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GENOTYPE BY ENVIRONMENT INTERACTION OF ADVANCED GENERATION SOYBEAN LINES FOR GRAIN YIELD IN UGANDA

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ABSTRACT

Grain soybean (*Glycine max* L.) is the primary source of vegetable protein for food and feed supplements, and accounts for much of the world's oil supply. In most parts of Africa, soybean production potential is yet to be realised largely due to lack of improved varieties. Uganda's soybean breeding programme has been actively involved in developing varieties to meet the needs of farmers in different parts of the country. This study was, conducted to determine the adaptation of new advanced generation soybean lines to identify high yielding stable lines, the most ideal testing environment and to determine the presence of soybean production mega environments in the country. Twenty one advanced generation soybean lines and three standard check varieties were evaluated in five sites and three consecutive rainy seasons. Results of AMMI analysis indicated the presence of a scale genotype-by-environment interaction for soybean grain yield. Through AMMI estimates and GGE visual assessment, BSPS48A was the highest yielding genotype in the most discriminating and stable environment, Nakabango. BSPS48A was, therefore, recommended for release subject to evaluation for commercial value. From the environmental focusing plot, the five multi-locations tested were grouped into two putative mega environments for soybean production.

Key Words: AMMI, genotype, GGE, *Glycine max*

RÉSUMÉ

Le grain de soja (*Glycine max* L.) est une importante source de protéine végétale comme supplément alimentaire, l'alimentation du bétail et produit une grande partie d'huile fournie au monde. Dans plusieurs contrées d'Afrique, la production potentielle du soja est pourtant affectée par le manque des variétés améliorées. Le programme ugandais d'amélioration du soja a été activement impliqué dans le développement des variétés afin de répondre aux besoins des fermiers de différentes parties du pays. Cette étude était conduite dans le but de déterminer l'adaptation des nouvelles lignées de générations avancées du soja pour identifier des lignées stables à haut rendement, l'environnement le plus idéal pour ce test et, déterminer la présence des méga environnement dans le pays. Vingt et une lignées de générations avancées de soja et trois variétés témoins étaient évaluées dans cinq sites en trois saisons consécutives de pluie. Les résultats d'analyse AMMI ont indiqué la présence d'une échelle d'interaction génotype-environnement pour le rendement en grain du soja. A travers AMMI estimé et l'évaluation visuelle de GGE, BSPS48A était le génotype à rendement le plus élevé dans laplupart d'environnement jugés stables, Nakabango. BSPS48A était, de ce fait récommendé pour une évaluation de la valeur commercial. Basé sur les différents environnements, les cinq multi-localisations testées étaient groupées en deux méga environnements reconnus pour la production du soja.

Mots Clés: AMMI, génotype, GGE, *Glycine max*

INTRODUCTION

Soybean (*Glycine max* L.) production constitutes 6% of all arable land in the world and has the highest percentage increase in area under production among crops annually. The global demand for the crop is expected to increase due to the crop's potential to improve the dietary quality of the vast majority of people and livestock (Hartman *et al*., 2011).

In Uganda soybean is increasingly an important food and cash crop. Consequently, the national soybean breeding programme has been actively involved in developing varieties to meet the needs of farmers in the diverse environments of the country. However, Uganda's climate is highly variable with mean annual rainfall of 510-2160 mm, varied soil productivity and land use influenced by soil depth, texture, acidity and organic matter (Wortman and Eledu, 1999). Therefore, widely adapted soybean varieties with dynamic yield stability are necessary to sustain soybean production country wide.

The differential response of genotypes across environments (GE) tends to limit response to selection and subsequently progress in plant breeding programme (Cross *et al*., 1999). Development of improved varieties of soybean, using exotic breeding materials from different maturity groups, causes a change in photoperiodic response and general adaptation of the progenies. Therefore, to determine the pattern of genotype response to environment and prioritise genotypes for use in a breeding programme, quantification of genotype by environment interactions is necessary (Gauch, 2006). This is important especially when dealing with advanced generation soybean lines not tested for adaptation to the main soybean producing areas of the country. In addition, the pattern of genotype response allows partitioning of test sites into mega environments and ideal environments based on their discriminating ability (Yan *et al*., 2007). This is crucial in plant breeding in order to rationalise resources and confine genotype testing to sites with informative data facilitating a rapid response to selection.

