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Article *in* African Journal of Agricultural Research · April 2018

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Vol. 13(17), pp. 890-896, 26 April, 2018
DOI: 10.5897/AJAR2018.13061
Article Number: 0E11A2156836
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Genotype by environment interaction (GxE) as a measure of yield stability of Dutch potato varieties in Uganda

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Received 16 February, 2018; Accepted 4 April, 2018

Twenty one (21) Dutch potato varieties were introduced in Uganda during 2015-2016 seasons for national yield performance and adaptability studies so that most stable varieties could be identified for production. The effect of genotype (G), environment (E) and their interaction (G x E) on tuber yield was assessed to establish variety adaptation in different agro ecologies. Five sites were used in the study that included; Kalegyere (2450 m/asl), Kachwekano (2225m/asl), Rwebitaba (1531m/asl), Buginyanya (1887m/asl) and Zeu-DFI (1642m/asl). The varieties that yielded highest were; El-mundo (22 t ha^{-1}), Sarpomira (22 t ha^{-1}), Connect (21.7T/ha), Rudolph (21.4t ha^{-1}), Arizona (20.3 t ha^{-1}), Voyager (20 t ha^{-1}), Faluka (19.9 t ha^{-1}) and Sagitta (19.9 t ha^{-1}). GxE analysis was done using Additive main effects and multiplicative interaction (AMMI) and results showed that GxE interaction accounted for 12.6% of the total variation, while genotypes and environments accounted for 5.7% and 59.7% of the total variation respectively. The AMMI bi-plots identified varieties Caruso, Derby, Voyager, Royal, Navigator, Manitou, Destiny, Musica and Markies to have the lowest (0.00033-0.6609) IPCA 1 score hence were most adapted. Varieties Rwagume, Sarpo Mira, Connect and Kachpot 1 were more adapted at Kalegyere site (-3.601 IPCA1 score) while Sarpo Mira, Connect, El-Mundo and Rudolph were adapted at Kachwekano site (-0.562 IPCA1 score). Varieties Arizona, Faluka, Panamera and Connect were adapted at Zeu (0.125 IPCA1 score). Varieties El-Mundo, Arizona, Rudolph and Connect were more adapted at Buginyanya ZARDI (0.498 IPCA1 score) while El-Mundo, Rudolph, Sagitta and Royal most adapted at Rwebitaba ZARDI (3.54 IPCA1 score). The most interactive genotype was Rwagume with interaction score of -2.30516 while the least interactive genotype were Caruso and Taurus with IPCA 1 score of 0.00033 and 0.01086 respectively.

Key words: GXE, adaptation, yield stability, Dutch potatoes.

INTRODUCTION

Uganda is one of African countries with good environmental conditions for potato growing (Gildemacher et al., 2009). Potato (*Solanum tuberosum* L.) plays a major role in national food and nutritional

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security (Ebert et al., 2014; Maina and Chui, 1999; Kikafunda et al., 1998). The growing regional markets in East African have created a demand for certain types of potato varieties with specific processing qualities for French fry production and crisps. The Dutch based potato varieties were identified as one of the sources of these types of potato varieties that can be used for production of processed products (Fiches, 2014). New varieties must show high performance in respect to yield and other essential agronomic traits. Their superiority over other varieties should be reliable over a wide range of environmental conditions. The basic cause of differences between genotypes in their yield stability is the wide occurrence of genotype-environment interactions (GxE-interactions), that is, the ranking of genotypes depends on the particular environmental conditions where they are grown. These interactions of genotypes with environments can be partly understood as a result of a differential reaction to environmental factors like drought or diseases and rainfall (Becker and Leon, 1988).

Stability of varieties over environments is closely linked with GxE interaction. When the interaction is present, it indicates that the genotype is statistically non additive, indicating that the genotypic performance is largely depending on the environment (Cotes et al., 2002). Genotype by environment interaction may occur in both the short and long terms (several years and several locations) for crop performance trials. Therefore, analysis of genotype by environment interaction is very necessary in any variety performance evaluation in order to interpret the genotypic or environmental main effects (Yan et al., 2006; Huhn, 1996) so that one can make informed decision when making variety selections (Cooper and Delacy, 1996). A number of statistical approaches are available to understand GxE interactions, but the most powerful of these is additive main effects and multiplicative interaction (AMMI) analysis (Gauch, 2006). AMMI uses analysis of variance (ANOVA) and principle component analysis to study GxE interactions. An ANOVA table and a bi-plot are key outputs from AMMI analysis that help plant breeders and agronomists to make decisions on the adaptation and stability of varieties at various locations (Gauch, 2006). Therefore, this study was conducted to determine the adaptation and yield stability of different Dutch based potatoes varieties in different agro ecologies in Uganda.

