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Yield performance and stability of elite groundnut varieties in multi-location experiments in central Uganda - A short communication

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Abstract

Groundnuts (*Arachis hypogaea.* L.) is a grain legume crop grown by resource poor farmers all over Uganda, for food and household income. In Central Uganda, farmers are still planting traditional cultivars, which do not respond well to agronomic manipulation and have a low yielding capacity. The study set out to evaluate the yield performance and stability of elite groundnut varieties in the Serenut series 1R, 2, 3R, 4T and a local test variety, Red beauty, in field experiments in four on-farm sites in Gomba district and one on-station site in Wakiso district, both found in central Uganda. The varieties were planted out in a Randomized Complete Block design (RCBD), with three replications at the different locations. The dependent variables included number of pods, pod dry weight, kernel dry weight, and kernel yield in kg ha^{-1}. ANOVA results indicated significant ($p<0.001$) differences in yield parameters as a result of variety, location and their interaction. Serenut 2 was the most productive in all yield parameters across locations while the reverse was true for Red beauty. Kyegonza 1(Gomba district) was the most productive site in all yield components and MUARIK (Wakiso district) the least. Serenut 1R was ranked as stable in grain yield.

Key words: AMMI analysis, Genotype x Environment, on-farm, Gomba, Wakiso

Introduction

Groundnuts (*Arachis hypogaea*. L.) is an important grain legume crop containing 25-30% crude protein and 12-18% carbohydrate (Alemayehu *et al*., 2016) grown by resource poor farmers all over Uganda, for food and as a source of income. It is also a major oil seed crop containing 46-52% oil, and is second to beans as the most important legume in Uganda (NAADS, 2000). However, most groundnut varieties grown in Central Uganda are mainly traditional cultivars, with poor agronomic characteristics like low grain yield and are reported to respond poorly to improved cultural farming practices (Busolo-Bulafu, 1998). These cultivars are predominantly cultivated by smallholder farmers on less than an acre of land mainly for food security but are increasingly becoming commercially important. The average yield of groundnuts in Uganda is about 290 kg per acre as opposed to the yield potential of 1200 kg per acre (NAADS, 2000). The National Semi Arid Resources Research Institute (NaSARRI) has over the last three decades developed better yielding genotypes like Serenut 1R, 2, 3R, 4T and Serere Red which yield 3000-3500, 1900-2500, 2000-2700, 2500-2700 and 2500-3500 kg ha^{-1}, respectively (ICRISAT, 1987; NAADS, 2000; Busolo-Bulafu, 2004; Okello *et al*., 2010; Mugisa *et al*., 2015). These are now widely used is eastern, northern, and north eastern Uganda. Their diffusion to resource poor farmers in Central Uganda has been poor at best. The drawback could be the lack of exposure or appreciation by farmers in this region for these varieties. However, before efforts to disseminate the varieties are made in Central Uganda, there is a need to confirm the suitability and yielding potential of these varieties in local conditions. The purpose of this study, therefore, was to evaluate the yield performance and stability of elite groundnut varieties in central Uganda. The study used additive main effects and multiplicative interactions (AMMI), genotype and genotype by environment interaction (GGE) bi-plot models to achieve the set objective. These are well documented tools for effective analysis and interpretation of multi-environment data structure in these multi-location trials. AMMI is a unified approach that fits the additive effects of genotypes and the environments by the usual analysis of variance and then describes the non-additive parts by principal component analysis (Alemayehu *et al*., 2016).

Materials and methods

Experimental sites

Multi-location experiments were conducted in 2007 on-station at the Makerere University Agricultural research Institute, Kabanyolo (MUARIK) in Wakiso district and on-farm at 4 different sites in Gomba District in central Uganda. In Gomba, on-farm trials were conducted in the villages of Kyegonza 1, Kyegonza 2 (Kyegonza