This multi-environment trial (MET) used Additive Main effects and Multiplicative Interactions (AMMI) and Genotype main effects plus genotype-by-environment interaction (GGE) to (i) determine the adaptability and stability of advanced generation soybean breeding lines in different environments of Uganda, (ii) identify the most ideal test environment capable of discriminating yield differences between the genotypes and (iii) determine the presence of soybean production mega environments in Uganda.

MATERIALS AND METHODS

The experiment was conducted at five different sites across Uganda; namely, Namulonge and Nakabango, located in the Lake Victoria Crescent; while Bulindi in the Western Grasslands, Ngeta in the north western savannah grasslands and Iki-iki in the Kyoga plains. These areas represent high and low potential environments, with different edaphic and environmental conditions. A more detailed biophysical description of the variation explored in the test environments is provided in Table 1.

The study was conducted for three consecutive seasons in 2008B, 2009A and 2009B (A and B refer to first and second season, respectively). The first rainy season stretches from mid-February to May, while the second season is from mid-July to November. Locations were selected based on the national agro-ecological zones (NARO, 2001) and level of soybean production.

The grain yield of 21 advanced breeding soybean genotypes developed by the breeding programme and three check varieties, Duiker, Maksoy 1N and Nam1 with similar growth cycles (maturity period 95-105 days) were evaluated (Table 2). Each entry was planted in three 4-m rows, with spacing of 60 cm between rows and 5 cm between plants. A randomised complete block design, with three replications was used for all the genotypes across locations and seasons. Standard agronomic practices were done in accordance with the requirements of soybean in Uganda (Tukamuhabwa, 2006).

After harvest maturity (R8 stage), data on yield of each genotype were standardised to 12% moisture content, using a Steinlite moisture meter (Model 400G) and converted into kilogrammes per hectare. Analysis of variance for yield was

TABLE 1. Description of the five selected experimental sites used to evaluate grain yield during season 2008A, 2008B and 2009A in Uganda

Site	Coordinates	Altitude(masl)	Mean annual temperature (^{0}C)	Mean annual rainfall (mm)	Soil type
Namulonge	00°32'N 32°53'E	1155	12.5	700-2100	Sandy clay loam
Nakabango	00°31'N 33°12'E	1178	12.5	700-2100	Crystalline basic
Iki-iki	01°06'N 34°00'E	1156	15.0	700-1700	Sandy
Ngeta	02°17'N 32°56'E	1085	15.0	700-1700	Sandy loam
Bulindi	01°28'N 31°28'E	1230	10.0	500-1700	Sandy loam

Source: NARO (2001); masl= metres above sea level

combined across locations. AMMI and GGE bi-plots were constructed using GenStat 13th Edition (Payne *et al.*, 2010). AMMI analysis was based on the model by Gauch (1988) and GGE was based on the model for two Principal Components according to Yan and Kang (2003).

RESULTS AND DISCUSSION

Across environments, the highest seed yielding genotype was G5 (BSPS48A) with an average of 1409 kg ha^{-1}; whereas a commercial variety G21 (Nam 1) was the least yielder with a mean of 1044kg ha^{-1}. Genotype G5 was also the highest yielder (2204 kg ha^{-1}) in the highest yielding (Nakabango) and lowest yielding (Ngeta) environments, with 656 kg ha^{-1} (Table 2). The lowest yield was recorded from the commercial variety G20 (Maksoy 1N) with 383 kg ha^{-1} in the lowest yielding environment (Ngeta). AMMI analysis also showed highly significant GE ($P<0.05$), indicating great diversity among the genotypes with a scale GE interaction. The presence of a scale GE interaction among the soybean genotypes signifies the need to breed for general as opposed to specific adaption for soybean grain yield (Matus-Cadiz *et al*., 2003) in Uganda.

