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Stability and adaptability of cotton (*Gossypium hirsutum* L.) genotypes based on AMMI analysis

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Abstract

Evaluation of the stability and adaptability of genotypes across different environment conditions is important for release and recommendation of new varieties to ensure their high adaptability. Plant breeders evaluate germplasms in multi-environment trials to study the stability and adaptability of genotypes (G) and to recommend the genotypes to different environments (E). Multi-environment trials for 11 genotypes including 4 check varieties of cotton were carried out during 3 seasons in 3 locations in Mozambique. The objective of this study was to assess the G x E pattern and to evaluate the stability and adaptability of seed cotton yield of a new germplasm in Mozambique. The experiment was set up in Namialo (district of Meconta province of Nampula), Namara (district of Balama, province of Cabo Delgado) and Nhamatanda (district of Nhamatanda province of Sofala). The treatments consisted of 11 varieties, which were established in a randomized complete block design with four replications. The graphic analysis of additive main effect and multiplicative interaction (AMMI) were used to understand the G x E interaction pattern and to study the stability and adaptability. The results showed significant effect of genotype, environment and G x E interaction. The first two principal components explained about 80% of the detected interaction. The pair of Environment/Genotype showed the E/G combination for high performance. The genotypes and environments showed genetic and environmental performance dissimilarity. The AMMI revealed that genotypes FK 37, BA 919 and Flash were the most adaptable, while BA 2018 and BA 320 were the most stable across the variation of environments.

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Keywords: AMMI, Biplot, GGE, genotype x environment interaction, seed cotton yield.

Abbreviations: AMMI_Additive main effect and multiplicative interaction; GE_Genotype by Environment interaction; GGE_ Genotype main effect plus genotype by environment interaction; GOT_Ginning out-turn; PCA_Principal component analysis.

Introduction

Cotton is an important commodity in the world economy and it is grown as crop in more than 100 countries (ITC, 2007). The world uses more cotton than any other fiber and over 150 countries are involved in exports or imports of cotton (Carvalho et al., 2015). In Mozambique, cotton is important and involves 300,000 small-scale farmers in its production as a cash crop and is the most important agricultural export crop in the country, contributing close to 17 percent of total agricultural exports and almost 2 percent of total exports (Dias, 2012; IAM, 2015). The cotton sector in Mozambique is generally characterized by low yields (500 kg.ha^{-1}) compared to the world average yield (800 kg.ha^{-1}) and to the neighboring countries such as Malawi (800 kg.ha^{-1}), Tanzania (750 kg.ha^{-1}) and Zambia (800 kg.ha^{-1}) (Dias, 2012; Mekuria, 2012). One of the reasons is the low yielding and less adaptable varieties (Maleia et al., 2010). The cotton research program in the country has been developing and introducing new different germplasm/genotypes, in order to find the suitable varieties to the local edaphoclimatic conditions (Maleia et al., 2010). However, recommendation of varieties has been a challenge, as it depends largely on the variety adaptability to the soil and climatic conditions of the region. The crop is grown under unpredictable weather patterns which cause a need for the identification of stable genotypes having specific adaptation to specific environments (Pretorius et al., 2015). This factor has given the great variations on the performance of the same variety in different locals of production (Maleia et al, 2010; Pretorius et al., 2015). So, before recommending, any variety should be assessed for adaptability and stability (Cruz and Carneiro, 2006). Among the various statistical procedures developed for this kind of study, AMMI (Additive Main effects and Multiplicative Interaction) has been frequently used by researchers. The AMMI has shown efficient in stability analyses (Ebdon and Gauch, 2002; Miranda et al., 2009; Riaz et al., 2013; Abuali et al., 2014; Bose et al., 2014, Akter et al., 2014; Agyeman, et al., 2015). The Additive Main effects and Multiplicative Interaction (AMMI) is a tool to study GE interaction pattern and so to estimate the adaptability of different varieties on multi-environment trials. Since, GE interaction is naturally multivariate; the AMMI offers an appropriate statistical analysis of yield trials that have a G x E interaction (Anandan et al., 2009; Sabaghpour et al., 2012). The AMMI model, which combines ANOVA with principal components analysis (PCA) extracts genotype and environment main effects and uses the PCA to explain patterns in the GxE interaction, which provides a multiplicative model and is used to analyze the interaction effect from the additive ANOVA model (Zobel et al., 1988; Sabaghpour et al., 2012). This model also allows conclusions regarding phenotypic stability, genotypic behavior of the cultivars, and the degree of genetic divergence between cultivars and the environments that optimize performance (Miranda et al., 2009). This study aimed to assess the G x E pattern and to evaluate the stability and adaptability for seed cotton yield of new cotton germplasm in Mozambique based on AMMI analysis.

