieties (BARI Gom 25, BARI Gom 26, BARI Gom 27 and BARI Gom 28) of 40 districts under 8 agricultural regions in Bangladesh during 2013-14. Objectives of this study were to evaluate the mean yield performance and yield stability of the newly released varieties in different regions of the country in different environmental status. Yield of 4 varieties significantly varied among the locations. The highest mean yield was obtained from Rangpur region (4275.15 kg ha^{-1}) followed by Jessore region (4266 kg ha^{-1}). Yield of these two regions were statistically similar but significantly higher than other regions. In AMMI analysis, AMMI-1 biplot showed that Rangpur and Rajshahi were favorable environments; Sylhet and Comilla were unfavorable environments. Among varieties, BARI Gom 26 and BARI Gom 25 were more stable and can be recommended for growing in poor environments. On the other hand BARI Gom 27 was more sensitive to changing production environments. In AMMI-2 biplot, Comilla, Sylhet and Dhaka were the most discriminating environments, while BARI Gom 26 and BARI Gom 25 were the more stable genotypes. The most suitable varieties for Rangpur, Rajshahi and Mymensingh were BARI Gom 26; BARI Gom 25 for Sylhet; BARI Gom 27 for Comilla, Jessore and Barishal while variety BARI Gom 28 was suitable for Dhaka. Among the varieties, BARI Gom 26 and BARI Gom 25 had higher mean grain yield values coupled with small positive IPCA 1 scores and hence these are recommended for all locations.

Key words: Yield stability; *Triticum aestivum*; Adaptability; AMMI analysis

1. INTRODUCTION

The agricultural sector plays a very significant role in the Bangladesh economy as well socially and culturally agriculture accounts for about 20% of the country's Gross Domestic Product (GDP). In addition agriculture provides more than 60% of the national employment. The agriculture sector is an important tool to reach different goals stated in the Poverty Reduction Strategy as it directly reaches the poorest in the rural areas, proving both food and cash at the same time. Wheat is one of the major cereals in Rabi (winter) season in the northwestern part of Bangladesh (Sarker et al. 2014) and its consumption is increasing 3% per year (Karim *et al.*, 2010). The tragic irony is that the wheat production in the country (1.4 million tons, USDA 2014) is much bellow than the requirement (4.0 million ton). This deficit accounts about 75% of country's annual consumption and it is met, through imports (Hussain, 2012). Wheat production has increased steadily from around 0.115 million tons in 1971-72 to 1.9 million tons in 1999 and then gradually decreased to 0.763 million tons in 2006-07 (BBS, 2007). This low production is mainly due to the reduction of area under wheat cultivation. The highest wheat growing area was 0.85 million hectares in 1999 which now came down to 0.45 (2013-14) million ha (BBS, 2014). Wheat is to compete with other profitable crops like Boro rice, corn, potato and winter vegetables which insisting farmers to push wheat crop in marginal lands from fertile ones and this is considered as the main reason for decreasing area under wheat (WRC, 2009). Yield was also decreasing due to cultivation of old varieties that are susceptible to leaf rust and BpLB, knowledge gap about recommended technologies (Sufian, 2005).

Adoption of Wheat Research Centre (WRC) developed technologies like heat tolerant and disease resistant/tolerant new varieties, timely seeding, use of recommended irrigation, fertilizers including boron and dolochun etc. are very important to increase yield (WRC, 2014). Use of power tiller operated seeder (PTOS) to confirm timely seeding and use of wheat thresher is also important to save the quality of seeds from early monsoon. WRC of Bangladesh Agricultural Research Institute (BARI) has released 28 varieties in conventional breeding approach and most of the later released varieties are better than previous one (Rashid *et al.*, 2004) in respect of yield, disease and terminal heat tolerance. But those varieties and other technologies are not being adopted by the farmers in a satisfactory rate due to their inadequate knowledge about the varieties and technologies and insufficient extension efforts (Pandit *et al.*, 2007).

