Additive main effects and multiplicative interaction analysis of genotype x environmental interaction among sweetpotato genotypes

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1   SUMMARY

Sweetpotato is an important food, feed and cash crop in Eastern Africa. Highly stable and adaptable genotypes are important in sweetpotato productivity and evaluation across sites would form a basis for breeding varieties that are stable. Seventeen sweetpotato genotypes were evaluated for two seasons in three sites which have differentials in sweetpotato virus disease prevalence and climatic conditions in the coastal region of Kenya to determine their stability and adaptability in the region. The experimental design was randomized complete block design. Harvesting was done at four and half months after planting and tuber yield was determined. Data was analysed using the additive main effects and multiplicative interaction model (AMMI) to establish the genotype x environmental interactions (GEI). There was wide variation across the environments in the two seasons. Stability and adaptability was identified among sweetpotato genotypes. Varities Jonathan, Exshimba, SPK 004 and Kemb 10 were highly adapted across all the environments whereas Ejumula, Jewel, Jubilee, Bungoma, and sponge were stable. The highly adapted genotypes can be used as a basis for further improvement through breeding by crossing with the stable genotypes.

2   INTRODUCTION

Sweetpotato is among the most important food crops in the world, ranked seventh (based on total production) and being cultivated in more than 100 countries. It is the fifth most important crop in terms of consumption in developing countries (FAO, 2005). There is a wide range of sweetpotato genotypes in the world. Both the genotype and the environment determine the phenotype of an individual. These two effects are not always additive, which indicates that genotype x environment interaction (GEI) is present. The interaction
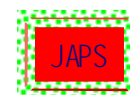
makes it difficult to select the best performing and most stable genotypes in plant breeding Genotype stability across environments is important in breeding programmes because it enhances the progress from selection in any one environment (Yau, 1995). A genotype is considered to be stable if its response in all environments is constant (Martin, 2004). This type of stability is called the dynamic or agronomic stability (Becker & Léon, 1988). A genotype is also considered to be stable if the residual mean squares from the regression model on the environmental index are small programmes due to need to select for multiple environments (Hill, 1975; Yau, 1995). relative to the genotype (treatment) mean squares. The environmental index implicates the mean yield of all the genotypes in each location minus the grand mean of all the genotypes in all locations. This stability is also part of the dynamic or agronomic stability concept. The two types of stability in genotypes are important in breeding because the breeding programme can be successful across environments in different agro-ecological zones (Becker & Léon, 1988).

3   MATERIALS AND METHODS

Seventeen sweetpotato genotypes were tested in three sites for two seasons; short (May to September 2006) and long (October 2006 to February 2007) rainy season, thus in a total of six environments. The 17 varieties were either improved or local landraces. The flesh colour was white, cream, yellow or orange while the skin colour was red, cream white or brown (Table 1).

Table 1: Sweetpotato genotypes which were evaluated across the three sites for two seasons.

Variety	Category	Flesh colour	Skin colour
Jonathan	Improved	Light cream	Cream white
Japonese	Improved	Orange	Cream white
Zapallo	Improved	Orange	Cream white
Kemb10	Improved	Cream	Cream white
Jewel	Improved	Orange	Orange
Mugande	Local landrace	White	Red
Marooko	Local landrace	Light cream	Brown
Ex-shimba	Local landrace	White	Red
Jubilee	Local landrace	Orange	Orange
Ejumula	Local landrace	Orange	Orange
SPK004	Improved	Orange	Red
440015	Improved	Orange	Red
K135	Improved	Orange	Cream
Salyboro	Local landrace	Orange	Cream white
Muibai	Local landrace	White	Red
Bungoma	Local landrace	Yellow	Red
Sponge	Local landrace	Orange	Red

The three trial sites were KARI-Mtwapa farm in Kilifi district, Lukore and Mwaluvanga in Shimba hills, Kwale district. The environmental conditions are as shown in Table 2 according to Michieka, *et al.* 1978 and Jaetzold *et al.* 1983. The three sites were chosen on the basis of sweetpotato virus disease prevalence which greatly reduces sweetpotato productivity.
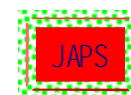
Table 2: Environmental conditions of three sites where sweet potato experiments were conducted.

