Research Article **ISSN: 2393 – 9540**

International Journal of Nutrition and Agriculture Research

Journal home page: www.ijnar.com

MAGNITUDE OF GENOTYPE BY ENVIRONMENT INTERACTION ON BETA-CAROTENE AND DRY MATTER CONTENT OF 25 IMPROVED SWEETPOTATO VARIETIES IN KENYA

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ABSTRACT

This study aimed to determine the magnitude of genotype-environment interaction on beta-carotene and root dry matter content of twenty five sweetpotato genotypes across two environmental conditions (Kabete and Kiboko) during two different seasons (short and long rains). Plots of four rows for each genotype were planted under Randomized Complet Bloc Design. Data were collected on beta-carotene and root dry matter content. An Additive Main Effects and Multiplicative Interaction was performed using GENSTAT 15th edition to determine the GxE effects. Beta-carotene content ranged from 0.00 to 11.83mg.100g^{-1}. Most of the genotype had a concentration of root dry matter that ranged from 16.52 to 30.62%. Genotypes Naspot13 and Ejumula consistently produced the highest beta-carotene content across sites. In addition, the findings indicated that the beta-carotene and dry matter content were mostly influenced by genetic factors. Genotypes, Kenspot 4 and Irene were the stable clones for beta carotene and root dry matter content, respectively.

KEYWORDS

Additive Main Effects and Multiplicative Interaction, Environmental conditions and Genotype.

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INTRODUCTION

The sweetpotato (*Ipomoea batatas* [L.] Lam.) of the Convolvulaceae family, is a tuberous plant that grows in tropical and subtropical areas. Originating from Latin America (Lewthwaite, 2004[1], Mandal, 2006)[2], it occupies an important place in the agricultural production of sub-Saharan Africa

countries where it covers approximately 8.35 million hectares for an annual production estimated at 106.6 million tons of tubers in 2014 (FAOSTAT, 2015)[3]. It is has many advantages as it grows easily, matures quickly (4-5 months), produces abundant food with respect to the space used for the plant and stores more well (Islam *et al.*, 2003[4], Islam, 2006[5], CIP, 2006, Amoah, 2013)[6]. In many countries, its culture is essential, because it contributes to reduce food shortages in periods of crisis. This crop is much more important in Africa where the estimated harvested area was 3.8 million hectares with a total production estimated at 22.6 million tons of tubers (FAOSTAT, 2015)[3]. Vitamin A deficiency (VAD) is common among women and children in sub-Saharan Africa, South Asia and Southeast Asia; it causes impaired growth, risk of morbidity from common infections and night blindness in children (Birol *et al*. 2015). Vitamin A deficiency (VAD) is a chronic and widespread public health problem affecting mainly women and children aged under five years in Kenya (Low *et al*, 1997, 2017)[7]. According to WHO (2009), Sanderson and Auricht (2012), 84% of preschool aged Kenyan children have a serum retinol level of less than 7.0µml/g which is considered as a severe level of vitamin A deficiency. In 2003 night blindness affected 6.4% of pregnant women in Kenya (WHO, 2009). Sanderson and Auricht (2012) respectively reported that 46.4% and 69.0% pregnant Kenyan women aged between 15-49 years and preschool children aged between 6-59 months suffer from anaemia. This situation is more recurrent in rural than in urban areas.

Orange-fleshed sweetpotato provides beta-carotente which is precurcor of vitamin A (Low et al, 2009[8], Stathers *et al*., 2015, Mbusa *et al*., 2018). Vitamin A is an essential nutrient which has many roles in regulation of visual cycle, normal growth and development as well as for immune function (Low *et al*., 2017[7], Rahajeng and Rahayuningsih, 2017)[9].

Sweetpotato is grown around the world in diverse environments, often by small farmers in marginal soil, using less inputs (Manrique and Hermann, 2000)[10]. In spite of its ability to adapt to harsh growing conditions, sweetpotato is sensitive to environmental variation as shown by previous G x E studies on several traits (Mbwaga *et al*., 2008).