Crop adaptability is commonly understood as wide or local adaptation as a result of high mean grain yield and yield stability across environments and seasons. On the other hand, yield stability of a cultivar is defined as consistency of yield response of variety(ies) across environments or seasons (Farshadfar et al. 2012). Varietal adaptability to environmental fluctuations is important for the stabilization of crop production on both region and season. Information on the genotype x environment interaction is essential to the successful evaluation of stable genotypes (Yan et al. 2000). Multi-environment trials (MET) are conducted to evaluate the yield stability performance of different genetic materials under different environmental conditions (Delacy et al. 1996, Yan et al. 2000). Oftentimes, genotypes subject to different environments show significant fluctuations on the yield responses. These changes are influenced by different environmental conditions commonly referred to as genotype-by-environment interaction (Allard & Bradshow 1964). The action of GE interaction makes genetic progress difficult since it minimizes the association of phenotypic and genotypic values (Comstock & Moll 1963). Hence, GE interaction should be exploited through selection of superior genotypes on specific location or avoided by selecting genotypes with wide adaptability and stable yield response across diverse locations (Ceccarelli 1989). Recently, several methods in analyzing genotype x environment (GE) interaction and MET data to reveal patterns of GE have been reported. These methods include regression coefficient (Finlay and Wilkinson, 1963), sum of squared deviations from regressions (Eberhart & Russel1966), stability of variance (Shukla 1972), coefficient of determination (Pinthus1973) coefficient of variability (Francis & Kanneber 1978), and multiplicative main effects and multiplicative interaction (AMMI) (Gauch & Zobel 1988, Zobel et al. 1988; Gauch 1992) which have been commonly used. Another method proposed by Yan et al. (2000) proposed another method called GGE biplot analysis for graphical display of GE interaction pattern in MET data. GGE biplot is an effective method based on principal component analysis (PCA) which graphically displays GE in a two-way table and allows visual examination of the relationship interactions among test environments, genotypes, and GE interaction. The main objective of this study was to evaluate the yield performance and yield stability of the newly released varieties in different regions of the country in different environmental status.

2. MATERIALS AND METHODS

One thousand six trials were conducted with 4 newly released wheat varieties viz., BARI Gom 25 & BARI Gom 26 (released 2010) and BARI Gom 27 & BARI Gom 28) (released 2012) in the farmers' fields of 40 districts out of 64 under 8 agricultural regions in 2013-14 (Table 1 & Fig. 1) in collaboration with Department of Agricultural Extension (DAE), Non-government Organizations (NGOs), On Farm Research Division (OFRD), Cereal Systems Initiative for South Asia (CSISA) & Agricultural Research Station (ARS) of BARI. Seven hundred twenty three trials were conducted in collaboration with DAE, 84 through NGOs, 48 through CSISA and 151 trials by BARI scientists (36 through WRC & ARS and 115 through OFRD). The pedigree of these varieties are BARI Gom 25 (ZSH 12/HLB 19//2*NL 297), BARI Gom 26 (ICTAL123/3/RAWAL87//VEE/HD2285), BARI Gom 27 (FRANCOLIN # 1) and BARI Gom 28 (CHIL/2*STAR/4/BOW/CROW//BUC/PVN/3/2*VEE#10). Each trial had a single variety with a plot size 800 sq.m. Each variety was established in one farmer's field. Only seed, fertilizers, signboard and printed documents on wheat production technologies were supplied to farmers. All other management practices were done by farmers. One day training was given to the farmers, related Sub Assistant Agricultural Officer (SAAOs), Scientific Assistance (SA)/ Scientific Assistances (SSAs), Upazila Agriculture Officers (UAOs) and Crop Protection Specialist (CPS) of the respective districts about trials, wheat production and seed preservation technologies. Seeds were sown from 10 November to 16 December 2013.

Yields were taken from 4 samples of 5 m^2 (total 20 m^2) areas from each trial. A format was supplied to farmers for sending data on yield, sowing & harvesting date, no. of irrigations, seed preservation, overall comments, etc. through supervising officials of DAE, NGOs and BARI.

