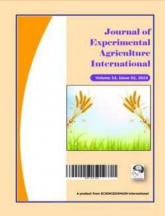

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GGE Biplot Analysis for Identification of Ideal Soybean [*Glycine max* L. Merrill] Test and Production Locations in Zambia

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The aim of the study was to Identify an ideal soybean testing environment in Zambia. The specific objectives were to determine the adaptation of new soybean lines (IITA) in different locations and also identify the existence of soybean mega-environments in Zambia.
Study Design: A Randomised Complete Block Design with four (4) replications at each location was used to carry out the experiment. Each plot had 4 rows of 6 m long each.
Place and Duration of Study: A multi- environment was carried out in the 2013/2014 agricultural season in four locations (Golden Valley Agricultural Research Trust (GART), Kabwe, Msekera and Masumba Research stations) in agro -ecological regions 1 and 2 of Zambia.
Materials and Methods: The experimental material consisted of 15 genotypes of soybeans viz., TGX 1740-2F (G1), TGX 1830-20E (G2), TGX 1835-10E (G3), TGX 1887-65F (G4), TGX 1904-6F (G5), TGX 1987-11F (G6), TGX 1987-23F (G7), TGX 1988-9F (G8), TGX 1988-18F (G9), 1988-22F (G10), TGX 1989-60F (G11), TGX 1990-129F (G12), Magoye (G13), Safari (G14) and Lukanga (G15). Planting was done in the last week of December (2013) to the first week of January (2014) across the locations and weed control was done by hand. Fertilisation with basal dressing at

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a rate of 200 kg/ha compound D was done with no inoculation for all the genotypes at planting across all locations. Data collection started when the crop had reached 50% flowering and the other parameters were recorded when the crop had reached maturity. Data analysis was done using Genstat version 16 and GGE biplot.

Results: The results showed that the best soybean location for Zambia was Kabwe; which was representative and discriminating. The genotypes yield mean score was 1239 Kg/ha and TGX 1988-22F was the highest yielding genotype with 1517 kg/ha while the lowest was TGX 1835-10E with 418 kg/ha. In terms of variability in accordance to GGE biplot, Safari was the most variable while the most stable was TGX 1988-22F. Therefore, the study concluded that the best genotype for general adaptability was the variety TGX 1988-22F which was ideal across all the locations as it was high yielding and stable. Six genotypes had a yield which was below the mean performance of the genotypes across all the locations; these were Lukanga, TGX 1835-10E, TGX 1830-20E, TGX 1988-18F, TGX 1987-23F and TGX 1987-11F. Also, three mega-environments were identified, Kabwe/Msekera which had TGX 1988-22F as the winning genotype, GART had safari and Masumba had Magoye.

Conclusion: The study was able to establish that Kabwe was the best test and production location for soybean in Zambia.

Keywords: GGE biplot; genotype x environment interaction; mega environment.

1. INTRODUCTION

Soybean is one of the most important cultivated crops in the world with about 6% of the world's arable land dedicated to its production [1]. The increase in production of soybeans is being spurred by the growth of edible oil consumption in the developing countries [2]. The increase has been concentrated in South America, USA, and Asia. Africa has however lagged behind, producing less than 1% of world production. Zambia being one of the African countries with high-potential arable land has yet to make significant strides in increasing soybean production [3]. Production has remained concentrated in the agro-ecological region II of Zambia, a region in which soybean performance also varies across locations. The main objective of the current study was to determine an ideal location for testing and growing of soybean in Zambia. The specific objectives were; to determine adaptation of new soybean lines (IITA) by identifying high yielding stable lines and also the determination of the existence of soybean mega-environments. The output from this study would improve soybean production and productivity by way of identifying areas which have a similar genotype response (mega-environments) and also genotypes which would perform well in the different mega-environments.

Genotype by environment interaction is the change in the relative performance of a character of two or more genotypes measured in two or more environments [4,5]. Genotypes by environment interactions are ascribed to differences in sensitivity, which means that a given environmental difference affects some genotypes more than others [6]. Therefore, information on variety stability to varied environments is very important in isolating genotypes which are responsive to better environments and maintain satisfactory yields under poor management [7]. Among the ways that have been used in an effort to resolve this problem is that of grouping environments into mega-environments by way of genotype response. A mega-environment is defined as a subset of locations that consistently share the best set of genotypes and the regions are relatively homogenous with similar biotic and abiotic stresses and cropping system requirements [8]. The pattern of genotype response allows partitioning of test sites into ideal environments and ideal mega-environments based on their discriminating ability [9].

Genotype x environment interactions in soybean like in many other important crops has been widely studied. Some of the aspects studied are comparison of the discriminating powers of GGE to the AMMI model in soybean selection [10], the effects of genotype by environment interaction on soybean agronomic traits [11], stability of soybean isoflavone content [12], Genotype by Environment and stability for grain yield and nutritional quality [13] and Soybean stability across several soil pH environments [14]. Soybean nutritional factors such as oil and protein content have been studied for stability

due to their importance in human nutrition [11] and the studies carried out have shown that oil and protein in soybean are apart from the yield strongly affected by the environment and the genotype by environment interaction [13].

Though several traits have been studied on soybean genotype x environment interaction, yield was found to be the most sensitive trait to genetic by environment interactions [9] and efforts to resolve this has received attention from researchers in an attempt to assess the adaptability and stability of soybean.

2. MATERIALS AND METHODS

Zambia is located on the African subcontinent between latitude 8-18^{o} S and longitudes 22-33^{o} E and covering an area of 752,620 km^{2}, which is 2.5% of the African continent [15]. It is a country with three agro-ecological zones which are characterised by differences in climatic conditions most important of which is the amount of rainfall received annually [15]. The other climatic parameters which are notable in these agro-ecological regions are temperature, soil characteristics and the vegetation type.