Sweetpotato nutrient contents, agronomical performance and root yield vary across environmental conditions, therefore the determination of genotype by environment interaction effects on beta carotene content, dry matter content and root yield of sweetpotato varieties is essential prior to variety release and/or their use in a breeding program. It was demonstrated that the beta carotene content in sweetpotato varies in a negative correlation with dry matter content (DMC) across environments. In fact, Gruneberg *et al*. (2005)[11] showed an extremely low G x E interactions for nutrient traits such as β-carotene, dry matter, Fe, Zn in sweet potato while Manrique and Hermann (2000)[10] observed an increase in concentration of beta-carotene at high altitudes. Similar results were founf by Gurmu *et al*. (2017) who reported a magnitude of environment and G x E interaction of 66.8% for fresh root yield, 44.0 for root dry matter content and 7.6% for beta-carotene content in six Ethiopian agro-ecological zones. The objective of this study was to determine the effects of G x E interaction on fresh root yield, beta carotene and dry matter content of 25 improved Eastern African sweet potato varieties across two agroecological conditions in Kenya for two different growing seasons.

MATERIAL AND METHODS

Experimental sites

Field experiments were conducted in two sites; namely at Kenya Agricultural and Livestock Research Organization (KALRO), Kiboko station (2° 15'S, 37° 45' E and 993 m asl) and at Kabete Field Station of the University of Nairobi(1°15’ S, 36°44’ E and 1930 m asl). The KALRO-Kiboko research station is located in Agro-ecological Zone 5, in Makueni county at 187km East from Nairobi. The station receives bimodal precipitation with short rains season from late October to December (330 mm) and long rains from March to May (230 mm). The average annual temperature is 24°C. The soil is rhodic ferrosols (Kivuva, 2013)[12]. Kabete Field Station of University of Nairobi is located in Nairobi county at approximately 15 km from Nairobi city.

Kabete receives binomial rainfall with the short rain season from October to December and the long rain season from March to May. The annual rainfall is 1006 mm and the overage annual temperature is 18°C. The sol is well drained, deep, darkish brown to dark red, the sol type is humic nitrisol (Onyang *et al*., 2012)[13].

Planting materials

The planting material was collected from virus-free plants grown by International Potato Centre (CIP) at Kenya Plant Health Inspectorate Services (KEPHIS), Muguga Station. The 25 sweetpotato varieties comprised genotypes with different agronomic and nutrional features (high yield, high beta carotene content, and low beta carotene and moderate yield content). Those genotypes originated from different countries mainly Kenya, Mozambique, Tanzania and Uganda. Table No.2 presents the names, origin, root flesh color and skin color of the 25 improved sweetpotato varieties used in this study.

Experimental design

The two trials were laid out in field at KALRO-Kiboko and Kabete Field Station of University of Nairobi between July and November 2016, and a second set of trials was conducted in the same sites between November 2016 and March 2017. The experiment was laid out using a randomized complete block design (RCBD) with three replications spaced by 1.5m. Each replication comprised 25 plots corresponding to the 25 clones. The plot size was 4.32m^2 (3.6m x 1.2m) where 16 cuttings of 30 cm of length were planted on ridges. The spacing between ridges was 90 cm whereas the spacing of 30 cm was used for plants within a ridge. The total area covered by experimental field was 696m^2.

Fresh roots were harvested 120 days (4 months) after planting using hand hoe. Data were collected on eight plants within the harvested plot of 2.16m^2

Diammonium phosphate (DAP) fertilizer was applied two weeks after the time of sowing at a rate of 115 kg/ha. Cut worms were controlled with insecticide, IMAX 200SC which was sprayed every week at a rate of 10ml in twenty litters of water. The clones were regularly irrigated to maintain growth and weeded by hand when it was necessary to do so.

Data collection

Two major traits were assessed for this study including the root dry matter and beta-carotene content. Root dry matter content (RDMC) was determined by the air-own method as the ratio of root dry weight and fresh root weight (expressed in the percentage). The beta-carotene content in approximately 2g of the fresh homogenised sweet potato samples was analysed in duplicate by high pressure liquid chromatography (HPLC) as previously described by Low and van Jaarsveld (2008) and Burgos *et al.* (2014)[14] in mg per 100g of fresh weight.

Statistical Analysis

Collected data on beta carotene (BCC) and fresh root dry matter content (DMC) for the two locations and the two seasons were combined to give a total of four environments and analysed using the additive main effect and multiplicative interaction (AMMI) analysis. The AMMI model separates the additive variance from the G x E interaction, and then the Interaction Principal Component Analysis (IPCA) was used to explain the residual matrix as well as the extraction of the new set of coordinate axe. The model used was:

$$y_{ij} = \mu + G_i + E_j + GE_{ij} \qquad (1)$$

Where y_{ij} is the variable of i^{th} genotype and j^{th} environment; μ is the total mean; G_i and E_j are the effects of the i^{th} genotype and j^{th} environment, respectively; and GE_{ij} is the effect of G x E interaction.