In AMMI model the contribution of each genotype and each environment to the GEI is assessed by use of the biplot graph display in which yield means are plotted against the scores of the IPCA1 (Zobel *et al.* 1988). The stability parameters and regression coefficient (bi) were estimated according to Eberhart and Russell (1966). All the data were subjected to analysis using statistical analysis package software Cropstat version 7.2 after Zobel *et al.* (1988).

The AMMI model does not make provision for a quantitative stability measure, such a measure is essential in order to quantify and rank genotypes according their yield stability, the following measure was proposed by Purchase (1997):

$$ASV = \sqrt{[\frac{IPCA1 sum\ of\ squre}{IPCA2\ sum\ of\ squre}(IPCA1\ score)]^2 + [IPCA2\ score]^2}$$

Table 1 Region-wise distribution of new wheat variety trials in 2013-14

Sl #	Region	Conducted through					
		DAE	NGO	WRC & ARS	CSISA	OFRD	Total
1	Rangpur	204	36	12	0	0	252
2	Rajshahi	190	36	12	0	0	238
3	Jessore	116	0	0	0	24	140
4	Mymensingh	72	0	12	36	12	132
5	Dhaka	24	0	0	0	15	39
6	Comilla	12	0	0	0	12	24
7	Sylhet	12	0	0	0	12	24
8	Barisal	93	12	0	12	40	157
	Total	723	84	36	48	115	1006

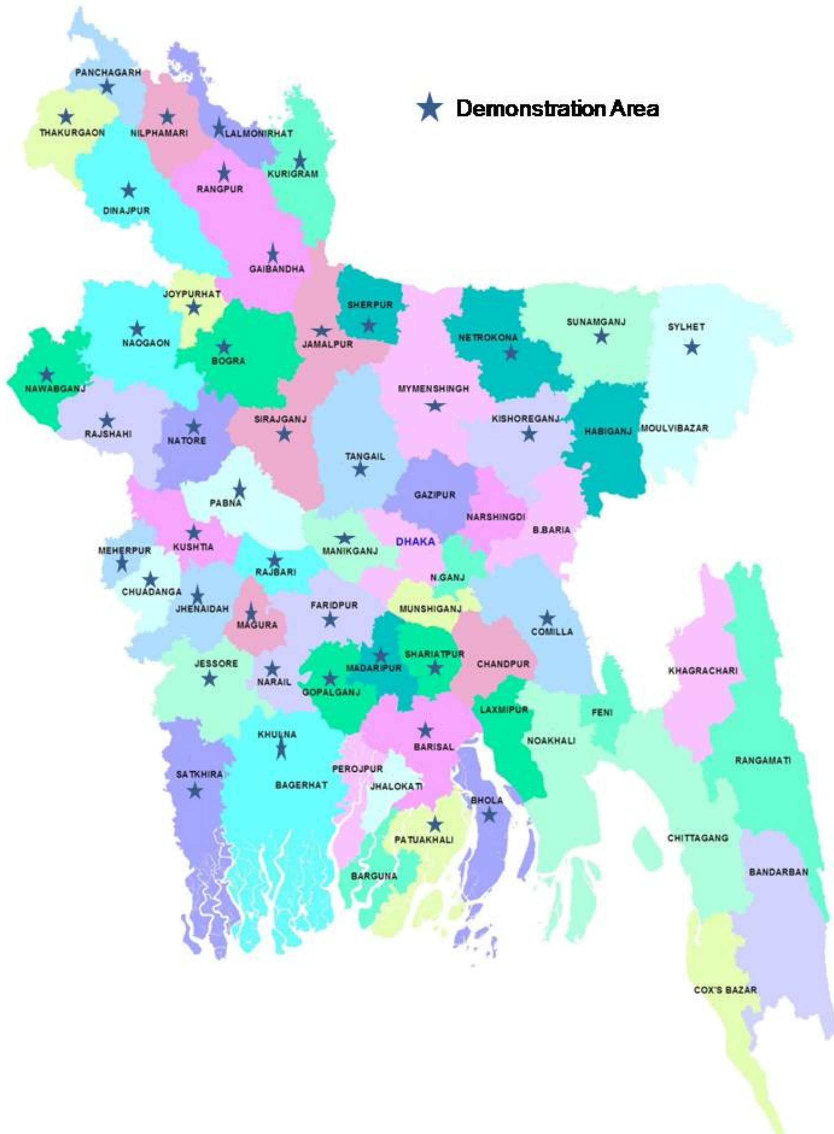

Fig. 1. District-wise distribution of wheat variety trials during 2013-14 in Bangladesh