Region I comprise the valley areas of the country and lie between 300 and 900 m above sea level. The annual rainfall received in this area is low, not exceeding 800 mm with relatively high mean temperatures of 38^{o}C received in October. Region 2 is the most agricultural active region receiving between 800 mm to 1000 mm of annual rainfall. The elevation of this region is between 900 and 1300 meters above sea level. The mean daily temperatures during the growing season range between 23-25^{o}C. Most of the national soybean production in Zambia is done in region II. The last region is region III at an elevation ranging between 1100-1700 meters above sea level and receives above 1000 mm of rainfall per year. The average monthly temperature in the growing season is 16^{o}C. This region has a soil acidity set back in agricultural production. Table 1 shows the soil characteristics of the three agro-ecological regions of Zambia and their limitations to crop production.

2.1 Experimental Sites

The multi-environment trials were carried out in the 2013/2014 agricultural season at four locations described in Table 2 and shown in Fig. 1.

Table 1. Soils in the agro-ecological regions and their limitations to crop production

Region	General description of soils	Limitations
Region I	Loamy and clay with course to fine tops	Slightly acidic to alkaline. Minor fertility limitations
	Reddish course sandy soils	Low pH, available water and nutrient capacity reserve
	Poorly drained sandy soils	Severe wetness, acidic and low fertility
	Shallow and gravel soils in rolling to hilly areas	Not suitable for cultivation
Region II	Moderately leached clayey to loamy soils	Low nutrient and water holding capacity
	Slightly leached soils	Slight to moderate acidity. Heavy textured soils
	Course sandy loams in large dambos	Imperfectly to poorly drained. Limitations due to wetness
	Sandy soils on Kalahari sand	Medium to strong acidity, course textured topsoil, low water holding capacity and nutrient capacity.
Region III	Red brown clayey loamy soils	Very strong acidity and highly leached
	Shallow and gravel soils	Limited depth
	Clayey soil, red in colour	Fewer limitation but moderately leached
	Poorly to very poorly drained floodplain soils	Variable texture and acidity
	Course sandy soils in pan dambos on Kalahari sand	Very strong acidity

Source: Compiled from Bunyolo. A Chirwa. B and Muchinda M. Agroecological and Climatic conditions in Muliokela. S (ed), 1997: Zambia Technology handbook, Ministry of Agriculture Food and Fisheries, Lusaka

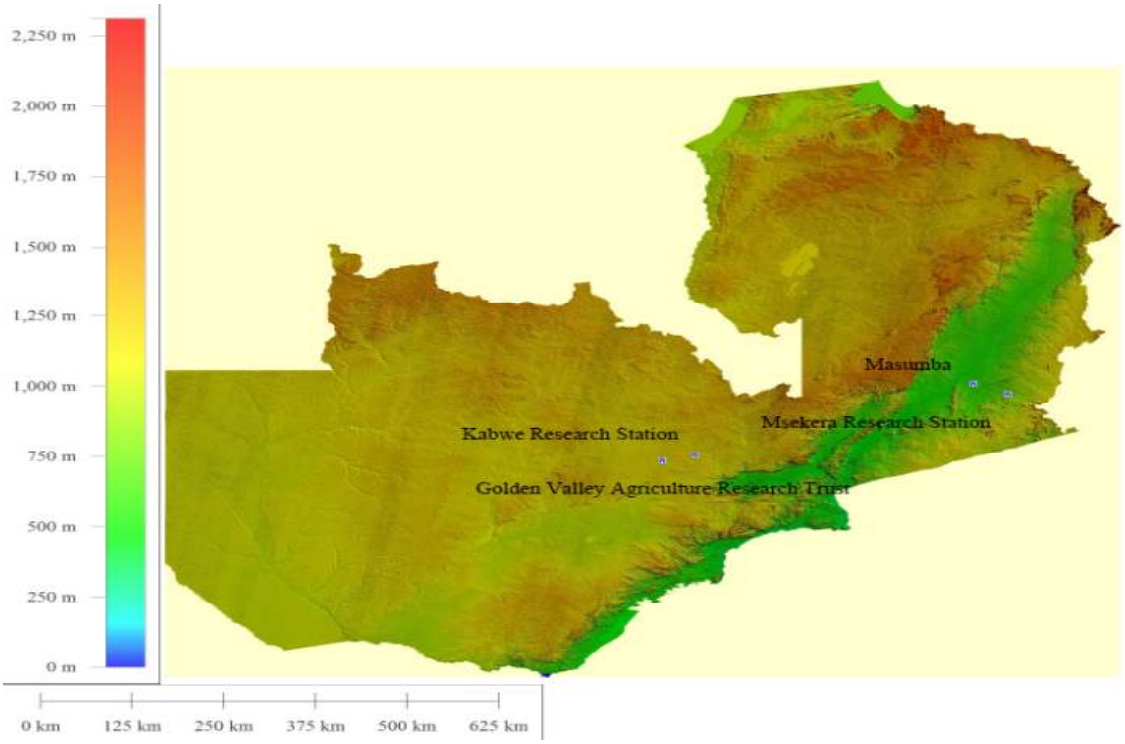

Fig. 1. Map of Zambia showing the trial location

Table 2. Experiment sites description

Location name	Coordinates	Agroecological region	Altitude (M)
Masumba	13.22 S, 31.93 E	I	546
Golden Valley Agriculture Research Trust (GART)	14. 50 S, 28.10 E	II	1139
Kabwe research station	14.39 S, 28.49 E	II	1176
Msekera research station	13.38 S, 32.34 E	II	1032

Composite soil samples were collected at the 4 locations to a depth of 30 cm and soil analysis was done at the University of Zambia soil science laboratories. The soil analysis results are indicated in Table 3 and show that the locations had relatively similar soil texture of sandy loam in three locations namely Masumba, Msekera and Golden Valley Research Trust (GART) while one location (Kabwe) had loamy sands. The pH range for the locations was between 5.52 and 5.95. The locations varied on NPK and the trace elements.