Sub County), Mweese (Mpenja Sub County) and Bukinda (Kabulasoke Sub County). The sub counties were selected as a result of a joint study carried out by Makerere University (Uganda) and Hitotsubashi University (Japan) between 1999 and 2000 in a participatory poverty assessment (PPA) that established high levels of poverty and malnutrition(Makerere University, 2000). These were attributed to a wide range of inhibiting factors to agricultural productivity, most prominent among which was lack of good quality crop planting varieties and materials. The particular sites for the on-farm experiments were selected with the help of local leaders from the different sub counties. Gomba District is located sixty miles (96.6 kms) North West of Kampala city at $00^0$11'S $31^0$55'E (Mpigi District local Government, 2021). It lies slightly above 1200m above sea level. It has a bi-modal rainfall distribution in the months of March- May and August- November ranging between 1125-1320mm per annum, with mean annual minimum and maximum temperature averaging 11^0C and 27.5- 30^oC, respectively. Relative humidity fluctuates between 80-95%. The soils are sandy-loam with adequate organic matter (Nkuba, 1999). MUARIK is located in Nangabo sub-county, Kyadondo County, Wakiso district. MUARIK is twelve miles (19.3 kms) north-east of Kampala city and lies adjacent to the equator at Latitude $0^{\text{æ\%}}$28000.38" N, Longitude $32^{\text{æ\%}}$36046.01" E (0^o28'N32^o37'E) (Mibulo and Kiggundu, 2018) at 1200m.a.s.l. It is a semi-humid zone with two rainy seasons; the first occurring between March - May, accounting for over 40% of the total yearly rainfall, while the second rains occur between August and November. The total mean annual rainfall is about 1389mm. The soils are deep ferralitic type, relatively high in potash, aluminium and ferric oxides but low in Nitrogen and phosphorus. The mean annual minimum and maximum temperatures are 15.1^oC and 29.0^oC, respectively ((Mibulo and Kiggundu, 2018, Nyiramugisha et al, 2016). The mean monthly humidity during the experiment was 85%.

Materials

Five groundnut varieties (four elite releases and one local cultivar); Serenut 1R, Serenut 2, Serenut 3R, Serenut 4T and local cultivar, Red beauty (Table 1) were evaluated at the five locations. The seeds of elite groundnut varieties were obtained from NaSARRI releases while the local check was from the farmers' stored seed.

Experimental design

The experiment was set up on-station in Wakiso and on each of the 4 farms in Gomba in a Randomized Complete Block design (RCBD) with three replications. At each location, the five groundnut varieties: Serenut 1R, Serenut 2, Serenut3R, Serenut 4T and local test variety Red beauty were tested out at a same spacing of 50x20 cm. The experimental units had a plant population of 100,000 plants ha^{-1}. Each experimental unit was 5x5 m.

Table 1. Characteristics of the studied groundnut varieties

Variety	Mean yield	Pod characteristics	Seed characteristics	Botanical group	Branching characteristics	Leaf characteristics	Average days to maturity
Serenut 1R	2747 kg ha^{-1}	-Moderately reticulated pods -moderate beak -moderate constrictions	-Red seeds -Average 100 seed mass = 64.9g-43.9% oil content - 72% average shelling%	Virginia spreading botanical group	-Alternate branching -5 to 7 primary branches -2 to 4 secondary branches	Medium sized elliptic dark green leaves	110-125 days
Serenut 2	2776 kg ha^{-1}	-Moderately reticulated pods -prominent beak -moderate constrictions -2 seeded pods	-Tan seeds -Average 100 seed mass= 52.0g -41.9% oil content - 69.7% average shelling%	Virginia spreading botanical group	-Alternate branching -5 to 7 primary branches -2 to 4 secondary branches	Medium sized elliptic dark green leaves	110-125 days
Serenut 3R	2505 kg ha^{-1}	-Moderately reticulated pods -little beak -moderate constrictions -2 seeded pods -thick pod	-Red seeds -Average 100 seed mass= 40.3g -47% oil content - 58% average shelling%	Spanish bunch botanical group	Sequential branching pattern -6 to 7 primary branches -2 to3 secondary branches	Medium sized dark green leaves	100 days

Table 1. Contd.

Variety	Mean yield	Pod characteristics	Seed characteristics	Botanical group	Branching characteristics	Leaf characteristics	Average days to maturity
Serenut 4T	2494 kg ha^{-1}	-Moderately reticulated pods - no or little beak -moderate constrictions -2 seeded pods -very thin pod	-Tan seeds -Average 100 seed mass= 37.0g -43% oil content -27.1% protein - 73% average shelling% - Like R/ beauty, no fresh seed dormancy	Spanish bunch botanical group	Erect growth habit Sequential branching pattern -4.5 primary branches -2.5 secondary branches	Medium sized light green leaves	90 days
Red beauty	2500 kg ha^{-1}	Moderately reticulated 3-4 seeded pods	Red seeds Average 100 seed weight =32.0g No fresh seed dormancy	Valencia erect botanical group	Small plant with erect growth habits No branches other than main stem	Medium sized seeds, light green leaves	85-90 days