Parameter	Kari-Mtwapa	Lukore	Mwaluvanga
Altitude	30 m	46 m	46 m
Rainfall	1200 mm	1400 mm	1400 mm
Temp min	22°C	16°C	16°C
Temp max	33°C	27°C	27°C
Soil types	Sandy	Sandy loam	Sandy loam

Apparently clean planting materials were obtained from the International Potato Centre (CIP, Nairobi) and Kenya Agricultural Research Institute (KARI) and multiplied at KARI-Mtwapa under stringent spraying program (once every two weeks using dimethoate and karate alternately) to control aphids and whiteflies which are key vectors of sweetpotato virus diseases. The vines were distributed to farmers who planted in May 2006 in addition to the research managed trials. There were a total of twenty farmers in each of the two sites in Shimba hills (Lukore and Mwaluvanga) who had been previously identified in a focussed group discussion addressing key sweetpotato production constraints. At the beginning of the short rain season (October 2006) vines were obtained from the previous season crop and planted in new fields' approximately two hundred metres away in all sites.

The experimental design was randomised complete block design (RCBD) with three replications of each treatment at each site. The land was ploughed, harrowed and ridged before planting. The sweetpotato clones were planted at a spacing of 0.8 m x 0.3 m on plots measuring 4 m x 3 m. Weeding was done using hoe twice a month in the first two months and rogued once thereafter.

The vine fresh mass, tuber yield, dry matter and harvest index were determined at harvest (four and half months after planting). The tubers were harvested from two middle rows of each plot and grouped into marketable and non-marketable tubers based on size and attack by the sweetpotato weevil tubers which were weighed. Additive main effects and multiplicative interaction (AMMI) model was used to establish genotype adaptability and stability in the trial environments. This was done to obtain insight on the effect of genotype and environmental interaction on sweetpotato yield. The two seasons were regarded as different environments in combination with the three sites.

4   RESULTS AND DISCUSSION

The ANOVA indicated highly significant environment, genotype, and genotype x environment interaction (GEI) effects (Table 3). Similarly the principal component analysis (PCA1 and PCA2) axes were also highly significant. The importance of genotype and environment was evident because the sum of squares for genotypes, environment and PCA 1 and 2 accounted for 97% of treatment sum of squares, an indication that the AMMI model effectively partitioned treatments sum of squares (Steyn *et al*, 1993). The environment, genotypes and G x E interaction accounted for 54, 30 and 17 % of the treatment sum of squares, respectively.

The total proportion contributed by environment and G x E interaction accounted for 70 % of the variation in tuber yield. Similar observations have been made in cassava showing that the proportion of sum of squares due to difference among sites ranged from 50 to 90 % in cassava (IITA, 1993; Dixon & Nukenine, 1997; Ntawuruhunga *et al.*, 2001).