Climatic conditions namely rainfall and temperature were recorded and aggregated by month. The data for three locations; Masumba, Kabwe, and Msekera was obtained from the Zambia Meteorology Department, while the data for Golden Valley Agriculture Research Trust was obtained from the research station. The recorded data is tabulated in Table 4. The highest amount of rainfall was received at Msekera (1097.7 mm). The other locations received 642.8 mm (Masumba), 601.2 mm (GART) and 583.3 mm (Kabwe). The mean temperatures for the locations were 32.88^{o}C (Masumba), 29.5^{o}C (Msekera), 23.12^{o}C (kabwe) and 24.24^{o}C (GART).

2.2 Experimental Design

The experimental material consisted of 15 genotypes of soybean (Table 5). There were twelve promiscuous lines obtained from the International Institute of Tropical Agriculture, two lines from Zambia Agricultural Research Institute (ZARI) and one from SeedCo. There was one ZARI promiscuous variety (Magoye) while the other (Lukanga) and the Seedco variety (Safari) are not promiscuous.

Table 3. Soil analysis results for the four (4) trial locations

Location	pH	N	Organic matter	P	K	Na	Ca	Mg	Cu	Fe	Mn	Zn	S	Sand	Clay	Silt	Class
			%	mg/kg	cmol/kg		cmol/kg		mg/kg		mg/kg		mg/kg	%	%	%	
Kabwe	5.52	0.063	0.56	15.21	0.17	0.05	1.83	0.57	0.14	6.44	6.43	0.58	14.79	80	6	14	Loamy sand
GART	5.95	0.07	1.92	7.56	0.66	0.08	6.50	2.47	3.24	3.38	6.26	0.92	17.75	64	16	20	Sandy loam
Msekera	5.63	0.08	2.40	12.27	0.90	0.10	10.00	2.25	0.64	9.46	8.03	0.74	13.81	70	10	20	Sandy loam
Masumba	5.52	0.07	3.52	1.99	0.43	0.06	6.83	1.51	0.97	6.92	9.61	0.55	12.82	64	12	24	Sandy loam

Table 4. Mean Monthly meteorological data for the four locations over the study period

Month	Location	Mean temp (℃)	Total monthly rainfall (mm)
December	Masumba	35.6	106.9
	Msekera	31.6	143.1
	Kabwe	24.9	191.7
	GART	25.2	307.6
January	Masumba	31.8	246.3
	Msekera	28.5	306.5
	Kabwe	23.5	204.2
	GART	25.1	69.2
February	Masumba	31.8	214.1
	Msekera	28.5	407.8
	Kabwe	22.95	97
	GART	24.4	99.4
March	Masumba	33	75.5
	Msekera	30.1	216.8
	Kabwe	22.95	88.4
	GART	24.1	65.1
April	Masumba	32.2	0
	Msekera	28.8	23.5
	Kabwe	21.3	2
	GART	22.4	60.2

Table 5. List of genotypes used in the trial and their assigned codes

Genotype	Genotype assigned code	Source
TGX 1740-2F	G 1	IITA
TGX 1830-20E	G 2	IITA
TGX 1835-10E	G 3	IITA
TGX 1887-65F	G 4	IITA
TGX 1904-6F	G 5	IITA
TGX 1987-11F	G 6	IITA
TGX 1987-23F	G 7	IITA
TGX 1988-9F	G 8	IITA
TGX 1988-18F	G 9	IITA
TGX 1988-22F	G 10	IITA
TGX 1989-60F	G 11	IITA
TGX 1990-129F	G 12	IITA
Magoye	G 13	ZARI
Safari	G 14	SeedCo
Lukanga	G 15	ZARI

**The IITA lines were obtained from a pool recommended for Zambian trials under the USAID-funded feed the future project*

The treatments (genotypes) were arranged in a Randomised Complete Block Design with 4 replications at each location. Each plot consisted of 4 rows of 6 meters long. An interrow spacing of 50 cm and intrarow spacing of 5 cm were used.

Planting was done at different times; GART (24th December 2013), Kabwe (25th December 2013), Msekera (31st December 2013) and Masumba (1st January 2014) depending on the onset of the rains while weeding was done by hand as and when required. Fertilizer application consisted of basal dressing with Compound 'D' (N= 10, P_2O = 20, K_2O = 10, S = 6-8) at a rate of 200 kg/ha. There was no inoculum applied in all the trials.

2.3 Data Collection and Analysis

Data collection started when the crop had reached 50% flowering and most of the other parameters were recorded when the crop had reached maturity. At maturity, the entire two (2) middle rows were harvested and data on grain yield was calculated on the two rows. The other parameters recorded at physiological maturity were plant height, number of pods per plant, stand count at harvest and 100 seed weight following procedures by Ngalanu et al. [16]. The yield was computed after the soybean had been dried to a moisture content of 13.5%.

