African Crop Science Journal, Vol. 27, No. 2, pp. 267 - 280
ISSN 1021-9730/2019 $4.00

DOI: https://dx.doi.org/10.4314/acsj.v27i2.11

ADAPTATION AND STABILITY OF VEGETABLE SOYBEAN GENOTYPES IN UGANDA

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(*Received 30 April 2018.; accepted 15 May 2019*)

ABSTRACT

Vegetable soybean (*Glycine max* L. Merr.) is a specialty soybean, harvested as a vegetable when seeds are immature (R6 stage) and have expanded to fill 80 to 90% of the pod. The objective of the study was to assess the adaptation and stability of vegetable soybean genotypes in different agro-ecological zones of Uganda to enable selection of genotypes. A total of 21 genotypes were planted in Uganda for two consecutive seasons. Genotypes PI615437-B had the highest number of pods, while AGS 329 matured earliest in 64 days. Only AGS 292, AGS 329 and AGS 338 had 100 seeds weight above 30 g. G10427 was the ideal genotype in terms of adaptation and stability for fresh seed yield, with mean yield of 4281kg ha^{-1}; followed by G2843 with 4039 kg ha^{-1}. PI615437-B came third with fresh seed yield of 4024 kg ha^{-1}. The least stable and adapted genotype was AGS 329 with only 1609 kg ha^{-1}. Nakabango 1 and MUARIK 1 were the ideal environments, which were the most discriminative and representative. We recommend that G10427 be used as a test genotype and for improvement to produce a variety with good attributes, especially large seed, high yield and adaptable to Uganda.

Key Words: Discriminative, *Glycine max,* specialty bean

RÉSUMÉ

Le soja (*Glycine max* L. Merr.) Est un soja de spécialité, récolté comme légume quand les graines sont immatures (stade R6) et s'est développé pour remplir 80 à 90% de la gousse. L'objectif de l'étude était d'évaluer l'adaptation et la stabilité des génotypes de soja végétal dans différentes zones agro-écologiques de l'Ouganda pour permettre la sélection des génotypes. Au total, 21 génotypes ont été plantés en Ouganda pendant deux saisons consécutives. Les génotypes PI615437-B avaient le plus grand nombre de gousses, tandis qu'AGS 329 est arrivé à maturité plus tôt en 64 jours. Seulement AGS 292, AGS 329 et AGS 338 avaient un poids de 100 graines supérieur à 30 g. G10427 était le génotype idéal en termes d'adaptation et de stabilité pour le rendement en semences fraîches, avec un rendement moyen de 4281 kg ha^{-1}; suivi de G2843 avec 4039 kg ha^{-1}. Le PI615437-B est arrivé troisième avec un rendement en graines fraîches de 4024 kg ha^{-1}. Le génotype le moins stable et le plus adapté était AGS

329 avec seulement 1609 kg ha^{-1}. Nakabango 1 et MUARIK 1 étaient les environnements idéaux, les plus discriminants et les plus représentatifs. Nous recommandons que G10427 soit utilisé comme génotype de test et pour l'amélioration afin de produire une variété en particulier des graines de grande taille, à haut rendement et adaptable à l'Ouganda.

Mots Clés: sélectif, *Glycine max*, spécialité du haricot

INTRODUCTION

Vegetable soybean (*Glycine max* (L.) Merr.) is a specialty soybean, harvested as a vegetable when the seed is immature (R6 stage) and is expanded to fill 80 to 90% of the pod width (Konovsky *et al.*, 1994). Although soybean is said to have originated from China, the earliest reliable evidence of consumption of vegetable soybean (*edamame*) dates from 1275 AD in Japan (Shurtleff and Aoyagi, 2009). *Edamame* is consumed mainly as a snack, but also as a vegetable, in addition to soups; or processed into sweets. As a snack, the pods are slightly cooked in salted boiling water, and then the seeds are pushed directly from the pods into the mouth. As a vegetable, the beans are mixed with salads, stir-fried or combined with mixed vegetables (Mentreddy *et al.,* 2002).

The fresh vegetable soybean seed can provide 35 to 38% protein and 5 to 7% lipid on fresh weight basis; and is one of the few natural sources of isoflavones (Mentreddy *et al.*, 2002). Isoflavones are important nutraceuticals (Hartman *et al.*, 2011), for human health, which help to prevent the buildup of arterial plaques, reduce breast cancer by blocking the cancer-causing effects of human estrogen, prevent prostate cancer by hindering cell growth, fight osteoporosis by stimulating bone formation and inhibiting bone resorption (Bolla, 2015). Other health benefits include, decreasing low density lipoprotein (LDL) cholesterol levels and reducing the risk of cardiovascular diseases. The benefits have made the demand for vegetable soybean to increase throughout the world (Duppong and Hatterman-valenti, 2005). Despite the fact that vegetable soybean fulfils dietary protein requirements, its production still remains low in Africa where malnutrition is widespread due to low production, which is essentially caused by lack of well adapted varieties (Mebrahtu and Devine, 2009).

Uganda is one of the leading soybean producers in Africa (Tukamuhabwa and Oloka, 2016), but very little effort has been made to develop and promote vegetable soybean cultivars. Burker (2001) introduced a vegetable soybean variety AGS 292 to Uganda. This variety was tasted as vegetable in Serena Hotel (Shurtleff and Aoyagi, 2009), but no efforts were made to grow it. Chadha and Oluoch (2004) also reported that between 1998 and 2003, Uganda received 28 vegetable soybean lines from Taiwan - AVRDC. However, according to the national soybean programme, these genotypes have not been evaluated in different locations in Uganda to determine their performance in major soybean producing areas.