The AMMI bi-plot showed that the tested 15 environments (3 seasons x 5 locations) were scattered without any definite grouping, with most of the genotypes clustered around the midpoint. This suggests that most of the genotypes responded to environmental index in a similar manner (Fig. 1). This could be attributed to a narrow genetic base of the test soybean lines, whose progenies shared common parentage as shown in the pedigree codes of BSPS and DxT (Table 2). Three genotypes, G7 (Duiker), G23 (NAMIIXG CBLP20.2) and G21 (Nam 1) were the most interactive, having high eigen vector scores (Table 2). Genotypes along the same horizontal (IPCA1) had the same interaction across environments. Genotypes and location combination along the same perpendicular axis had the same mean yield.

In all the environments assessed, genotype G5 was the highest seed yielder, having a relatively low interaction value. The potential of each of the test environments across seasons showed consistency in the performance of high and low yielding locations (Fig. 1). This is important evidence in breeding that the pattern of variation explored was consistent over seasons. Genotype G21 was highly interactive and had the lowest yield. Genotypes G24 (NGDT8.10-10), G8 (DXTBLP (SRB) 12.4) and G16 (DXTPYT06A8.11) had high static stability due to low levels of GE (Table 1). Genotype G5 (BSPS 48A) was, however, outstanding in terms of adaptation and relative stability in all the environments. The dynamic stability exhibited by the genotype is a desirable trait as it performs well irrespective of the site and prevailing environmental conditions.

GGE bi-plot analysis gave good visual assessment of GE with PCA1 and PCA2 explaining 73.87% of total GE sum of squares. The environmental vector bi-plot identified Nakabango and Bulindi as highly discriminating for the genotypes tested, as evidenced by the large environment vectors (Fig. 2). A long environment vector represents good discriminating ability for a given environment.

TABLE 2. Grain yield (kg ha^{-1}) of 24 soybean genotypes in five environments (sites) in Uganda and the first two Principal Components derived from AMMI analysis

Genotype code	Pedigree	Experimental sites					Genotype mean	PCA1	PCA2
		Iki-Iki	Bulindi	Nakabango	Namulonge	Ngeta			
G1	BSPS17B	920	1208	1954	1161	443	1137	-6.51297	2.47224
G2	BSPS34	989	1186	1611	1320	400	1101	1.37406	-9.22584
G3	BSPS42	826	1412	1726	1258	399	1124	3.53202	2.39470
G4	BSPS43	990	1289	1826	1602	416	1224	-2.20269	-8.47837
G5	BSPS48A	1000	1714	2204	1472	656	1409	-1.03290	10.22586
G6	BSPS85	1074	1270	1915	1328	532	1224	-3.93516	-3.49656
G7	DUIKER[†]	1136	1498	1358	1323	436	1110	14.95493	-6.50662
G8	DXTBLP(SRB)12.4	958	1479	1902	1376	517	1246	0.92523	2.14105
G9	DXTBLP(SRB)4.21	942	1498	1767	1395	488	1218	4.63788	-0.09961
G10	DXTPROGENIES1.3	978	1221	1788	1467	444	1191	-2.39016	-8.93354
G11	DXTPROGENIES4.17-4	882	1343	2075	1405	437	1228	-6.95477	3.65643
G12	DXTPROGENIES4.7	1036	1295	2053	1449	571	1298	-6.89420	-3.62276
G13	DXTPYT06A2.14	813	1410	1513	1184	371	1058	8.90291	-0.07112
G14	DXTPYT06A4.22	894	1274	1682	1251	390	1098	1.54413	-2.64932
G15	DXTPYT06A7.10	773	1615	1770	1328	428	1183	6.98918	7.27159
G16	DXTPYT06A8.11	881	1442	1873	1417	441	1212	0.53872	1.71696
G17	DXTPYT06A8.12	880	1380	1968	1306	451	1197	-3.17759	4.37396
G18	DXTPYT06A8.3	959	1449	2040	1403	522	1275	-3.30898	3.65369
G19	DXTSPS4.19	902	1372	1980	1338	460	1211	-3.68064	3.34953
G20	MAKSOY 1N[†]	823	1352	1736	1223	383	1103	1.92347	2.07197
G21	NAM 1[†]	910	1430	1515	863	505	1044	10.38710	4.67006
G22	NAMIIXGCBLP11.3	1108	1386	2075	1274	631	1295	-4.92658	2.42588
G23	NAMIIXGCBLP20.2	990	1095	2026	1281	438	1166	-11.06689	-2.34527
G24	NGDT8.10-10	939	1189	1657	1206	385	1077	0.37389	-4.99490
Mean		939	1367	1834	1318	464	1184		
SE±		18.7	29.0	42.9	28.9	15.5			