3. RESULTS AND DISCUSSION

3.1 Agronomic Performance

Yield of 4 varieties significantly ($F_{(8,20)}$ =8.65; P= <0.001) varied among the locations. The highest mean yield was obtained from Rangpur region (4275.15 kg ha^{-1}) followed by Jessore region (4266 kg ha^{-1}). Yield of these two regions were statistically similar but significantly higher than other regions (Table 2). The lowest mean yield was recorded in Sylhet region due to the water stress. The yield of BARI Gom 26 was highest (4725 kg ha^{-1}) in Rangpur region followed by BARI Gom 28 (4530 kg ha^{-1}) in Dhaka region and BARI Gom 25 (4370.70 kg ha^{-1}) at Jessore region. At Rajshahi region, the yield of BARI Gom 26 was highest (4302.29 kg ha^{-1}) followed by BARI Gom 25 (4006.71 kg ha^{-1}). The BARI Gom 27 produced lowest yield (27.20 kg ha^{-1}) in Sylhet region. The highest mean yield was recorded in BARI Gom 26 (3977.83 kg ha^{-1}) followed by BARI Gom 28 (3828.01 kg ha^{-1}), BARI Gom 25 (3819.31 kg ha^{-1}) and BARI Gom 27 (3709.78 kg ha^{-1}). BARI Gom 26 produced the highest yield but statistically ($F_{(3,20)}$ =1.42; P= 0.265) similar with all other varieties.

Table 2. Region-wise results of variety trials conducted through all organization (DAE, OFRD, ARS, WRC, CSISA & NGOs) in 2013-14

Districts	No. of demo.	Results of demo.	BARI Gom25 (kg/ha)	BARI Gom26 (kg/ha)	BARI Gom27 (kg/ha)	BARI Gom28 (kg/ha)	Mean yield ± SE (kg/ha)	Seeds pres. By farmers (kg)
Rangpur	252	98	4002.50	4725.00	4116.50	4256.60	4275.15±4.45 a	17281
Rajshahi	238	118	4006.71	4302.29	3739.40	3895.71	3986.03±3.85 abc	23423
Jessore	140	140	4370.70	4212.80	4157.00	4324.40	4266.23±2.48 a	27925
Mymensingh	132	132	3692.88	3755.25	3363.63	3703.63	3628.84±3.34 bdc	11780
Dhaka	39	39	3983.33	4180.00	4050.00	4530.00	4185.83±3.90 ab	4770
Comilla	24	19	3290.00	3445.00	3840.00	3325.00	3475.00±3.97 cd	1807
Sylhet	24	10	3715.00	3640.00	2720.00	2950.00	3256.25±5.57 d	1170
Barishal	157	93	3493.33	3562.33	3691.67	3638.75	3596.52±2.33 bdc	7270
Total	1006	**649**						**95426**
Mean			**3819.31**	**3977.83**	**3709.78**	**3828.01**		

The farmers have preserved 95426 kg seeds of the new varieties. The highest seed stored (27925 kg) in Jessore region followed by Rajshahi region (23423 kg). In total 50050 farmers of the same and neighbouring villages visited the trials and expressed their interest to collect seeds of new varieties in next year. The results demonstrated that all of 4 new varieties (BARI Gom 25, BARI Gom 26, BARI Gom 27 and BARI Gom 28) were preferred by the farmers.

3.2 Stability Performance

Adaptability of the new wheat varieties over wide ranges of environments (40 districts) were presented in Fig. 2 indicated that BARI Gom 25 and BARI Gom 26 were more stable than other varieties. These varieties had comparatively high yields in poor environment and can be recommended for growing in poor environments. BARI Gom 27 was more sensitive to changing production environments. It had low yields in poor and very high yields in better environments. This variety could be recommended for growing in better environments. BARI Gom 28 had average sensitivity to changing production environments.

