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LEVERAGING FROM GENOTYPE BY ENVIRONMENT INTERACTION FOR BREAD WHEAT PRODUCTION IN EASTERN AFRICA

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ABSTRACT

Developing high yielding and stable genotypes for wide and specific adaptation is important in wheat (*Triticum aestivum* L.) production. The objective of this study was to exploit the gains from genotype by environment interaction for increased bread wheat production in eastern Africa. Thirty-three advanced bread wheat lines, along with two check varieties (Danda'a and Hidasse) were evaluated at ten locations in Ethiopia and Kenya. The experiment was laid out in alpha lattice design in three replications. The analysis of variance for AMMI model of grain yield showed that environment, genotypes and genotype by environment interaction (GEI) effects were highly significant ($P<0.01$), and accounted for 62.4, 4.8 and 15.8% of the total sum of squares variations, respectively. High environmental and significant GEI indicated that the environment had major influence for inconsistent performance. Grain yield of the genotypes ranged from 1.58 t ha^{-1} (G30) to 9.05 t ha^{-1} (G31). Genotypes G31, G18 and G35 were the best performing lines across environments. The AMMI biplot, using the first two principal components, showed that testing sites Njoro and Arsi-Robe highly discriminated the tested genotypes. Njoro was negatively interacting with high yielding genotypes, and was a different environment from any of the testing locations of Ethiopia for these sets of genotypes. It may be difficult to develop high yielding and stable varieties for the two countries, but one should look for specific adaptation. Genotypes G31 and G18 produced high grain yield, with low stability across locations which were favouring high yielding environments. However, G21 and G8 had above mean grain yield and good stability across locations. Therefore, wheat breeding for specific adaptability is very important to exploit the genetic advantage of specific genotypic performances across the region. However, extensive testing considering many locations across East African countries is vital for delineating and exploiting wheat environments for marked developments.

Key Words: AMMI, GEI, *Triticum aestivum*

RÉSUMÉ

Le développement de variétés stables et a rendements élevés dans le but d'adoption a grande échelle, est important dans la production du blé tendre (*Triticum aestivum* L.). L'objectif de cette étude est d'exploiter l'effet de l'interaction entre génotypes et environnements (IGE) pour accroitre la production du blé tendre en Afrique de l'Est. Trente-trois lignées avancées de blé tendre ensemble avec deux variétés de référence (Danda'a and Hidasse) ont été évaluées dans dix locations. Le plan expérimental était en treillis alpha avec trois répétitions. La méthode de l'interaction des effets additifs and multiplicative (AMMI) avait été utilisée pour le rendement en grain. L'analyse des variances selon ce modèle a montré que l'environnement, le génotype et l'interaction des deux ont des effets significatifs sur le rendement en grains ($P<0,01$), et contribuent respectivement, 62,4 ; 4,8 et 15,8% à la variation totale. Un effet important de l'environnement et une interaction significative indiquent que l'environnement a un rôle majeur dans les différences de rendements. Les rendements en grains des génotypes testes varient de 1.58 t ha^{-1} (G30) a 9.05 t ha^{-1} (G31). Les génotypes G31, G18 et G35 étaient de façon générale, les plus performants. Le biplot génère par AMMI a montré que les sites Njoro and Arsi-Robe discriminent nettement les génotypes testés. Njoro était négativement corrélé avec les génotypes a rendement élevé et constituait un environnement différent de toutes les autres locations de l'Ethiopie ou ces génotypes ont été testes. Il peut s'avérer difficile de développer des variétés à haut rendement et stable dans les deux pays, mais l'on doit rechercher des variétés adaptées à chaque milieu. Les génotypes G31 et G18 ont eu des rendements élevés mais n'ont pas été stables dans les milieux qui se sont avérés à haut rendement. Néanmoins, G21 et G8 ont eu des rendements plus élevés que la moyenne et se sont montres stables d'un milieu à un autre. Il s'ensuit donc que le développement de variété de blé tendre adapté à chaque milieu serait une bonne approche pour une exploitation efficiente des avantages génétiques des génotypes à haute performance. Néanmoins, il est important de faire des essais extensifs prenant en compte plusieurs localités des pays de l'Afrique de l'Est afin d'explorer et identifier les milieux propices au blé tendre.

