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

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Abstract
Finger millet is one of the important cereals in Ethiopia, preferred for food and local drink preparation and animal feed. In spite of its importance, yield is low due to production problems, such lodging, moisture stress, disease (blast), weed, shortage of improved varieties and poor agronomic managements. Breeding of improved varieties with the farmers' desired traits is one of the strategies of the national finger millet improvement programs. Multi-location trail is a basic task of breeding programs, for identifying and recommendation of a stable and high yielder variety. 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 better performing stable genotypes. AMMI, ASV and GGE methods of genotype by environment interaction analysis, identified KNE#622 as relatively with low interaction accompanied with high grain yield performance, which can be recommended for moisture stressed areas. All the parameters indicated the local check and standard check were the worst varieties for their high interaction and low grain yield.
Keywords: Advanced lines, AMMI stability value Ethiopia, finger millet, genotype by environment interaction

1. 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). Ethiopia as a general and the semi-arid environment in Tigray region, northern Ethiopia specifically has 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 variety development process for successful variety recommendation in the area.

Different methods haven been used to explore genotype by environment interaction and identify superior genotypes with wide or specific adaptation for 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) biplot analysis (Yan & Kang 2003; Yan &Tinker 2005; Yan et al. 2007). The advantages and disadvantages of the AMMI and GGE biplot analysis dealt with in detail by Gauch (2006) and Yan *et al*. (2007). The main difference between the two analyses is being 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)* 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 & 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 & Raghuvanshi 2012; Shobana *et al*. 2013). Finger millet has wide agro-ecology adaptation (Mbithi-Mwikya *et al.* 2000). Worldwide the crop has an 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 hat^{-1} (CSA 2014). While as compared to its genetic potential of 4-5 hat^{-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 & 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. Yet, nationally about 13 improved varieties have released and varieties namely Tadese and Padet are among the relatively widely adopted varieties. Tadesse has been introduced in the finger millet growing areas of Tigray region. But its adaptation is limited because of its late maturity while a rainy season is becoming short in the areas. Similarly Gebre (2015) reported only 15% of the farmers adopted improved varieties in South zone of Omo, Ethiopia and the author 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, easy of threshing, and preference in market. Axum agricultural research center collaborate 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 varieties'

adaptable to the northern Ethiopia. Therefore the objective of this study was to select and recommend better yielder varieties with stable performance across moisture stressed areas of northern Ethiopia.

2. Materials and methods
2.1 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 rain fall of ten years data indicates 717.1, 618.1 and 789.3 mm per annum for Ahferom, Rama and Maistebri, respectively. Even though the rainfall was intermediate the sloppy 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 low in 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.

2.2 Planting Material and Experimental Management
Nine advanced finger millet genotypes developed for moisture stressed areas; 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) were used in the study. Genotypes were laid down in RCBD design with three replications. Seed rate of ten kgha^{-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. Weeding was done twice, at three weeks and five to six weeks after planting. Harvesting was done from the one central rows only, leaving the two border rows.

2.3 Data Collection and Analysis
Grain yield of genotypes harvested from net plot area in gram was converted to kgha^{-1} for analysis. Analysis of variance was conducted for experiments in each environment. Yield data was checked for homogeneity of variance using Bartlett's test. Pearson correlation coefficient was done using proc corr procedure of SAS 9.3 (SAS Institute 2011), to investigate the relationship of environment. 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 kth 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 normally distributed with a mean zero and variance; $\varepsilon_{ij} \sim N(0, \sigma2)$.

However, the AMMI model does not make provision for a quantitative stability measure, and as such a measure is essential 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:

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

Where, IPCA1SS and IPCA2SS stand for the sum of squares of 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:

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

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*.

3. Results and discussion
3.1 Genotype yield and yield components performance across environments
Genotype Acc#29FMB/01WK/ was ranked first for its high grain yield in three environments (Rama2012, Rama2014 and Maistebri2014) while third in Rama2013, fourth in Ahferom 2014 and 7th in Ahferom2013

(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 & Melak, 2013). Therefore, besides grain yield, biomass yield is among the major criteria for selection of a superior variety. The local check was least ranked in terms of grain yield in Rama 2012, Rama2013 and Rama2014, while fist ranked in Ahferom2013, third in Ahferom2014 and was fifth rank for its intermediate grain yield in Maistebri2014. The standard check was ranked tenth in Rama2013, Rama2014 and Ahferom2014, third in Rama2012, and eight in Maistebri2014 (Table 2).