Source: IBPGR and ICRISAT, 1992, Okello *et al*., 2014

Data collection

The outermost rows on either side of each plot were left to act as guard rows. Four plants per plot, from the inner rows, were sampled randomly for number of pods at harvest time, pod dry weight, kernel dry weight and kernel yield in kg/ ha, computed as plant population per experimental unit x kernel dry weight yield per plant. Early maturing varieties; Red beauty, Serenut 4T, and Serenut 3R were sampled at 100 days and later maturing Serenut 1R and Serenut 2 at 120 days (DAP). The dry weight of the sampled pods and kernels was established by weighing with the electronic balance (SF-400, WeighCom UG Ltd) after thorough drying for several weeks to a moisture content of 13% (until there was no further change in weight).

Data analysis

Data from on-farm and on-station locations was subjected to combined ANOVA using GenStat statistical analysis programme (GenStat Release 7.22 DE, Crozat, 2008). Location and variety were the main effects and yield in kg ha^{-1}, number of pods, pod dry weight and kernel dry weight were the dependent variables. Mean separation were done using Fisher protected Least Significance Difference (LSD) at 0.05 level of significance. A Genotype by environment (GxE) analysis was also carried out using AMMI (Additive Main Effect and Multiplicative Interaction) Mat model to evaluate variety performance by environment interactive effect (Gauch, 1992; Gauch and Zobel, 1996; Kendal *et al.*, 2019). AMMI is one of the best analyses for testing genotype stability. According to Kindeya *et al.* (2020), the AMMI model and GGE biplot are the best methods to assay the G X E interactions. It establishes yield stability of different varieties over different experimental locations and ranks varieties according to yield in kg ha^{-1} (Gauch, 2006). Grain yield was also analysed using genotype plus genotype by environment (GGE) biplot methodology.

Results

Effect of Variety (G) and Location (E) on groundnut yield parameters

All the studied yield parameters were highly influenced by Variety, Location and the interaction between Variety*location in the AMMI ANOVA ($P<0.001$; Table 2). For all yield parameters, Location contributed more to the total sum of squares than Variety. The first and second interaction principal component analyses were all significant for all traits (Table 2).

Number of pods harvested/plant

Results showed that Serenut 4T, Serenut 3R, Serenut 2 and Serenut 1R, though not significantly different ($p<0.001$), performed better than Red beauty, the local test variety in number of pods harvested from 4 plants (Table 3). According to locations, Kyegonza 1 significantly ($p<0.05$) out yielded all the others locations in number of

Table 2. AMMI Analysis of variance for number of pods, pod and kernel dry weight and yield of groundnut genotypes in five different environments

Source of variation	df	Number of pods/plant			Pod dry weight (gm/plant)			Kernel dry weight (gm/plant)			Grain yield kg ha^{-1}		
		SS	MS	F	SS	MS	F	SS	MS	F	SS	MS	F
Total	299	45744	153		54012	181		26566	88.8		265658403	888490	
Treatments	24	41973	1749	171.11***	47272	1970	108.19***	22487	936.9	88.96***	224867075	9369461	88.96
Variety	4	5297	1324	129.57***	6686	1672	91.82***	3365	841.2	79.87***	33648641	8412160	79.87***
Locations	4	19668	4917	46.25***	27641	6910	36.08***	13022	3255.4	25.27***	130216092	32554023	25.27***
Interactions	16	17007	1063	10.40***	12945	809	44.44***	6100	381.3	36.20***	61002342	3812646	36.20***
IPCA1	7	11183	1598	156.31***	9608	1373	75.405***	4135	590.7	56.09***	41351957	5907422	56.09***
IPCA2	5	5010	1002	98.04***	2776	555	30.50***	1887	377.4	35.84***	18871387	3774277	35.84***
Residuals	4	814	203	19.90	560	140	7.69	78	19.5	1.85	778998	194749	1.85
Error	265	2708	10		4824	18		2791	10.5		27910590	105323	

*** Significant at $p<0.001$

Table 3. Effect of varieties and location on number of pods/plant at harvest

Variety	Location					Variety mean
	Kyegonza 1(E1)	Kyegonza 2(E2)	Mweese (E3)	Bukinda (E4)	MUARIK (E5)	
Serenut 1R (G1)	52.00	19.00	11.67	28.00	24.00	26.93b
Serenut 2 (G2)	55.33	26.00	30.33	20.33	16.33	29.66b
Serenut 3R (G3)	31.33	31.00	32.67	32.00	20.00	29.40b
Serenut 4T (G4)	41.67	29.00	47.67	24.33	7.00	29.93b
Red beauty (G5)	21.00	29.33	25.00	22.33	12.00	21.93a
Location mean	40.27c	26.87b	29.47b	25.40b	15.87a	27.57

