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Stability Analysis of Finger Millet Genotypes in Moisture Stressed Areas of Northern Ethiopia

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Abstract
Nine advanced finger millet genotypes along with local check and standard check (Tadesse) were evaluated at moisture stressed finger millet growing areas of northern Ethiopia. Experiments were conducted in Rama during 2012, 2013 and 2014, in Ahferom during 2013 and 2014 and in Maistebri during 2014 cropping season, to select and recommend best yielding stable genotypes. AMMI, ASV and GGE methods of genotype by environment interaction analysis, showed that KNE#622 gave high grain yield performances and was relatively stable. Therefore, this genotype can be recommended for moisture stressed areas. Results indicated that the local check and standard check were the worst varieties for their high environmental interaction and low grain yield.
Keywords: Advanced lines, genotype by environment interaction, GGE biplot, multi-environment trial.

Introduction

Selection of genotypes for wide adaptability is often limited by the existence of genotype by environment interaction, making the variety development process more complex and expensive. Multi-environment trails are among the basic procedure to identify and recommend superior cultivar with wide adaptation (Yan et al. 2001). All Ethiopia and, more specifically, the semi-arid region of Tigray (northern Ethiopia) are characterized by a wide environmental variability, leading to high genotype by environment interaction (Conway 2000; Di Falco et al. 2007; Gebrehiwot et al. 2011; Meze-Hausken 2000). This strengthens the importance of multi-environment experiments in the process of variety development and for successful varietal recommendation in the area.

Different methods have been used to explore genotype by environment interaction and identify superior genotypes with wide or specific adaptation to different environments. Currently, most breeders are using the Additive Main Effects and Multiplicative Interaction (AMMI) analysis (Guach 1992; Guach and Zobel 1997; Zobel et al. 1988) and the Genotypes and Genotype by Environment (GGE) analysis (Yan and Kang 2003; Yan and Tinker 2005; Yan et al. 2007). The advantages and disadvantages of the AMMI and GGE analysis have been treated in detail by Gauch (2006) and Yan et al. (2007). The main difference between the two analyses is that AMMI biplots the genotypes main effect is included as a multiplicative effect and not as an additive main effect (Yan and Kang 2003).

Finger millet (*Eleusine coracana (L.) Gaertn.)* is one of the orphan crops indigenous to east Africa (Vavilov, 1951). In Ethiopia, the crop is among the food security crops, widely used for food, local beverage preparation and animal feed (Mulualem and Melak 2013). It is also nutritionally rich containing high ash, calcium and iron content, which is essential for strengthening bone and teeth and reduce incidence of anemia (Singh and Raghuvanshi 2012; Shobana et al. 2013). Finger millet has wide agro-ecology adaptation (Mbithi-Mwikya et al. 2000). Worldwide the crop has area coverage of 33,810,000 ha with 29,900,000 ton production (FAO 2012). In Ethiopia finger millet ranks 6th of the cereals in terms of area coverage of 455417.19 ha and its productivity is 18.7 t ha^{-1} (CSA 2014) Compared to its genetic potential of 4-5 t ha^{-1} (Dida et al. 2008), yield in Ethiopia is low, which is mainly due shortage of seed of improved variety, poor agronomic managements, high lodging, moisture stress, disease (mainly blast) and weeds (Fentie 2012; Mulualem and Melak 2013).

Developing improved varieties with high yield and wide adaptation is one of the major objectives of the national breeding finger-millet improvement program in Ethiopia. So far, about 13 improved varieties have released and some of those, namely Tadese and Padet, have relatively become widely adopted. Tadesse has been introduced in the finger millet growing areas of Tigray region, although its adaptation is limited because of its late maturity, when rainfall becomes limiting in the area. Similarly, Gebre (2015) reported that only 15% of farmers adopted improved varieties in South zone of Omo (Ethiopia) and added that farmers prefer to grow the local varieties' for their better grain yield, straw quality, grain color, early maturity, quality for local consumptions, weed tolerance, ease of threshing and preference in market. Axum Agricultural Research Center co-operates with the Ethiopian national finger millet improvement program based at Melkassa Agricultural Research Center, to conduct variety trials with the objective of identifying moisture stress tolerant genotypes, which might be adaptable to northern Ethiopia.

The objective of this study was to select and recommend varieties with improved yield and stable performance across moisture stressed areas of northern Ethiopia.

