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# Genotype by environment interaction effects on grain yield of highland maize (*Zea mays* L) hybrids

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## Abstract

Maize varieties adapted to highland environments are generally scarce in East and Central Africa (ECA) since most breeding efforts have focused on mid-altitude maize. As a result, farmers in the highlands of Uganda mainly grow varieties that are bred for the mid-altitude zones. Since these maize varieties are not adapted to highland conditions, their productivity in this region rarely exceeds 2 t $ha^{-1}$. This study was aimed at determining the effect of genotype by environment interactions (GEI) on the grain yield of highland maize hybrids. The study was conducted in three highland locations of Uganda in the maize growing season of March to October 2015. Thirty-six $F_1$ hybrids and two checks were arranged in a 2 x18 (0, 1) alpha lattice design with two replications. Hybrid by location interaction had highly significant differences ($P \leq 0.001$) and explained 46.2% of phenotypic variance. Genotype by environment interactions (GEI), thus, had a strong effect on grain yield. Analyses revealed two maize mega-environments, with AMH701-9/AMH703-22 hybrid emerging the best genotype in Kachwekano and Kalengyere (6.69 t $ha^{-1}$ and 14.30 t $ha^{-1}$), and AMH701-9/AMH701-20 hybrid being the best in Buginyanya (14.39 t $ha^{-1}$). Efforts to breed for high yielding maize cultivars for the highland areas of Uganda should therefore focus more on specific adaptation than broad adaptation.

**Keywords**: Genotype environment interaction, grain yield, highland, maize hybrids

## Introduction

Maize is an important staple cereal in sub-Saharan Africa. The crop fits well in farming systems across agro-ecological zones in the region, meeting the nutritional needs of people with varying socio-economic circumstances (Macauley, 2015). More than half the daily calorie and protein intake of the region's population is acquired from maize (Twumasi-Afrriye et al, 2001). In Uganda, maize is produced in mid altitude and highland zones across the country. However, breeding efforts have for long concentrated on the mid altitude zones yet the majority of farmers in these zones produce at a subsistence level. Highland production is therefore emerging as a potential avenue for production to supplement mid-altitude production and target new markets (Twumasi-Afrriye et al, 2001). However, the productivity of varieties grown by farmers in the highland areas of Uganda is low mainly because these varieties are never tested for adaptability in such areas (Kagoda, 2013). Even more critical, is the fact that the lower temperatures in the highland areas delay maturity of the maize (Brewbaker, 2003). Research efforts should therefore concentrate on developing high yielding and early maturing maize varieties for the highland areas.

Genotype by environmental interactions (GEI) have a significant effect on the grain yield of highland maize hybrids. According to Yan and Rajcan (2002), environments explains 80% or more of the total variation in yield. However, GEI are also relevant in yield variation, and have the ability to reduce the correlation between phenotype and genotype hence lowering the progress of selection in a breeding program (Dehghani et al, 2006). In order to sustain food production, breeders need to select superior genotypes whose performance in terms of grain yield is stable in many environments. Being quantitative in nature, grain yield usually exhibits GEI, which necessitates evaluation in multi-environment trials before doing advanced selection (Khalil et al, 2010). In this study, Genotype and genotype by environment Effects (GGE) biplot analysis was used to show the «which - won - where» pattern of data (Dehghani et al, 2006) which helped in identifying high yielding and stable $F_1$ maize hybrids in Ugandan highlands. This biplot was also used to show discriminating and representative test sites hence giving a clear effect of GEI on grain yield in these sites.