Mots Clés: AMMI, IGE, *Triticum aestivum*

INTRODUCTION

Wheat (*Triticum aestivum* L.) is grown worldwide on roughly 200 million hectares, with average total production of 700 million metric tonnes (FAOSTAT, 2014). Global average productivity is around 3 t ha^{-1}, with high variability among countries and regions. It is the most important food grain for humans, supplying 40% of the world's food and 25% of calories consumed in developing countries. In Eastern Africa, wheat is one of the most important cereal crops cultivated in a wide range of agro-ecologies. Despite the enormous economic and dietary values of the crop in the region, the average yield has remained extremely low. This has been attributed to multifaceted biotic and abiotic factors, including insufficient and erratic rainfall, poor agronomic practices, poor soil fertility, diseases and insect pests (Hailu *et al.,* 1991).

The development of cultivars or varieties, which can be adapted to a wide range of environments, is the ultimate goal of plant breeders in a crop improvement programme. The adaptability of a variety over diverse environments is usually tested by the degree of its interaction with different environments. A variety or genotype is considered to be more adaptive or stable if it has a high mean yield, but with a low degree of fluctuation in yielding ability when grown in diverse environments. Hence, the genotype-by-environment interaction is probably the main reason why traditional plant breeding failed to develop widely adaptable varieties (Ceccarelli *et al.,* 2003). Developing high yielding and stable genotypes for wide and specific adaptation are important in wheat variety development strategies, and evaluation across locations would form a basis for breeding. The objective of this study was to exploit the gains from genotype by environment interaction for increased bread wheat production in eastern Africa.

MATERIALS AND METHODS

Thirty three bread wheat advanced lines (Table 1), along with two check varieties (Danda'a and Hidasse) were evaluated in different locations of Ethiopia (9 location) and Kenya (1 location), during 2013/2014 main cropping seasons (Table 2). These locations represent the major wheat growing agro-ecologies of the two countries ranging from mid to high altitude. The genotypes were planted in alpha lattice (5x7), with three replications in all experimental sites. Each plot had six rows of 2.5 m length, with a spacing of 0.2 m between rows and 3-5 cm within rows. Planting date of each location was at the onset of the main rainy season. Fertiliser and other agronomic practices were carried out as per the recommendation of each location. Grain yield data were collected from the middle four rows and measured after moisture of the seed is adjusted to 12.5%.

Statistical analysis. Separate analysis of variance for grain yield, for each location, was performed prior to combined analysis using AGROBASE 20 (Agronomix Software Inc., 1999). The mean squares of genotype by environment interactions (GEI) for grain yield were used to test the effect

TABLE 1. Bread wheat genotypes evaluated across ten locations in 2013/2014 cropping seasons in eastern Africa