Materials and methods

Study Areas Description

Experiments were conducted in six environments; in Rama during 2012, 2013 and 2014; in Ahferom during 2013 and 2014 and in Maistebri during 2014 main production seasons. The altitude of Rama, Ahferom, and Maistebri were 1395, 2014, 1444 meter above sea level (m.a.s.l) respectively. The rainfall amount of the study areas was variable across seasons (Table 1) and the mean rainfall of ten years data indicates 717.1, 618.1 and 789.3 mm per year for Ahferom, Rama and Maistebri, respectively. Even though the rainfall level does not appear to be very low, the hilly topography of the areas leads to high erosion and runoff (Araya et al. 2010) and most of the rainfall is concentrated during July and August, while it is low during the grain filling stages (September – October). Soil types were sandy in Rama and sandy loam in Ahferom and Maistebri, which were with low water holding capacity.

Planting Material and Experimental Management

Nine advanced finger millet genotypes developed for moisture stressed areas were included in this study, namely Acc#29FMB/01WK/, KNE#622, KNE#741, KNE#1034, KNE#628, KNE#814, KNE#1012, Gulule, KNE#1149 and local check and standard check (Tadesse). Genotypes were laid down in Randomised Complete Block Designs (RCBD) with three replicates. Seed rate of ten kg ha^{-1} was drilled in 3 rows of 0.4 m inter-row spacing with 5 m length. Fertilizers in the form of Di-Ammonium Phosphate (DAP) and Urea were applied at 100 kg ha^{-1} at each experiment. DAP was applied all at planting time, while regarding Urea half was applied during emergence and the rest half after first weeding.Hand-weeding was done twice, at three weeks and five to six weeks after planting. Harvesting was done from the one central row only, leaving the two border rows.

Data Collection and Analysis

Grain yield of genotypes harvested from net plot area in gram was converted to kg ha^{-1} for analysis. Separate analysis of variance was done for each environment. Combined analysis was done following Bartlett's homogeneity of variance test. Pearson correlation coefficient was calculated by using proc corr procedure of SAS 9.3 (SAS Institute 2011), to investigate the relationship among environments. AMMI analysis, as suggested by Gauch (1988), was done using AGROBASE 20 (Agrobase 20 1999). The AMMI model is written as:

$$\mu_{ij} = \mu + G_i + E_j + \sum_{k=1}^{k} \lambda_k b_{ik} z_{jk} + \varepsilon_{ij}$$

where, the mean of genotype *i* in environment *j*, μ_{ij}, is described as the result of common fixed intercept term μ, a fixed genotypic main effect corresponding to genotype *i*, G_i, plus a fixed environmental main effect corresponding to environment *j*, E_j, while the GEI is explained by *K* multiplicative terms(*k*=1...K), each multiplicative term formed by the product of the singular values of the k^{th} axis in the principal component analysis, a genotypic sensitivity b_{ik} (genotypic score) and an environmental characterization z_{jk} (environmental score). And finally the random term ε_{ij}, representing the error term, typically assumed as normally distributed with a mean zero and variance σ^2.

In order to quantify and rank genotypes in terms of yield stability, the AMMI Stability Value (ASV) (Purchase et al. 2000) was worked out as follows:

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

Where, IPCA1 Sum of Squares and IPCA2 Sum of Squares stand for the sum of squares explained by the first two Principal Components (IPCA1 and IPCA2), respectively.

To evaluate the test environments, which is not possible with the AMMI, the Genotype plus Genotype-environment (GGE) biplot analysis was carried out using the method suggested by Yan (2001) for multi-environment data:

$$Y_{ij} - \mu_j = \lambda_1 \alpha_{i1} \gamma_{j1} + \lambda_2 \alpha_{i2} \gamma_{j2} + \varepsilon_{ij}$$

Where Y_{ij} is mean of genotype i in environment j; μ_j is mean value of environment j; k is the number of principal components retained in the model; λ_1 and λ_2 the singular value of PC1 and PC2, respectively; αi_1 and αi_2 are the PC1 and PC2 scores, respectively, for genotype i; γ_{j1} and γ_{j2} are the PC1 and PC2 scores, respectively for environment *j*; and ε_{ij} is the residual of the model associated with the genotype i in the environment *j*.

Results and discussion

grain yield and YIELD components

Genotype Acc#29FMB/01WK/ ranked first for its high grain yield in three environments (Rama-2012, Rama-2014 and Maistebri-2014), while it ranked third in Rama-2013, fourth in Ahferom-2014 and 7th in Ahferom-2013 (Table 2). However, due to its short plant height, low biomass yield and susceptibility to disease (head blast) (Table 3), this genotype was not selected by farmers.