[†] Local check genotypes

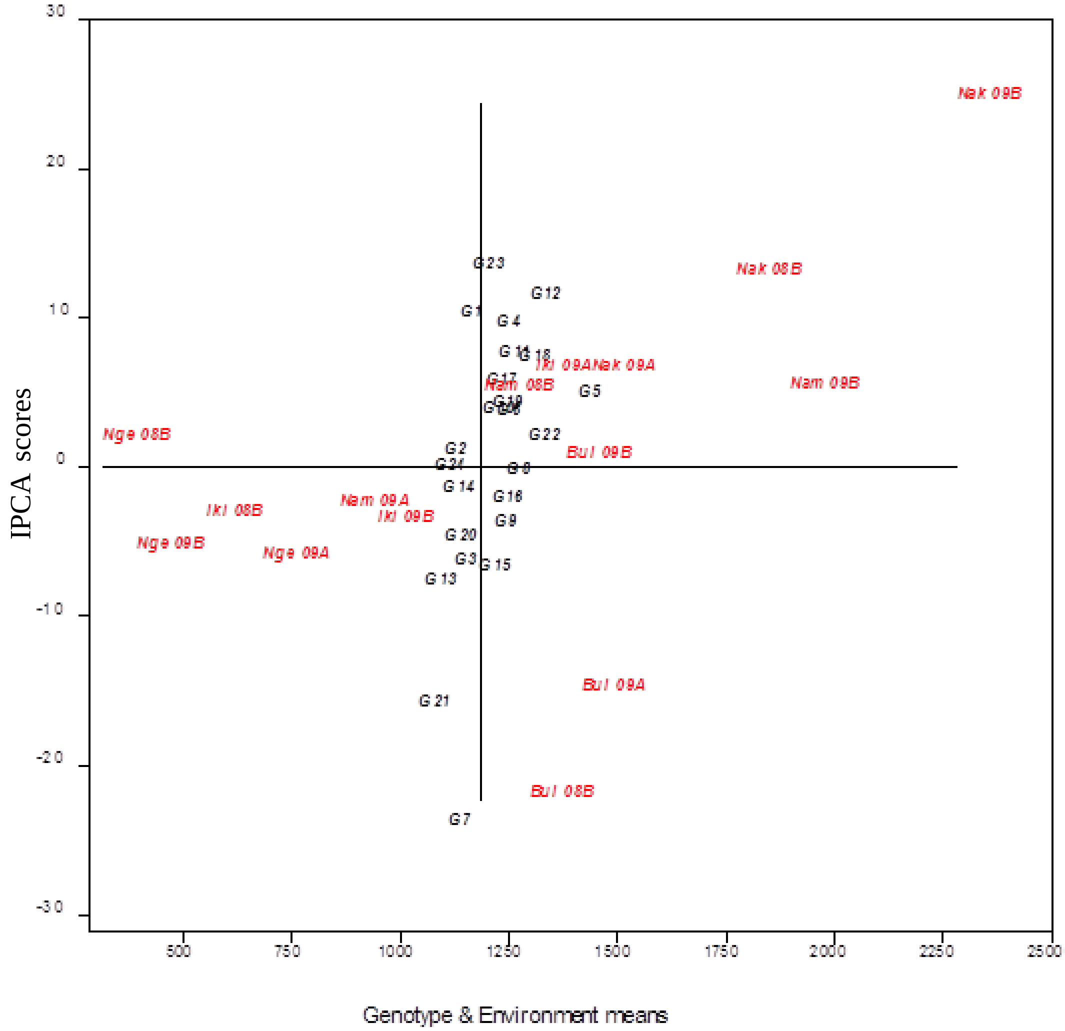

Figure 1. Bi-plot of Principal Component Analysis (PCA) Axis 1 versus Mean Yield (kg ha^{-1}) of 24 genotypes grown in five test environments during 2008A, 2008B and 2009A seasons in Uganda.