Code	Designation	Pedigree
G1	Danda'a	KIRITATI//2*PBW65/2*SERI.1B
G2	ETBW 6832	CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/HAR311
G3	ETBW 6837	CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/FH6-1-7
G4	ETBW 6839	CAL/NH//H567.71/3/SERI/4/CAL/NH//H567.71/5/2*KAUZ/6/PASTOR/7/YANAC/8/CAL/NH//H567.71/3/SERI/4/CAL/NH//H567.71/5/2*KAUZ/6/PASTOR
G5	ETBW 6840	PRL/2*PASTOR*2//FH6-1-7
G6	ETBW 6841	PBW343*2/KUKUNA*2//FRTL/PIFED
G7	ETBW 6845	ATTILA*2/PBW65*2//MURGA
G8	ETBW 6847	ROLF07*2/5/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES
G9	ETBW 6848	ROLF07*2/5/FCT/3/GOV/AZ//MUS/4/DOVE/BUC
G10	ETBW 6850	FRNCLN/ROLF07
G11	ETBW 6852	ROLF07/MUU
G12	ETBW 6853	BECARD/5/PGO//CROC_1/AE.SQUARROSA (224)/3/2*BORL95/4/CIRCUS
G13	ETBW 6861	WAXWING*2/HEILO
G14	ETBW 6862	KIRITATI/4/2*BAV92//IRENA/KAUZ/3/HUITES
G15	ETBW 6866	KLDR/PEWIT1//MILAN/DUCULA
G16	ETBW 6869	MURGA//WAXWING/KIRITATI
G17	ETBW 6870	ATTILA*2/PBW65//MURGA
G18	ETBW 6871	ROLF07*2/4/CROC_1/AE.SQUARROSA (205)//BORL95/3/2*MILAN
G19	ETBW 6875	WAXWING/KIRITATI*2//YANAC
G20	ETBW 6876	CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/HAR311
G21	ETBW 6882	PRL/2*PASTOR*2//FH6-1-7
G22	ETBW 6883	FINSI/METSO//FH6-1-7/3/FINSI/METSO
G23	ETBW 6886	KAUZ/PASTOR//PBW343/3/HAR311/5/OASIS/SKAUZ//4*BCN/3/PASTOR/4/KAUZ*2/YACO//KAUZ
G24	ETBW 6890	ATTILA*2/PBW65*2//MURGA
G25	ETBW 6911	REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES/5/PVN
G26	ETBW 6921	ALTAR 84/AE.SQUARROSA (221)//3*BORL95/3/URES/JUN//KAUZ/4/WBLL1*2/5/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES
G27	ETBW 6928	KIRITATI/4/2*BAV92//IRENA/KAUZ/3/HUITES
G28	ETBW 6932	SKAUZ/BAV92//2*WBLL1*2/KKTS
G29	ETBW 6937	AGUILAL/FLAG-3
G30	ETBW 6939	UTIQUE 96/FLAG-1
G31	ETBW 6943	SKAUZ/BAV92/3/CROC-1/AE.SQUARROSA (224)//OPATA
G32	ETBW 6947	WON-D 82/3/NS732/HER//KAUZ'S'=(FIDIYA-26)
G33	ETBW 6948	REBWAH-12/ZEMAMRA-8
G34	ETBW 6953	CROW'S'/BOW'S' -3-1994/95//TEVEE'S'/TADINIA
G35	Hidasse	YANAC/3/PRL/SARA//TSI/VEE#5/4

ETBW = Ethiopian Bread Wheat

TABLE 2. Description of the test locations for the wheat regional trial in eastern Africa

Location	Location code	Altitude (m.a.s.l)	Annual R.F (mm)	Representing agro-ecology
ADET	AD	2240	869	Optimum5 area
AREKA/ANGACHA	AR	2400	1656	Optimum area
BEKOJI	BK	2780	1020	Optimum and high RF area
HOLETTA	HO	2400	1100	Optimum area
JAMA	JM	2600	-	Low potential area
KULUMSA	KU	2200	820	Optimum area
MEHONI	MH	1754	500	Low potential area
NJORO	NJ	2120	-	Optimum area
SINANA	SN	2400	950	Optimum area
WUKRO	WK	2020	646.6	Optimum area

of genotypes. The genotypes (G) and environments (E) were subjected to AMMI analysis (Gauch and Zobel, 1997). The bi-plot constructed from main effect of means *vs* the first Interaction Principal Component Analysis Axis (IPCA) from AMMI analysis, was used to study the pattern of response of G, E and GEI. It was also used to identify genotypes with broad or specific adaptation to target environments for grain yield. AMMI-II biplot was constructed in the dimension of first two IPCA, using a singular-value decomposition procedure (Yan *et al.,* 2000). The genotypes were represented on the biplots as the points derived from their scores and the environments as the vectors from the biplot origin to their points. IRRISTAT (IRRI, 2005) was used to construct AMMI-1 and AMMI-2 biplot (Zobel *et al.,* 1988).