Finger millet is one of the preferred feed source crops, for its palatable straw (Mulualem and Melak, 2013). Therefore, besides grain yield, biomass yield is among the major criteria for selection of a superior variety. The local check was lowest ranking in terms of grain yield in Rama-2012, Rama-2013 and Rama-2014, while it ranked first in Ahferom-2013, third in Ahferom-2014 and fifth for its intermediate grain yield in Maistebri-2014. The standard check ranked tenth in Rama-2013, Rama-2014 and Ahferom-2014, while it ranked third in Rama-2012, and eighth in Maistebri-2014 (Table 2).

Regarding the overall mean grain yield performance in all environments, Acc#29FMB/01WK/ ranked first, followed by KNE#622, whereas local and standard checks were lowest ranking for their low grain yield. Highest environmental mean grain yield was showed in Rama-2013, followed Rama-2014 and Ahferom-2014. Lowest mean grain yield was observed in Ahferom-2013 (Table 2).

AMMI analysis

AMMI ANOVA (Table 4) indicates significant ($P \leq 0.01$) effects of genotypes, environments and genotype by environment interaction, showing the high environmental variations and differential responses of genotypes to the environments, thus leading to inconsistent ranking of genotypes. Also Lule et al. (2014) reported significant genotype by environment interaction for finger millet varieties tested across four locations for two seasons in Ethiopia.

The highest proportion of variation (37.4%) was explained by the environment effect, followed by the genotype by environment interaction effect and genotype effect, explaining 23.2% and 8.5% of variation, respectively. This may indicate the existence of a considerable amount of differential response for the genotypes to changes in environmental conditions and the differential discriminating ability of the test environments. Adugna et al. (2011) reported 79.13, 18.34 and 2.53% of variation explained by environments, genotype by environment interaction and genotype respectively for finger millet genotypes tested over ten environments in Ethiopia.

The genotype by environment interaction effect was almost three times higher than the genotype effect. IPCA1 and IPCA2 were significant and explained respectively 54.4 and 22.1% of the interaction variability, leading to a cumulative 76.5% of explained variation (Table 4).

AMMI Biplot: classification of genotypes and environments

The AMMI biplot based on IPC1 scores on y-axis and mean yields on x-axis for both environments and genotypes is considered as an important tool to assess the pattern of adaptation and stability (Figure 1; Zobel et al. 1988). Genotypes KNE#1012 and KNE#741 were close to the x-axis and showed a grain yield slightly above the average level, indicating their low interaction with the environment coupled with intermediate grain yield performances. According to Annicchiarico (1997) a reliable genotype should show low interaction with the environment (high stability) and high yield. Accordingly, Genotype KNE#622 was second in grain yield and showed a relatively low interaction, thus it should be regarded as a reliable genotype. Genotype Acc#29FMB/01WK/, on the other hand, showed the highest mean grain yield, but also a high IPCA1 score, indicating its relatively high interaction with the environment (Figure 1).

A great majority of genotypes and environments lie in the first and fourth quadrant of the biplot (Figure 1). Rama-2013 and Ahferom-2014 lie on the first quadrant, due to their high mean grain yield and high interaction, while Maistebri-2014 was also in this quadrant, but with a relatively lower score on IPCA1 (lower interaction). Genotypes Acc#29FMB/01WK/, KNE#622, KNE#814 and KNE#628 were in this same quadrant therefore interacted positively with the aforementioned environments. Rama-2014 lies in the fourth quadrant, due to its above mean grain yield and negative IPCA1 score. Genotypes KNE#1012, KNE#741, gulule and KNE#1034 showed the same negative score for IPCA1. Ahferom-2013 lies in the third quadrant for its low mean grain yield and negative IPCA1 score. Likewise, the local variety and standard check (Tadesse) were in this same third quadrant, far from the origin of axes, indicating their low grain yield performance and high interaction (Figure 1).

Differential responses of genotypes in low and high yielding environments often reflect the consequences of differences in rainfall regimes (Soliman and Allard 1991; Vanoosterom et al. 1993; Voltas et al. 1999c). Indeed, rainfall variability across locations and seasons within locations was observed in this current study (Table 1), which may be regarded as the main cause for the inconsistent performances of genotypes.

Correlation of test environments

Yields from the three seasons in Rama were positively correlated between each other. This guarantees that the selection of a variety for its performance in this location could be done based on the results obtained in only one season. Tolessa et al. (2013) reported the advantages of having information on the correlation of testing environments in deciding the number of testing environments and seasons to be used for evaluating and recommending a variety. Yield in Ahferom-2013 was negatively correlated with all the environments and Ahferom-2014 was negatively correlated with all environments except with Rama-2014 and Maistebri-2014. This was related to the fact that Ahferom showed very low average yields, due to erratic rainfall. Yield in Maistebri-

2014 was positively correlated with all environments, except with Ahferom-2013 (Table 5).