CV % = 17.3; LSD (Location*Varieties) = 7.838; Means followed by same letter are not significantly different ($p<0.001$)

pods. Mweese, Kyegonza 2, and Bukinda locations though not significantly different, significantly ($p<0.05$) out yielded MUARIK in number of pods at harvest (Table 3)

Pod and kernel (grain) dry weight/plant

Serenut 2 gave the highest pod dry weight than all other varieties ($p<0.001$). Serenut 1R, Serenut 3R and Serenut 4T though not significantly different from each other, produced significantly ($p<0.001$) higher pod dry weight than Red beauty (Table 4). As regards locations, Kyegonza 1 significantly ($p<0.001$) had the heaviest pod dry weight of all locations. Mweese, Kyegonza 2 and Bukinda, though not significantly different, produced significantly ($p<0.001$) higher pod dry weight than MUARIK (Table 4). Kernel (grain) dry weight (gm/plot), which was later converted into kg/ha as indicated above, also followed the same trend (Table 5).

Grain yield performance and stability

It was observed that there are highly significant differences for environment, genotype and their interactions on grain yield. The combined ANOVA on grain yield showed that Variety explained 12.7%, Location 49%, and their interaction 23% (Total treatments = 84.7%) of the total sum of squares (Table 2). The observed G × E interaction in the AMMI model have been partitioned among the first and second IPCA (Interaction Principal Components Axes) accounting for 67.8% and 30.9%, respectively, together explaining 98.7% of the total variation (Table 2).

The biplot showed that Serenut 2 (G2) and environment Kyegonza 1(E1) had the biggest contributions to the two main effects as exhibited by the wider displacement

Table 4. Effect of varieties and location on pod dry weight (gm/plant) after harvest

Variety	Location					Variety mean
	Kyegonza 1(E1)	Kyegonza 2(E2)	Mweese (E3)	Bukinda (E4)	MUARIK (E5)	
Serenut 1R (G1)	52.81	34.08	18.77	18.41	15.40	28.49b
Serenut 2 (G2)	60.97	31.90	41.63	33.07	16.57	36.83c
Serenut 3R (G3)	34.76	29.14	28.31	28.14	19.94	28.06b
Serenut 4T (G4)	38.33	17.46	34.27	30.25	7.45	25.55b
Red beauty (G5)	22.31	22.42	27.48	24.30	9.30	21.16a
Location mean	42.44c	27.00b	30.09b	26.83b	13.73a	28.02

CV % = 17.4; LSD (Location*Variety) = 8.019; Means followed by same letter are not significantly different (p<0.001)

Table 5. Effect of varieties and location on kernel (grain) weight (gm/plant) after harvest

Variety	Location					Variety mean
	Kyegonza 1(E1)	Kyegonza 2(E2)	Mweese (E3)	Bukinda (E4)	MUARIK (E5)	
Serenut 1R (G1)	36.14	21.34	12.40	12.34	9.93	18.43b
Serenut 2 (G2)	39.96	21.22	25.04	22.34	8.78	23.47c
Serenut 3R (G3)	23.57	19.85	18.03	24.46	11.19	19.42b
Serenut 4T (G4)	26.86	13.18	28.55	28.66	3.76	20.20b
Red beauty (G5)	14.90	16.44	16.09	19.53	5.49	14.49a
Location mean	28.29c	18.41b	20.02b	21.47b	7.83a	19.20

CV % = 20.2; LSD (Location*Varieties) = 6.38; Means followed by same letter are not significantly different (p<0.001)

from the abscissa line. In the AMMI biplot Serenut 2 (G2) and Serenut 4T (G4) grouped together and showed similar adaptation. Environments Mweese (E3) and Kyegonza 1(E1) grouped close together and hence exerted similar influence on the genotypes (Fig. 1). Red beauty and Serenut 3R had yield below the mean; MUARIK and Kyegonza 2 have yield below the mean (Table 6; Fig. 1). AMMI biplot gave a visual indication that showed that genotypes far from the X-axis and on the left of the

Table 6. The genotype/environment means and Interaction Principal Component scores for grain yield (Kg ha^{-1}) for the five genotypes/environments