A Combined Analysis of Variance across locations for each of the parameters recorded was done using Genstast version 16 to determine the magnitude of the main effects and interactions. The locations and genotypes were taken as random. With respect to yield, a further analysis was done using GGE biplot [17]. This was applied for visual examination of the genotype by environment interactions. The GGE biplots were constructed using the first two principal components (PCI and PC2).

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Analysis of variance

A combined analysis of variance was done and there were significant differences (P=.05) among locations with respect to yield, days to 50% flowering, plant height, 100 seed weight and pods per plant. Significant differences (P=.05) were also obtained among genotypes with respect to yield, days to 50% flowering, plant height and 100 seed weight (Table 6). There were also significant (P=.05) genotype x environments interactions for yield, days to 50% flowering, plant height, and 100 seed weight.

The results presented in Tables 7 to 11 show the means and least significance differences (LSD) for differences determination.

Table 6. Analysis of variance for the various studied traits

Source of variation	Degrees of freedom	Yield (kg/ha)	D_50% flowering	Plant height (cm)	100 Seed_w (g)	Pods per plant
Location	3	16158777**	289.54**	5358.09**	140.46**	24379.20**
Reps/Location	12	415793	2.63	121.93	3.21	365.72
Genotypes	14	1192617**	232.72**	880.56**	38.82**	477.30
Location * genotypes	42	472487*	10.77*	124.13	9.30*	736.10
Error	167	128231	3.28	63.87	2.67	459.60
Total	238					

*Note * and ** indicates statistical significance at the 0.05 and 0.01 levels of probability respectively*

Table 7. Genotype mean yield within and across locations

Genotypes	Locations				
	GART	Masumba	Msekera	Kabwe	Mean
TGX 1740-2F	1412	751	1267	2003	1358
TGX 1830-20E	1064	842	669	1228	951
TGX 1835-10E	594	388	478	213	418
TGX 1887-65F	1239	611	1414	2316	1395
TGX 1904-6F	1419	1238	1001	2262	1480
TGX 1987-11F	798	850	890	1834	1093
TGX 1987-23F	1008	1205	420	1610	1060
TGX 1988-9F	852	809	1078	2364	1276
TGX 1988-18F	1465	417	719	2121	1180
TGX 1988-22F	1309	807	1340	2610	1517
TGX 1989-60F	1396	1172	944	2076	1397
TGX 1990-129F	1389	1107	1392	2124	1503
Magoye (check)	991	1164	1109	2459	1431
Safari (check)	1731	236	1061	2409	1359
Lukanga (check)	1640	372	630	2047	1172
Mean	1220	801	958	1978	1239
LSD	A (locations=135.9) x B (Genotypes=263.1)=AxB= 526.2				
CV (%)	A (locations) x B (Genotypes)=AxB= 30.4				

Table 8. Genotypes mean days to 50% flowering within and across locations

Genotypes	Locations				
	GART	Masumba	Msekera	Kabwe	Mean
TGX 1740-2F	49.00	47.00	48.00	56.25	51.00
TGX 1830-20E	61.00	57.00	59.75	61.75	59.88
TGX 1835-10E	54.50	57.00	53.50	54.75	54.94
TGX 1887-65F	60.75	57.75	63.50	59.75	60.44
TGX 1904-6F	54.50	51.25	55.25	59.50	55.12
TGX 1987-11F	52.50	50.75	54.75	50.75	53.69
TGX 1987-23F	55.75	52.75	57.00	60.50	56.50
TGX 1988-9F	53.75	52.50	53.75	56.50	54.12
TGX 1988-18F	49.00	43.50	49.75	52.25	48.62
TGX 1988-22F	51.00	52.75	53.50	57.50	53.69
TGX 1989-60F	49.25	47.75	52.75	55.00	51.19
TGX 1990-129F	52.50	50.25	54.00	56.25	53.25
Magoye (check)	51.00	50.00	51.00	56.00	52.00
Safari (check)	49.25	47.00	50.25	49.50	49.00
Lukanga (check)	46.25	45.00	48.00	48.50	46.94
Mean	52.67	50.82	53.90	56.05	53.36
LSD	A (locations=0.65) x B (Genotypes=1.26)=AxB= 2.53				
CV (%)	A (locations) x B (Genotypes)=AxB= 3.4				

Table 9. 100 seed mean weight of the genotypes for within and across locations

	Locations				
Genotypes	**GART**	**Masumba**	**Msekera**	**Kabwe**	**Mean**
TGX 1740-2F	10.75	15.00	11.97	11.25	12.24
TGX 1830-20E	9.75	12.25	12.75	9.25	10.99
TGX 1835-10E	14.50	8.97	11.30	11.50	11.57
TGX 1887-65F	9.25	10.77	13.95	12.00	11.49
TGX 1904-6F	10.25	13.87	13.70	11.00	12.05
TGX 1987-11F	11.25	16.75	14.65	13.25	13.97
TGX 1987-23F	9.00	13.25	12.05	10.75	11.26
TGX 1988-9F	9.75	17.50	13.25	11.00	12.87
TGX 1988-18F	14.50	19.50	14.62	15.25	15.97
TGX 1988-22F	9.50	16.25	13.60	13.00	13.09
TGX 1989-60F	11.50	17.75	13.68	13.75	14.17
TGX 1990-129F	11.25	15.75	13.12	13.00	13.28
Magoye (check)	8.50	12.25	13.07	9.75	10.89
Safari (check)	14.50	13.08	16.17	16.25	15.00
Lukanga (check)	14.00	16.25	13.80	15.00	14.76
Mean	11.22	14.61	13.40	12.40	12.90
LSD	A (locations=0.59) x B (Genotypes=1.12) AxB= 2.28				
CV (%)	A (locations) x B (Genotypes)=AxB= 12.7				