AMMI stability value (ASV)

ASV was proposed to rank genotypes based on their stability and mean yield (Purchase et al. 2000). ASV is the distance from the origin of axes for genotype markers in a bi-dimensional scatterplot of IPCA1 scores against IPCA2 scores. Since the IPCA1 score contributes more to the genotype by environment interaction sum of squares, scores have to be weighted in proportion to the difference between IPCA1 and IPCA2 scores to compensate for the relative contribution of IPCA1 and IPCA2 to the total genotype by environment interaction variation.

Stability *per se* should however not be the only parameter for selection, because the most stable genotypes would not necessarily give the best yield performance (Mohammadi and Amri 2008). Hence, there is the need for approaches that incorporate both mean yield and stability in a single index, which was attempted by several authors (Eskridge 1990; Kang 1993; Dashiell et al. 1994; Bajpai and Prabhakaran 2000; Rao and Prabhakaran 2005; Farshadfar 2008; Babarmanzoor et al. 2009).

Genotypes KNE#1012, Tadesse (standard check) and KNE#741 ranked first, second and third respectively, for their low ASV value; however, these genotypes showed low mean grain yields (Table 6). AMMI biplot (Figure 1) also revealed low interaction with the environment for these genotypes. KNE#622, the second high yielding genotype, ranked fourth for its intermediate ASV value, and could be considered as relatively stable. The highest yielding genotype Acc#29FMB/01WK/ and the intermediate yielding genotypes KNE#628 and KNE#814 ranked respectively ninth, eighth and seventh, for their high ASV. The local check ranked eleventh for its high ASV value, indicating its high interaction with the environment (Table 6).

Genotype and genotype by environment interaction (GGE) biplot analysis

Relationships among the test environments

GGE biplot based on environment focused scaling, was used to estimate the pattern of environments (Figure 2). Environment has showed negative and positive Principal component (PC) score indicating that there was a difference in rankings of yield performance among genotypes across environments leading to a cross-over genotype by environment interactions. To visualize the relationship between environments, lines are drawn to connect the test environments to the biplot origin known as environment vectors. The cosine of the angle between two environments is used to approximate the correlation between them as described and used in Dehghani et al. (2010), Kaya et al. (2006). Accordingly Rama-2012, Rama-2013, Rama-2014 and Maistebri-2014 were positively correlated. Rama-2014 and Ahferom-2014 were not correlated. The presence of wide obtuse angle (that is, strong negative correlations) among test environments is an indication of high cross over genotype by environment interaction (Yan and Tinker 2006). Rama-2013, Rama2014 were negatively correlated with Ahferom-2013 and Ahferom-2014. Rama-2014 for its high yield and Ahferom-2013 for its low yield showed strong negative relationship (Figure 2).

The distance between two environments measures their dissimilarity in discriminating the genotype, therefore Rama-2014, Rama-2013 and Ahferom-2014 were far from the origin indicating their higher discriminating ability for the genotypes, while Ahferom-2013 and Maitsebri-2014 were the least discriminating environments (Figure 2).

Identification of best performing finger millet varieties

The polygon view of the GGE biplot is presented in Figure 3. This biplot indicates the best performing genotype(s) for each environment and the group of environments (Yan and Hunt 2002). The rays of the biplot divided the plot in to six sections. The environments appeared in three of them, revealing three mega environments. According to Yan et al. (2007), when different environments fell in to different sectors, it is implied that they had different winning cultivars, suggesting that the test environments could be divided in to mega-environments. The vertex families for each quadrant represented the genotypes with the highest yield for the environment that fell within it. The highest yielding genotype in Maistebri-2014 was Acc#29FMB/01WK/. In Ahferom-2014 genotypes KNE#1034 showed specific adaptation. The local check was low yielding with specific adaptation in Ahferom-2013 (Figure 3). The standards check (Tadesse), KNE#741 and KNE#1149 were also low to intermediate yielding genotypes (Figure 3). Yan and Tinker (2005) described the ideal genotypes as having high yield and stable across environments.

Ranking of genotypes based on mean yield and stability

Figure 4 presents the mean grain yield and stability of genotypes. Yan et al. (2001) described high yielding and stable genotypes, should be close to the origin and had the shortest vectors from the Average environment coordinate (AEC) lines. Accordingly, genotype KNE#622 was the second large yielder genotype and shortest AEC, indicating its stable performance and genotype Acc#29FMB/01WK/ was the first high yielding while with intermediate AEC, indicating its relatively high interaction to environmental changes (Figure 4). Genotypes

KNE#628 and KNE#814 were also with above mean grain yield performance and relatively short length from the AEC. The local and standard check varieties were the worst in terms of grain yield performance and stability, for their high vector from the AEC and PC1 below 0.