Regarding the overall environment mean grain yield performance, Acc#29FMB/01WK/ was first ranked followed by KNE#622, whereas local and standard check were least ranked for their low grain yield performance. Highest environmental mean grain yield was showed in Rama2013, followed by the grain yield in rama2014 and ahferom2014. Least mean grain yield was observed in ahferom2013 (Table 2).

3.2 AMMI analysis

AMMI ANOVA (Table 4) indicates significant (P≤0.01) effects of genotypes, environments and genotype by environment interaction, indicating the high environmental variations and differential response of genotypes to the variable environments thus leading to inconsistency ranking of genotypes. Lule *et al*. (2014) reported significant genotype by environmental interaction for finger miller varieties tested across four locations for two seasons in Ethiopia. Highest (37.4%) variation was explained by environment effect, followed by genotype by environment interaction and genotypes explaining 23.2% and 8.5% of variation, respectively. This may indicate the existence of a considerable amount of deferential response among the genotypes to changes in growing environments 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 genotypes effect. IPCA1 and IPCA2 were significant explaining 54.4 and 22.1% of the interaction, respectively, leading to a cumulative of 76.5% of variation and the rest 23.5% was contributed due to noise (Table 4).

3.3 AMMI Biplot: classification of genotypes and environments

The AMMI biplot based on the relative magnitude of the position and direction of genotypes on the plane of stability parameter regressed on the environmental mean yields is considered an important measure of the pattern of adaptation and stability (Zobel *et al*. 1988). Figure 1 presents plotting of the first IPCA against the mean for both the genotypes and environments. Genotypes KNE#1012 and KNE#741 was close to the origin (x-axis) and with above mean grain yield, indicating their low interaction to environmental changes accompanied with intermediate grain yield performance. According to Annicchiarico (1997) a stable genotypes should be that with low interaction to environmental changes and high yielder. Accordingly, Genotype KNE#622 was second high grain yielder and relatively low interaction, being as stable genotype. Genotype Acc#29FMB/01WK/ on the other hand showed highest mean grain yield however high IPCA1 indicating its relatively high interaction to environmental changes (Figure 1).

Majority of the genotypes and environments were plotted in the first and fourth quadrant of the biplot (Figure 1). Rama2013 and Ahferom2014, plotted on the first quadrant for their high mean grain yield while with high interaction and Maistebri2014 was also in this quadrant but relatively with low interaction. Genotypes Acc#29FMB/01WK/, KNE#622 KNE#814, and KNE#628 were in this quadrant for their similar performance and the same IPCA sign. Rama2014 was in the fourth quadrant for its above mean grain yield and negative IPCA1 and genotypes KNE#1012, KNE#741, gulule and KNE#1034 showed the same IPCA1 sign. Ahferom2013 was plotted in the third quadrant for its low mean grain yield and negative IPCA1 which was far from the origin and the local variety and standard check (Tadesse) were in this quadrant far from the origin, 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 & Allard 1991; Vanoosterom *et al*. 1993; Voltas *et al*. 1999c). Similarly, rainfall variability across location and seasons within the location was observed in the current study environments (Table 1), which was the main cause for the inconsistent genotype performance.

3.4 Correlation of test environments

Yield from the three seasons in Rama was positively correlated. This guarantees that, selection of a variety for its performance in this location could be done based on one season result. Tolessa *et al*. (2013) reported the advantages of information on the correlation of testing environments in deciding on the number of testing environments and seasons to be used for testing a variety performance. Yield in Ahferom2013 was negatively corrected with all the environments and Ahferom2014 was negatively correlated with all environments except with Rama2014 and Maistebri2014. This indicates that Ahferom was low yielding environments and even within

the location, seasons were variable, which could be mainly, due to the erratic rain fall. Yield in Maistebri2014 was positively correlated with all environments except with yield from Ahferom2013 (Table 5).

3.5   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 zero in a two dimensional scatter gram of IPCA1 scores against IPCA2 scores. Since the IPCA1 score contributes more to genotype by environment interaction sum of square, it has to be weighted by the proportional 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 & Amri 2008). Hence there is a need for approaches that incorporate both mean yield and stability in a single index, that is why various authors introduced different selection criteria for simultaneous selection of yield and stability (Eskridge 1990; Kang 1993; Dashiell *et al*. 1994; Bajpai & Prabhakaran 2000; Rao & 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 were with low mean grain yield (Table 6). AMMI biplot (Figure 1) also revealed low interaction of these genotypes for the environmental change. KNE#622, the second high yielding genotypes was ranked fourth for its intermediate ASV value, which can be considered as relatively stable. The high yielding genotype, Acc#29FMB/01WK/ and intermediate yielding genotypes KNE#628 and KNE#814 ranked ninth, eight and seventh in that order, for their high ASV. The local check was ranked eleventh for its high ASV value, indicating its high interaction (Table 6).