Discriminant test environments accurately resolve genotype differences, thereby providing the necessary information for selection by a breeder. Ngeta was the least discriminating of the five environments, as evidenced by the short environment vector. Therefore, testing soybean genotypes for yield in Nakabango only may suffice, as it is the most representative and discriminating site for soybean yield in Uganda. Bulindi is discriminating but not representative; therefore, it can be useful as a "culling environment" for quickly eliminating unstable genotypes during the selection process (Yan and Kang, 2003). Evaluation in other environments may give misleading results because of their low discriminating capability and lack of representativeness.

Environment comparison using the Average Environment Axis (AEA) identified Nakabango as the highest yielding and representative environment (Fig. 3). The AEA is a measure of the representativeness of the average environment. The innermost concentric rings represent the most ideal test environment for genotypes with the greatest yield. The high yielding potential of Nakabango was consistent with results presented by AMMI estimates. In addition, the small angle that Namulonge, Ngeta

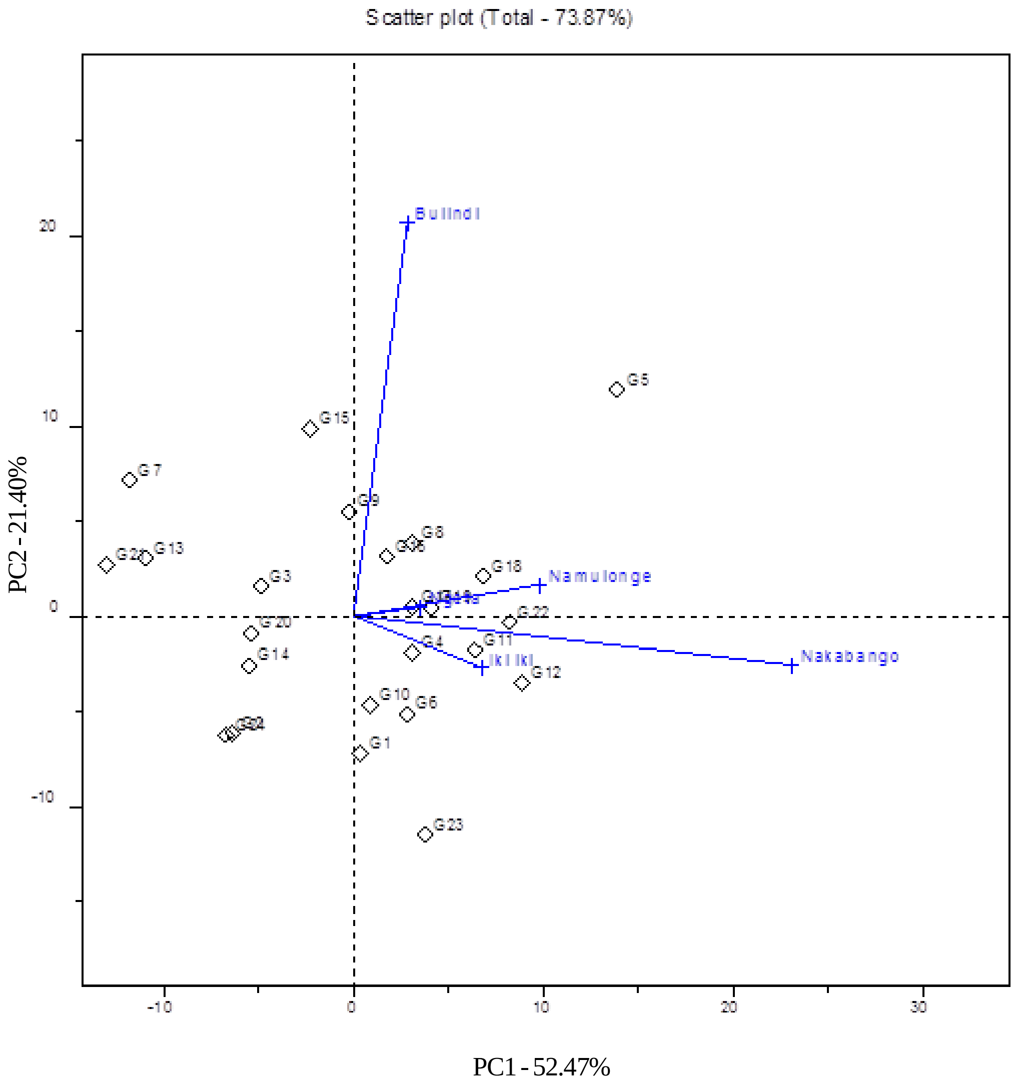

Figure 2. The environment vector bi-plot showing environmental differences in discriminating the 24 genotypes for grain yield at the five test environments during 2008A, 2008B and 2009A seasons in Uganda.

and Nakabango vectors had with AEA indicates greater relative stability of these environments across the three seasons 2008A, 2008B and 2009A for soybean production. Yan and Rajcan (2002) defined an ideal test environment as having small PC2 scores (more representative of the overall environment) and large PC1 scores (power to discriminate).

Based on the five locations used in this study, two mega environments with different “winning” genotypes were identified using a scatter plot with polygon bisectors (Fig. 4). Mega environments are test environments with different winning genotypes located at the vertex of the polygon. Locations within mega environment I were Namulonge, Bulindi, Nakabango and Ngeta. For this mega environment, G5 was the highest yielder with genotypes G22 (NAMIIXGCBLP11.3) and G18 (DXTPYT06A8.3) being second and third best, respectively. Mega environment II only had the location Iki-iki found in the Kyoga plains ecological zone, where genotypes G11 (DXTPROGENIES4.17-4) and G12 (DXTPROGENIES4.7) were most adapted. This implies that the country has two broad regions