Furthermore, AMMI's stability value for each parameter was estimated as shown as follows (Purchase, 1997)[15],

$$ASV = \sqrt{\left[\frac{SS\,IPCA1}{SS\,IPCA2}(IPCA\,1\,Score)\right]^2 + (IPCA\,2\,Score)^2} \qquad (2)$$

Where ASV is the AMMI stability value, SS IPCA 1 and SS IPCA 2 are sum of squares of IPCA 1 and 2 respectively and IPCA is the interaction principal component analysis.

The combining analysis of variance was performed using the GenStat 15th edition statistical package.

RESULTS

Combined AMMI analysis of variance

Beta carotene content

The combined analysis of variance for beta carotene content (BCC) revealed very highly significant differences for the treatments and genotypes. High significant differences were observed for G x E interaction ($p<0.01$); while no significant differences were detected for the environments. The Table No.3 indicated that treatments (G, E, G x E) and genotypes were the most important source of beta carotene content variations that accounted for up to 99.7 and 99.5% for the total variations, respectively. The findings also indicated that IPCA 1 contributed for up to 75.0% to the G x E interaction; while IPCA 2 accounted for 25.0 % (Table No.3).

Root dry matter content

The resultas in the Table No.3 showed very high significant differences for the treatments, genotype, environment and their interaction($p<0.001$). Treatments and genotypes accounted for 97.5 and 84.8 % to the total variation, respectively. Environments and G x E interaction contributed less than 10 % to the total variation with 6.1 and 6.6 %, respectively. The interaction principal component one (IPCA 1) accounted for 96.7 %, while the interaction principal component two (IPCA 2) accounted for 2.8 % to the G x E interaction variation sum of squares.

Genotypic root yield performance, beta carotene and dry matter content in tested environments

Beta carotene content

Resultats in the Table No.4 showed that the genotype Naspot13 yielded the highest means for the beta carotene content (11.83 mg 100^{-1}g); while Mayai, Naspot 1 and Naspot 2 produced the lowest means (0.00mg100^{-1}g). In addition, the genotype Delvia had the largest IPCA 1 (-0.58) followed by Tio-Joe and Naspot13 which had -0.43 and -0.40, respectively for beta carotene content. At the other hand, Tanzania (0.00), Erica (-0.02) and Kenspot4 (-0.02) had the least IPCA 1 for that trait. Regarding to the AMMI stability value (ASV), the genotypes Devia, Tio-Joe and Naspot 13 had the highest ASV with 1.75, 1.31 and 1.20, respectively; while Kenspot4 (0.080) had the lowest ASV for beta carotene content (Table No.4).

Root dry matter content

The genotype Amelia had the highest root dry matter content (30.62 %) while Melinda (16.52 %) had the lowest. According to IPCA 1, genotypes Naspot10 (-1.52) and Kenspot5 (-1.39) recorded the largest IPCA 1 for root dry matter content. In contrast, Irene (0.13) and Sumaia (0.13) had the lowest IPCA 1. The AMMI stability value showed that Naspot 10 and Kenspot 5 had the largest ASV with 53.17 and 48.62, respectively. Irene (4.49) and Sumaia (4.67) recorded the least ASV values for root dry matter content (Table No.4).

DISCUSSION

The analysis of variance of AMMI model showed very highly significant variation for for treatments (G, E, G xE), genotypes and IPCA 1. Highly significant differences were observed for G x E interaction; in contrast for environments and IPCA 2. The significant variation among genotypes showed that the planting materials can be used for beta carotene and root dry matter content in a breeding programme. Regarding to the total percentage explaining the variation, genotypes accounted for 99.5 %, while the environments contributed only for 0.1 % for beta carotene content. This indicated that total variation for that trait is function to genotypes. Woolfe (1992)[16] stated that beta carotene content in sweet potato root is due to gene actions. G x E interaction yielded 0.1 % for the total variation. Similar results were found by Mosta *et al.* (2015)[17] who reported that sweetpotato nutrient content variation is mostly due to genetic factors, authers added that environmental condition may contribute less in this variation.