3.6   Genotype and genotype by environment interaction (GGE) biplot analysis
3.6.1   Relationships among the test environments

GGE biplot, which was 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 Rama2012, Rama2013, Rama2014 and Maistebri2014 were positively correlated. Rama2014 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). Rama2013, rama2014 were negatively correlated with ahferom2013 and ahferom2014. Rama2014 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 Rama2014, Rama2013 and Ahferom2014 were far from the origin indicating their higher discriminating ability for the genotypes, while Ahferom2013 and Maitsebri2014 were the least discriminating environments (Figure 2).

3.6.2   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 & 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 implied that they had different high yielding cultivars for those sectors and it showed cross over genotype by environment interaction, 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 Maistebri2014 was Acc#29FMB/01WK/. In Ahferom2014 genotypes KNE#1034 showed specific adaptation. The local check was low yielding with specific adaptation in Ahferom2013 (Figure 3). The standards check (Tadesse), KNE#741 and KNE#1149 were also low to intermediate yielding genotypes (Figure 3). Yan & Tnker (2005) described the ideal genotypes as having high yield and stable across environments.

3.6.3   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.

4. 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.

5. Acknowledgments

6. References

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Tables

Table 1 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 2 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	Ahferom2 013	Ahferom2 014	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 3 Mean yield components performance of the eleven genotypes tested in six environments in northern Ethiopia

Genotypes			Yield components				
	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 4 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
Block	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 5 Pearson correlation of six testing environments for the 11 finger millet genotypes

Environments	Rama2012	Rama2013	Rama2014	Ahferom 2013	Ahferom 2014	Maistebri 2014
Rama2012	1					
Rama2013	0.38ns	1.00				
Rama2014	0.64*	0.69*	1.00			
Ahferom2013	-0.53ns	-0.28ns	-0.47ns	1.00		
Ahferom 2014	-0.25ns	-0.21ns	0.01ns	-0.05ns	1.00	
Maistebri2014	0.57ns	0.17ns	0.64ns	-0.06ns	0.38ns	1.00

Table 6 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
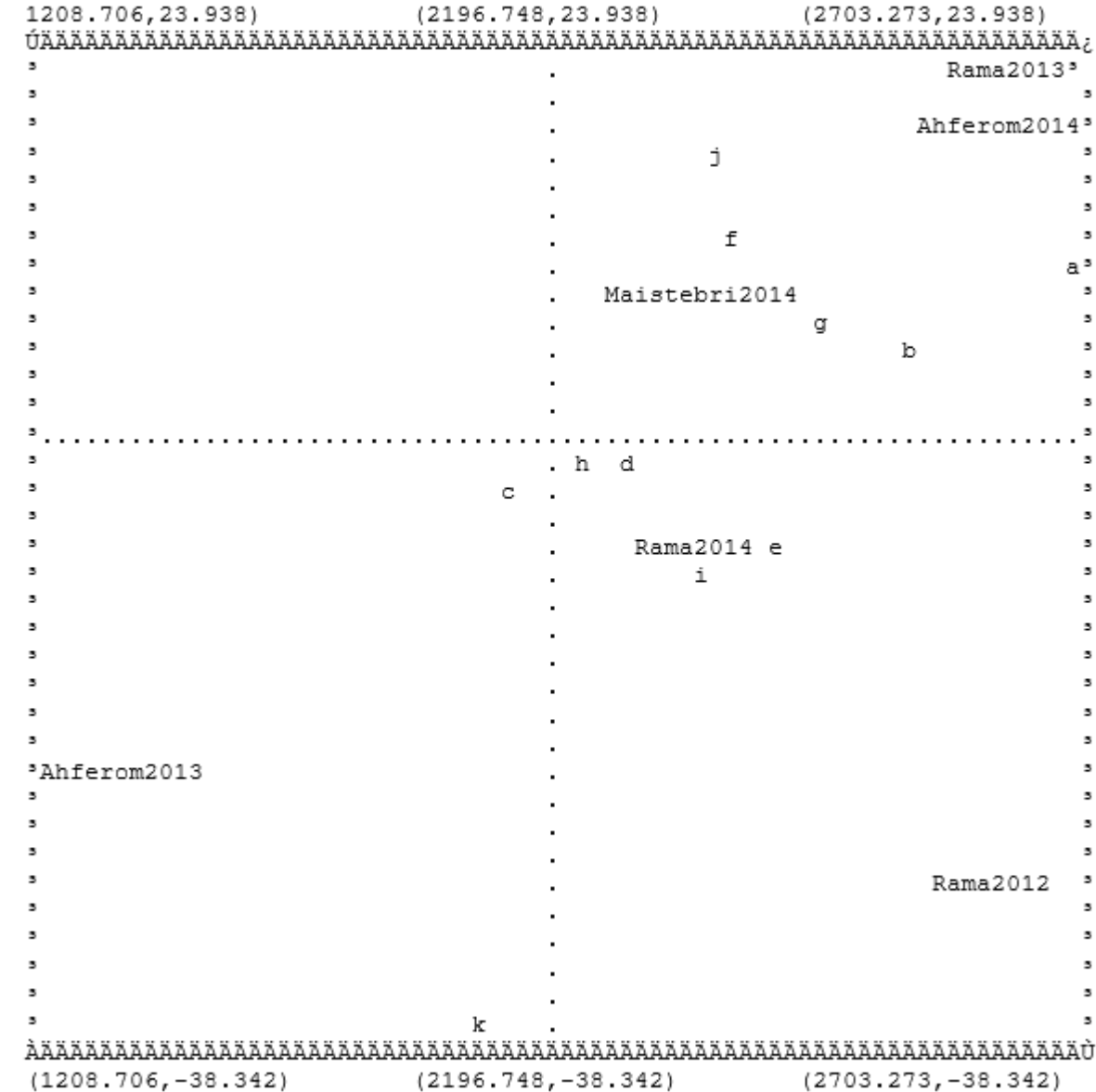
Figures