For these genotypes to be grown commercially by farmers in Uganda, there is need to evaluate the genotypes in different environments to ascertain their performance that is to assess genotypes by environment interaction (GxE). The presence of GxE interactions can hinder progress from selection by masking genotypic effects (Mebrahtu *et al.*, 1991). Genotype by environmental interaction (GxE) governs the identification of stable genotypes that are suitable for some particular environments (Mustapha and Bakari, 2014), as well as of genotypes with a general performance that are suitable for several environments (Mohamed, 2013), which can then be released for production by farmers or developed further. The objective of the study was to assess the adaptation and stability of vegetable soybean genotypes in different agro-ecological zones of Uganda to enable selection of genotypes.

MATERIALS AND METHODS

Experimental sites. This research was carried out in six sites, in major soybeans producing areas of Uganda; namely, Makerere University Agricultural Research Institute Kabanyolo (MUARIK), National Crops Resources and Research Institute - NaCRRI (Namulonge), Jinja (Nakabango), Budaka (Iki-Iki), Lira (Ngetta) and Kasese (Mubuku). The geographical description of the areas is summarised in Table 1.

Treatment and design. A total of 21 soybean genotypes were planted in a randomised complete block design (RCBD), with 2 replications in each of the six locations. Each entry was represented by two rows, each measuring 2 m; with 0.05 m in-row and 0.6 m inter row spacing. The study was conducted for two consecutive rainy seasons; the first and second seasons of 2014. Thus, the GXE analysis was based on 12 testing environments. Standard agronomic practices for weeding and pest control were applied (Kokobun, 1991).

Data collection. The following traits were recorded according to the International Descriptors for Soybean by International Board for Plant Genetic Resources (IBPGR, 1984); plant height, days to 50% flowering, number of pods per plant, days to harvest/ maturity. Data was also recorded on fresh seed yield. A total of 100 seeds were weighed using a Cen-Tech ® digital scale. The absolute values in grammes for the weight of each genotype were recorded.

At pod filling stage (R6 stage), all pods were harvested by hand picking. Total pods weight was taken per plot for each genotype at all the locations, using a Cen-Tech ® digital scale. The pods were shelled and the fresh seed weight per plot was recorded and extrapolated into kilogrammes per hectare using the following conversion formula:

$$\text{Fresh seed yield (kg ha}^{-1}\text{)} = \frac{\text{The yield obtained per plot (kg)}}{\text{Plot size (m}^2\text{)}} \times 10000$$

Data analysis. All data collected were evaluated using Analysis of variance in GenStat version 13. Significant means were separated using Fishers Least Significant Difference, at P<0.05.

AMMI analysis was performed for fresh seed yield to determine the contribution of each component (genotype, environment and genotype by environment interaction) to the total variation. AMMI biplots were generated for fresh seed yield to display the genotypic

TABLE 1. Characteristics of experimental sites used for the evaluation of vegetable soybean in Uganda

Location	Position	Location in Uganda	Altitude (m.a.s.l)	Mean annual temperature (°C)	Mean annual rainfall (mm)
Namulonge	0°32'N/32°37'E	Central	1.160	22.6	1,400
Nakabango	0°29'N/33°14'E	Eastern	1.210	22.8	1,400
Iki-Iki	1°06'N/34°00'E	Eastern	1.156	24.7	1,200
Ngetta	2°17'N/32°56'E	Northern	1.103	24.7	1,200
Mubuku	0°13'N/30°08'E	Western	1.007	27.8	750
MUARIK	0°27'N/32°36'E	Central	1.170	21.5	1150

Source: Meteorological stations at the study sites; m.a.s.l = meters above sea level stability and yielding ability. GGE biplots were used to determine the mega environments and to display the "which won were" pattern of the genotypes in the 12 environments. GGE Comparison biplots were plotted to determine the ideal genotype and environment.

RESULTS

Plant height. There were significant differences (P<0.001) in plant height among the 21 genotypes (Table 2). Genotypes PI615437-B and PI606405 had the tallest plants. However, they were grouped together with the other nine genotypes (AGS 338, SRE-B-15, G10427, GC 85037-2-3-54, G8527, PI628919, PI628908, SERENADE and GC 84051-31-1) as tall plants, since they were more than 45 cm tall. Nine genotypes (AGS 292, AGS 329, KUNTZ, G548360, G2843, PI615437, K-LOCAL, SRED-11-13 and G50) had heights ranging from 30.7 cm for AGS 292 being the shortest to 51.7 cm for PI615437 (Table 2). Only G78 had dwarf plants with average height of 24.5 cm and was also significantly different from all other genotypes.