The equation for AMMI model is:

$$Y_{ij} = \mu + G_i + E_j + \sum_{n=1}^{N} \lambda_n \alpha_{in} \gamma_{jn} + e_{ij}$$

Where:

Y_{ij} is the yield of the i^{th} genotype in the j^{th} environment; μ is the grand mean; G_i and E_j are the genotype and environment deviations from the grand mean, respectively; λ_n is the eigen value of the PCA axis n; α_{in} and γ_{jn} are the genotype and environment principal component scores for axis n, respectively; N is the number of principal components retained in the model and e_{ij} is the error term.

AMMI model does not make provision for a specific stability measure to be determined; such a measure is essential in order to quantify and rank genotypes according to their yield stability. Since the IPCA-1 score contributes more to GEI sum of squares, it has to be weighted by the proportional difference between IPCA-1 and IPCA-2 scores to compensate for the relative contribution of IPCA-1 and IPCA-2 in to the total GEI sum of squares called AMMI stability values (ASV). The following measure proposed by Purchase (2000) was used:

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

RESULT AND DISCUSSION

Pooled analysis of variance for grain yield showed highly significant ($P < 0.05$) differences among genotypes, environment and genotype by environment interaction (Table 3). Highly significant differences between the G and E for grain yield indicate the presence of genetic variability among the genotypes, as well as the environments under study. The mean yield of genotypes across environment ranged from 1.58 t ha^{-1} (G30) to 9.05 t ha^{-1} (G31). The environmental index range from 2.30 t ha^{-1} (JAMA) to 6.93 t

TABLE 3. AMMI analysis of variance for grain yield (t ha^{-1}) of 35 genotypes tested ten locations of Ethiopia and Kenya

Source	Df	SS	MS	Sum of square explained (%)		
				Total variation	G x E explained	G x E cumulative
Environments	9	1459.185	162.132***	62.4		
Reps within Env.	20	31.943	1.597	1.4		
Genotype	34	112.089	3.297***	4.8		
Genotype x Env.	306	370.546	1.211***	15.8		
IPCA 1	42	122.74	2.922***		33.12	33.12
IPCA 2	40	71.975	1.799***		19.42	52.55
IPCA 3	38	64.437	1.696***		17.39	69.94
IPCA 4	36	40.161	1.116***		10.84	80.78
IPCA 5	34	24.277	0.714 ns		6.55	87.33
IPCA 6	32	19.454	0.608 ns		5.25	92.58
IPCA 7	30	12.241	0.408 ns		3.30	95.88
IPCA 8	28	9.278	0.331 ns		2.50	98.39
IPCA 9	26	5.983	0.230 ns		1.61	100
Residual	680	364.419	0.536	15.6		
Total	1049	2338.182				
Grand Mean = 4.12 t ha^{-1}		R-squared = 0.84	C.V = 17.7%	LSD (5%)= 0.37		

***, 0.001 '**' 0.01 '*' 0.05
*** = significant at P<0.001 and ns = non-significant; IPCA = Interaction principal component axis

ha^{-1} (BEKOJI) (Table 4). Significant GEI suggest a linier function of the additive environment effects, and was reflected by the change in the ranking order of genotypes under varying environments. Similar results were reported by earlier authors (Amin *et al.*, 2005; Ali, 2006; Cotes *et al.*, 2006). However, the overall performance of the genotypes depends upon the magnitude of GEI.

The highest grain yield over environments was recorded from BEKOJI location from G31, G21 and G5, respectively (Table 4). The standard check variety G35 (Hidasse) remained the third highest yielder over all locations; followed by G31 and G18. This revealed least two promising genotypes, better than the standard check based on grain yield potential across locations. Whereas, the other check, G1 (Danda'a), ranked 20th with a grain yield of 4.04 t ha^{-1}. BEKOJI, AREKA and KULUMSA were among the first three high yielding locations; while JAMA, WUKRO and SINANA were the lowest yielding environments.