Table 10. Mean plant height at harvest within and across locations

Genotypes	Locations				
	GART	**Masumba**	**Msekera**	**Kabwe**	**Mean**
TGX 1740-2F	74.50	62.00	56.30	63.80	64.15
TGX 1830-20E	69.25	44.25	45.30	55.55	53.59
TGX 1835-10E	44.75	37.75	32.30	35.58	37.59
TGX 1887-65F	74.00	55.25	67.85	67.32	66.11
TGX 1904-6F	75.75	50.25	43.27	71.55	60.21
TGX 1987-11F	77.75	61.00	46.98	60.80	61.63
TGX 1987-23F	68.00	57.00	44.30	62.42	57.93
TGX 1988-9F	75.00	51.75	46.88	70.68	61.07
TGX 1988-18F	72.25	52.50	48.25	64.22	59.31
TGX 1988-22F	79.75	59.75	51.15	66.23	64.22
TGX 1989-60F	68.00	66.75	43.80	61.08	59.91
TGX 1990-129F	74.75	59.50	48.77	61.30	61.08
Magoye (check)	63.00	41.50	42.55	44.55	47.90
Safari (check)	63.00	46.50	41.80	53.37	51.17
Lukanga (check)	56.50	44.25	40.48	43.40	46.16
Mean	69.08	52.67	46.67	58.79	56.80
LSD	A (locations=2.88) x B (Genotypes=5.58)=AxB= 11.72				
CV (%)	A (locations) x B (Genotypes)=AxB= 14.7				

3.1.2 Mega environment identification

Fig. 2 is a scatter plot which shows the yield response analysis for identification of mega-environments. The winning genotype in each of those mega-environments was identified. A polygon was drawn on genotypes that are furthest from the biplot origin so that all the other genotypes are contained within the polygon. Then perpendicular lines to each side of the polygon were drawn starting from the biplot origin [8]. Based on the interpretations of the polygon view on the biplot; the genotypes on the vertices are either the worst or the best yielding genotypes [7]. The perpendicular lines in the polygons are equality lines between adjacent genotypes [8]. Therefore the study results show that for the locations Kabwe and Msekera, TGX 1988-22F (G10) was the best genotype, Safari (G14) was the best for GART and the genotype Magoye (G13) was the best performer for Masumba. Based on the GGE principle that any number of environments with the same “winning” genotype form a mega-environment, the results

in Fig. 2 show 3 mega-environments. The mega-environments were Kabwe/Msekera, GART, and Masumba.

3.1.3 Discriminating ability determination

Results in Fig. 3 show the discriminating ability of the locations. The lengths of the environment vectors on the vector view biplot approximate the standard deviation within each environment, which is the measure of the discriminating ability [18]. The results in Fig. 3 show that Kabwe was the most discriminating environment followed by Masumba, Msekera and the least was GART.

Table 11. Mean number of pods per plant within and across locations

Genotypes	Locations				
	GART	Masumba	Msekera	Kabwe	Mean
TGx 1740-2F	60.20	25.90	16.30	64.60	41.80
TGx 1830-20E	69.60	35.10	18.40	57.80	45.20
TGx 1835-10E	86.00	42.60	24.50	31.30	46.10
TGx 1887-65F	47.20	40.80	17.00	78.00	45.70
TGx 1904-6F	70.90	34.70	17.80	36.50	40.00
TGx 1987-11F	43.20	32.00	22.60	76.60	43.60
TGx 1987-23F	52.30	36.50	17.60	73.90	45.10
TGx 1988-9F	49.70	36.80	24.40	58.10	42.20
TGx 1988-18F	53.90	38.30	16.10	116.00	56.10
TGx 1988-22F	57.00	59.90	21.60	81.90	55.10
TGx 1989-60F	56.10	48.80	25.10	72.90	50.70
TGx 1990-129F	45.60	46.50	16.90	70.70	44.90
Magoye (check)	52.60	51.70	25.40	70.90	50.10
Safari (check)	58.50	45.10	14.80	42.60	40.20
Lukanga (check)	49.60	34.90	14.40	51.10	37.50
Mean	56.80	40.60	19.50	65.50	45.60
LSD	A (locations=7.73) x B (Genotypes=14.96)=AxB= 29.94				
CV (%)	A (locations) x B (Genotypes)=AxB= 46.8				