Methodology

Experimental site

The study was conducted in five locations in Uganda that are known to grow potatoes extensively (Kalegyere (2450 masl), Kachwekano (2225 masl), Rwebitaba (1531 masl), Buginyanya (1887 masl) and Zeu-DFI (1642 masl). These locations have differing edaphic and climatic conditions that are known to influence potato growth. Each location constituted an environment, resulting in 5 environments in which data were collected.

Experimental design

One hundred tubers of each variety under study were planted at a spacing of 75 x 30 cm using completely randomized block design (CRBD) in five sites. Three blocks were used and each variety was replicated 3 times at each site, and plot size of 3.75 x 6 m per replicate was used. Straight line trenches of about 10 cm deep were dug and 200 kg/acre of NPK 17:17:17 fertilizer was applied using hands and then sprouted tubers were placed into the trenches with sprouts facing upwards and then covered making a mound on the tubers.

Field management

Standard agronomic practices which involved weeding, disease and pest control were done. Weeding was done 3 times across all sites while protection against late blight disease was done on a weekly basis (7 days interval using systemic fungicides (Macozeb 640 g/kg + 80 g/kg of metalazyl) alternated with contact fungicide (Macozeb), while pest protection was done using systemic insecticide Dimethoate.

Data collection

Following trial establishment, data on growth parameters was collected during the growing phase of the varieties. At harvest, all tubers were graded into 3 categories. The weights and numbers of tubers in each category were recorded. The following categories were used: Category I: commercial tubers/big tubers or measuring > 60 mm, Category II: commercial tubers/medium tubers 30 to 60 mm, Category III: non-commercial/small tubers or measuring < 30 mm.

Data analysis

Differences in genotype yield and within location were analyzed using REML of breeding View software in Genstat 11th edition. Genotype mean yields were separated using the least significant difference (LSD). GxE interactions were analyzed using AMMI that utilizes standard analysis of variance and principal component analysis (PCA) to identify patterns in the data (Gauch, 2006; Yan et al., 2007). The AMMI procedure identifies how genotypes interact with each environment, captures the true structure of the interactions, and helps to improve the accuracy of the statistical analysis. Greater accuracy from such analyses provides more reliable variety recommendations. The following AMMI model equation was used to assess the genetic stability of the varieties.

$$Y_{ijk}=M+\frac{B}{E_{jk}}+G_i+E_j+GE_{ij}+\epsilon_{ijk'}$$

Where, Y_{ijk} represent the i^{th} genotype in the j^{th} environment and k^{th} block; M is the overall mean; B/E_{jk} corresponds to the block within the j^{th} environment and in the k^{th} block, G_i is the effect of the j^{th} genotype; E is the effect of the j^{th} environment; GE_{ij} is the effect of interaction of the i^{th} genotypes with the j_{th} environment and $\in_{ijk}$ is the effect of experimental error.

RESULTS AND DISCUSSION

Adaptability and yield stability of the potato varieties

Analysis of variance (ANOVA) indicated that treatments

Table 1. ANOVA table for AMMI model based on marketable yield across sites for 3 seasons.

Source	df	SS	MS	F	Fprob (P=0.005)
Total	359	44195	123.1	*	*
Treatments	119	18416	154.8	6.75	0
Genotypes	23	2060	89.6	3.91	0
Environments	4	13003	3250.8	1.59	0.17904
Block	10	20507	2050.7	89.46	0
Interactions	92	3352	36.4	1.59	0.00292
IPCA	26	2039	78.4	3.42	0
IPCA	24	680	28.3	1.24	0.21297
Residuals	42	633	15.1	0.66	0.94765
Error	230	5272	22.9	*	*

Table 2. Genotype mean marketable yield and IPCA scores.

Genotype	NG	Gm	IPCAg[1]	IPCAg[2]
Ambition	1	19.71	0.81263	0.14047
Arizona	2	20.3	0.6609	-2.10355
Caruso	3	17.42	0.00033	0.21554
Challenger	4	16.75	1.18295	-0.56179
Connect	5	21.73	-1.16655	0.48032
Derby	6	17.29	0.59479	0.27269
Destiny	7	15.49	-0.68169	-0.23389
El-mundo	8	22.03	1.79582	0.78221
Faluka	9	19.75	0.90974	-1.0312
Kachpot 1	10	18.21	-2.15162	-0.04906
Manitau	11	19.93	-0.13186	0.46723
Markies	12	19.52	-0.44672	0.16978
Misica	13	18.03	0.26464	0.08031
Navigator	14	18.55	-0.30131	0.18582
Panamera	15	18.33	-0.99248	-0.67616
Rudolph	16	21.43	0.95269	0.72794
Royal	17	19.01	0.73033	0.94083
Rwagume	18	19.62	-2.30516	0.66838
Sagitta	19	19.9	0.89785	0.6114
Sarpo Mira	20	22.04	-1.04721	1.11135
Sifra	21	17.67	1.0767	-0.39421
Taurus	22	14.87	0.01086	-0.56005
Victoria	23	11.4	-1.1432	-1.79421
Voyager	24	20	0.47758	0.54986