Location tested in Kenya (NJORO) recorded average yield of 4.03 t ha^{-1}, which was near to the grand total mean 4.12 t ha^{-1} (Table 4). From the total treatment sum of square of the model, 62.4% was attributed to environmental effects, and the rest to genotypic effects (4.8%) and GEI (15.8%) (Table 3). The highly significant mean squares of environment, indicated that the environments were diverse, with large differences among means, causing most of the variation in grain yield. This shows the predominant influence of environments on the yield performance of wheat genotypes.

The GEI component of variation was partitioned into nine possible interaction principal component axes (IPCA) (Fig. 1). The F-test indicated that only the first four IPCA were highly significant (P<0.01) (Table 3). The first four significant IPCA explained 80.8% of the total GEI sum of square; while the remaining IPCA explained only 19.2%. Therefore, the first four significant IPCA can be taken as adequate dimensions for this dataset. However, the

TABLE 4. Mean grain yield (t ha^{-1}) of 35 genotypes tested across ten locations of Ethiopia and Kenya

Genotypes	KU	AD	AR	BK	JMA	WK	MH	NJ	SN	HO	Gen mean	Rank	IPCA-1	IPCA-2	ASV	Rank
G1	4.20	3.46	5.27	7.37	2.40	2.49	4.73	4.05	3.40	2.85	4.04	20	-0.182	-0.250	0.399	9
G2	4.92	3.54	4.23	6.42	2.13	2.87	4.06	4.99	4.15	3.90	4.18	15	-0.319	0.458	0.711	18
G3	3.51	3.49	4.73	5.93	2.71	2.96	4.90	4.08	3.31	3.02	3.93	22	-0.465	-0.332	0.860	25
G4	4.43	3.90	5.37	5.85	2.06	2.78	4.23	3.53	3.54	2.98	3.9	25	-0.135	-0.391	0.454	12
G5	4.38	4.69	5.87	8.45	2.18	3.03	3.88	3.17	3.69	4.39	4.44	9	0.723	-0.211	1.251	30
G6	4.34	3.77	4.45	6.02	2.62	3.17	3.97	4.41	2.94	2.58	3.89	27	-0.498	-0.157	0.864	26
G7	4.75	3.96	3.73	6.80	2.50	2.91	5.29	5.99	3.23	4.33	4.28	12	-0.667	0.723	1.348	33
G8	5.70	4.45	4.30	7.04	2.45	3.27	4.13	3.87	4.62	4.00	4.51	6	0.104	0.335	0.379	8
G9	4.48	4.21	4.10	5.81	1.96	2.50	5.47	4.41	3.28	3.37	4.07	19	-0.521	0.145	0.900	27
G10	5.39	4.11	5.59	6.68	3.00	2.83	4.12	3.75	3.75	2.42	4.19	14	-0.053	-0.420	0.430	10
G11	3.02	3.95	6.12	6.36	2.28	3.23	4.27	2.70	2.59	1.61	3.57	34	-0.044	-1.276	1.278	31
G12	4.86	4.09	5.04	6.69	1.71	2.90	3.82	4.13	3.47	2.50	3.91	24	-0.112	-0.185	0.266	6
G13	6.08	4.60	5.48	8.30	2.26	2.75	3.81	2.05	4.49	4.96	4.44	8	1.108	0.169	1.897	35
G14	3.05	3.92	4.20	5.49	2.67	3.01	4.52	3.57	3.74	3.78	3.92	23	-0.349	-0.209	0.631	15
G15	4.60	4.10	5.22	7.09	1.89	3.09	3.29	5.00	3.14	3.66	4.11	18	-0.097	0.106	0.196	4
G16	3.43	3.58	3.51	6.42	1.94	3.21	4.54	4.07	2.37	4.13	3.64	33	-0.322	0.308	0.630	14
G17	3.99	3.54	4.96	6.47	2.13	2.53	3.35	4.56	3.25	3.17	3.77	31	-0.190	-0.044	0.327	7
G18	4.09	4.77	6.11	7.94	3.17	2.71	4.35	4.12	4.30	5.60	4.59	2	0.467	-0.027	0.797	21
G19	6.00	4.22	5.33	6.78	2.49	2.92	4.00	5.76	3.59	3.87	4.48	7	-0.347	0.375	0.701	17
G20	5.41	3.58	4.05	6.09	2.20	2.85	4.33	4.97	3.71	3.90	4.13	16	-0.435	0.553	0.925	28
G21	4.80	4.64	4.76	8.67	2.61	2.39	5.43	4.35	3.63	4.35	4.54	5	0.275	0.321	0.568	13
G22	3.57	4.10	4.76	6.55	2.10	2.77	4.55	3.91	2.99	4.68	4.03	21	-0.032	0.077	0.094	2
G23	4.79	4.20	6.52	7.35	1.78	2.72	4.76	3.42	4.49	3.50	4.28	13	0.386	-0.501	0.827	23
G24	4.77	3.59	3.86	6.75	2.21	2.29	3.68	4.81	3.13	3.74	3.89	26	-0.218	0.577	0.686	16
G25	4.13	3.75	5.42	8.35	2.57	3.06	3.90	4.30	4.71	4.72	4.55	4	0.423	0.125	0.732	20
G26	5.12	3.98	5.42	7.07	2.04	2.81	5.27	4.30	3.67	3.54	4.31	11	-0.075	-0.046	0.136	3
G27	2.91	4.27	5.09	5.96	2.43	3.46	4.19	4.22	3.49	3.26	3.85	29	-0.392	-0.523	0.849	24
G28	4.58	4.42	5.25	7.14	1.98	2.98	3.45	3.69	3.97	3.31	4.13	17	0.231	-0.187	0.436	11
G29	5.44	3.63	4.77	8.39	2.61	2.42	4.26	2.32	4.33	5.11	4.39	10	0.940	0.402	1.653	34
G30	5.23	3.74	4.64	5.99	1.58	2.20	4.56	3.04	3.02	3.20	3.85	30	0.025	0.032	0.053	1
G31	4.38	4.54	5.36	9.05	3.15	3.27	5.39	4.11	4.35	5.24	4.96	1	0.469	0.137	0.811	22