Results and Discussion

Tests for normality and homogeneity of variances

Shapiro-Wilk's normality of the error (1995) and Bartlett's homogeneous variance of errors (1937) for the seed cotton yield allowed preceding the individual ANOVA in each of six environments. Then, the assessment of the Hartley's Fmax test (1950) indicated homogeneous error variances among the evaluated environments that allowed conduction of combined ANOVA. It shows that the assumption of homogeneous variance and normality of the error was proved; so the ANOVA could be validated. According to Ghasemi and Zahediasl (2012), statistical errors are common in scientific literature, so the assumption of homogeneous variance and normality of the error need to be checked before, for many statistical procedures, namely parametric tests such as analysis of variance (ANOVA), because their validity depends on it. The use of statistical tools in any research work is very important. However, many researchers often fail to pay attention to the important concepts prior to any parametric tests. So, prior to the application of any inferential or parametric test two characteristics of data sets must be considered, normal distribution and uniformity of variances (Granato et al., 2014).

Analysis of variance

The combined ANOVA revealed a significant difference among genotypes, environments and a significant GxE interaction (Table 1), which indicates that the environment had an impact over the differentiated performance of the genotypes and the broad range of diversity among them (Anandan et al., 2009). In this study, we also found that the GxE interaction accounted for less variation than the main effect of genotype and environment, showing that the environment had a greater effect on seed cotton yield than either genotype or GE interaction alone. This is in corroboration with Maleia et al. (2010), Pretorius et al. (2015) and Farias et al. (2016), evaluating cotton genotypes in different environments. In addition, it shows that some varieties had better performance in one environment and low performance in others, which provided a change of their performance standard under the environmental variation revealed by the significant of GxE interaction (Table 1). This is often observed when a complexed (multigenic) trait such as seed cotton yield or a trait governed by multiple genes that cause changes in the performance of genotypes over different environments being studied. Similar significant effects of genotype and GxE interaction were observed by Maleia et al. (2010), Riaz et al. (2013), Moiana et al. (2014), Pretorius et al. (2015), Carvalho et al. (2015) and Faria et al. (2016), evaluating cotton genotypes in multi-environmental trials in Mozambique, Pakistan, South Africa and Brazil.

AMMI analysis

The GxE interaction composed of 5 principal components (Table 2), among which the first two (PC1 and PC2) were highly significant ($p < 0.01$) and explained about 80% of the detected interaction (54.59% and 24.97% for PC1 and PC2, respectively). This makes the stability and adaptability study based on the AMMI method more concise (Gauch, 1992). The Genotypes G3 (BA 919) and G4 (Flash) were grouped together on the biplot of PC1 against PC2. It shows that they differed only on the main effect but not in interaction effect, while G5 (BA 525) and G9 (Albar SZ9314) differed only on the interaction effect but not on the main effect (Fig.1). These differences among genotypes over interaction and main effects might have been due to the environment diversity. The AMMI graphic (Fig.1) emphasizes that there were a year to year variation, indicating the importance of seasonal climatic variation in the same local, as the environments were scattered without any grouping on different quadrants (Anandan et al., 2009). The biplot graphic (Fig.1) also revealed that there are 4 mega-environments: two main ones, represented by 2 environments (E3; E6, in the 2nd quadrant and E4; E5, in the 3rd quadrant) while the 2 minor ones were represented by 1 environment (E1, in the 1st quadrant and E2, in the 2nd quadrant). Classifying genotype in mega-environment can minimize the GxE interaction by identifying the group of environments, in which the interaction is not significant for the group of genotypes under evaluation. In fact, in multi-environmental trials the number of environment should be high, whenever possible, in order to group similar environments. Cotton is a rain fed crop in Mozambique, as it is in many other cotton growing countries in sub-Saharan Africa. Its yield is closely related to climate, in particular to rainfall variability. Seed cotton yields drop during drought seasons or when the rainfall distribution is abnormal during the growing period. The environmental conditions of cotton growing regions are highly diversified and it leads to cultivar environmental variability. Gul et al. (2014) studied the genotype by environment interaction and association of yield variables in cotton and found that the seed cotton yield is highly affected by environment complex than genotype itself. So, identification of genotypes with high adaptability and stability to the different growing conditions is an option to deal with this fact (Cruz and Carneiro, 2006). The genotypes showed a dissimilar genetic performance once they were positioned in opposing quadrants as can be observed for BA919 (G3), Flash (G4), FK37 (G6) and BA2018 (G1), Churedza (G8), CA324 (G10), ISA 205 (G11); (G5) and BA320 (G2), QM 301 (G7), Albar SZ9314 (G9). These results suggest that the 3 new varieties (BA919, Flash, FK37) performed better and differently compared to the most of the check varieties (Churedza, CA324, ISA 205) used in this study. The pair of environments comprising Namialo 2014 (E3)/ Nhamatanda 2014 (E6) and Balama 2014 (E5)/ Balama