(specific genotype and environment combinations) were highly significant (P = 0), showing that genotypes responded differently to the environments used during the study (Table 1). Results from ANOVA by AMMI partitioned the main effects of treatments into genotype, environment and genotype x environment (GxE) interactions. GxE interactions were significant (P =0.00292). Genotypes and environments accounted for 5.7 and 59.7% of the total variation, respectively. The interaction accounted for 12.6% of the total variation, which was greater than the variation due to genotypic effects.

The results also indicated that the first interaction principal component axis (IPCA 1) was highly important (60.8%) in explaining the interaction, while IPCA 2 explained only 20% of the interaction. The results for IPCA scores and means of 24 genotypes in 5 environments showed that many genotypes were highly interactive (Table 2). The varieties that yielded highest were: El-mundo (22 t ha^{-1}), Sarpomira (22 t ha^{-1}),

Table 3. Environment means and IPCA scores based on marketable yield.

Environment	NE	Em	IPCAe[1]	IPCAe[2]
Buginyanya	1	19.63	0.49803	-0.60875
Kachwekano	2	20.23	-0.56185	1.64912
Kalegyere	3	12.75	-3.60057	0.8015
Rwebitaba	4	28.71	3.53966	1.27246
Zeu	5	12.23	0.12474	-3.11432

Table 4. First four AMMI selections per environment based on marketable yield for 2 seasons.

Number	Environment	Mean	Score	1	2	3	4
4	Rwebitaba	28.71	3.54	El-mundo	Rudolph	Sagitta	Royal
1	Buginyanya	19.63	0.498	El-mundo	Arizona	Rudolph	Connect
5	Zeu	12.23	0.125	Arizona	Faluka	Panamera	Connect
2	Kachwekano	20.23	-0.562	Sarpo Mira	Connect	El-mundo	Rudolph
3	Kalegyere	12.75	-3.601	Rwagume	Sarpo Mira	Connect	Kachpot 1

Table 5. Environment means and variances.

Site	No. observed	Mean (T/HA)	Variance
Buginyanya	72	19.63	41.33
Kachwekano	72	20.23	98.77
Kalegyere	72	12.75	50.16
Rwebitaba	72	28.71	193.52
Zeu	72	12.23	55.55
Margin	360	18.71	123.11

Connect (21.7 t ha^{-1}), Rudolph (21.4 t ha^{-1}), Arizona (20.3 t ha^{-1}), Voyager (20 t ha^{-1}), Faluka (19.9 t ha^{-1}) and Sagitta (19.9 t ha^{-1}) (Table 2).

The best 4 selected varieties based on the model per site include: at Kalegyere site (Rwagume, Sarpo MiraConnect and Kachpot 1); at Kachwekano site (Sarpo Mira, Connect, El-mundo and Rudolph; at Zeu (Arizona Faluka, Panamera and Connect); at Buginyanya ZARDI (El-mundo, Arizona, Rudolph and Connect) and at Rwebitaba (El-mundo, Rudolph, Sagitta and Royal) (Table 4). The average yield across seasons was noted to vary from 12 to 28 T/ha with Rwebitaba site having highest (28.7 T/ha) followed by Kachwekano (20.2 T/ha), Buginyanya (19.6 T/ha), Kalegyere (12.7 T/ha) and lastly Zeu (12.2 T/ha).

Based on the first IPCA, the most interactive genotype was Rwagume with interaction score of -2.30516, while the least interactive genotype were Caruso and Taurus with IPCA 1 score of 0.00033 and 0.01086, respectively (Table 2). Some of the environments used were highly interactive with Kalegyere, showing the highest IPCA 1 score of -3.60057 followed by Rwebitaba with IPCA of 3.53966 (Table 3). The least interactive environment was Zeu with IPCA 1 score of 0.12474 (Table 5).