The PCA scores biplot for both genotypes and environments showed wide variability among environments and less among genotypes (Figure 1). The high yielding genotypes Ex-shimba, Kemb10, Japonese, Jonathan, Zapallo and SPK004 had large principal component scores (either positive or negative) thus indicating their adaptability. Cultivars Ejumula, Jubilee, Muibai and Sponge had low yield in all the environments and were stable genotypes because their PCA values were close to zero. Low yielding genotypes have stable yield that does not benefit from favourable environments (Hill *et al*, 1998). These four varieties are also moderately resistant to the sweetpotato virus disease hence they can be used as sources of resistance. They also have high dry matter and high foliage cover hence can be used as an animal feed source. Cultivars Marooko, Muibai, 440015, K135, Salyboro and Jewel were at
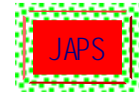
or near the middle of the biplot and did not show a distinct pattern of stability or adaptability, hence they may be considered to be either adapted to the favourable or adverse environments. There was overlap of some genotypes in the biplot which was an indication of cross-over interaction among genotypes in the different environments, e.g Muibai and Marooko, 440015 and K135, Ejumula, Jubilee and Sponge, Sponge and Bungoma and finaly Jewel and Salyboro.
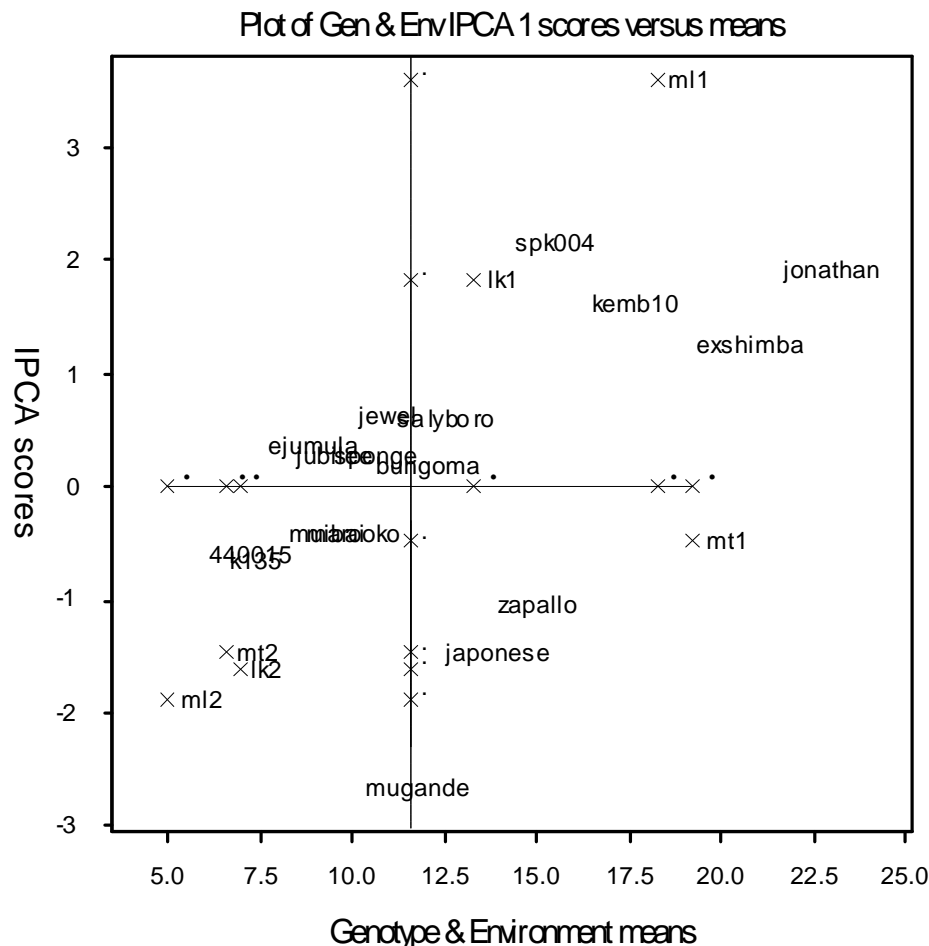

Figure 1: The additive main effects and multiplicative biplot of IPCA scores of seventeen sweetpotato genotypes and environment against mean yield (t/ha) of both genotypes and environments.

Key: mt1-Mtwapa long rain season; mt2-Mtwapa short rain season; lk1-Lukore long rain season; lk2-Lukore short rain season; ml1-Mwaluvanga long rain season; ml2-Mwaluvanga short rain season; IPCA-Interaction Principal component analysis.