Conclusion

The investigated stability analysis parameters (AMMI, ASV and GGE) enabled to classify genotypes and environments for their stability. AMMI, ASV and GGE identified KNE#622 as relatively with low interaction accompanied with high grain yield performance. All the parameters indicated the local check as worst variety for its high interaction and low grain yield. The GGE biplots gave more visual interpretations than just selecting the best performing genotypes and it also allowed visualization of cross over genotype by environment interaction through the polygon view. Over all, the AMMI and GGE biplot analysis resulted in more or less similar selections of superior, stable genotypes and classification of environments.

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Tables

Table 9 Annual rainfall, mean minimum and maximum temperatures (2005-2014) of the study sites.

	Ahferom			Rama			Maistebri		
	Annual rainfall (mm)	Temperature (°C)		Annual rainfall (mm)	Temperature (°C)		Annual rainfall (mm)	Temperature (°C)	
Year		Mean max	Mean min		Mean max	Mean min		Mean max	Mean min
2005	822.6	24.2	10.9	699.0	26.9	11.0	987.0	36.1	16.7
2006	806.6	24.7	5.8	742.0	28.9	5.8	1254.0	19.8	6.1
2007	845.8	28.9	16.0	549.0	24.2	7.7	767.0	28.6	16.0
2008	719.7	28.6	10.3	987.0	24.6	10.9	742.0	26.9	11.0
2009	660.0	24.7	16.7	505.0	36.1	16.7	1095.0	26.1	12.6
2010	608.4	36.1	8.0	552.0	28.6	16.0	699.0	24.7	10.3
2011	500.4	23.0	15.1	361.0	23.0	7.9	620.0	24.2	7.7
2012	1025.1	23.3	13.2	554.0	24.7	10.3	599.0	28.9	5.8
2013	457.2	35.0	12.4	692.0	23.3	15.0	552.0	27.3	11.3
2014	992.8	27.5	10.9	540.0	35.0	22.8	578.0	24.0	11.4
mean	717.1	27.1	11.3	618.1	27.5	12.4	789.3	26.7	10.9

Ethiopian Metrology Agency, Mekelle branch (2014)

Table 10 Mean grain yield (kg ha^{-1}), standard error, minimum and maximum, coefficient of variation and rank of genotypes for grain yield performance across test environments and over all environments.

	Environments						
Genotype	Rama 2012	Rama 2013	Rama 2014	Ahferom 2013	Ahferom 2014	Maistebri 2014	Grand mean
Acc#29FMB/01WK/	2791.1	3126.3	3640.4	1099.3	2981.8	2550	2698.15
KNE#622	2582.3	2974.9	2895.4	1223.7	2629.7	2450.0	2459.3
Tadesse (standards check)	2550.8	2139.3	1731.4	954.3	2004.6	1950	1888.4
KNE#741	1673.3	2962	2065.8	1678.9	2008.2	1975	2060.5
KNE#1034	1945.8	2560.2	2716.0	872.7	3230.1	2191.7	2252.8
KNE#628	2206.4	2606.3	3193.8	945.8	2187.7	2183.3	2220.6
KNE#814	2110.3	3226.7	2852.1	1346.8	2360.9	2202.8	2349.9
KNE#1012	1971.9	2443.7	2297.7	1147.7	2276.3	1861.1	1999.7
gulule	1599.3	3087.1	2222.2	1051.8	3200.1	1888.9	2174.9
KNE#1149	2211.2	3267.9	2835.8	1185.2	1764.6	1936.1	2200.1
local	1387.5	1341.7	1423.1	1789.4	3092.1	2125	1859.8
Mean	2093.6	2703.3	2534	1208.7	2521.5	2119.4	2196.8
Standard Error	342.1	726.0	482.7	255.8	435.2	220.0	25908.1
Minimum	1387.5	1341.7	1423.1	872.7	1764.6	1861.1	1859.8
Maximum	2791.1	3267.9	3640.4	1789.4	3230.1	2550	2698.2
CV (%)	20.0	32.9	23.3	25.9	22.0	12.7	24.9
LSD (0.05)	590.0*	1252.2ns	832.5**	441.2*	781.6*	379.5ns	

CV = coefficient of variation; LSD = least significant difference

ns, *, ** denotes non-significant, significant and highly significant difference respectively

Table 11 Mean for phenological traits and yield components in the eleven genotypes tested in six environments in northern Ethiopia