Days to 50% flowering. There were significant differences (P<0.001) among the genotypes in number of days to 50% flowering

TABLE 2. Characteristics of genotypes used in the vegetable soybean study of in Uganda

Genotype	Source (Origin)	Mean plant height (cm)	Days to 50% flowering	Average number of pods per plant	Average number of days to maturity	100-seed fresh weight (g)
AGS 292	AVRDC	30.7	30	11	83	30.5
AGS 329	AVRDC	40.3	30	10	64	33
KUNTZ	USA	39.2	30	16	79	19.5
AGS 338	AVRDC	54.6	34	13	79	30.5
SRE-B-15	AVRDC	45.8	30	13	97	25.5
G10427	AVRDC	49.7	35	15	77	24.5
G548360	AVRDC	38.3	30	12	81	28.5
PI615437B	USA	80.9	44	31	70	21.5
G2843	AVRDC	42.5	31	22	87	25.5
G78	USA	24.5	28	20	70	27.5
PI 615437	USA	51.7	39	23	88	20
K-LOCAL	Unknown	46.4	27	21	86	20
GC 85037-2-3-54	AVRDC	53.9	34	20	96	16
G8527	AVRDC	49.8	31	30	75	15.5
PI606405	USA	82	43	18	77	15.5
PI628919	USA	55.9	45	23	106	24
SRED-11-13	AVRDC	42.5	31	17	80	20.5
PI628908	USA	63.5	44	23	82	13
SERENADE	USA	57.4	39	23	97	18.5
GC 84051-31-1	AVRDC	55.5	34	10	88	21
G50	USA	40.4	32	14	76	27.5
L. S. D (0.05)		8.26	5.57	9.13	15.58	2.78
C.V(%)		8	7.8	24.7	9	5.9

AVRDC = Asian Vegetable Research and Development Center; USA= United States of America

(Table 2). Genotype PI628919 had the longest period (45 days), although it was not significantly different from PI615437-B, PI606405 and PI628908, which took 44, 43 and 44 days to reach 50% flowering, respectively. On the other hand, K-LOCAL had the shortest period to 50% flowering (27 days). However, this was not significantly different from genotypes AGS 292, AGS 329, KUNTZ, SRE-B-15, G548360, G2843, G78, G8527, SRED-11-13 and G50 all of which had their 50% flowering time ranging from 28 to 32 days. Most of the genotypes were classified as early flowering because they had less than 36 days to reach 50% flowering. Only six genotypes (PI615437-B, PI615437, PI606405, PI628919, PI628908 and SERENADE) were classified as medium flowering, having days ranging between 36 and 45 to reach 50% flowering. No genotype was classified as late flowering.

Maturity. There were significant differences ($P<0.001$) among genotypes for number of days to maturity (Table 2). The number of days to maturity ranged from 64 to 106. AGS 329 matured earlier than all other genotypes, with days to maturity of 64. PI628919 had the longest maturity period of 106 days; followed by SRE-B-15 and SERENADE both having the same number of days to maturity of 97.

Pod number. Significant differences ($p<0.001$) among genotypes for pod number were also observed (Table 2). Genotypes PI615437-B and G8527 had the highest number of pods per plant (31 and 30 pods per plant, respectively). These were the only genotypes which qualified to be classified as having medium number of pods per plant. AGS 329 and GC 84051-31-1 had the least number of pods both having 10 pods per plant, which were also not significantly different from AGS 292, KUNTZ, AGS 338, SRE-B-15, G10427, G548360, G78, GC 85037-2-3-54, PI606405, SRED-11-13 and G50. Genotypes PI615437 PI628919, PI628908 and SERENADE produced similar pods per plant of 23; and were not significantly different from the genotypes KUNTZ, G10427, G2843, G78, PI615437, K-LOCAL, GC 85037-2-3-54, PI606405, PI628919, SRED-11-13, PI628908, SERENADE and G50; which bore pods ranging from 14 to 21 per plant.

100 seed weight and total yield. There were significant differences among genotypes ($P<0.05$) for 100-seed weight (Table 2); ranging from 13 to 33 g. Only three genotypes AGS 292, AGS 329 and AGS 338 had a 100 seeds weight above 30 g. PI628908 had the least weight of 13 g.

There were significant differences ($P<0.05$) for fresh seed yield among genotypes and environments (Table 3). Ngetta, Namulonge and Iki Iki had higher seed yield in the first season than in the second season; while MUARIK, Mubuku and Nakabango had higher yield in the second growing season of 2014. Overall, the highest performing genotypes for fresh seed yield were G10427 with 4,281kg ha^{-1} and G2843 with 4039 kg ha^{-1}; while the least performing genotype was AGS 329 with only 1609 kg ha^{-1} (Table 3).

AMMI analysis. AMMI analysis showed that environment, genotype and genotype x environment interaction (GXE) components were all significant ($P<0.001$) (Table 4). The environment had the highest contribution (63.28%) to the total variation, GXE had a contribution of 27.74%, and genotype had the least contribution (8.97%) to the total variation. The first two Interaction Principal Component Axis (IPCA) captured 52.97 % of the variation with IPCA1 capturing 36.26% and IPCA2 capturing 16.71 % (Table 4).

The AMMI Biplot for fresh seed yield showed that genotypes AGS 329, AGS 292, G50, G548360 and G8527 were low yielding and unstable (Fig. 1). High yielding and moderately stable genotypes included K-LOCAL, PI628919, SRE-B-15C and GC-85037-2-3-54. Genotypes GC 81051-31-1,

TABLE 3. Yield (kg ha^{-1}) of 21 vegetables soybeans evaluated at 12 testing environments in Uganda