Those significant variations among genotypes for beta carotene and root dry matter content, and no significant differences among environnments and genotype x environment interaction imply that beta carotene and root dry matter content are quantitative genetic controlled trait. In this study, genotypes with orange to deep orange flesh color yielded the highest amount of beta carotene content than those with white and yellow flesh color. The obtained results

were in accordance with those of Woolfe (1992)[16] and Burgos *et al.* (2009)[18] who reported that beta carotene content is a genetically controlled trait. Low *et al.* (2009)[8] reported that orange fleshed sweetpotato varieties are rich in beta carotene content and sometime poor in root dry matter content while white fleshed sweetpotato cultivars provide roots with high dry matter content with little or no beta carotene content.

Most of the genotype tested were stables regarding to the beta carotene content impying no variability in genotype responses for beta carotene content across the environments. Similar view was held by Balcha (2015)[19].

Table No.1: Description of the experimental area during the two seasons

S.No	Location	Season	Environment code	Rainfall (mm)	Temperature (°C)		
					Minimum	Main	Maximum
1	KIBOKO	Long rain	Kib1	40.0	16.0	23.5	31.0
		Short rain	Kib2	8.0	17.0	25.0	33.0
2	KABETE	Long rain	Kab1	185.0	13.0	18.5	24.0
		Short rain	Kab2	165.0	14.0	19.0	24.0

Table No.2: Sweetpotato clones used in the study, their names, origin, flesh color and skin color

S.No	Names	Origin	Flesh color	Skin color
1	Amelia	Mozambique	Orange	Purple
2	Cecilia	Mozambique	Pale orange	Brownish orange
3	Delvia	Mozambique	Orange	Purple
4	Ejumula	Uganda	Deep orange	Cream
5	Erica	Kenya	Yellow orange	Light purple
6	Gweri	Uganda	Intermediate orange	Purple red
7	Ininda	Mozambique	Orange	Pink
8	Irene	Mozambique	Orange	Purple red
9	Jane	Kenya	Intermediate orange	Cream
10	Kakamega	Kenya	Intermediate orange	Purple red
11	Kenspot4	Kenya	Orange	Purple red
12	Kenspot5	Kenya	Orange	Purple red
13	Lourdes	Mozambique	Intermediate orange	Cream
14	Mayai	Tanzania	Yellow	Brown
15	Melinda	Mozambique	Light orange	Cream
16	Naspot1	Uganda	Cream	Purple red
17	Naspot10 (Kabode)	Uganda	Deep orange	Purple red
18	Naspot12	Uganda	Intermediate orange	Purple red
19	Naspot13	Uganda	Deep orange	Cream
20	Naspot2	Uganda	Cream	Purple red
21	Naspot8	Uganda	Intermediate orange	Purple red
22	Naspot9 (Vita)	Uganda	Deep orange	Purple red
23	Sumaia	Uganda	Deep orange	Cream
24	Tanzania	Tanzania	Yellow	Cream
25	Tio Joe	Mozambique	Dark orange	Brown

Source: Mwanga *et al.* (2003)[20], Kapinga *et al.* (2010)[21] and Tumwegamire *et al.* (2014)[22].

Table No.3: Sources of variation, mean squares and significance, their contribution to total and genotypes-environments interaction variation of the genotypes

S.No	Parameters		Beta Carotene Content			Dry Matter Content		
	Sources of variation	d.f.	MS	% CTV	% CGEI	MS	% CTV	% CGEI
1	Total	299	14.09	100.0		20.16	100.0	
2	Treatments (G, E, G x E)	99	42.45***	99.7		59.35***	97.5	
3	Genotypes (G)	24	174.81***	99.5		212.96***	84.8	
4	Environments (E)	3	1.03^{ns}	0.1		122.57***	6.1	
5	Replications	8	0.61	0.1		5.50	0.7	
6	Interaction (G x E)	72	0.06**	0.1		5.52***	6.6	
7	IPCA 1	26	0.13***	0.1	75.0	14.77***	6.4	96.7
8	IPCA 2	24	0.03^{ns}	0.0	25.0	0.45^{ns}	0.2	2.8
9	Residuels	22	0.01^{ns}	0.0		0.12^{ns}	0.0	
10	Error	192	0.04	0.2		0.56	1.8	

Legend: ^{ns}, *, ** and *** = no significant, significant, highly significant and very highly significant at pvalue tresholds of $p > 0.05$, < 0.05, < 0.01 and < 0.001, respectively; d.f. = degree of freedom; IPCA 1 and IPCA 2 = interaction principal component one and two, respectively; MS = mean squares; % CTV = percent of contribution to the total variation; % CGEI = percent of the contribution to the G x E interaction.