	Yield components						
Genotypes	DH	DM	FNL (cm)	NOFNG	NTILL	PLHT (cm)	BM kg ha^{-1}
Acc#29FMB/01WK/	73.6	107.4	6.1	6.2	6.1	71.2	7699.0
KNE#622	70.4	105.0	6.0	6.8	6.0	83.6	9902.0
Tadesse (standards check)	75.8	108.9	6.5	6.7	6.1	82.5	8733.0
KNE#741	69.9	105.3	6.5	6.7	6.2	77.0	8071.0
KNE#1034	72.6	105.6	5.6	6.9	6.4	75.0	8716.0
KNE#628	76.4	108.7	6.3	6.8	5.9	80.2	9451.0
KNE#814	67.7	103.2	10.3	6.3	5.7	80.7	7246.0
KNE#1012	76.7	106.8	5.9	6.7	5.4	79.7	8552.0
gulule	75.9	106.7	6.0	6.2	5.7	80.3	8633.0
KNE#1149	74.6	106.1	6.0	6.5	5.6	78.2	9085.0
Local check	79.2	108.9	8.6	7.9	6.7	82.3	7874.0
Environment							
Rama2012	80.7	118.6	4.9	6.8	7.5	79.7	14727.0
Rama2013	66.5	104.2	8.1	6.0	4.7	103.9	6015.0
Rama2014	71.4	108.1	7.3	5.6	5.3	76.2	5333.0
Aherfom2013	85.8	106.1	7.2	7.2	5.1	53.9	3763.0
Ahferom2014	70.3	108.4	5.6	7.2	6.2	86.9	10985.0
Maistebri2014	68.6	94.2	7.3	7.5	7.1	74.5	10429.0

DH = days to heading; DM = days to maturity; FNL = finger length; NOFNG = number of fingers per plant; NTILL = number of productive tillers per plant; PLHT = plant height; BM = biomass yield

Table 12 ANOVA of AMMI of finger millet genotypes tested for yield performance across six environments in northern Ethiopia

Source	df	SS	MS	% of explained variation
Total	197	129763066	658696	27.6
Treatments	65	89574424	1378068**	1.5
Genotypes	10	11052130	1105213**	8.5
Environments	5	48462025	9692405**	37.4
Blocks in Environments	12	4297903	358159ns	3.3
Genotype by environment interaction	50	30060269	601205**	23.2
IPCA	14	16343959	1167426**	54.4
IPCA	12	6630392	552533*	22.1
IPCA	10	5104255	510426ns	17.0
IPCA	8	1891975	236497ns	6.3
Residuals	6	89688	14948ns	0.3
Error	120	35890739	299089	2.5

df = degree of freedom; SS = sum of squares; MS = mean squares; IPCA = interaction principal component analysis
ns, *, ** denotes non-significant, significant and highly significant difference respectively

Table 13 Pearson correlation of six testing environments for the 11 finger millet genotypes

Environments	Rama 2012	Rama 2013	Rama 2014	Ahferom 2013	Ahferom 2014	Maistebri 2014
Rama-2012	1					
Rama-2013	0.38ns	1.00				
Rama-2014	0.64*	0.69*	1.00			
Ahferom-2013	-0.53ns	-0.28ns	-0.47ns	1.00		
Ahferom-2014	-0.25ns	-0.21ns	0.01ns	-0.05ns	1.00	
Maistebri-2014	0.57ns	0.17ns	0.64ns	-0.06ns	0.38ns	1.00

Table 14 Mean grain yield, IPCA1, IPCA2 and ASV value of the 11 genotypes tested across six environments in northern Ethiopia

Genotype	Mean yield ($kgha^{-1}$)	IPCA1	IPCA2	ASV value	Rank
Acc#29FMB/01WK/	2698.15	-12.2	-16.0	62.8	9
KNE#622	2459.3	-5.8	-2.2	29.1	4
Tadesse (Standard check)	1888.4	2.4	9.6	15.2	2
KNE#741	2060.5	1.7	21.3	22.9	3
KNE#1034	2252.8	6.0	-19.6	35.5	5
KNE#628	2220.6	-12.5	-6.6	62.3	8
KNE#814	2349.9	-8.5	4.8	42.5	7
KNE#1012	1999.7	1.0	3.2	6.0	1
Gulule	2174.9	8.1	-8.5	41.3	6
KNE#1149	2200.1	-18.5	11.8	92.5	10
Local check	1859.8	38.3	2.4	190.4	11