Genotype	MUARIK		Namulonge		Ngetta		Iki Iki		Mubuku		Nakabango		Means
	2014A	2014B	2014A	2014B	2014A	2014B	2014A	2014B	2014A	2014B	2014A	2014B	
AGS 292	3883	7700	1992	692	3458	3042	304	363	250	4233	2267	2696	2573
AGS 329	4183	6346	1729	858	313	538	400	8	1912	1937	208	871	1609
AGS 338	2733	9929	1275	925	5263	3283	1904	142	2146	4892	771	5775	3253
G10427	5896	6621	2037	8513	6250	2829	4433	342	2142	3704	5154	3446	4281
G2843	6008	9408	2188	1554	2758	3300	2883	50	6442	6521	4217	3142	4039
G50	3204	6213	1212	1238	1446	1842	2212	229	2125	3896	913	2379	2242
G548360	779	6225	2075	383	3471	2054	1179	158	2046	3533	975	3888	2231
G78	3629	9017	2113	1408	2313	2471	1258	67	2387	3558	1521	3304	2754
G8527	2713	8662	2067	662	2825	1225	1271	79	1413	3562	363	2833	2306
GC 84051-31-1	5342	5175	3542	1233	8888	2921	5142	117	3258	2329	863	2688	3458
GC-85037-2-3-54	5792	7917	3833	2775	5308	1842	1967	225	2417	3171	3442	2575	3439
K-LOCAL	6133	8754	3271	2000	3175	3275	3233	317	1737	2308	2413	4067	3390
KUNTZ	3963	8171	2854	1721	3092	3192	912	54	3158	5517	896	2329	2988
PI606405	6296	6346	4283	1325	6013	1450	3208	96	5517	5238	3446	2808	3835
PI615437	6246	6792	3958	1971	5700	1617	4792	271	2617	2492	3533	2508	3541
PI615437-B	6304	9146	3779	1071	7933	1688	4117	58	3133	4021	3488	3546	4024
PI628908	5133	7450	2263	1117	6329	1475	4333	267	3308	5296	3529	2479	3582
PI628919	1692	8650	2992	1992	5233	2125	3408	204	2837	5383	3633	1917	3339
SERENADE	7263	9129	2708	2383	8446	1087	3525	75	2275	2675	1887	1629	3590
SRE - B-15C	4763	6446	2671	2004	5125	1192	2967	258	2233	4012	3846	3554	3256
SRED-11-13	3513	6217	1850	1375	2838	2167	2442	575	2392	5008	2629	5429	3036
LSD (0.05)	2318.8	2167.1	1519.4	3910.5	3015.9	1739.4	1926.4	262.1	2617.2	2338.7	2594.6	1047.5	1314.7

Each location in one season constitute an environment

TABLE 4. AMMI analysis of variance for fresh seed weight for the 21 vegetable soybean genotypes evaluated at 12 environments in Uganda

Source	Df	SS	MS	F	F_prob
Total	503	2874321653	5714357		
Treatments	251	2512941375	10011719	8.20	0.00
Genotypes	20	225502770	11275138	9.24	0.00
Environments	11	1590292456	144572041	25.33	0.00
Block	12	68485347	5707112	4.68	0.00
Interactions	220	697146149	3168846	2.60	0.00
IPCA 1	30	252773882	8425796	6.90	0.00
IPCA 2	28	116504431	4160873	3.41	0.00
IPCA 3	26	93443368	3593976	2.94	0.00
Residuals	136	234424468	1723709	1.41	0.01
Error	240	292894931	1220396		

SERENADE, PI61543, AGS 338 and G2843 were high yielding, but environmentally unstable. Environments MUARIK 2 (E7), MUARIK 1 (E1) and Ngetta 1 (E3) were high yielding, but unstable for fresh seed yield. On the other hand, Namulonge 1 (E2), Nakabango 1 (E6), Namulonge 2 (E8) and Mubuku 1 (E5) were low yielding but stable; while Nakabango 2 (E12), Ngetta 2 (E9), Iki Iki 1 (E4) were low yielding and unstable environments.

GGE Biplots for mega-environment. The scatter plot for the fresh seed yield demarcated three mega environments (Fig. 2). The first mega environment comprised of Iki Iki 2, MUARIK 2, Ngetta 2, Mubuku 1, Mubuku 2, Nakabango 1; and Nakabango 2. The best performing cultivar was G2843, and other genotypes that performed well in this first mega environment were PI628919, AGS 338, KUNTZ and SRED-11-13. The second mega environment had MUARIK 1, Iki Iki 1 and Namulonge 2 with a best cultivar G10427. The third mega environment consisted of Ngetta 1 and Namulonge 1. Genotype GC 84051-31-1 was the best genotype; and AMMI biplot explained 55.79% of the G+GE variation.

Results for comparison biplot which was genotype focused for fresh seed yield are presented in Figure 3. The biplot shows G104227 as the ideal genotype for fresh seed yield. The other genotypes which were close to the ideal were PI606405, PI615437-B and PI628906. Genotypes AGS 329, G548360 and G8527 were the least ideal genotypes.

The results of environment focused comparison biplot are shown on Figure 4. The biplot shows that the ideal environment to be Nakabango 1, while MUARIK 1 was closer to the ideal. The worst environment for fresh seed yield was Iki Iki 2.