Genotype (Variety)	NG[1]	GM[2]	IPCAg(1)[3]	IPCAg(2)[4]
Red beauty (G5)	1	1446	15.39688	22.83533
Serenut 1R (G1)	2	1774	-30.75053	4.26839
Serenut 2 (G2)	3	2401	-12.93485	-13.94432
Serenut 3R (G3)	4	1748	6.85554	8.14000
Serenut 4T (G4)	5	2154	21.43296	-21.29940
Environment (Location)	NE[1]	EM[2]	IPCAe(1) [3]	IPCAe(2) [4]
Bukinda (E4)	1	2017	21.34979	-5.30755
Kyegonza 1 (E1)	2	2855	-31.31002	-18.00340
Kyegonza 2 (E2)	3	1859	-9.98670	26.39927
MUARIK (E5)	4	790	2.17812	8.45725
Mweese (E3)	5	2002	17.76880	-11.54558

[1]Number of main effect (G/E); [2]main effect (G/E) means; [3]First Interaction Principal Component Eigen values; [4]Second Interaction Principal Component Eigen values

y-axis (Red beauty – G5) is unstable and low yielding (Fig. 1). According to the correlation between IPC1 and IPC2, the genotypes that were positioned near the origin had the least interaction, and the genotypes positioned near to the axis had more general stability (G1). Furthermore, any genotypes that are close to each location have specific stability in that environment, for example Serenut 3R (G3) to Kyegonza 2 (E2) (Fig. 1).

The GGE plot revealed that the first principal component (PC1) accounted for up to 55.81%; while the second principal component (PC2) was responsible for 41.82% of the total G+GE variation in grain yield. The first two PCs explain 97.63% of the variability in the data. The GGE plot confirmed results of the AMMI analysis. Genotypes with PC1 scores > 0 (Serenut 1R, Serenut 2 and Serenut 4T) are recognized as high yielding and that those with PC1 scores < 0 (Serenut 3R and Red beauty) are identified as low yielding (Fig. 2). Phenotypic stability, however, is visualized by the second Principal Component (PC2); whereby genotypes with PC2 scores close to zero (PC2~0) would be the highly stable ones. Kyegonza 1, with the highest vector on the Average Environment Coordination (AEC) abscissa was close to the ideal environment (Fig. 2).