## Materials and Methods

A total of 59 inbred lines were sourced from CIMMYT-Ethiopia in 2013 and were screened on-station at Buginyanya Zonal Agricultural Research and Development Institute (BugiZARDI), Ikulwe Satellite Station

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in eastern Uganda during the 2014A season (April to June) to enable selection of superior genotypes based on resistance to biotic and abiotic stresses. At the end of the season, one set of nine most promising inbred lines were crossed on-station in a half diallel mating design [p (p-1)/2] to get 36 single cross $F_1$ hybrids. These $F_1$ hybrids were evaluated in 2015 (March to October) across the three highland sites of Buginyanya in Bulambuli District; Kachwekano and Kalengyere satellite station in Kabale District. The three highlands are found under the Montane agro-ecology (Wortman and Eledu, 1999) characterized by elevations between 1,500 - 3,000 m above sea level (masl), annual average rainfall of 1,500 - 2,000 mm, average minimum temperature of 15°C and maximum of 28°C, and 80% relative humidity. Buginyanya has a latitude of 01°22'N, a longitude of 34°09'E, an altitude of 1,800 masl and rainfall of 1,297 mm, with temperatures ranging from 12°C to 22°C. Kachwekano has a latitude of 01°17'S, longitude of 29°41'E, an altitude of 1,980 masl, rainfall of 1,170 mm and temperatures of 6.1°C - 23.3°C. Kalengyere has a latitude of 01°15'S, a longitude of 30°30'E, an altitude of 2,450 masl, rainfall of 1,000 mm and temperatures ranging from 10°C to 23°C. Two checks, a local landrace and a commercial hybrid, were included in the evaluation trial making a total of 38 genotypes evaluated across the three sites. The trial was laid out in a 2 x 18 alpha (0, 1) lattice design, with two replications per site, and 15 plants per row spaced at 0.75 m x 0.3 m.

Data collection was done on field weight of cobs per plot (kg), and moisture content (%) of each plot was recorded using a moisture metre. Grain yield (t $ha^{-1}$) of each plot was then calculated according to Sesay et al (2016) as follows:

$$GY(t\,ha^{-1}) = \frac{FW\_P \cdot 0.8 \cdot (100 - MC) \cdot 10{,}000}{(100 - 12.5) \cdot 3.15 \cdot 1{,}000}$$

where FW_P = Field Weight (kg) of maize per plot, MC = Moisture Content of grain for each plot, 0.8 = Shelling co-efficient, and 3.15 = plot area.

Using Genstat software (12th edition, VSN International), grain yield data was subjected to analysis of variance across sites. Since the GEI was significant, GGE biplot analysis was used to generate graphs that showed; the «which-won-where» pattern, determined the mega environments and enabled comparison

Table 1 - Analysis of variance of grain yield for maize hybrids across three highland sites of Uganda.

| Source of variation | d.f. | Mean square | F-stat | F-prob | % Phenotypic variance explained |
|---|---|---|---|---|---|
| Site | 2 | 439.67* | 15.51 | 0.03 | |
| Rep (Site) | 3 | 28.34*** | 12.89 | 0.00 | |
| Hybrid | 37 | 8.48 | 1.30 | 0.17 | 6.89 |
| Hybrid x Site | 74 | 6.54 *** | 2.97 | 0.00 | 46.26 |
| Error | 90 | 2.20 | | | 46.85 |
| %CV | | 17.61 | | | |
| s.e.d. | | 0.86 | | | |
| $\sigma^2$Hybrid | | 0.32 | | | |
| $\sigma^2$Hybrid x site | | 2.17 | | | |
| $\sigma^2$error | | 2.20 | | | |

* - P ≤ 0.05, ** - P ≤ 0.01, *** - P ≤ 0.001

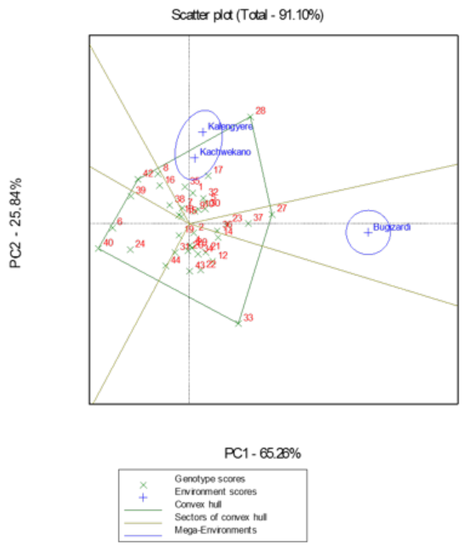


Figure 1 - Mega environments and winning vertex hybrids of grain yield for maize hybrids across three highland environments in Uganda.