TABLE 4. Contd.

Genotypes	KU	AD	AR	BK	JMA	WK	MH	NJ	SN	HO	Gen mean	Rank	IPCA-1	IPCA-2	ASV	Rank
G32	3.08	3.97	4.45	6.02	2.58	2.28	4.59	3.41	3.53	3.97	3.75	32	-0.106	-0.146	0.232	5
G33	3.89	3.63	5.32	7.48	1.83	2.62	3.23	3.45	2.97	4.06	3.86	28	0.428	-0.052	0.732	19
G34	3.79	3.08	4.01	4.88	2.11	2.87	4.39	4.31	3.07	2.50	3.55	35	-0.771	-0.124	1.321	32
G35	6.20	5.68	6.01	8.88	2.32	3.06	4.93	4.37	4.48	4.98	4.55	3	0.586	0.238	1.027	29
ENV Mean	4.49	4.03	4.95	6.93	2.30	2.83	4.33	4.03	3.61	3.75						
IPCA-I	0.21	0.10	0.53	1.47	-0.39	-0.57	-0.69	-1.66	0.31	0.69						
IPCA-II	0.83	-0.34	-1.43	0.29	-0.33	-0.55	-0.20	0.698	-0.04	1.08						

AD = Adet, AR = Areka, BK = Bekoji, HO = Holetta, JM = Jama, KU = Kulumsa, MH = Mehoni, NJ = Njoro, SN = Sinana, WK = Wukro

prediction assessment indicated that AMMI model, with only two IPCA, was the best predictive model (Yan *et al.*, 2002).