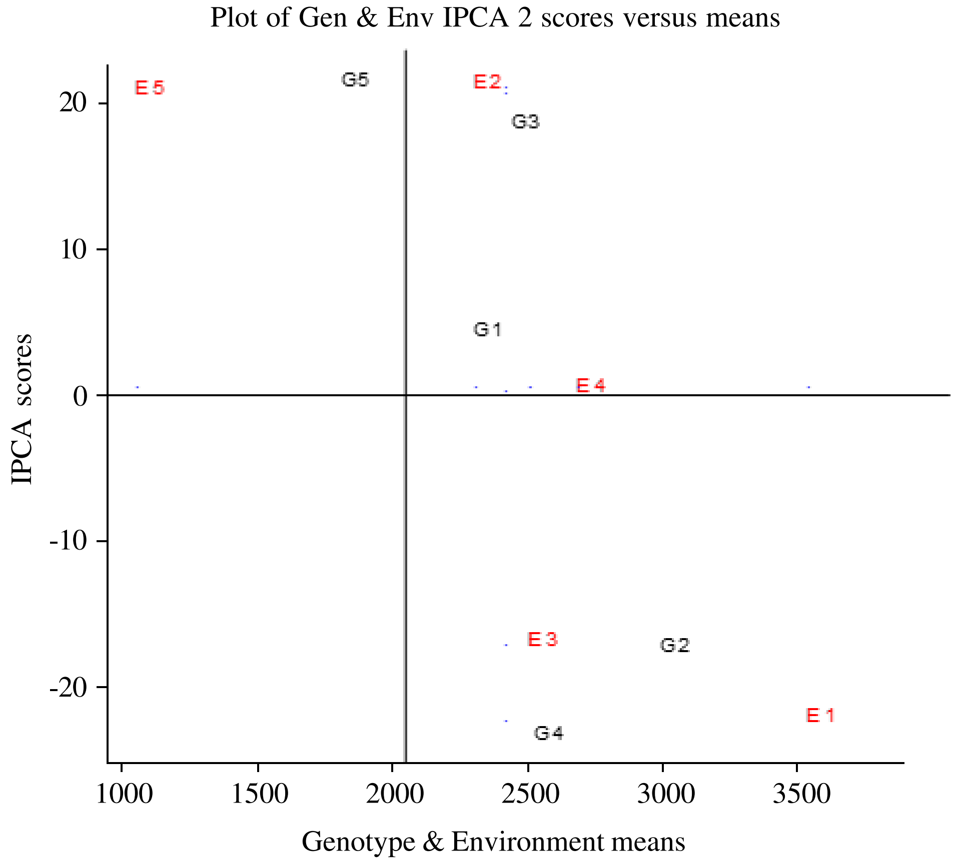

Figure 1. AMMI bi-plot for kernel yield (kg ha^{-1}) of five varieties (genotype) in 5 locations (environments) using genotypic and environmental scores (E1 = Kyegonza 1, E2 = Kyegonza 2, E3 = Mweese, E4 = Bukinda, E5 = MUARIK; G1 = Serenut 1, G2 = Serenut 2, G3 = Serenut 3, G4 = Serenut 4, G5 = Red beauty).

Discussion

Evaluation of varieties or genotypes in contrasting environments and across time is an essential step in determining their adaptability response across the environments (Agbahoungba *et al.*, 2017). The differences in number of pods, pod dry weight, kernel dry weight and yield among Varieties, Locations and their Interaction could be accounted for by the AMMI model used. This indicated that diversity existed among the genotypes and environments tested. Genotypes responded differently to different locations due to divergent edaphoclimatic conditions, particularly variations of temperature, total precipitation, and soils properties; which is in agreement with Anandan *et al.* (2009). In this study, environment explained most of the variation accounted for by treatments (49% for location, 12.7% for variety and 23% for their