Table No.4: Mean beta carotene content, dry matter content and their IPCA scores and ASV of the genotypes

Parameters	Beta Carotene Content								Dry Matter Content							
Genotypes	Kab1	Kab2	Kib1	Kib2	Mean	IPCA1	IPCA2	ASV	Kab1	Kab2	Kib1	Kib2	Mean	IPCA1	IPCA2	ASV
Amelia	4.28	4.51	4.06	4.20	4.26	0.08	-0.37	0.44	30.34	30.34	30.76	31.05	30.62	0.49	-0.08	17.18
Cecilia	5.89	5.69	5.83	5.70	5.78	0.09	0.22	0.34	22.76	22.52	23.94	24.56	23.45	0.20	0.24	6.81
Delvia	5.11	4.82	4.72	4.03	4.67	-0.58	0.10	1.75	24.48	24.55	29.74	29.70	27.12	-0.89	0.24	30.92
Ejumula	11.24	11.27	11.13	11.19	11.21	0.15	-0.07	0.45	29.53	29.49	29.97	30.33	29.83	0.47	-0.03	16.43
Erica	1.74	1.76	1.56	1.52	1.65	0.02	-0.10	0.12	16.56	16.53	17.04	17.37	16.88	0.47	-0.04	16.23
Gweri	0.90	1.04	0.72	0.79	0.86	0.08	-0.25	0.34	29.00	28.94	29.99	30.34	29.57	0.31	0.04	10.74
Ininda	5.11	4.95	4.97	4.76	4.95	-0.04	0.13	0.18	18.96	19.23	26.16	25.72	22.52	-1.38	0.19	48.21
Irene	7.84	7.89	7.74	7.86	7.83	0.20	-0.09	0.60	20.97	20.74	22.39	22.99	21.78	0.13	0.25	4.49
Jane	5.08	4.96	4.96	4.82	4.96	0.02	0.10	0.11	17.54	17.51	17.15	17.52	17.43	0.72	-0.11	25.03
Kakamega	3.68	3.58	3.52	3.37	3.54	-0.21	-0.03	0.64	26.87	26.75	27.71	28.17	27.37	0.20	0.11	6.93
Kenspot 4	3.95	3.76	3.77	3.48	3.74	-0.02	0.05	0.08	24.40	25.61	32.69	30.74	28.36	0.33	0.09	11.57
Kenspot 5	5.26	5.16	5.10	4.94	5.12	-0.13	0.14	0.42	26.64	26.70	27.51	27.69	27.13	-1.39	-0.73	48.62
Lourdes	9.88	9.87	9.80	9.86	9.85	-0.03	0.04	0.10	21.49	21.39	22.87	23.27	22.26	0.38	-0.10	13.20
Mayai	0.00	0.00	0.00	0.00	0.00	0.18	-0.00	0.53	27.97	28.81	31.67	30.49	29.73	0.18	0.11	6.31
Melinda	4.98	5.05	4.90	5.04	4.99	0.19	0.05	0.57	16.28	16.47	16.67	16.66	16.52	-0.19	-0.72	6.49
Naspot 1	0.00	0.00	0.00	0.00	0.00	0.23	-0.10	0.69	25.06	25.73	33.20	32.08	29.02	0.56	-0.28	19.55
Naspot 10	11.01	10.92	10.75	10.46	10.78	0.19	0.05	0.57	28.32	28.21	29.63	30.04	29.05	-1.52	-0.17	53.17
Naspot 12	8.01	8.03	7.83	7.79	7.91	0.02	-0.10	0.12	23.39	23.28	24.61	25.03	24.08	0.22	0.10	7.82
Naspot 13	12.15	12.02	11.80	11.35	11.83	-0.40	-0.04	1.20	22.29	22.23	23.54	23.89	22.99	0.23	0.06	8.10
Naspot 2	0.00	0.00	0.00	0.00	0.00	0.19	0.05	0.57	23.03	22.94	24.05	24.46	23.62	0.29	0.07	10.00
Naspot 8	2.73	2.71	2.58	2.52	2.64	0.04	-0.03	0.12	25.60	25.51	26.91	27.29	26.33	0.21	0.09	7.16
Naspot 9	10.81	10.80	10.39	10.00	10.50	0.06	0.15	0.22	22.72	22.70	22.04	22.40	22.47	0.13	0.13	4.67
Sumaia	7.18	7.03	7.08	6.96	7.06	0.12	0.08	0.38	21.06	20.95	22.59	23.00	21.90	-1.18	0.63	41.30
Tanzania	0.52	0.43	0.43	0.40	0.45	0.00	0.25	0.25	25.73	25.49	31.68	32.09	28.75	0.24	0.06	8.44
Tio Joe	10.20	9.97	10.11	9.89	10.04	-0.43	-0.24	1.31	21.22	21.15	22.43	22.79	21.90	0.80	-0.15	28.00
MEAN	5.50	5.45	5.35	5.24	5.38				23.69	23.75	25.88	25.99	24.83			
LSD					0.39								1.38			
C.V (%)					4.50								3.40			