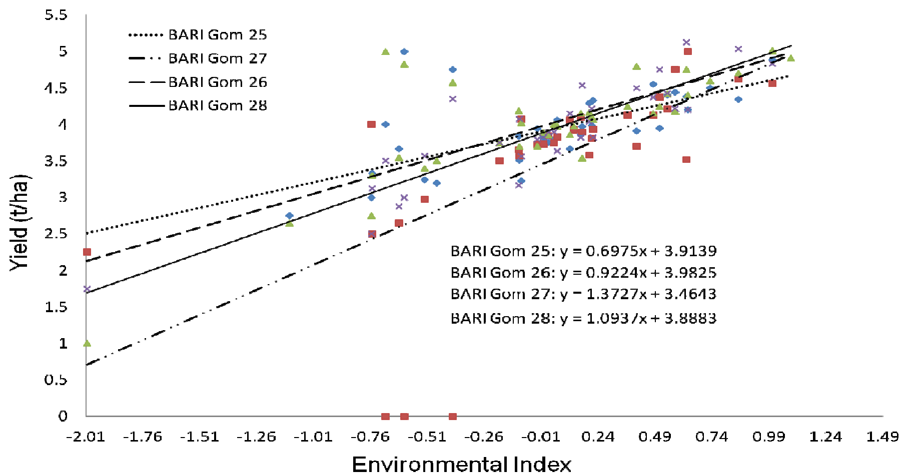

Fig. 2 Adaptability of the new wheat varieties conducted by DAE

3.3 AMMI Biplot Analysis

Table 3 reflects IPCA score and AMMI stability value (ASV). BARI Gom 28 showed the lowest scores in the IPCA 1, followed by BARI Gom 26 and BARI Gom 25. BARI Gom 27 scored the highest IPCA 1 value. Considering The AMMI stability value (ASV) that take into account the scores of the IPCA 2, the variety BARI Gom 28 appeared to be among those showing low ASV. The variety BARI Gom 26 became the second lowest in ASV. With regards to locations, Rangpur and Jessore gave the lowest IPCA 1 scores whereas Mymensingh, Rajshai and Dhaka gave medium score and Comilla scored the highest IPCA 1 value.

Table 3. IPCA axes scores for genotypes and environments, AMMI stability value (AVS) and mean performance for grain yield (kg/ha) of 4 wheat varieties grown at 8 agricultural regions in Bangladesh (2013-14)

Variety	Yield	Rank	IPCA1 Score	IPCA2 Score	bi	ASV	Rank	Location	IPCA1 Score
BARI Gom 25	3819.31	3	16.71	8.955	0.697	57.7	3	Rangpur	0.52
BARI Gom 26	3977.83	1	13.01	-4.08	0.994	44.6	2	Rajshahi	6.39
BARI Gom 27	3709.78	4	-20.75	11.89	1.007	71.8	4	Jessore	-1.52
BARI Gom 28	3828.01	2	-8.959	-16.76	1.303	34.9	1	Mymensingh	3.43
								Dhaka	-8.32
								Comilla	-14.56
								Sylhet	23.22
								Barishal	-9.15

The AMMI1 biplot provide a graphical representation of the relationship between the first interaction principal component axis (AMMI component 1) and mean of varieties and location (Kempton 1984) with the biplot according for up to 91.5% of the treatment sum of squares (Fig. 3). Variety and locations on the same parallel line, relative to ordinate, have similar yields and a variety or location on the right side of the midpoint of this axis has higher yields than those on the left hand side (Zobel *et al.* 1988). According to AMMI-1 biplot analysis (Fig. 3), environments showed high variation in both main effects and interactions (IPCA1). While the Rangpur and Jessore had low interaction; Sylhet and Comilla were highly interactive. Rajshahi was the most favorable environment and Comilla and Barishal was the least favorable environments, while Mymensingh and Dhaka were the average environments. Environment Rangpur and Jessore with IPCA1 scores near zero had no interaction effects, Variety BARI Gom 26 and location Rangpur combinations with IPCA1 scores of the same sine produced positive specific interaction effects and BARI Gom 28 and location Jessore combinations with IPCA1 score produced positive specific interaction effects. This result is in agreement with the findings of Adugna *et al*., (2007) and Anandan *et al*., (2009).