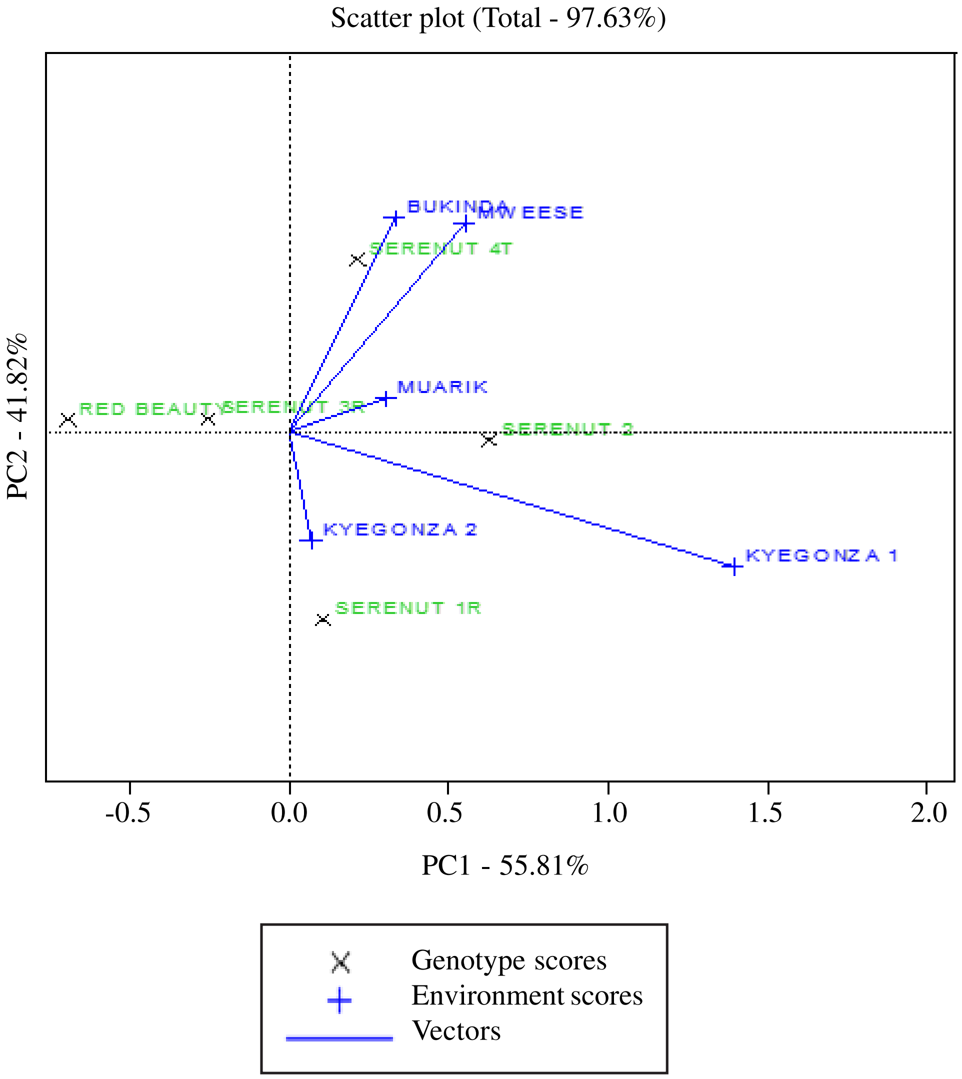

Figure 2. The GGE biplot of relationships among genotypes and test environments

interaction). These results concur with those of Ngirazi *et al.* (2017) who in their G x E groundnut trials in Zimbabwe reported that environments (E) and genotype x environment interactions (GEI) were highly significant ($p < 0.001$) for pod yield of twenty-five groundnut genotypes, indicating that the environment influenced the yielding ability of the groundnut genotypes. The result is also in agreement with Agbahoungba *et al.* (2017) who in their analysis of yield variance and AMMI on Cowpea varieties in 3 locations, established a very high percentage (69.16%) of total variation attributable to environmental effect, only 5.36% to genotypic effects and 12.74% to GxE interaction effects.

The analysis of variance results were backed by the AMMI and GGE plots to confirm that Red beauty was the most underperforming genotype. This could have been due its inherent low seed weight compared to the other varieties as shown in Table 1. It has also been shown to have a higher susceptibility to the devastating Groundnut rosette virus disease (Mugisa *et al.*, 2015). The AMMI and GGE plot confirmed Serenut 2 as the best performer with regard to grain yield. The better performance of Serenut 2 could be attributed to its high genetic capability and resistance to ground nut rosette disease. The Serenut series varieties are reported to have host plant groundnut rosette resistance (Okello et al., 2014). Serenut 1R gave moderate yields but was the most stable and is therefore the least influenced by location (environment).

MUARIK was consistently the worst environment in performance in yield parameters for all the groundnut varieties. This could have been due to the fact that MUARIK experienced erratic rains in the study period. The mean monthly humidity for the study period was at 85% and total rainfall was as low as 497.1 mm. The inadequate rains coupled with the nature of soil may have interfered with flowering, pegging and pod elongation subsequently reducing the overall pod and kernel yield. Low rainfall and prolonged dry spells during the crop growth period were reported to be main reasons for low average groundnut yields in most of the regions of Asia and Africa (Camberlin and Diop, 1999; Reddy *et al.*, 2003; Okello *et al.*, 2010).

The results of this study show that Central Uganda can embrace the Serenut varieties of groundnut as they were shown to yield well there. Serenut 2 and Serenut 4T especially performed closest to their potential.

Conclusion

The AMMI model showed that the largest proportion of the total variation in groundnut grain yield was attributed to environment (locations). The genotype Serenut 2 was the highest yielding whilst Red beauty was least yielding across the locations. Serenut 1R was the least influenced by locations.

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References

Agbahoungba, S., Karungi, J., Talwana, H, Badji, A. 2017. Additive main effects and multiplicative interaction analysis of yield responses in cowpea genotypes under Ugandan environments. *International Journal of Advanced Research* 5(6): 349-360. DOI: 10.21474/IJAR0/4419

Alemayehu Dabessa, Biru Alemu, Zerihun Abede, Dagnachew Lule. 2016. Genotype by environment interaction and kernel yield stability of groundnut (*Arachis hypogaea* L) varieties in Western Oroma, Ethiopia. *Journal of Agriculture and Crops* 2(11):113-120. ISSN (e):2412-6381, ISSN (p): 2413-886x.

Anandan, A., Eswaran, R., Sabesan, T. and Prakash, M. 2009. Additive main effects and multiplicative interactions analysis of yield performances in rice genotypes under costal saline environments. *Advance in Biological Research* 3 (2): 43-47.

Busolo-Bulafu, C.M. 1998. A century of agricultural research development of oil crops in Uganda: History, aims and achievements. P*aper presented at the centenary conference, Imperial Botanical Beach Hotel, 5-7th October 1998.*

Busolo-Bulafu, C.M. 2004. Development of groundnut rosette disease and vector resistant varieties. *Uganda Journal of Agricultural Sciences* 9:574-577.