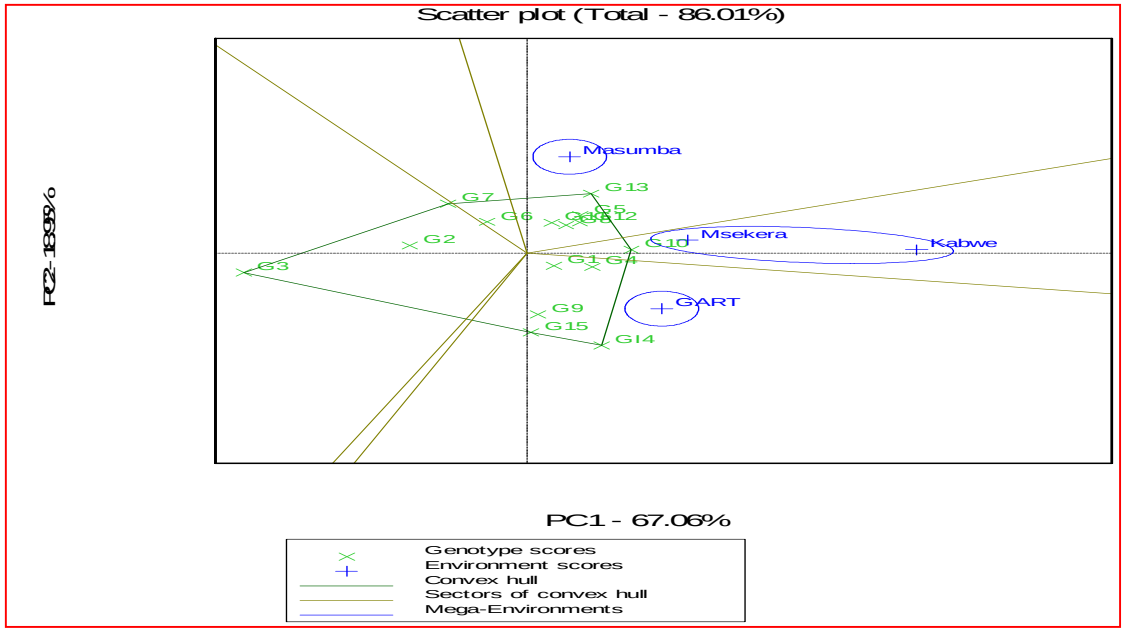

Fig. 2. The GGE biplot showing the mega-environments and "which won where pattern "among the genotypes

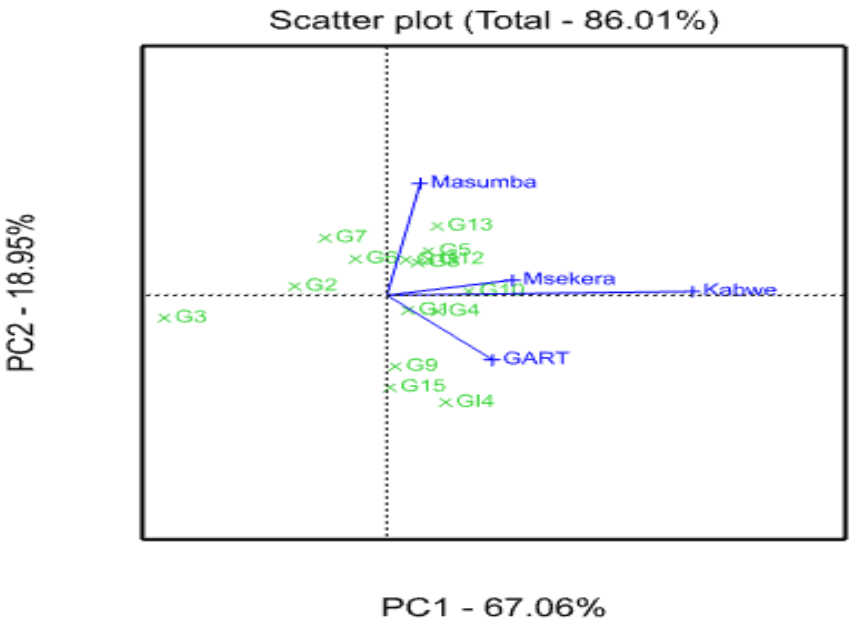

Fig. 3. Vector view GGE biplot showing the discriminating abilities of the locations

3.1.4 Representative location identification

The GGE biplot in Fig. 4 shows the relative ranking of the locations relative to the ideal. The average environment is represented by the centre of the concentric circles [14]. The average environment has the average coordinates of all test environments and AEA is the line that passes through the average environment and the biplot origin [18]. This average environment should project the average performance of the target environment [17]. The environment closest to the centre of the concentric circles is the most representatives of the locations. The results below, therefore, show Kabwe to be the most representative environment followed by Msekera while Masumba is the least representative of the test sites.

3.1.5 Ideal test environment identification

The ideal test environment/location for soybean genotypes in Zambia was identified based on the results from Figs. 3 and 4. An ideal test environment should be both discriminating and representative [17]. Kabwe was identified as an ideal test environment since it was both discriminating and representative of the test environments/locations. A Location like Msekera was representative but was not highly discriminating hence making it not an ideal environment. Masumba and GART were not discriminative and representative environments.

3.1.6 Genotype yield and stability determination

The result in Fig. 5 show the relative yields of the genotypes and their stability. The ideal genotype should have high mean performance coupled with high stability to give wide adaptability in the target region [10]. The average yield of a genotype is approximated by the projections of their markers on the AEC x-axis while the stability is determined by the projection onto the AEC ordinate line (y-axis) [19]. The single arrowed Average Environmental coordinate (AEC) points to higher mean seed yield across locations. The perpendicular line to the AEC which is the Average Environmental Ordinate (AEO) points to greater variability (Poor stability) in both directions [10]. The results in Fig. 5 show that TGX 1988-22F is the highest yielding genotype and the lowest is TGX 1835-10E. In terms of variability, Safari was the most variable and the genotypes TGX 1835-10E and TGX 1830-20E were nonresponsive. In choosing the best genotypes for general adaptability the variety TGX 1988-22F is the most ideal across all the environments as it was high yielding and stable. Six genotypes had a yield which was below the mean performance of the genotypes across all the environments; these are Lukanga, TGX 1835-10E, TGX 1830-20E, TGX 1988-18F, TGX 1987-23F and TGX 1987-11F.