of sites to the ideal site and genotypes to the ideal genotype (Yan and Tinker, 2006). The statistical linear model used was: $Y_{ijk} = \mu + L_i + G_j + L \times G_{ij} + R/L_{ik} + e_{ijk}$, where $Y_{ijk}$ = grain yield of the $j^{th}$ genotype in the $k^{th}$ replication within the $i^{th}$ location, μ = population mean, $L_i$ = main effect of the $i^{th}$ location, $G_j$ = main effect of $j^{th}$ genotype, $R/L_{ik}$ = the effect of $k^{th}$ replication within the $i^{th}$ location and $e_{ijk}$ is the experimental error.

## Results

### *Analysis of grain yield across sites*

The analysis of variance revealed significant differences (P ≤ 0.05) in grain yield across sites. Hybrid x site interaction effects resulted in highly significant (P ≤ 0.001) grain yield differences (Table 1).

### *Genotype and Genotype by Environment Biplot (GGE) analysis*

The two principal component analysis (PCA) axes explained 91.1% of the total variation in grain yield across environments, with PCA1 axis explaining the majority (65.26%) of variation for grain yield (Figure 1). Five genotypes AMH701-9/AMH703-22, AMH701-9/AMH701-20, AMH701-20/AMH703-34, AMH703-34/AMH703-37, and AMH703-35/AMH703-37 delineated the polygon that was made of five sectors. There were two mega-environments, with Kalengyere and Kachwekano being in one mega-environment; the winning genotype in this mega environment was AMH701-9/AMH703-22. The second mega-environment consisted of Buginyanya, with AMH701-9/AMH701-20 being the winning genotype (Figure 1). Kalengyere emerged as the best environment as its position on the concentric circle was closest to the ideal environment (Figure 2). This was followed by Buginyanya and Kachwekano, respectively. Overall, hybrid AMH701-9/AMH703-22 was the most superior

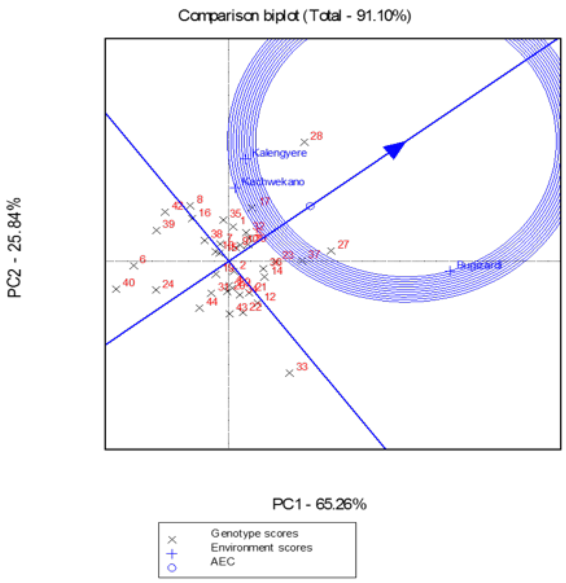


Figure 2 - GGE Biplot graph for comparing test environments used in evaluating maize hybrids in Uganda to an ideal environment.

genotype, with the highest grain yield and best yield stability given its location on the circle of the ideal genotype (Figure 3). Other high yielding and stable hybrids were AMH704-22/AMH703-37 and AMH701-20/AMH703-22, respectively.