AMMI-1 biplot for grain yield of 35 wheat genotypes and ten locations plotted from the main effect against IPCA-1 scores of the genotypes and environment are presented in Figure 1. The IPCA-1 scores ranged from 1.472 down to -1.656; and grain yield means from 2.83 up to 6.93 t ha^{-1}, which explained 87.6% of the total sum of square. Locations were dispersed widely in all quadrants, more than the genotypes in the biplot (Fig. 1). The lowest IPCA-1 values were scored by G11, G22 and G30. However, these genotypes scored lower grain yields across tested locations than G31, G18 and G35. On the other hand, G13, G29 and G34 scored the highest IPCA-1 and were non-stable, except for G34. The other genotypes showed better grain yield performance across the locations (Table 4).

All location and genotypes having the same sign of IPCA-1 score, interacted with each other positively, and different IPCA-1 score signs interacted negatively (Yan *et al.,* 2002). Therefore, Bekoji, Areka, Kulumsa, Adet, Sinana and Holeta interacted positively with the highest yielding genotypes G31, G18 and G35; and negatively with G11, G16 and G34. Njoro negatively interacted with the high yielding genotypes, across locations. This made it complicated to develop high yielding and stable varieties for the two countries (Fig. 1).

In addition, AMMI-2 biplot generated by using the first two interaction principal component axes (IPCA 1 and 2) used to visual interpretation of the GEI patterns and identify genotypes or locations that exhibit low, medium or high levels of interaction effects (Yan, 2002). Accordingly, Areka, Njoro, Holeta and Bekoji were the most discriminating environments among the genotypes evaluated, as indicated by the longer vectors projected from the origin, indicating that these locations gave good information among genotypes. On the contrary; Sinana, Adet, Jama and Mehoni identified, as a least interactive environment with the tested genotypes, indicated lower interaction of these locations with the genotypes evaluated. Njoro had a different environment from any of the tested locations from Ethiopian (Fig. 2).

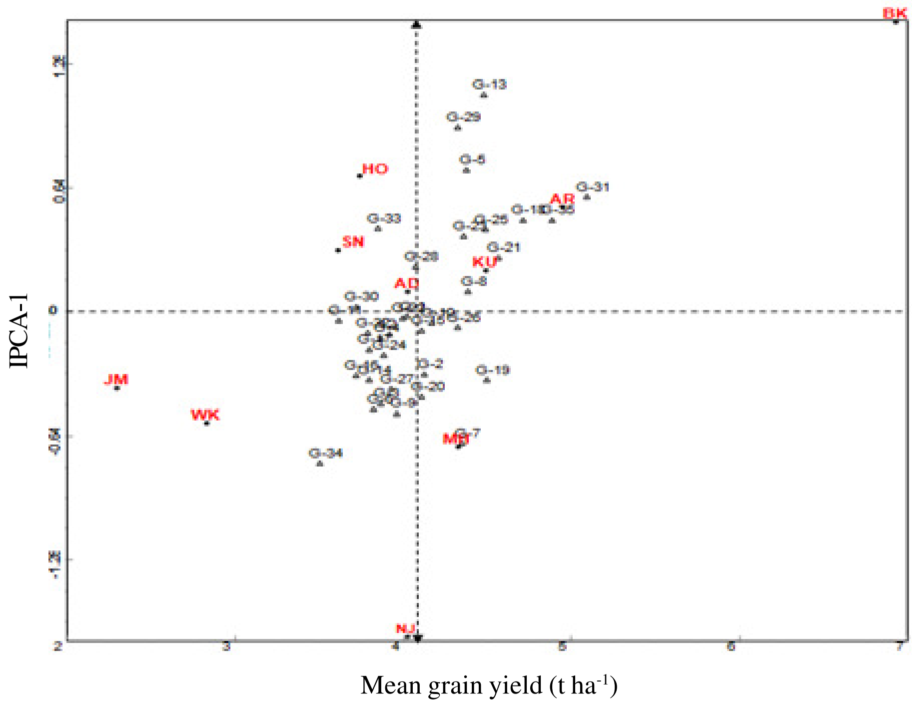

Figure 1. AMMI-1 biplot for grain yield of 35 wheat genotypes evaluated in Ethiopia and Kenya.