DISCUSSION

Plant height. Genotypes were grouped as tall, medium and dwarf showing the different natural abilities of the different genotypes in height (Table 2). Different genotypes tend to have different genetic abilities for height, which is quantitatively influenced by the environment. Most vegetable soybean varieties do not grow tall (Sharma and Kshattry, 2013), which was confirmed in this study (Table 2). The vegetable soybean height may have an impact on the final yield of the crop as was previously observed that main stem height of the vegetable soybean positively correlates with

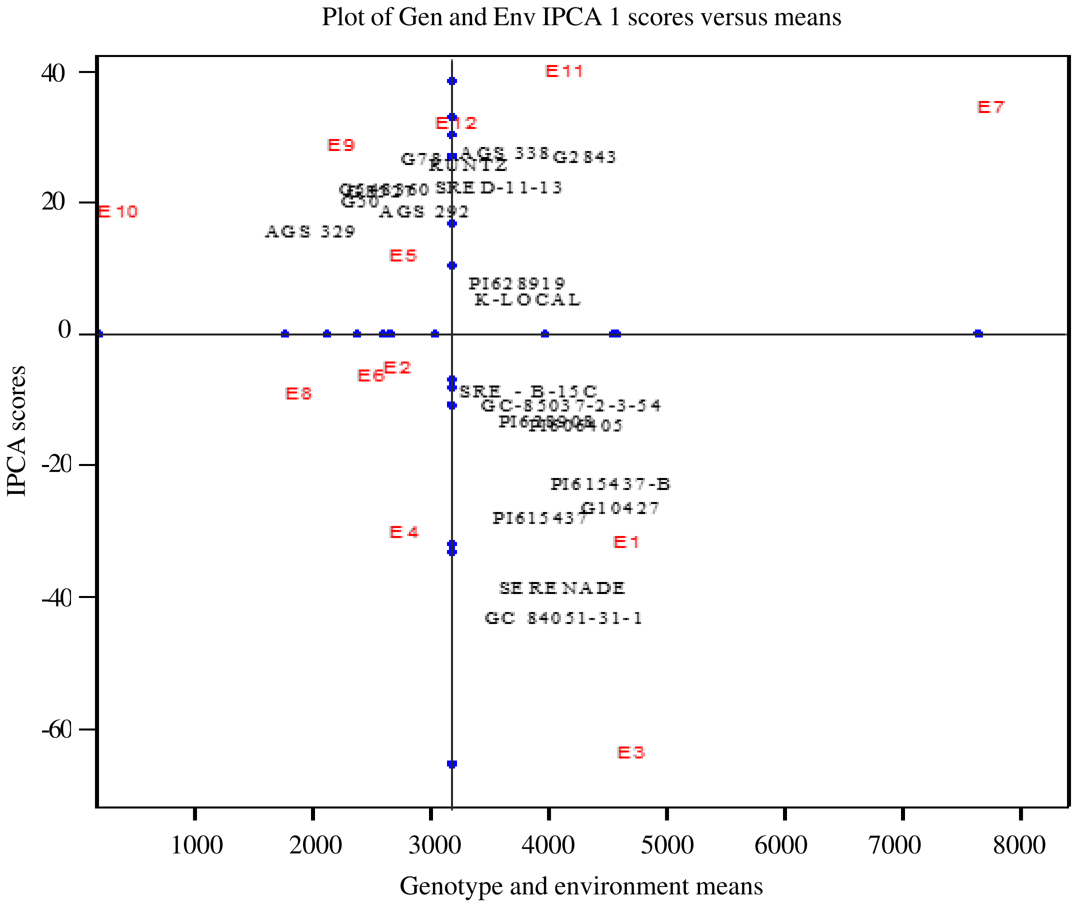

Figure 1. AMMI biplot of IPCA1 scores *versus* fresh seed yield means for 21 vegetable soybean genotypes evaluated in 12 environments in Uganda. E1 = MUARIK 1, E2 = Namulonge 1, E3 = Ngetta 1, E4 = Iki Iki 1, E5 = Mubuku 1, E6 = Nakabango 1,E7 = MUARIK 2, E8 = Namulonge 2, E9 = Ngetta 2, E10 = Iki Iki 2, E11 = Mubuku 2, E12 = Nakabango 2.

yield (Mebrahtu *et al.*, 1991; Sarutayophat, 2012).

Days to 50% flowering and to maturity. The genotypes flowering period ranged from 27 to 45 days for PI628919; and maturity period ranged from 64 (AGS 329) to 106 (PI628919) days after planting (Table 2). Flowering and maturity of the genotypes could have been influenced by temperature and latitude as soybean is sensitive to both (Jiang *et al.*, 2014; Santachiara *et al.*, 2017). Therefore, the genotypes used in the study exhibited the early maturing growth type in Uganda as expected. However, differences in maturity days were seen among the genotypes showing the different latitudinal adaptations for the different genotypes as reported in other studies (Salmeron *et al.*, 2014; Weller and Ortega, 2015; Santachiara *et al.*, 2017). In India most vegetable soybean varieties would mature around 75 days after planting (Sharma and Kshattry, 2013; Poornima *et al.*, 2014), but other varieties matured at 124 days after planting (Zhang and Boahen, 2007) a range which corroborates well with the current study. Variations could also be seen for the same genotype from season to the next in the same year; implying interactions with the environment. It is therefore important to select