### *Hybrid mean performance for grain yield across sites*

The mean performance of the hybrids is presented in (Table 3) with a range of 1.22-14.39 t ha$^{-1}$. About 53% of hybrids performed better than the commercial check (H614D) while 22.2% of them were worse than the local check (Nambanane). Hybrids AMH701-9/AMH701-20, AMH703-22/AMH703-35, and

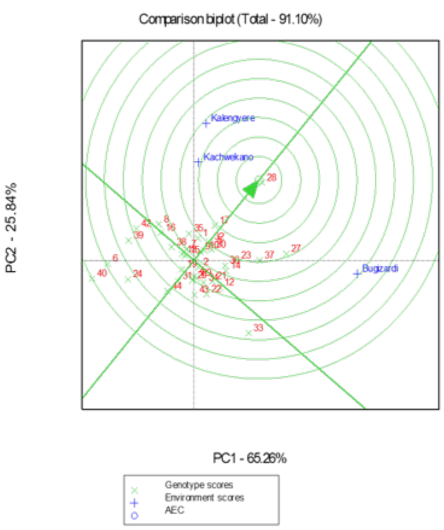


Figure 3 - GGE Biplot graph for comparing test maize hybrids evaluated in three highland environments to an ideal hybrid.

Table 2 - Correlation coefficients of grain yield and selected morphological and yield related traits for maize hybrids.

| ED | ED | EL | KR | K_R | GY | LLH | LLW |
|---|---|---|---|---|---|---|---|
| EL | 0.13 | | | | | | |
| KR | 0.27*** | 0.02 | | | | | |
| K_R | 0.53*** | 0.34 | 0.08 | | | | |
| GY | -0.36*** | 0.31*** | 0.1 | -0.06 | | | |
| LLH | 0.51*** | 0.11 | 0.1 | 0.29*** | -0.26*** | | |
| LLW | 0.59*** | 0.11 | 0.14* | 0.25*** | -0.26*** | 0.58*** | |
| NLS | 0.07 | 0.32*** | 0.02 | 0.18** | 0.27*** | 0.03 | 0.15* |

* - P ≤ 0.05, ** - P ≤ 0.01, *** - P ≤ 0.001, ED - Ear diameter, EL - Ear length, KR - number of kernel rows, K_R - Number of kernels per row, NLS - Total number of leaves, LLH - Leaf length, LLW - Leaf width.

AMH701-9/AMH703-22 had the highest grain yields (12.48-14.45 t ha$^{-1}$) across sites whereas AMH703-34/AMH703-37, AMH704-14/AMH703-22 had the lowest grain yield (1.85-2.79 t ha$^{-1}$) across sites.

The correlation matrix of grain yield with selected morphological and yield related traits of the $F_1$ maize hybrids across three highland sites is shown in Table 2. The correlation coefficient values of grain yield and these traits varied from -0.06 to 0.59. The strongest significantly positive correlation (P <0.001) was between ear diameter (ED) and leaf width (LLW) [r = 0.59], while grain yield (GY) and ear diameter had the strongest significantly negative correlation [r = -0.36; (P < 0.001)]. Grain yield had negative correlations with ear diameter, leaf length, leaf width and number of kernels per row. Correlations between GY and the rest of the traits were, however, positive.

## Discussion

The significant differences observed among the three highland sites are indicative of variation among their physical conditions affecting hybrid performance. Likewise, the highly significant yield differences due to hybrid by site interaction effects confirmed the existence of climatic variations across the different highland sites. One such climatic variation is the rainfall pattern and heat intensity in Kalengyere and Kachwekano compared to Buginyanya. Whereas average rainfalls in SW Uganda was 0.04 mm in 2015, SE Uganda received 7.2 mm yet all trials were planted in the same month of April. The heat intensities were 18.9°C and 20.32°C in SE and SW, respectively. Therefore, the heat intensity (or average temperature) for both sites was in the required range for maize growth which is 18°C - 27°C although the rainfall amount in south western Uganda was much lower compared to 600 - 1,100 mm which is the requirement for maize. Though there were no significant differences in the performance of hybrids across sites, the site x hybrid significant interaction effects are a proof that genetic diversity in highland maize can be site specific. Similar findings were observed by (Kamutando et al, 2013) where the GEI contribution to grain yield was large.