The GGE biplot (Figures 1 and 2) showed that genotypes Caruso, Derby, Voyager, Royal, Navigator, Manitou, Destiny, Musica and Markies had the lowest GxE interaction since they showed low IPCA scores. The most interactive genotypes during the 3 seasons included Rwagume, Kachpot 1, Sarpomira, Challenger, El-mundo, Victoria, Arizona and Connect which showed relatively high first IPCA scores.

The biplot also indicated that Zeu, Kachwekano and Buginyanya had low Eigen values and were therefore least interactive environments. The highly interactive environment was Kalegyere as indicated by high Eigen values (Table 3).

Genotype ranking in the different environments showed that El-mundo, Sagitta and Connect were among the best 4 in 5 environments (Table 4) Buginyanya, Rwebitaba and Kalegyere, while Rwagume, Connect and Sarpomira showed specific adaptation to Kachwekano and Kalegyere (Table 4). The 3 best environments were observed in which the majority of the varieties were

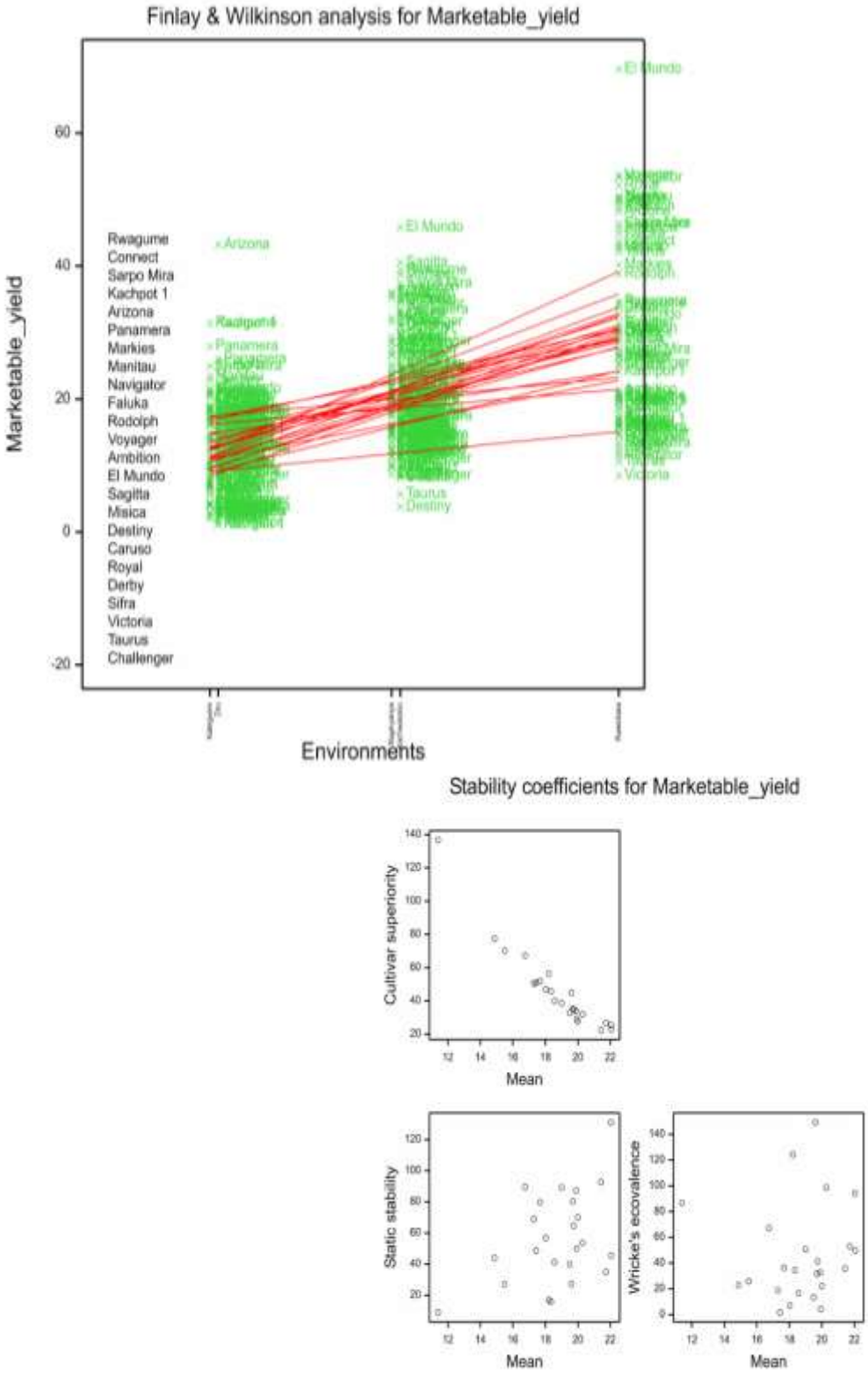

Figure 1. GXE interaction as measure of stability on marketable yield.

adapted. Environments_Rwebitaba, Buginyanya and Zeu clustered together while Kachwekano and Kalegyere were noted to appear as separate mega environments (Figure 2).