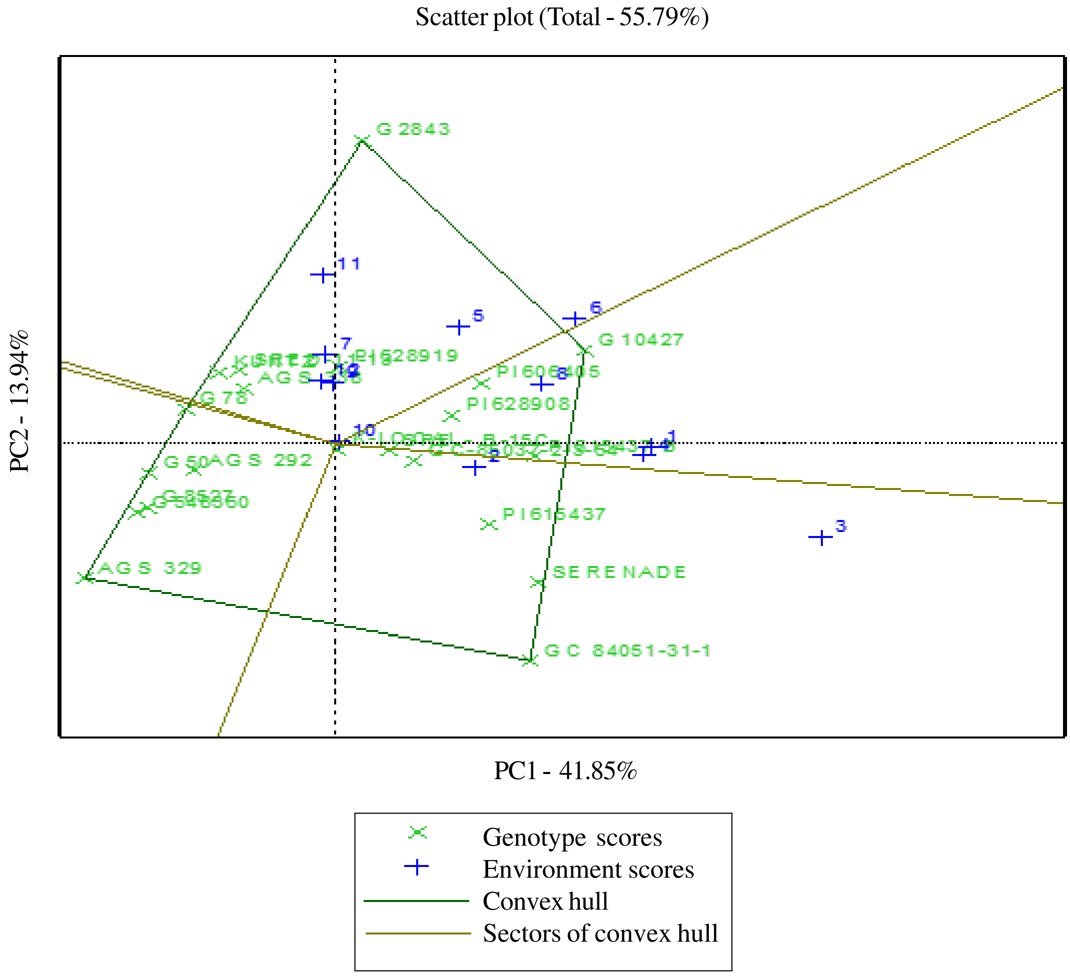

Figure 2. Mega environments and vertex genotypes for fresh seed yield (kg ha^{-1}) of the 21 vegetable soybean genotypes in Uganda.

the most appropriate season of the year in which maturity can be leveraged on, for example early maturity to allow for quick rotations. All the genotypes used in this research fell within the range expected of (75-125 days) vegetable soybean at R6 stage. This concurs with what was observed in India (Sharma and Kshattry, 2013; Poornima *et al.*, 2014) showing the genetic ability of vegetable soybean to mature early. AGS 329 had the shortest period to maturity of 64 days, a difference that was due to the high temperatures in Uganda when compared to Taiwan from which it originated.

Pod number. The vegetable soybean genotypes used in this study produced less pods per plant, with AGS 329 and GC 84051-31-1 producing as low as 10 pods per plant and only 2 genotypes (PI615437-B and G8527) producing above 25 pods per plant (Table 2). The low pod number of most of the genotypes like for AGS 329 and GC 84051-31-1 could be due to the short height and the less branching growth habit.

There was a positive correlation between height and pod number in vegetable soybean (Sarutayophat, 2012) hence breeders may take advantage of this correlation by practicing