Considering the mean squares values, site had

Table 3 - Hybrid mean performance for grain yield of maize hybrids within and across three highland sites in Uganda.

| Hybrid | Grain yield (t ha$^{-1}$) | | | |
|---|---|---|---|---|
| | Buginyanya | Kachwekano | Kalengyere | Across sites |
| AMH704-14/AMH704-22 | 8.6 | 5.7 | 10.4 | 8.6 |
| AMH704-14/AMH704-43 | 8.8 | 3.9 | 9.8 | 8.7 |
| AMH704-14/AMH701-9 | 8.9 | 3.3 | 9.5 | 8.5 |
| AMH704-14/AMH701-20 | 9.6 | 4.7 | 10.9 | 9.5 |
| AMH704-14/AMH703-22 | 3.2 | 3.9 | 9.6 | 2.8 |
| AMH704-14/AMH703-34 | 8.3 | 5.0 | 9.9 | 8.0 |
| AMH704-14/AMH703-35 | 6.0 | 5.8 | 11.7 | 5.9 |
| AMH704-14/AMH703-37 | 8.8 | 5.2 | 9.5 | 8.8 |
| AMH704-22/AMH704-43 | 9.5 | 4.8 | 10.1 | 9.0 |
| AMH704-22/AMH701-9 | 10.3 | 4.2 | 8.3 | 10.2 |
| AMH704-22/AMH701-20 | 7.7 | 5.5 | 9.7 | 7.6 |
| AMH704-22/AMH703-22 | 10.9 | 2.9 | 10.0 | 10.5 |
| AMH704-22/AMH703-34 | 7.9 | 5.2 | 9.1 | 7.8 |
| AMH704-22/AMH703-35 | 6.5 | 6.5 | 9.9 | 6.1 |
| AMH704-22/AMH703-37 | 10.1 | 6.5 | 10.8 | 9.6 |
| AMH704-43/AMH701-9 | 7.7 | 3.9 | 9.5 | 7.6 |
| AMH704-43/AMH701-20 | 8.8 | 5.7 | 7.4 | 8.5 |
| AMH704-43/AMH703-22 | 10.2 | 5.0 | 8.2 | 9.7 |
| AMH704-43/AMH703-34 | 9.8 | 3.9 | 7.7 | 9.4 |
| AMH704-43/AMH703-35 | 10.8 | 6.0 | 8.5 | 11.2 |
| AMH704-43/AMH703-37 | 3.7 | 4.0 | 8.5 | 4.2 |
| AMH701-9/AMH701-20 | 14.4 | 5.6 | 9.6 | 14.5 |
| AMH701-9/AMH703-22 | 12.4 | 6.7 | 14.3 | 12.5 |
| AMH701-9/AMH703-34 | 8.3 | 4.6 | 8.5 | 8.7 |
| AMH701-9/AMH703-35 | 10.0 | 5.7 | 9.9 | 9.5 |
| AMH701-9/AMH703-37 | 7.4 | 4.4 | 8.2 | 7.5 |
| AMH701-20/AMH703-22 | 8.9 | 4.8 | 10.8 | 9.3 |
| AMH701-20/AMH703-34 | 12.3 | 1.2 | 6.9 | 12.3 |
| AMH701-20/AMH703-35 | 9.1 | 4.6 | 7.5 | 9.2 |
| AMH701-20/AMH703-37 | 7.9 | 6.1 | 10.2 | 7.9 |
| AMH703-22/AMH703-34 | 10.4 | 4.7 | 8.9 | 10.5 |
| AMH703-22/AMH703-35 | 12.3 | 4.7 | 10.3 | 12.7 |
| AMH703-22/AMH703-37 | 7.0 | 4.2 | 10.6 | 6.8 |
| AMH703-34/AMH703-35 | 3.6 | 5.5 | 9.7 | 4.1 |
| AMH703-34/AMH703-37 | 1.4 | 3.9 | 8.4 | 2.0 |
| AMH703-35/AMH703-37 | 4.4 | 6.0 | 10.7 | 4.5 |
| H614D | 8.2 | 3.1 | 7.6 | 8.6 |
| Nambanane | 7.0 | 6.1 | 6.3 | 7.0 |
| Maximum | 14.4 | 6.7 | 14.3 | 14.5 |
| Minimum | 1.4 | 1.2 | 6.3 | 1.8 |
| Hybrid Average | 8.5 | 4.9 | 9.5 | 8.5 |
| Check Average | 7.3 | 4.6 | 6.9 | 7.8 |
| Overall Average | 8.4 | 4.8 | 9.4 | 8.42 |