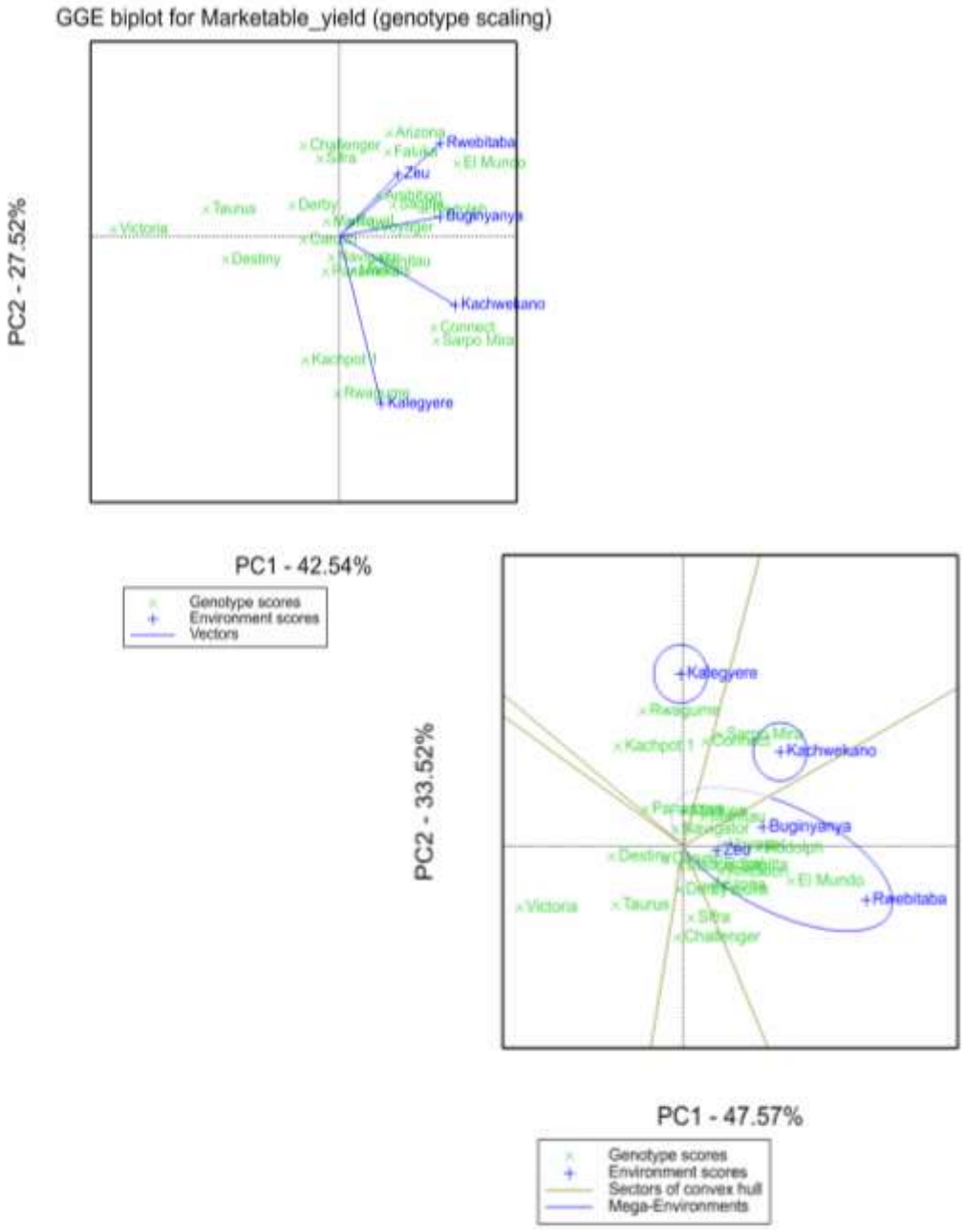

Figure 2. The GGE biplot marketable yield as a measure for stability based on three season's data.

Conclusion

The study indicated that 8 varieties were more adapted to Uganda agro-ecologies and had lowest GxE interaction, hence were recommended to be released for official utilization by the end users in Uganda.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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