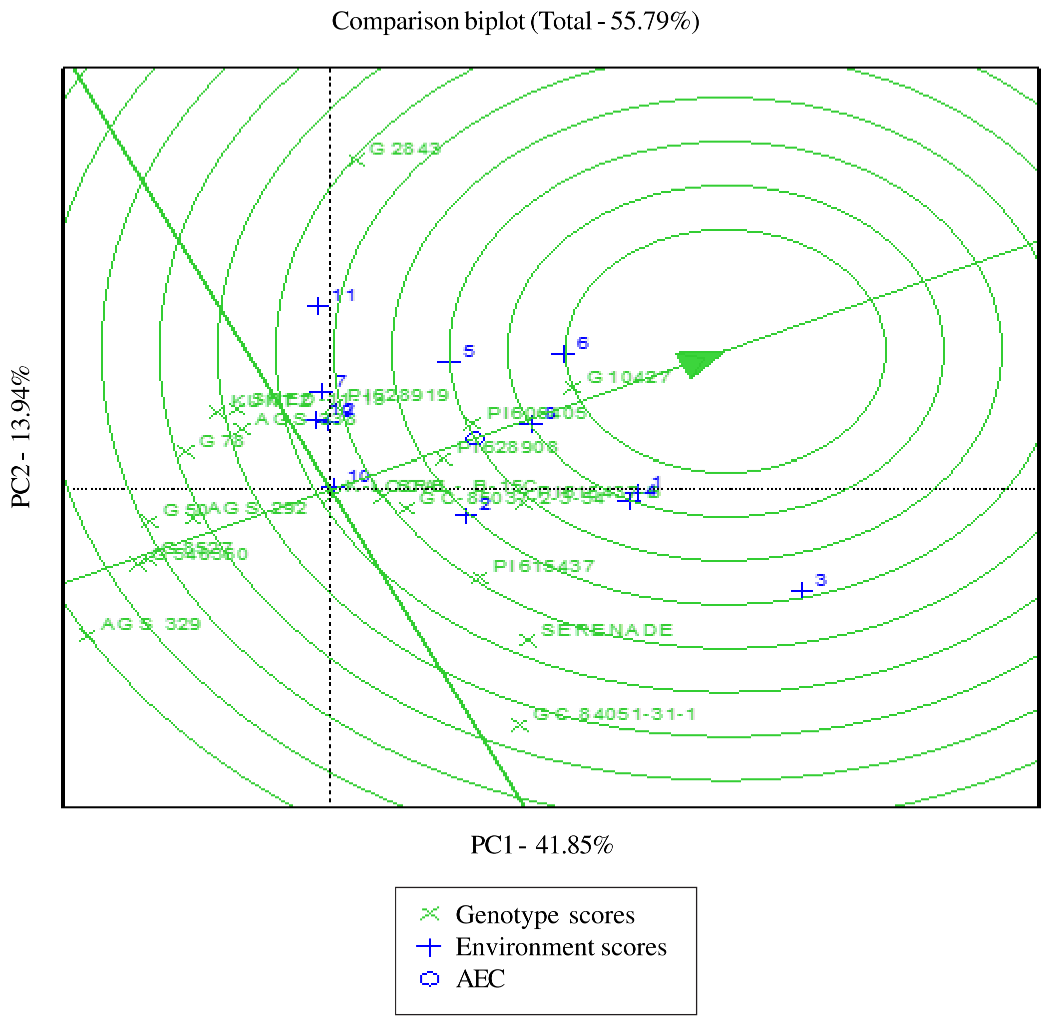

Figure 3. Genotype focused comparison biplot for fresh seed yield (kg $h^{-1}a$) of vegetable soybean in Uganda.

indirect selection, in which taller vegetable soybean genotypes can be selected to increase pod number.

The short height and less branching reduces the number of nodes from which pods can be formed, and thus less pods will be formed.

The number of pods produced by the AVRDC genotypes were much lower than previously reported by Poornima *et al.* (2014), which could rarely go below 20 pods per plant imposing a limit to final yield, thus calling for improvement of the current genotypes for more nodes to subsequently increase pod clusters.

100 seed weight and total yield. Only three genotypes, AGS 292, AGS 329 and AGS 338, managed to achieve a 100 seeds weight greater than 30 g. The large seed size of these genotypes contributed to the high weight of 100 seeds. These genotypes from AVRDC were specifically selected and bred for large seed size, since it satisfied the market requirements which also impacted on the protein and oil content (Mentreddy *et al.*,

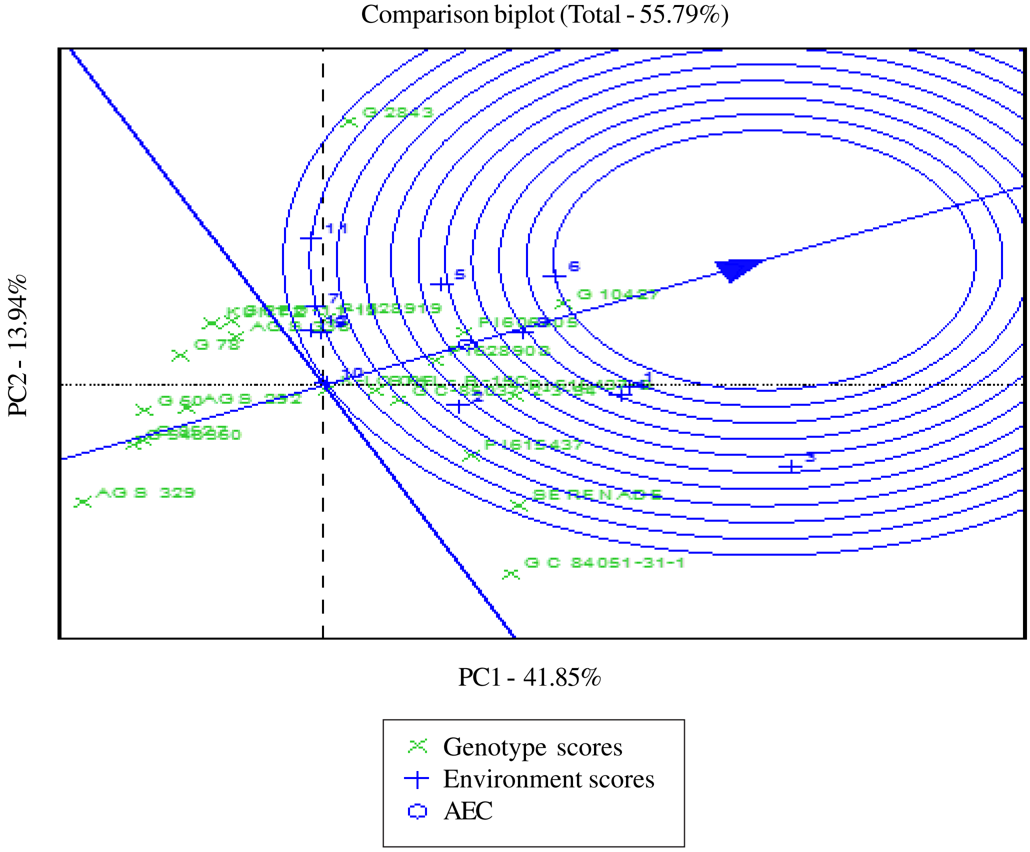

Figure 4. Environment focused comparison biplot vegetable soybean for fresh seed yield (kg ha^{-1}) in Uganda.