the highest proportion of total variance in grain yield, followed by the hybrids and lastly hybrid by site interaction. This is comparable to the results of Abdu et al (2013) and Mohammadi et al (2009) who recounted that the largest percentage of total variation in multilocation trials is due to sites whereas hybrid and hybrid by site interaction sources of variation were relatively smaller. Based on variance components, this study found that hybrid by site interaction effects explained 46.2% of the phenotypic variation; this interaction, hence, had a strong effect on the grain yield of the $F_1$ highland maize hybrids. This is further proof that breeding for high yielding highland maize should focus on specific adaptation.

The Genotype and Genotype by Environment (GGE) scatter plot also confirmed the presence of GEI effects as it showed the presence of two mega-environments; these were environments that fell in one sector of the polygon (Abdu et al, 2013), with AMH701-9/AMH703-22 being the winning hybrid in one of the mega environments (Kachwekano and Kalengyere). Kachwekano and Kalengyere have altitudes of 1,980 masl and 2,450 masl, respectively; the small difference in their altitudes would explain their placement in one mega environment. The second mega-environment, Buginyanya had a much lower altitude (1800 masl) compared to the previous two. Hybrids AMH701-9/AMH703-22, AMH701-9/AMH701-20, AMH701-20/AMH703-34, AMH703-34/AMH703-37 and AMH703-35/AMH703-37 either performed the best or poorest in one or more sites as they were the most responsive hybrids being the vertex genotypes (Yan and Tinker, 2006).

Based on the correlation coefficients, ear length had the highest correlation with grain yield while leaf length and leaf width were highly correlated to yield loss. The positive significant correlation between grain yield and total number of leaves corroborates with the studies conducted by (Pavlov et al, 2012) and (Pavlov et al, 2015).

The negative correlations between grain yield and both leaf length and leaf width were comparable with Beyene et al (2005) but in contradiction with Magorokosho (2006), whose study found positive correlation of leaf length and leaf width with grain yield. According to Fageria et al (2007), a reduction in leaf length leads to reduction in leaf area index (LAI) thereby reducing the amount of photosynthetic products produced by the plant hence reducing grain yield of the plant. Plants with longer leaves are, therefore, preferred by breeders.

### *Conclusions*

This study revealed that genotype by environment interactions had a strong effect on grain yield highland maize hybrids. This calls for breeding for specific adaptation instead of broad adaptation of high yielding highland maize hybrids. The three highland evaluation sites were divided into two maize mega-environments, namely (i) Kachwekano and Kalengyere, and (ii) Buginyanya, with AMH701-9/AMH703-22 and AMH701-9/AMH701-20 being the winning hybrids in the two mega-environments, respectively. Overall, the best site was Kalengyere while hybrids AMH701-9/AMH703-22 and AMH703-22/AMH703-35 were the most high yielding across the three highland sites. The performance of these hybrids should be confirmed through further evaluation across seasons and more sites in the highlands of Uganda. Morphological and yield related traits that had significantly positive correlation coefficients can be used in further evaluations to predict grain yield.

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