Table 1. Summary of combine ANOVA of seed cotton yield (Kg.ha^{-1}).

Source of Variation	DF	Mean Square
Blocks/Environment	18	556173.61
Environments (E)	5	15711132.87*
Genotypes (G)	10	426619.22**
G x E	50	173685.03*
Residue (Error)	180	196699.03
Total	263	
Overall Average		1530.61
CV (%)		28.98

** Significant at 1% of probability, *Significant at 5 % of probability.

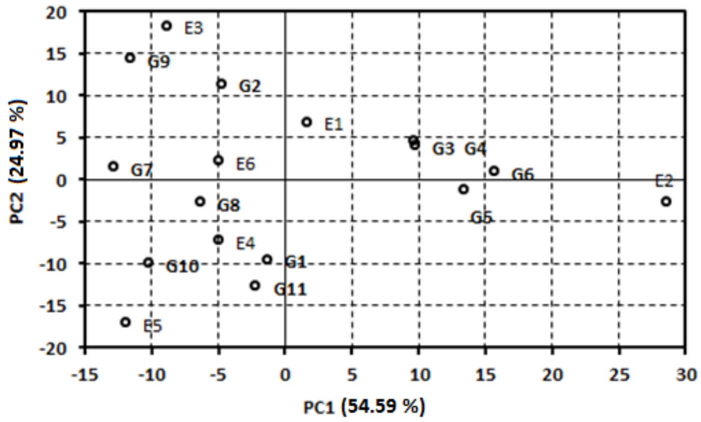

Fig 1. Graphics biplot of PC1 against PC2 and seed cotton yield of 11 genotypes (G1 to G11) in 6 environments (E1 to E6). G1: genotype BA2018; G2: genotype BA320; G3: genotype BA919; G4: genotype Flash; G5: genotype BA525; G6: genotype FK37; G7: genotype QM 301; G8: genotype Chureza; G9: genotype Albar SZ9314; G10: genotype CA324; G11: genotype ISA205. E1: Namialo, 2012 season; E2: Local: Namialo, 2013 season; E3: Local: Namialo, 2014 season; E4: Balama, 2013 season; E5: Balama, 2014 season; E6: Nhamatanda, 2014 season.

Table 2. Composition of GxE interaction into principal components.

Source of variation			DF	SS	MS
Interaction (G x E)			50	8684251.59	173685.03*
Principal Components	%	Accumulated %			
PC1	54.59	54.59	14	4740798.49	338628.46**
PC2	24.97	79.56	12	2168687.05	180723.92**
PC3	10.99	90.55	10	953994.47	95399.45
PC4	5.99	96.54	8	520413.37	65051.67
PC5	3.46	100.00	6	300358.21	50059.70
Residue (Error)	-	-	180	35405824.66	196699.03

** Significant at 1% of probability, * Significant at 5 % of probability

Table 3. The name and characterization of culivars.