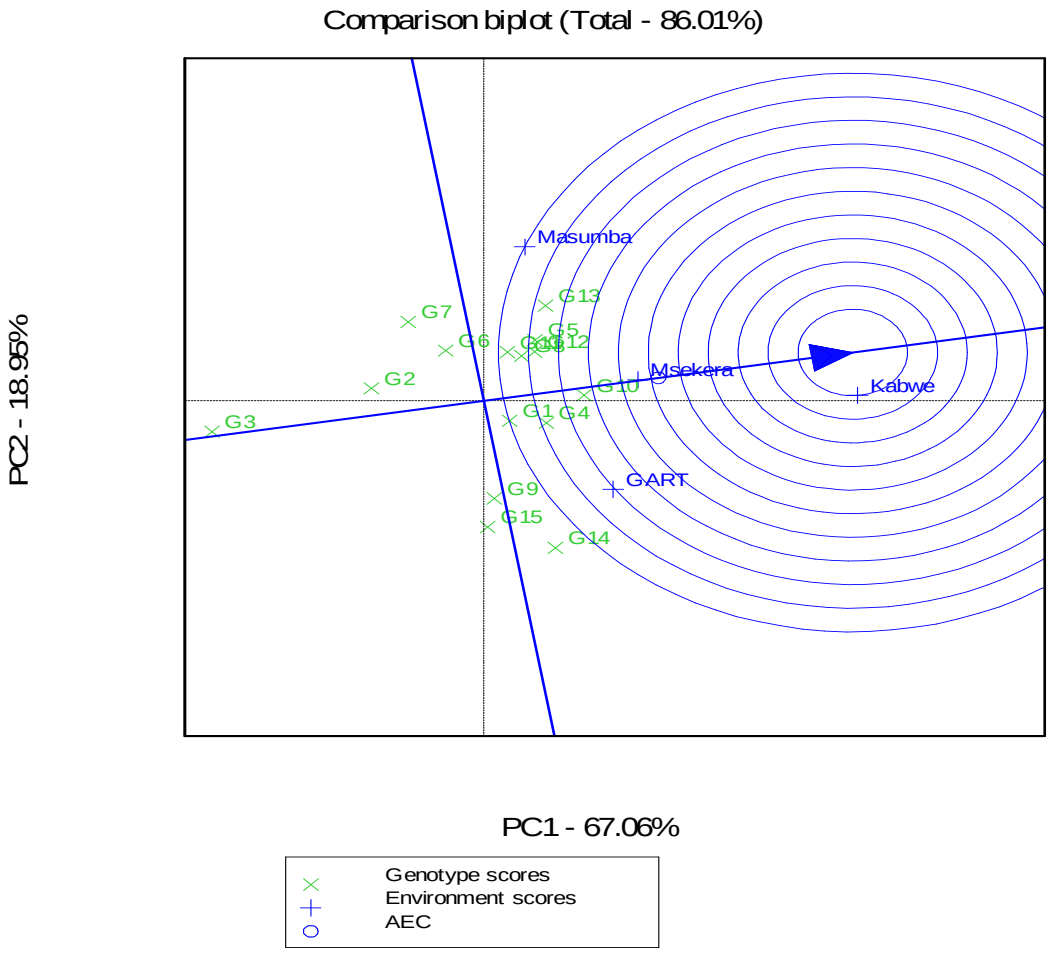

Fig. 4. Relative ranking of the locations to the ideal environment

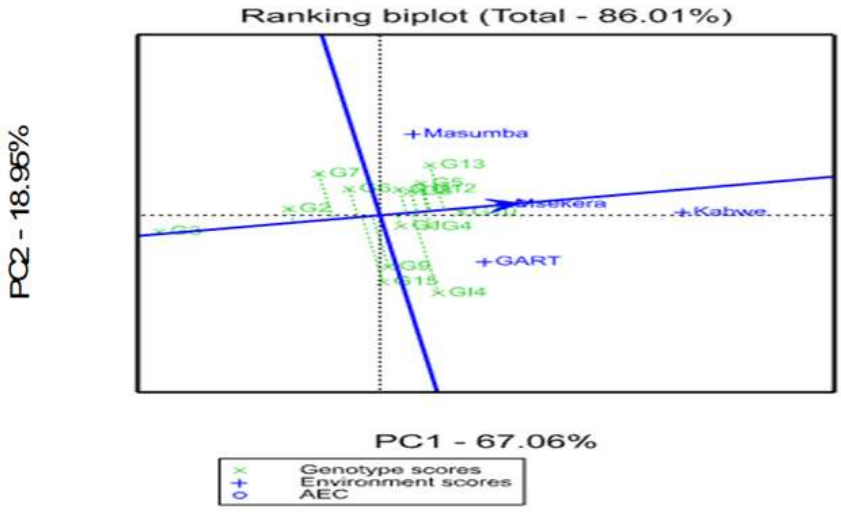

Fig. 5. Average environmental coordinate view showing the mean performance and stability of genotypes in seed yield

3.2 Discussion

3.2.1 Plant height and days to 50% flowering

Plant height varied among locations and genotypes with the character being influenced by location as testified by the significant genotype x location interactions. The significant differences among locations can be attributed to the individual and combined effects of edaphic and climatic factors. These results are contrary to what Khaswa et al. [20] reported that areas with relatively high P tended to have taller soybeans plants. GART in this study had one of the lowest levels of soil P but had the tallest plants. Similarly, the highest rainfall recorded was at Msekera but this location had the shortest plants. Hartman et al. [1] noted that drought is among the major causes of reduced growth and also lead to yield loss in soybean. The current study results do not confirm the effect of low soil moisture as shortest plants were at Msekera that had the highest rainfall. The differences in location ambient temperature at the locations during planting are the only plausible cause for the differences in plant height among the locations. GART had a temperature of 25.2℃ compared to Masumba and Msekera that had higher temperatures of 31.6℃ and 35.5℃, respectively. Temperature has been found to affect plant growth [21] and specifically, high temperatures have been known to affect photosynthesis by way of damaging the photosystem ii found in the thylakoid membranes of the chloroplasts thereby reducing the availability of photoassimilates needed for good growth [22].