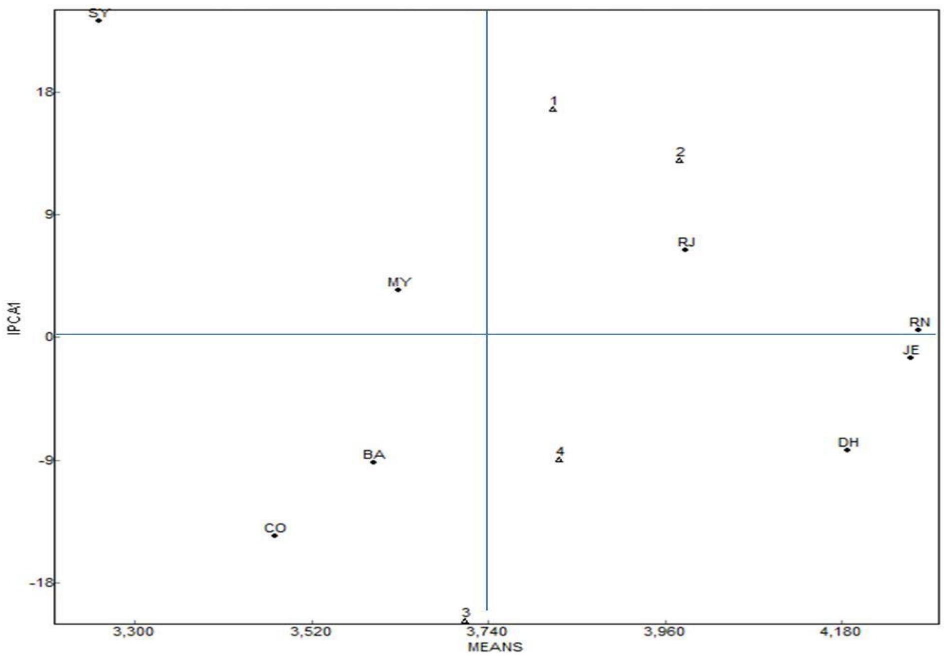

Fig. 3. AMMI 1 model for grain yield (kg ha-1) showing the means of varieties and locations against their respective IPCA 1 scores. RN = Rangpur, RJ= Rajshahi, JE= Jessore, MY= Mymensingh, DH= Dhaka, CO= Comilla, SY= Sylhet and BA= Barishal, 1 = BARI Gom 25, 2 = BARI Gom 26, 3 = BARI Gom 27, 4 = BARI Gom 28, Δ = Variety combination (genotypes), ● = Locations (8)

Consequently, the variety BARI Gom 26 was the high yielder followed by BARI Gom 28, BARI Gom 25 and BARI Gom 27. The AMMI1 estimation had a profound effect in producing clear and stratified ranking patterns and on this basis BARI Gom 26 and BARI Gom 25 would be considered more adapted to a wide range of environments than the rest of the varieties. BARI Gom 27 showed low yield and unstable and BARI Gom 28 showed high yield but moderately stable. Dixon and Nukenine (1997) and Crossa *et al.* (1991) obtained a similar stratification in cassava and wheat genotypes, respectively.