2002). Most of the USA genotypes had small seed size, thus had lower 100 seeds weight. The high temperatures in Uganda could have also hastened growth, thus reducing the time of grain filling and lowering the grain weight. From the results, it therefore means that only three genotypes could be classified as vegetable soybean as set out by Konovsky *et al.* (1994) that a 100-seed weight of vegetable soybean should exceed 30 g. Meanwhile, Roseboro (2012) found out that most USA varieties are three quarters the size of the Chinese varieties which were mostly sourced from AVRDC. This is in agreement with our research findings which generally found out that AVRDC genotypes weigh more than the USA genotypes because of the seed size.

Most of the AVRDC genotypes yielded less than the USA genotypes (Table 3), although several genotypes from AVRDC had been bred to adapt to the tropics (Chadha and Oluoch, 2004). The low yields could be attributed to the short height of the genotypes attained in Uganda, since there is a positive correlation between height and yield (Sarutayophat, 2012). The short plants in Uganda led to the low number of pods per plant due to limited number of nodes from which pods could be formed resulting in low fresh seed yields. The USA originating genotypes were taller, which facilitated more buds that gave more pods resulting in a higher yield. Genotypes G10427 and G2843, which were short managed to give higher fresh seed yield because of the large size sizes.

AMMI analysis. The AMMI analysis of variance for fresh seed yield showed that the environment explained a large percentage of the treatment total sum of squares indicating that the environments were diverse (Table 4). This might be due to differences in rainfall, which is known to impact on vegetable soybean yield (Mebrahtu *et al*., 1991). This ability of the environment to mask the genetic potential of different genotypes has an effect on selection and testing of vegetable soybean (Mebrahtu *et al*., 1991). Gauch and Zobel (1996) reported that in standard multi environmental trials (METs), the greater proportion of the treatment sum of square should be contributed by the environment, which is consistent with the study findings (Table 4). A significant GxE interaction for vegetable soybean fresh seed yield is an indication of different performance of genotypes across environments and this necessitates the investigation of the nature of different responses of the genotypes to the 12 environments.

GGE Biplots for mega-environments. The three mega environments with different winning genotypes that were identified; (i) mega environment with Iki Iki 2, MUARIK 2, Ngetta 2, Mubuku 1, Mubuku 2, Nakabango 1; and Nakabango 2; (ii) with MUARIK 1, Iki Iki 1 and Namulonge 2, and (iii) with Ngetta 1 and Namulonge 1. This implies that when focusing on fresh yield in vegetable soybean, the country could be divided into three broad regions with unique characteristics for specific high yielding genotypes (Fig. 2). The winning genotypes in the different mega environments could be recommended for these areas for production. Genotype G2843 could be recommended for the environments Iki Iki 1, MUARIK 1, Ngetta 2, Mubuku1, Mubuku 2, Nakabango 1 and Nakabango 2 (the first mega environment); while G10427 can be recommended for Iki Iki 1, MUARIK 1 and Namulonge 2. GC84051-31-1 could be recommended for the third mega environment which comprised of Ngetta 1 and Namulonge 1.

Genotype focused comparison biplots revealed that G10427 was the ideal genotype across all the environments. A genotype is more desirable if it is located closer to "ideal" genotype (Kaya *et al.,* 2006). This means that G10427 was stable and was able to maintain a sustainable yield across all the environments since it performed averagely well in the diverse environments. However, a fresh seed yield of 4281kg ha^{-1} attained by G10427 was relatively lower compared to fresh seed yield attained elsewhere (Sharma and Kshattry, 2013; Poornima *et al*., 2014) . For example, in Georgia, genotypes had fresh seed yield ranging from 7300 to 11600 kg ha^{-1}. Therefore, breeding for higher yields in Uganda may be pursued for future research.

The environment based comparison biplot showed that Nakabango 1 was ideal for fresh seed yield (Fig. 4). Nakabango received the highest rainfall compared to the other locations, during the first season, which could have created a suitable growing environment to be able to discriminate among the vegetable soybean genotypes more than the other environments. Iki Iki 2 was the least suitable environment, possibly due to the mid-season drought experienced during the season. Iki Iki is also characterised by poor sandy soils with low water retention capacity, which could have impacted on the performance of the different genotypes when there was moisture shortage (Tukamuhabwa *et al.,* 2012).

CONCLUSION

From this study, vegetable soybean genotype G10427 is the most adapted and stable genotype among the discriminating environments of Uganda agro-ecological zones, producing a mean of 4281kg ha^{-1}. Based on this study, Uganda can be divided into three mega environments for vegetable soybean fresh seed yield; with Nakabango 1 and MUARIK1 being the most discriminating environments; thus, they can be used as test environments for improvement of vegetable soybean yield in Uganda. It is recommended that G10427 be used as a test genotype, which can be improved to produce a variety with good attributes, especially large seed, high yield and adaptable to Uganda.

ACKNOWLEDGEMENT

We would like acknowledge Intra ACP STREAM for providing financial support for the research and the Makerere University Soybean Breeding Programme for hosting the research.

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