IPCA = interaction principal component analysis; ASV = AMMI stability value

Figures

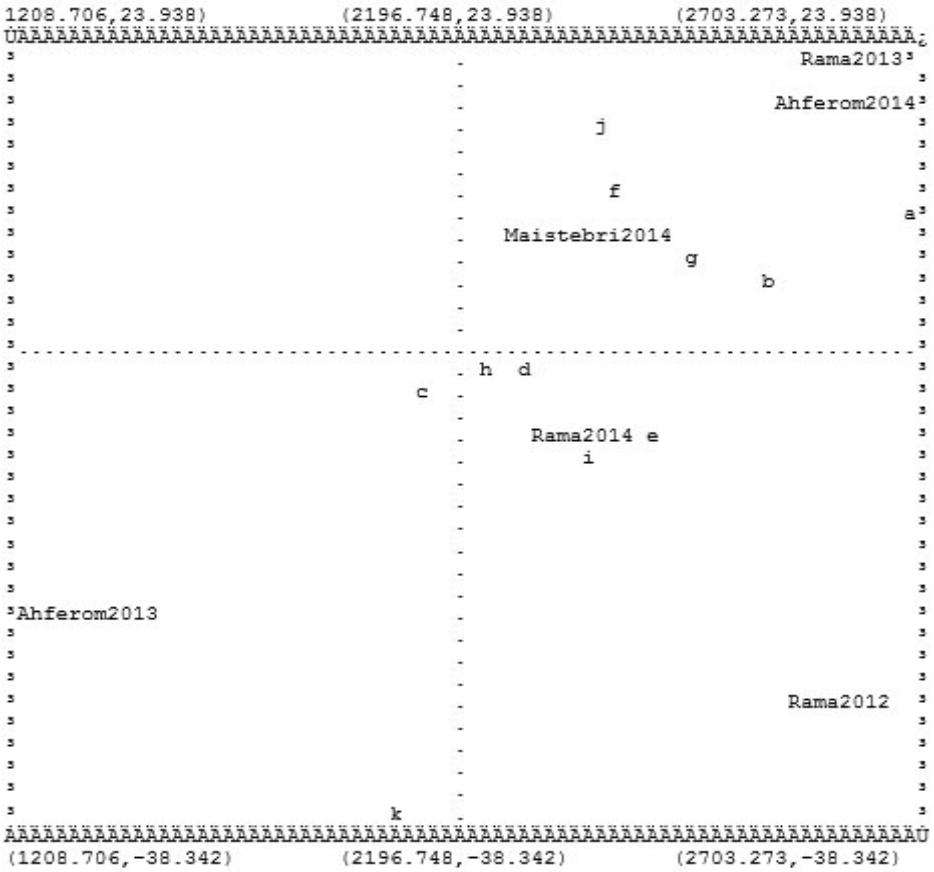
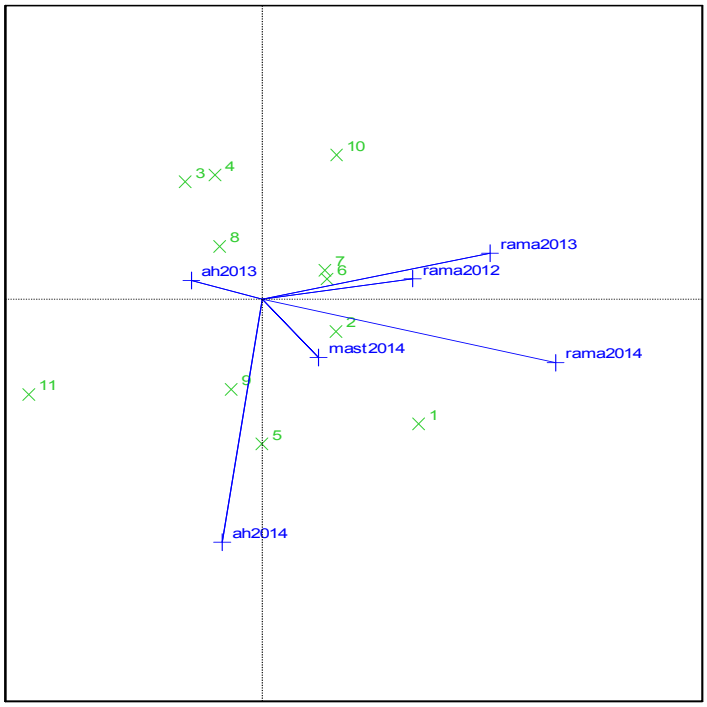