Treatment	Genotype/ cultivar	Origin (type)	Tolerance to sucking insects *(Empoasca fasciallis* and *aphis gossypii*)	GOT (%)	Crop cycle (Days)
1	BA2018	Turkey (OPV)	Poor	> 43	120 -140
2	BA320	Turkey (OPV)	Poor	> 43	120 -140
3	BA919	Turkey (OPV)	Poor	> 43	120 -140
4	Flash	Turkey (OPV)	Poor	> 43	120 -140
5	BA525	Turkey (OPV)	Poor	> 43	120 -140
6	FK37	Burkina Fasso (OPV)	Fair	40-42	130 - 150
7	QM 301	Zimbabwe (OPV)	Fair	> 41	130 -150
8	Chureza	Zambia (OPV)	Fair	40 - 41	130 - 150
9	Albar SZ 9314	Zimbabwe (OPV)	Fair	> 41	> 150
10	CA 324	Ivory Cost (OPV)	Fair	40-42	130 - 150
11	ISA 205	Cameron (OPV)	Fair	39	130 - 150

Source: IAM, 2015

2013 (E4) was similar and suitable for BA320 (G2), QM 301 (G7), Albar SZ9314 (G9) and BA2018 (G1), Churedza (G8), CA324 (G10) and ISA 205 (G11), respectively as are grouped into the same quadrant (Fig. 1). The environment Namialo 2012 (E1), suitable for the BA919 (G3), Flash (G4), FK37 (G6) and the environment Namialo 2013 (E2) for BA525 (G5) showed to be different to any others (Fig.1). The most stable genotypes, with less contribution for the G×E interaction captured by the axis PC1 and PC2, were G1 (BA 2018), G2 (BA 320) compared to the already used varieties

Churedza (G8) and ISA 205 (G11). This illustrates that these are the ones that revealed a lower variable response standard due to the environmental (local and year) variation. Therefore, the most stable genotypes showed low seed cotton yield (Fig. 1). Among the new genotypes, FK 37 (G6) and BA 919 (G3), followed by Flash (G4) showed above average seed cotton yield, indicating that was the most adaptable. The seed cotton yield performance of genotype G4 was not significantly differed to G10 (CA 324). The results show that the most stable genotypes across to the different environments were not the most adaptable. The limitations of farming inputs in development countries increase the need for the stable genotypes. Therefore, genotypes with good performance and stability should be recommended (Sabaghpour et al., 2012). For instance, from the tested genotypes, FK 37, BA 919 and Flash should be recommended, where the availability of farming input is ensured, while BA 2018 and BA 320 could be recommended for the places that availability of inputs is not secured. Riaz et al. (2003) and Pretorius et al. (2015) also identified stable and best performing cultivars when using AMMI analysis for stability, adaptability of cotton genotypes for yield improvement in Pakistan and to analyze cultivar by environmental interaction in cotton under irrigation in South Africa, respectively.

Materials and Methods

Genotypes, location and seasons

The seven genotypes, namely BA2018, BA320, BA919, Flash and BA525, originally from Turkey, FK37, from Burkina Fasso and QM301, from Zimbabwe were seen to have a high potential in the countries, where they were developed (Table 3). This was to determine their agronomic potential for varying environmental conditions prevailing in the cotton-growing regions in Mozambique, compared to the local and most cultivated ones, as check genotypes/varieties (Chureza, Albar SZ9314, CA324 and ISA 205). The seven genotypes (Table 3) were evaluated comparing with four actual used cultivars, during 3 seasons (2011/12; 2012/13; 2013/14) in Namialo (14S58' 00 and 39E51' 00) district of Meconta, province of Nampula; 2 seasons (2012/13; 2013/14) in Namara (13S 22' 58 and 38E25' 13) district of Balama, province of Cabo Delgado and 1 season (2013/14) in Nhamatanda (19S15' 15 and 34E14' 31), district of Nhamatanda, province of Sofala, providing 6 different environments through the combination between locals and seasons.

The cotton production in Mozambique is most concentrated in the agro-ecological regions 6, 7 and 8. Agro-ecological region 6 (R6) represents the semi-arid region of the Zambezi Valley and South Tete, this region consists of a vast dry area. In contrast, agro-ecological region 7 (R7) is a region of medium altitude in the Zambezia, Nampula, Tete, Niassa and Cabo Delgado provinces, the soil texture is variable and consistent with the topography. In almost all this region, there is great potential for cotton production that has been practiced for several decades. Agro-ecological region 8 (R8) represents the coast of the Zambezia, Nampula, and Cabo Delgado provinces and the soils of this region are generally sandy but heavy in the lower zones. Low soil fertility is one of the great limiting factors in this zone. Namialo village, located in between the R7 and R8 agro-ecological regions, is classified by an Aw type climate, dry sub-humid, according to Koppen (Koppen, 1948) classification, with an average annual rainfall of 800 to 1000 mm and potential evapotranspiration from 100 to 1,400 mm, and in some areas of this region have higher temperatures above 25 °C and other moderately warm (between 20 and 25 °C). The soil texture is variable generally weighed having low fertility. In most of the region there is a great potential for cotton production, which has been practiced for several decades (MAE, 2005a). Namara, located in the R7 agroeclological region, presents an Aw, tropical climate, with an average precipitation between 800 and 1200 mm and potential evapotranspiration varying between 1300 and 1500, the average annual temperature varies between 20 and 25 °C. The soils are classified as rhodic ferralsols with medium to weighed texture, deep and well drained (MAE, 2005b). The Nhamatanda, located in the R4 agroecological region, presents both Aw, rainy tropical savanna climate and Cw, tropical humid and temperate climate, with an average annual rainfall of 846 and potential evapotranspiration of 1559 mm. The average temperature is around 25 °C. The soils are deep, well drained, with good fertility and nutrient retention capacity (MAE, 2005c).