In contrast, cultivars Jonathan, SPK004, Kemb10, Ex-shimba, Japonese and Zapallo and environments Lukore Long Rain (1), Mwaluvanga-1 and Mtwapa-1 had the same relative direction hence they both contributed positively to the interaction. This indicates that the performance of these genotypes in these environments was optimal leading to high tuber yield. They were also far away from the vertical reference line, an indication that though highly adaptable, they were unstable across environments. However the six genotypes and
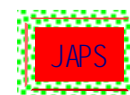
environments Lukore Short Rain (1), Mwaluvanga-2 and Mtwapa-2 contributed negatively to the interaction. As a result they had low tuber yield since their performance was not optimal.

The biplot provided information on the relative stability and clearly defined trends of similar or dissimilar genotypes and environments. To validate genotype stability, genotype yield standard deviations were computed to establish their association with principal component analysis (PCA) which partitions data under the least square principle. The stable genotypes had small standard deviation values whereas the highly adaptable ones had large values. The environmental yield means for stable and unstable genotypes were plotted in a scatter graph and it was noted that the stable genotypes had a gentle slope whereas the unstable and highly adapted genotypes had steep slopes (Figure 2).

Table 3: Analysis of variance of genotype and environmental interactions of sweetpotato genotypes

Source	df	SS	MS	F Value	Pr.>F
		Additive main effects and multiplicative model			
Total	305	21890	71.8		
Treatments	101	18628	184.4	14.47	≤ 0.01
Genotypes	16	5496	343.5	26.95	≤ 0.01
Environments	5	9999	1999.8	29.46	≤ 0.01
Block	12	815	67.9	5.33	≤ 0.01
Interactions	80	3133	39.2	3.07	≤ 0.01
IPCA 1	20	1851	92.6	7.26	≤ 0.01
IPCA 1	18	711	39.5	3.1	≤ 0.01
Residuals	42	571	13.6	1.07	0.375
Error	192	2447	12.7	*	*

Genotype response

High yielding genotypes exhibited large PCA1 scores (Jonathan, Kemb 10, SPK004, Ex-shimba, Japonese and Zapallo), which were either positive or negative (Table 4). The low yielding genotypes had small PCA1 score values (less than one). The PCA score values of genotypes in the AMMI analysis are an indication of the stability or adaptation over environments (Steyn *et al.,* 1993). The greater the PCA scores, either negative or positive (as it is a relative value) the more specific adapted is a genotype to certain environment. The closer the PCA scores to zero, the more stable or adapted the genotype is in all the environments (Gauch & Zobel, 1996). Based on the PCA scores, the four high yielding genotypes were the most adapted to all the environments.

The PCA1 and PCA2 accounted for 59% and 23% of the total GEI interaction respectively, adding to 82 %. This concurs with reports by Gabriel (1971) that the first and second principal components account for 80 % of the total variation in data set. It is noteworthy that local landrace Ex-shimba, Kemb10 and SPK004 which are popular varieties in the coastal region maintained high yield across the environments. Cultivars Jonathan, Zapallo and Japonese, which are improved genotypes also maintained high yields in all the environments indicating their adaptability hence they can be deployed in the region or used for further improvement of stable genotypes. Genotypes 440015, Jewel, K135, Muibai, Ejumula, Marooko and Jubilee were determined to be poorly adapted to the coastal region compared to their performance in central Kenya and had low yields across all the environments. The latter had small PCA1 score values (Table 4).

Environment

The six environments were grouped in order of the most favourable to the poorest as indicated by the scores and the first four genotypes in terms of best yield were selected. The grouping of the six environments into two categories indicated the importance of the AMMI model in establishing the
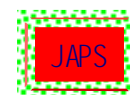
distinction among environments in terms of conditions necessary for potential growth. This aspect is important because environments are selected according to similarity of response and suitability, hence helping in decision making and selecting the best environments, thereby minimizing unnecessary costs to commercial farmers (Hill *et al.*, 1998).