Legend: LSD = Least significant difference; C.V. = Coefficient of variation; IPCA 1 and IPCA 2 = Interaction principal component one and two, respectively, ASV = AMMI stability value.

The trend was differentfor the Beta carotene content for which the highest means for beta carotene content was recorded at Kab 1 and Kab 2 of 5.505 and 5.446 mg 100^{-1}g, respectively. Kiboko station showed lower values for beta-carotene content indenpendantly to the growing season. The highest IPCA 1 value (0.841) was found at Kib2 whereas the lowest value was recorded at Kib 1 (Table No.4). The same table is showing that the highest root dry matter content was reported at Kib2 (25.99 %) while the Kab 1 produced the lowest root dry matter content (23.69 %). The highest IPCA 1 value was recorded at Kib 2 (0.918). The lowest IPCA 1 of 0.414 was observed at Kab 1.

Regarding to the AMMI stability value, Kib1 (ASV = 0.54) was the mostly stable environment for beta carotene content followed by Kab2 and Kab1 with a respectively ASV of 1.30 and 2.45. Whereas, Kib2 was stable environment for dry matter content with an ASV of 6.45.

Table No.5: Mean beta carotene content, dry matter content and their IPCA scores and ASV across environments

S.No	Parameters	Beta Carotene Content				Dry Matter Content			
	Environments	Mean	IPCA 1	IPCA 2	ASV	Mean	IPCA 1	IPCA 2	ASV
1	Kab1	5.505	-0.520	0.156	2.45	23.69	1.807	0.414	8.48
2	Kab2	5.446	-0.252	-0.550	1.30	23.75	1.522	-0.610	7.17
3	Kib1	5.347	-0.069	0.427	0.54	25.88	-1.974	-0.722	9.29
4	Kib2	5.239	0.841	-0.033	3.95	25.99	-1.355	0.918	6.45
5	MEAN	5.384				24.83			

Legend: IPCA 1 and IPCA 2 = Interaction principal component one and two, respectively, S1= Season 1, S2= Season 2.

CONCLUSION

Root yield, beta carotene and root dry matter content are the most important quality traits for sweet potato. This study revealed significant differences in fresh root yield, root dry matter content, beta carotene content and stability of sweet potato genotypes.

The range was between 0.00 to 11.830 mg 100 g^{-1} for the beta carotene content ranged from while most genotypes had a concentration in root dry matter that ranged between 16.52 and 30.62 %. Beta-carotene content differed within genotypes and across production sites. Genotypes Naspot 13 and Ejumula consistently produced highest amounts of beta-carotene across sites, while Naspot 1, Naspot 2 and Mayai consistently recorded the least amount.

Furthermore, the findings indicate beta carotene and root dry matter content were mostly influenced by genetic factors. Genotypes, Kenspot 4 and Irene were stable clones for beta carotene and root dry matter content respectively.

ACKNOWLEDGEMENT

The authors wish to express their sincere gratitude to Faculty of Agricultural Sciences, Universite Catholique du Graben, Butembo, Democratic Republic of the Congo for providing necessary facilities to carry out this research work.

CONFLICT OF INTEREST

We declare that we have no conflict of interest.

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Please cite this article in press as: Heritier Kambale Mbusa *et al*. Magnitude of genotype by environment interaction on beta-carotene and dry matter content of 25 improved sweetpotato varieties in kenya, *International Journal of Nutrition and Agriculture Research*, 5(1), 2018, 22-30.