The differences observed among genotypes for plant height could also be partly attributed to genetic differences and indeed to differential response to location factors. The genotype differences behaviour for soybean attributed to inherent genetic factors and hereditary variation of the cultivars was found in the soybeans study by Kandil et al. [23].

The other trait studied was days to 50 % flowering. There were significant differences among locations and among genotypes for 50% flowering. Indeed significant interactions were observed between genotypes and locations. The location Masumba had the shortest days to 50 % flowering while on the other hand, Kabwe had the longest days to 50% flowering. Soybean could have flowered early in Masumba due to the high temperatures consistently recorded at the location during the farming season. These temperatures were seconded by temperatures at Msekera. Soybean is a thermosensitive crop and its growth rate and blooming dates are affected by temperature from germination onwards. Junior et al. [24] reported that temperatures above 30 degrees celsius during the vegetative stage hastens flowering in soybean.

3.2.2 Yield and yield components

The results showed significant differences for location, genotypes and the interaction for grain yield and seed size. There were however only significant differences for locations on the pods per plant. There are supposedly many reasons for the differences observed in yield since yield is a quantitative trait hence interplay of many factors are responsible for the differences [25].

The locations in the study had major temperature differences over the growing season. The recorded high temperatures at Masumba followed by Msekera could be attributed to the lower yields [26,27] at these locations. Such temperatures induce heat stresses that adversely affect soybean yields [21]. Temperature requirements for soybean like in many other crops differ according to the stage of plant growth. Hemantaranjan et al. [22] found that general crop yields are predicted to decrease approximately 10% for every one-degree increase in temperature above the optimum. Studies in cereals have also found that heat stress induces a decrease of the duration of developmental phases leading to fewer organs, smaller organs, reduced light perception over the shortened life cycle and perturbation of the processes related to carbon assimilation [28,29]. In the current study, Masumba and Msekera had fewer numbers of pods compared to Kabwe and GART. Indeed temperatures at Masumba and Msekera were significantly higher than those at GART and Kabwe. These results are also in agreement with Avila et al. [10] who found that to obtain the greatest number of pods, soybean needs mild temperatures of up to 26 degrees celsius and higher temperatures were found to reduce the number of pods.

The observed 100 seed weight at Masumba against the emerging negative effect of temperature on growth and development of soybean, suggest that enhanced flowering while associated with reduced organs, seed weight was not negatively affected. Masumba and Msekera had the heaviest seeds. This could be

attributed to sufficient photoassimilates available to the reduced sink (pods per plant) in the two locations. This assertion is in agreement with Liu et al. [30] whose findings suggest that there is an increase in the seed size in the presence of reduced pod load in soybean. The results could be attributed to the internal mechanism that moderates the final seed size in soybean [30]. The photosynthate would, therefore, have allowed optimal pod filling hence the highest weight. The relationship of the reduction of number of pods to the yield is consistent with other findings who reported that reduction of pods will directly lead to the reduction in yield since number of pods is one of the most important yield components in soybean [29].

3.2.3 Characterisation of the environments

The highly significant differences contributed by the environment indicate that Zambia is highly variable from location to location. The results are in agreement with the findings by Setimela.et al., [31]. These results justify the need for carrying out multi-location trials in the country for soybean genotypes. Besides the locations, there were significant differences among the genotypes which would suggest that genotypes are favoured by specific locations. The specificity of soybean genotypes to specific locations is consistent with the findings of Tukamuhabwa et al. [9]. The genotype by environment interactions showed significant differences for almost all the traits under study apart from pods per plant. The significant genotype by environment interactions especially on yield justified a study for ideal environment identification. The study further identified three mega-environments in the two agro-ecological regions studied. The existence of more than one mega-environment in Zambia was also found in the maize studies by Setimela et al. [31].

3.2.4 Genotypes performance

The two genotypes Lukanga and safari had relative high grain yields at Kabwe and GART but had low yields at Msekera and Masumba. The two genotypes (Lukanga and Safari) are not self-nodulating (not promiscuous) hence the fact that they were not inoculated with rhizobium would partially explain their poor performance in the locations Msekera and Masumba which were relative high-stress locations.

Genotypes TGX 1830-20E and TGX 1835-10E had poor germination across all locations. These genotypes were the worst performing lines in the trials and ultimately the yield. Their poor performance was more to their genotype as compared to the environment as shown in the GGE biplot analysis (Fig. 5). The results showed that the two were least responsive genotypes to the environments. Though some of the IITA lines have been released in other countries as self-nodulating soybean lines [32], their performance in Zambia was not consistent with their performance elsewhere i.e. TGX 1835-10E and TGX-20E. The poor performance of the genotype TGX 1835-10E was also found by other researchers [33].

4. CONCLUSION

The study found that Kabwe was an ideal location for soybean in Zambia and Masumba was the worst location. Also, the study further identified three (3) mega-environments viz. Kabwe/Msekera, Masumba and Goldern Valley Agriculture Research Trust. Kabwe/Msekera had TGX 1988-22F as the winning genotype. GART had safari as the winning genotype. Masumba recorded Magoye as the winning genotype. The genotypes TGX 1835-10E, TGX 1830-20E, TGX 1988-18F, TGX 1987-23F and TGX 1987-11F performed poorly across all locations. This shows that the genotypes are not suitable for the Zambian environment studied.

As regards the genotypes, the study found that TGX 1988-22F was the highest yielding and stable genotype and the lowest non-responsive genotype was TGX 1835-10E.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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