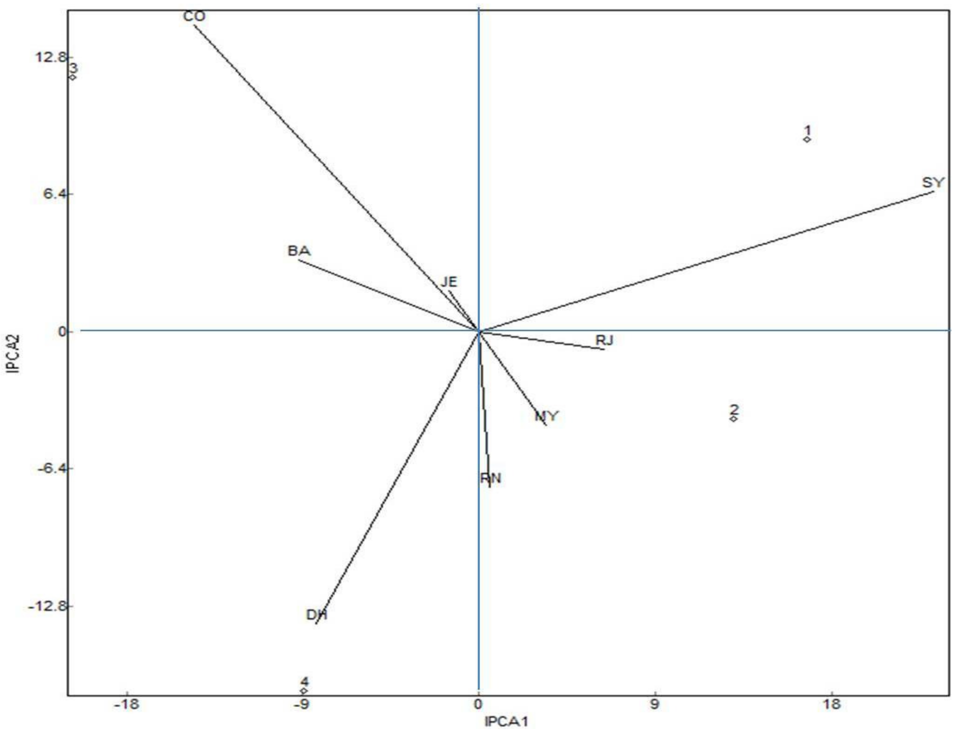

Fig. 4. AMMI 2 model for grain yield (kg ha-1) showing the IPCA scores of wheat varieties planted across locations.

According to AMMI-2 biplot analysis (Fig. 3), the varieties (and environments) that are located far away from the origin are more responsive. BARI Gom 27 BARI Gom 28 appeared unstable due to their dispersed position. Comilla, Sylhet and Dhaka were the most differentiating environments, while BARI Gom 27 and BARI Gom 28 were the most responsive genotypes. BARI Gom 26 and BARI Gom 25 appeared to be more stable when plotting the IPCA1 and IPCA2 scores. Genotypes and environments that fall in the same sectors interact positively; in contrast if they fall in opposite sectors interact negatively. If they fall into adjacent sectors, interaction is somewhat more complex. In this case, the best genotype with respect to sites Dhaka was BARI Gom 28 but unsuitable for Sylhet. Genotype BARI Gom 25 was suitable for Sylhet but unsuitable for Dhaka. With respect to Comilla, Barishal and Dhaka, genotype BARI Gom 27 was particularly suitable but unsuitable for Rajshahi and Mymensingh, while genotype BARI Gom 26 was well fit for Rajshahi and Mymensingh. For multivariate approach, the AMMI model is better for partitioning the G x E into the causes of variation, which ease identification of environments' potential and is used to identify superior genotypes either with specific adaptation or wide adaptation (Anandan *et al*., 2009., Crossa, 1990 and Kempton,1984).

4. CONCLUSION

The AMMI statistical model has been used to diagnose the G × E interaction pattern of grain yield of newly released wheat varieties. The most suitable varieties for Rangpur, Rajshahi and Mymensingh were BARI Gom 26; BARI Gom 25 for Sylhet; BARI Gom 27 for Comilla, Jessore and Barishal while variety BARI Gom 28 was suitable for Dhaka. BARI Gom 26 and BARI Gom 25 were hardly affected by the G × E interaction and thus will perform well across a wide range of environments and these can be recommended for all locations. Locations, such as Rangpur and Rajshahi, these could be regarded as a good selection site for wheat cultivation due to stable yields.

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