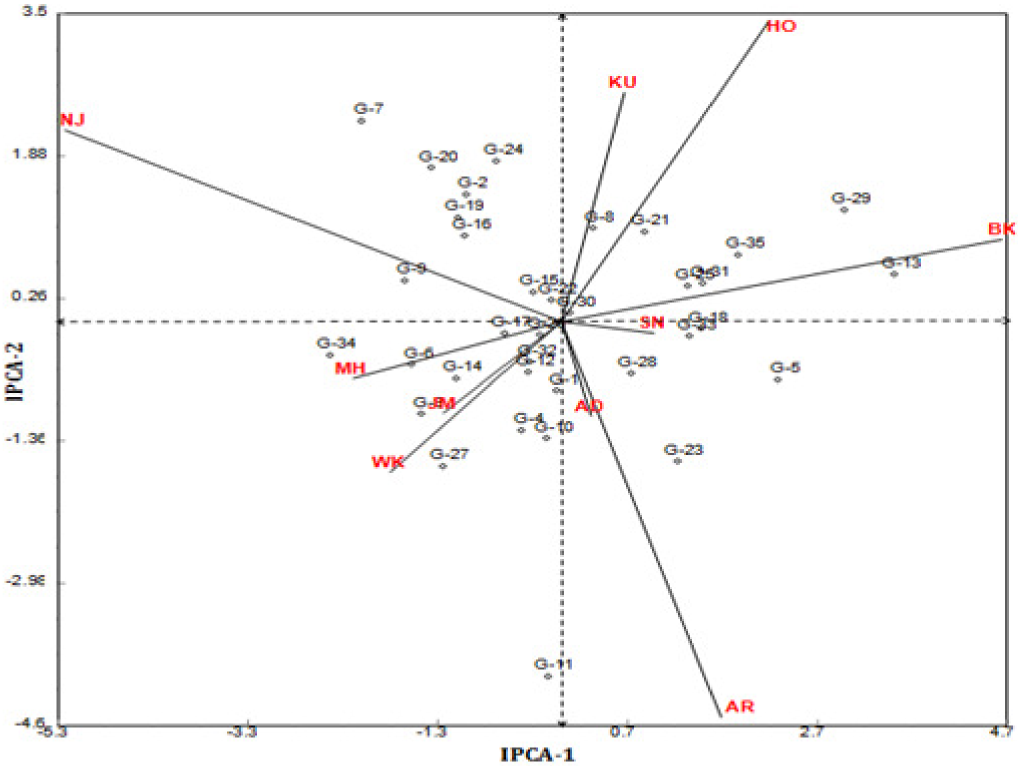

Figure 2. AMMI-2 interaction biplots for grain yield of 35 wheat genotypes tested in Ethiopia and Kenya.

Genotypes near the origin were non-sensitive to environmental interactive forces; and those distant from the origin were sensitive and had large interactions (Samonte *et al.,* 2005). Accordingly, genotypes G30, G26, G22 and G15 are non-sensitive to environmental interactive forces; and hence, these genotypes are considered as stable genotypes. Whereas G11, G7, G29 and G13 were highly influenced by the interactive force of environment and sensitive to environmental changes, so these varieties were considered as unstable genotypes due to the long projections from the origin (Fig. 2).

AMMI stability value (ASV). Genotypes with least ASV scores were more stable than those with higher ASV (Purchase *et al.,* 2000). Accordingly, genotypes with small ASV values i.e. G30, G22 and G26, were found to be stable, except G26. All the genotypes had low grain yield performance across locations (Table 4). The most unstable genotypes according to the ASV approach were G13, G29 and G7, having high ASV values. However, these genotypes had above average grain yield potentials. Therefore, genotypes having high ASV correlated with high yield performance and those with low ASV correlated with low yield potential.

CONCLUSION

GEI between tested locations across Ethiopian and Kenyan were very high. It will be difficult to develop high yielding and widely adaptable varieties common to both countries sine the interaction is inconsistent. More locations should be sampled for more than two years of testing to generate general conclusion or to recommend specific adaptation. In addition, developing the same genetic background varieties for the region could have its own negative impact.

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