The results showed that Mtwapa Short rain (SR), Lukore-SR and Mwaluvanga-SR were low yielding environments with negative interactions. The distinction in yields between the low and high yielding environments was due to the fact that there were conducive growth conditions in the latter. The low yielding environments were characterized by a long dry spell, high temperatures and high sweetpotato virus disease (SPVD) incidence which adversely reduced yield. Temperature and other seasonal factors influence plant growth, virus concentration within the plant and virus symptom expression (Thresh *et al.*, 1994). Yield stability of the genotypes is influenced by prevailing biotic and abiotic stresses (Cock, 1985). As a result there was a large negative contribution to the genotype x environment effects in these low yielding environments. Farmers in the region grow sweetpotato only in the long rain season, an indication of profound indigenous knowledge that matches crop production and environment.

Table 4: Mean performance and PCA score values of 17 sweetpotato genotypes evaluated in six environments.

Genotype	Mean yield (t/ha)	PCA 1	PCA 2
440015	6.15	0.21103	1.11489
K135	6.72	0.78610	0.11805
Ejumula	7.77	0.25358	1.7095
Muibai	8.31	-0.54699	0.14549
Jubilee	8.48	0.14074	1.74995
Marooko	8.79	-0.54432	0.23618
Sponge	9.52	0.16293	-0.07105
Jewel	10.14	0.50160	-0.02119
Mugande	10.33	-2.77580	-1.04664
Bungoma	10.67	0.06346	-1.31859
Salyboro	11.26	0.47819	-1.43259
Japonese	12.5	-1.56873	0.53524
Zapallo	13.95	-1.16534	-0.71990
SPK004	14.41	2.03336	-0.07105
Kemb10	16.46	1.51411	0.83716
Ex-shimba	19.32	1.14393	0.24013
Jonathan	21.7	1.8073	-1.01556

Key: PCA 1 and PCA 2 account for variation in data set so that the two dimensions picture of data given in biplot is a reasonable representation of the positions of genotypes; Large PCA values (whether negative or positive) indicate the adaptability of genotypes to all the environments

Cultivar Jonathan was the best performing genotype among the best four followed by Ex-shimba. In the short rain season when conditions were unfavourable for sweetpotato growth, Ex-shimba which is a local landrace was the best performer indicating its adaptability to the coastal region. The other genotypes that showed wide adaptability to both adverse and favourable conditions in terms of yield in comparison to Ex-shimba were SPK004, Kemb10, Jonathan, Japonese and Zapallo (Table 5), all of which are either yellow or orange fleshed.

The outcome of this trial shows that breeding programmes should target to develop high yielding genotypes which have stable yield and are adapted to a wide range of environments because these are traits that farmers prefer. Stakeholders involvement in the variety improvement process is crucial so that scientists can develop demand driven sweetpotato varieties i.e. considering taste, dry matter content,
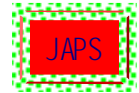
flesh and skin colour, tuber size and shape and long   shelve life.