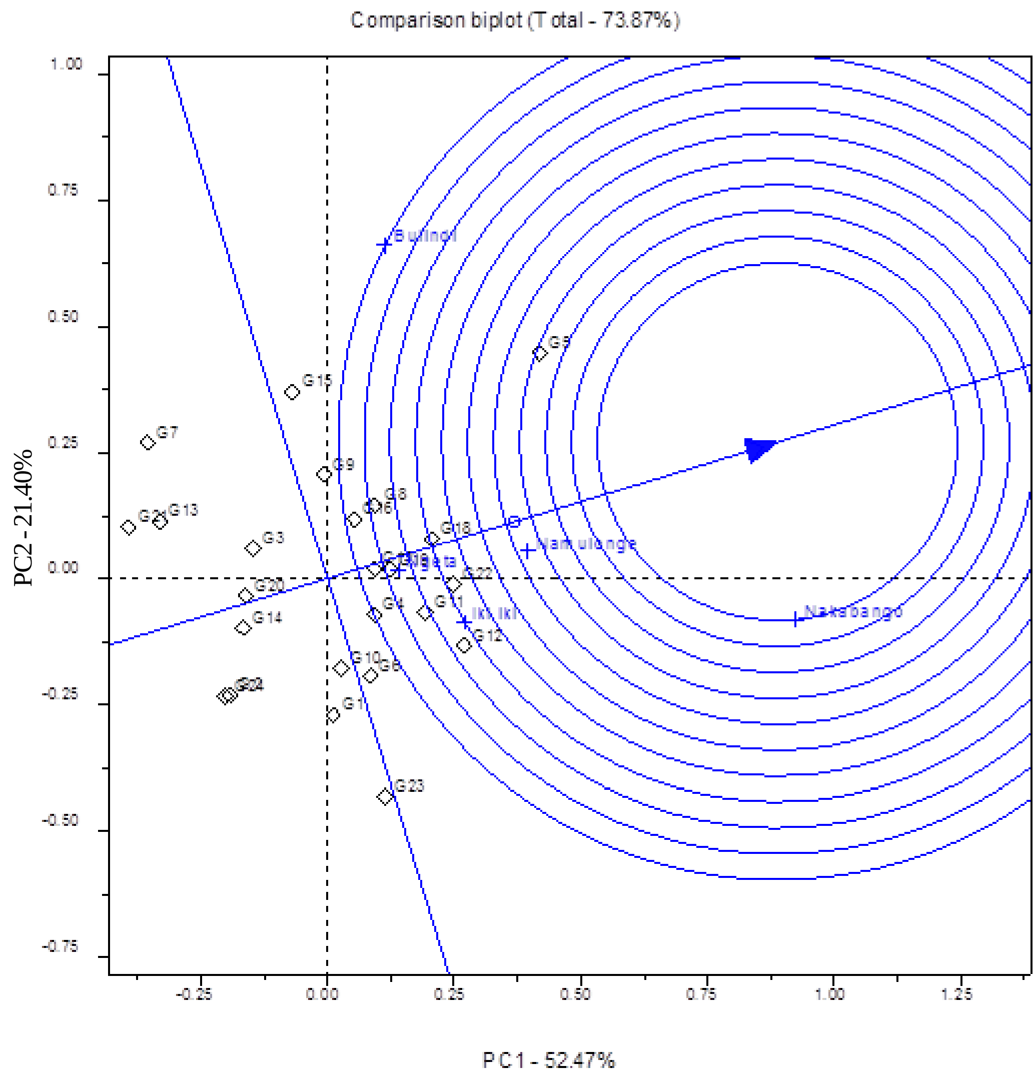

Figure 3. The environment comparison plot showing the Average Environment Axis (AEA) for grain yield of 24 genotypes at the five test environments during 2008A, 2008B and 2009A seasons in Uganda. Environments having a smaller angle with AEA are considered stable.

with unique environmental characteristics with specific high yielding genotypes. Therefore, soybean genotypes respond in a similar way for a greater part of the country; this is further corroborated by presence of a scale GE interaction for grain yield.

Interestingly, check genotypes G7 (Duiker), G20 (Maksoy 1N) and G21 (Nam 1) which are commercial varieties did not fit onto any mega environment during our study. This could be attributed to the susceptibility of Nam 1 and Duiker to soybean rust, and the breakdown of rust resistance reported in Maksoy 1N (Tukamuhabwa *et al*., 2009). However, the test locations within the two putative mega environments were close to one another, implying that targeted breeding for each of them may not be necessary before validation tests are done.

Iki-iki site, characterised by poor sandy soils, with low moisture retention capacity, was the only test location representing the second mega environment. Despite the relatively low potential for soybean grain yield at Iki-iki, G5 had the fifth highest mean yield, implying that it had good