Figure 1 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
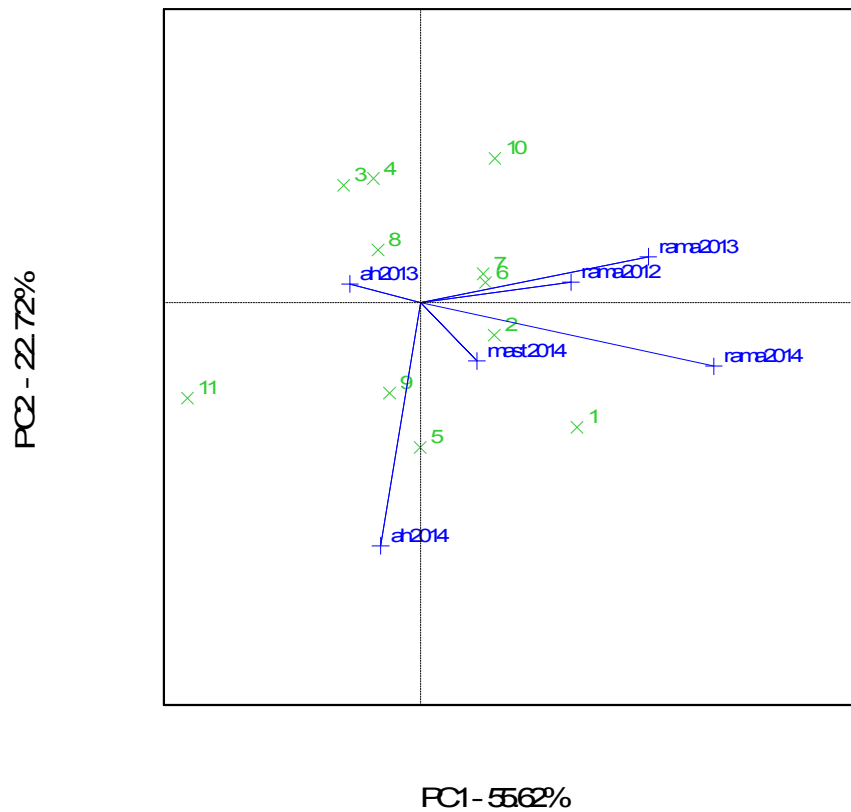
Figure 2 GGE biplot based on grain yield for the 11 genotype showing the relationship among environments
Genotypes are coded as 1. Acc#29FMB/01WK/, 2. KNE#622, 3. Tadesse, 4. KNE#741, 5. KNE#1034, 6. KNE#628, 7. KNE#814, 8. KNE#1012, 9. gulule, 10. KNE#1149, 11. Local
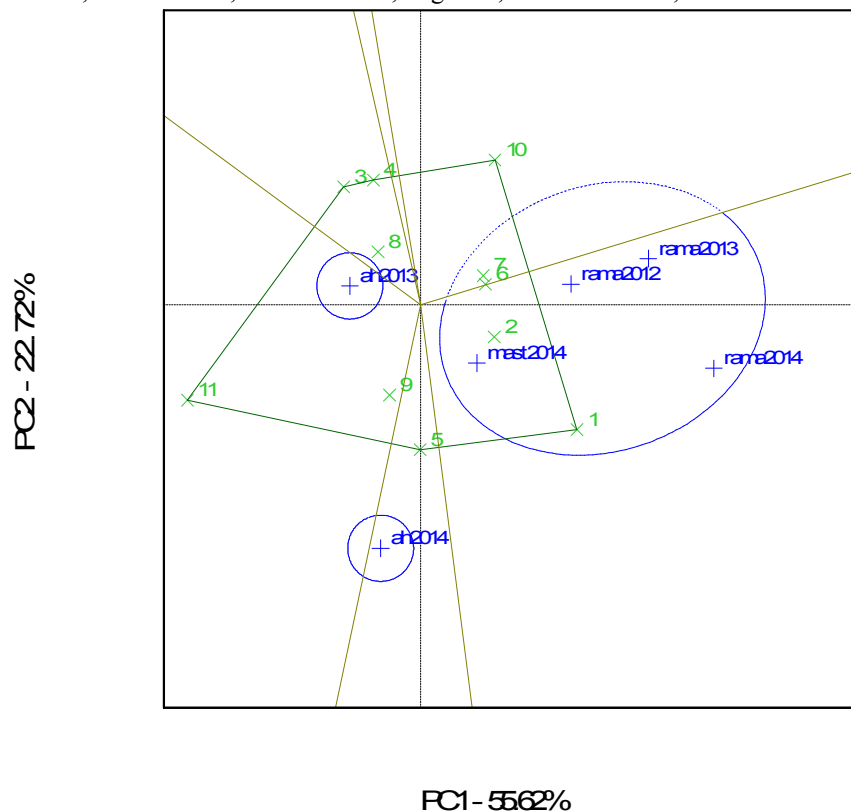