a: Stable genotypes
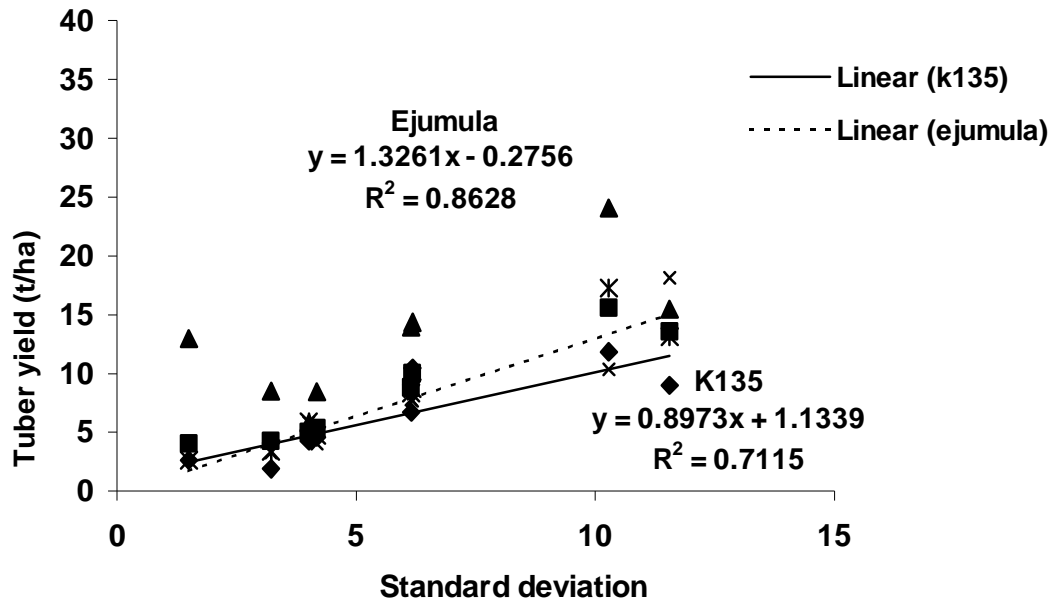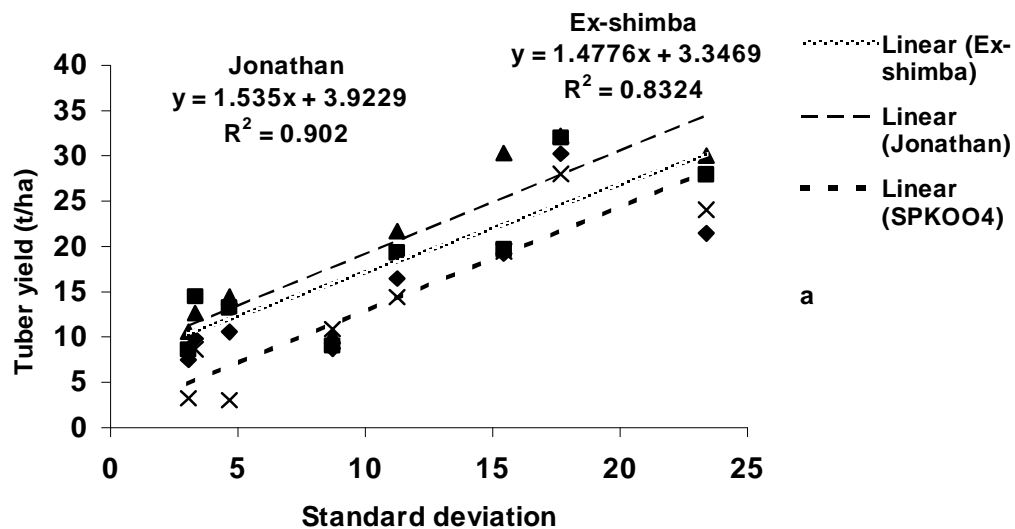

b: Unstable genotypes

Figure 2: Relationship between genotype environmental yield and standard deviation. The standard deviation and PCA scores are correlated since stable and adaptable genotypes had small and large values, respectively. The regression of genotype yield across environments against standard deviation of environment yield can be used to identify stable genotypes among environments.
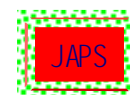
Table 5: Grouping of three sites in two seasons and ranking of the best performing genotypes within them in coastal Kenya (LR-Long rain season; SR-Short rain season).

Site	Season	Yield (t/ha)	PCA score	Genotype ranking 1	2	3	4
Mwaluvanga	LR	18.26	3.6	Jonathan	Ex-shimba	Kemb10	SPK004
Lukore	LR	13.31	1.83	Jonathan	Ex-shimba	SPK004	Kemb10
Mtwapa	LR	19.24	-0.48	Jonathan	Ex-shimba	Zapallo	SPK004
Mtwapa	SR	6.57	-1.48	Jonathan	Ex-shimba	Zapallo	Japonese
Lukore	SR	6.93	-1.6	Ex-shimba	Jonathan	Japonese	Kemb10
Mwaluvanga	SR	5.03	-1.88	Ex-shimba	Jonathan	Japonese	Zapallo

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