Experimental design

The treatments (Table 3) were set up in a randomized complete block design, with four replications. The plots were consisted of five rows of 5.0 m length, where the two lateral rows were considered as side borders and the three central as the useful ones, where the data was collected, in a spacing of 0.70 m between the rows and 0.20 cm between the plants. Sowing was carried out manually, putting 4-10 seeds per hole of about 4 cm of depth. The first thinning took place 15 days after the emergency, leaving two plants per hole and the second thinning was carried out leaving one plant per hole at 21 days after the emergency.

Management and evaluation of variables

Weeds were controlled manually using a hoe, whenever deemed necessary. Spraying was carried out once with acetamiprid insecticide (222 g.lt^{-1}) for the first control of pests in a dosage of 50 ml.ha^{-1}, followed by five applications of Lambda-cihalothrin (60 g L^{-1}) every two weeks from the fourth week after the emergency, in a dosage of 250 ml.ha^{-1}. Insecticides were applied with a micro-ulva (ULV). The variable evaluated was the seed cotton yield (Kg.ha^{-1}).

Statistical analysis

Before the analysis of variance (ANOVA), the data was submitted to tests of homogeneity of variances and normality (Bartlet, 1937; Shapiro-Wilk, 1965) to ensure the feasibility of ANOVA (Ramalho et al., 2000). For the Individual ANOVA, every combination of local and season/year was regarded as an environment. Before conducting the combined ANOVA, the assessment of homogeneity of the residual variances of the environments was conducted, using the Hartley's Fmax test (Hartley, 1950), at 5% of probability, to ensure the feasibility of combine analysis of variance (Cruz and Regazzi, 2001). The combine ANOVA was conducted after the residual variances of all the environments were regarded as homogeneous ($p > 0.05$), considering the effect of genotypes as fixed, and the effect of the environments and blocks as random (Cruz and Regazzi, 2001). When a significant genotypes x environments (GxE) interaction was revealed, stability and adaptability analysis based on the AMMI (Additive Main Effects and Multiplicative Interaction) model was applied, where the original GxE interaction was decomposed into the Principal Component analysis (Zobel et al., 1988; Gauch, 1988; Gauch, 1992; Cornelius et al., 1996). The AMMI model is:

$$Y_{ij} = \mu + G_i + E_j + \sum_{n=1}^{N} \lambda_n \zeta_{in} \eta_{jn} + \Theta_{ij} + \varepsilon_{ij}$$

Where, Y_{ij} is the observed mean yield of genotype *i* in environment *j*, μ is the grand mean yield, G_i is the genotype main effect, E_j is the environment main effect, λ_n is the eingen value of the n^{th} principal component, ζ_{in} and η_{jn} are genotype and environment scores for the n^{th} principal component, Θ_{ij} is the interaction residual, N is the number of principal components retained in the model and ε_{ij} is the random error term (Zobel et al., 1988; Gauch, 1988; Gauch, 1992; Cornelius et al., 1996). All analyses were conducted under the GENES (Cruz, 2006a; Cruz, 2006b) and SAS (SAS, 2008) statistical softwares.

Conclusion

The AMMI was useful to study the GxE interaction and to assess the stability and adaptability on the multi-environmental trial. The results illustrated that the genotypes and environments showed dissimilarity once they were positioned in opposing quadrants and the most stable genotypes across the different environments were not the most adaptable. The genotypes FK 37, BA 919 and Flash were the most adaptable to the Mozambican cotton growing environment, while BA 2018 and BA 320 were the most stable across the variation of environment.

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