Figure 3 Polygon view of the GGE biplot based on grain yield for the six environments
Genotypes are coded as 1. Acc#29FMB/01WK/, 2. KNE#622, 3. Tadesse, 4. KNE#741, 5. KNE#1034, 6. KNE#628, 7. KNE#814, 8. KNE#1012, 9. gulule, 10. KNE#1149, 11. Local
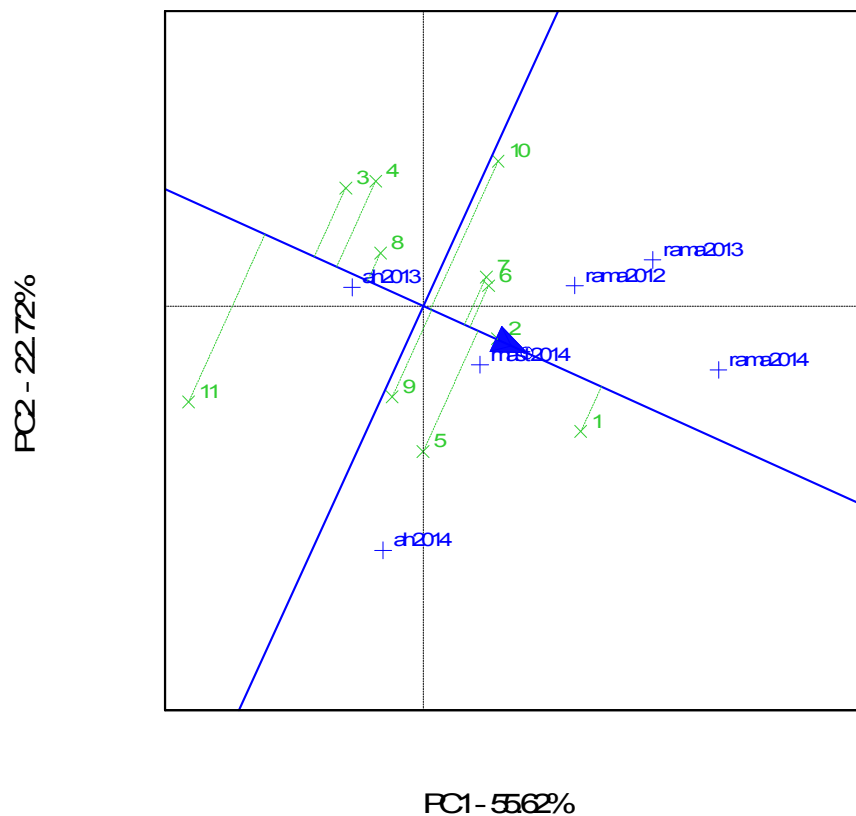
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Figure 4 GGE biplot on grain yield for the six environments ranking 11 finger miller genotypes based on the both mean grain yield and stability

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