Camberlin, P. and Diop, M. 1999. Inter-relationships between groundnut yield in Senegal, inter-annual rainfall variability and sea surface temperatures. *Theoret. Appl. Climatol.* 63(3&4): 163-181.

Crozat. Y. 2008. GenStat Release 7.22 de (PC/Windows) Copyright 2008.

Gauch, G. 2006. Statistical analysis of yield trials by AMMI and GGE."*Crop Science* 46:1488-1500.

Gauch, G. and Zobel, R.W. 1996. AMMI analysis of yield trials. In: Genotype by environment interaction. Kang, M. and Gauch, H. (Eds.). New York: Boca Raton. CRC Press. pp. 85-122.

Gauch.H.G. 1992. Statistical Analysis of regional yield trials: AMMI analysis of factorial Designs, Elsevier, Amsterdam, the Netherlands.

IBPGR and ICRISAT, 1992. Descriptors for groundnuts. International Board for Plant Genetic Resources (IBPGR); International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), 125p. https://www.bioversityinternational.org/e-library/publications/detail/descriptors-for-groundnutdescriptores-para-manidescripteurs-pour-larachide/

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1987. Annual Report 1986. Patancheru, Andhra. Pradesh. 502 324, India: ICRISAT

Kendal, E., Tekdal, S. and Karaman.M. 2019. Proficiency of Biplot Methods (AMMI & GGE) in the appraisal of Triticale Genotypes in Multiple environments. *Applied Ecology & Environmental Research* 17(3):5995-6007. DOI:htpp://dx.doi.org/10.155666/aeer/1703-59956007

Kindeya, Y.B., Mekbib, F. and Abraha, Alle E. 2020. AMMI and GGE bi-plot analysis for seed yield and oil content of sesame (*Sesamum indicum* L.) genotypes in Tigray, Northern Ethiopia. *J. Agric. Crops* 6(64):58–67.

Makerere University. 2000. The construction of Strategies for Poverty reduction and integrated rural development of Central, North eastern and Western Uganda. A case study of Mpigi District: Kyegonza sub county. *A Participatory Poverty Assessment Report*. Department of Sociology, Makerere University, Kampala, Uganda.

Mibulo, T. and Kiggundu, N. 2018. Evaluation of FAO Aqua Crop Model for simulating rain fed maize growth and yields in Uganda. *Agron. J. 2018.08.238.*

Mpigi District Local Government. 2021. Geographical Features, Mpigi District Data base, info@mpigi.go.ug

Mugisa, I.O., Karungi, J., Akello, B., Ochwo-Semakula, M.K.N., Biruma, M., Okello, D.K. and Otim, G. 2015. Assessing the effect of farmers practice on the severity of groundnut rosette virus disease in Uganda. *African Journal of Agricultural Research* 10(9):995-1003.DOI:10.5897/AJAR2014.9171

NAADS. 2000. Groundnut (peanut) production; Agriculture in Uganda; Transforming Livelihoods. www.naads.or.ug

Ngirazi, N. Savemore., Manjeru, P. and Ncube, B. 2017. Assessment of genotype x environment Interaction and pod yield evaluation of groundnut (*Arachis hypogaea* L) genotypes in Zimbabwe. *African Journal of Plant Science* II (3):54-60. http:// doi.org/10.5897/AJPS 2017.1517.

Nkuba Michael. 1999. Sustainable agricultural enterprises in two districts in Uganda, sustaining the global farm. http://www.tucsan.ars.ag.gov/isco 10

Nyiramugisha, J., Lamo. J., Oloka, B.M., Ongom.P., Gibson, P. and Edema.R. 2016. Response to cold stress at reproductive stage of introduced and adapted rice genotypes in Uganda. RURORUM Working Document Series (ISSN 1607-9345) No 14(2):633-638.

Okello, D.K., Biruma, M. and Deom, C.M. 2010. Overview of groundnut research in Uganda: Past. present and future. *African Journal of Biotechnology* 9(39):6448-6459. http://www.academicjournals.org/AJB

Okello, D.K., Okori, P., Naveen P., Boris, B.U., Deom, C.M., Ininda, J., Anguria, P., Biruma, M. and Asekenye. C. 2014. Groundnut seed production manual for Uganda. National Agricultural Research Organisation, Entebbe, Uganda.

Reddy, T.Y., Reddy, V.R. and Anbumozhi, V. 2003. Physiological responses of groundnut (*Arachis hypogaea* L.) to drought stress and its amelioration: a critical review. *Plant Growth Regul.* 41: 75-88.