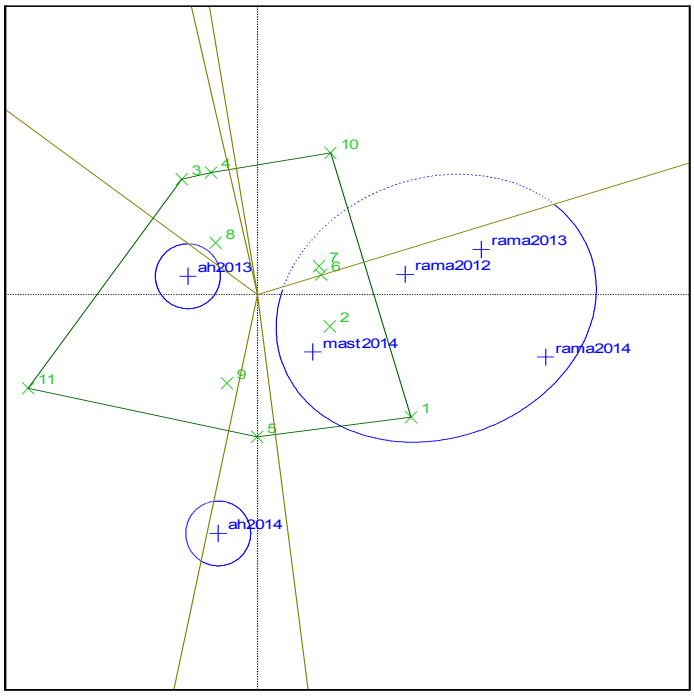
Figure 4 AMMI biplot of genotypes and Environment using IPCA1 and mean yield. The genotypes are coded as: a. Acc#29FMB/01WK/, b. KNE#622, c. Tadesse, d. KNE#741, e. KNE#1034, f. KNE#628, g. KNE#814, h. KNE#1012, i. gulule, j. KNE#1149, k. Local



PC1 - 55.62%

Figure 5 GGE biplot based on grain yield for the 11 genotype showing the relationship among environments

Genotypes are coded as 1. Acc#29FMB/01WK/, 2. KNE#622, 3. Tadesse, 4. KNE#741, 5. KNE#1034, 6. KNE#628, 7. KNE#814, 8. KNE#1012, 9. gulule, 10. KNE#1149, 11. Local



PC1 - 55.62%

Figure 6 Polygon view of the GGE biplot based on grain yield for the six environments

Genotypes are coded as 1. Acc#29FMB/01WK/, 2. KNE#622, 3. Tadesse, 4. KNE#741, 5. KNE#1034, 6. KNE#628, 7. KNE#814, 8. KNE#1012, 9. gulule, 10. KNE#1149, 11. Local

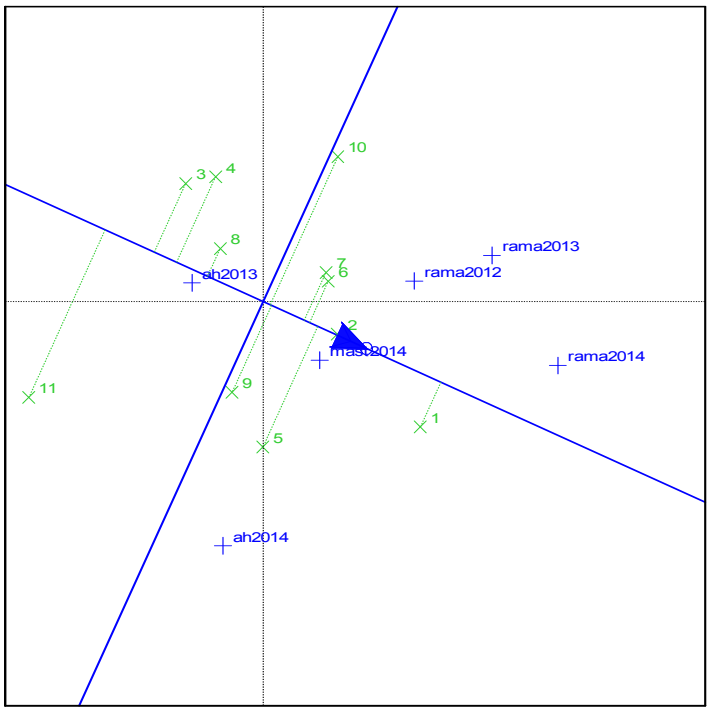


Figure 7 GGE biplot on grain yield for the six environments ranking 11 finger miller genotypes based on the both mean grain yield and stability

Genotypes are coded as 1. Acc#29FMB/01WK/, 2. KNE#622, 3. Tadesse, 4. KNE#741, 5. KNE#1034, 6. KNE#628, 7. KNE#814, 8. KNE#1012, 9. gulule, 10. KNE#1149, 11. Local