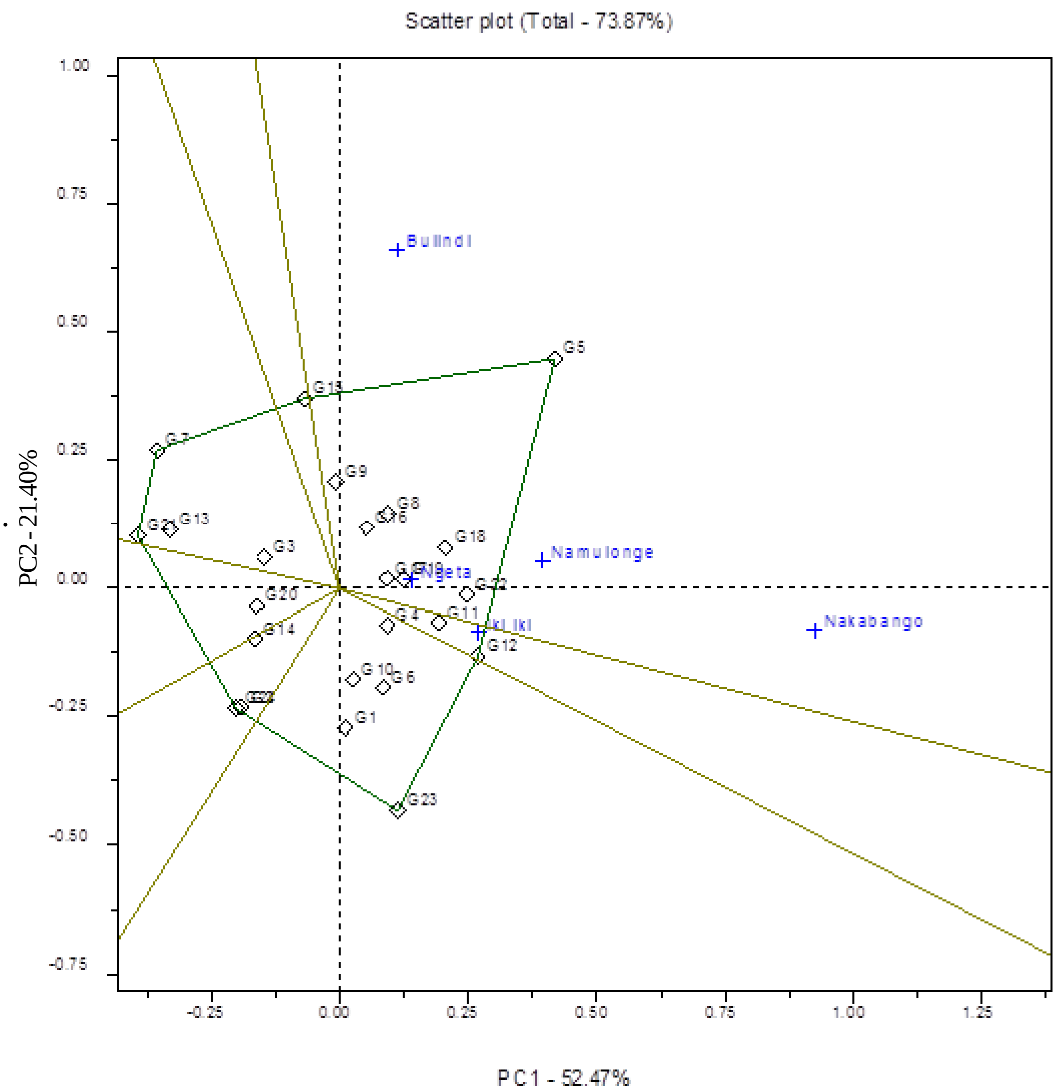

Figure 4. An environment focused bi-plot showing “winning” genotypes for the two different mega environments for grain yield at the five environments during 2008A, 2008B, and 2009A seasons in Uganda.

dynamic stability. This is an important attribute for any commercial variety given the unpredictable nature of rainfall in most parts of the country (Wortman and Eledu, 1999).

This is the first study to attempt to classify soybean production into mega environments and assess discriminating ability of test environments based on grain yield of soybean genotypes in Uganda. Such an attempt is important as it may reduce costs when conducting multi-locational trials for soybean grain yield. In this study, the tests were carried out in four zones; Victoria Crescent, western grasslands, north-western savannah grasslands and Kyoga plains. Further studies are recommended in south-western farmlands and north-eastern savannah grassland which were not represented in the test to determine which mega environment they fall in. This study, however, laid the basis for exploiting GE not only to identify stable genotypes but to classify environments into broader mega environments, and identify the most discriminating, high yielding and stable environment for soybean production in Uganda.

CONCLUSION

Genotype G5 is the most adapted as well as the best seed yielder in the most discriminating environment in Uganda. It is highly recommended for release after tests for its commercial value. Uganda can be divided into at least two putative mega environments in terms of soybean grain yield. Nakabango and Bulindi are the most descriminating sites and are therefore recommended as primary testing centres for new soybean genotypes.

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