On-farm phenotypic evaluation and stability analysis of provitamin A cassava (*Manihot esculenta*) varieties for agronomic traits, stress tolerance and tuber yield across Kwara state, Nigeria

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Cassava (*Manihot esculenta*) is a food security crop in many parts of Africa including Nigeria. Heavy reliance on cassava for food results in malnutrition because it lacks micronutrients such as vitamin A. Provitamin A cassava varieties have the potential to sustainably reverse this trend. More recently, efforts to release provitamin A cassava varieties have intensified. Therefore, there is need to compare the best available white fleshed cassava with provitamin A varieties and assess their stability using GGE biplots. Two provitamin A varieties namely, TMS 1368 and TMS 07/0593, as well as one local variety (TME 419), were laid out in randomized complete block design in three replicates, at three locations across Kwara state. Data collected were subjected to ANOVA and GGE biplots. The results showed that high genetic variation existed among the cassava varieties for fresh tuber weight, carotene content, plant height, number of stems and tubers, as well as pest and disease severity. This implies that there is room for improvement. TMS 1368 was better yielding and adaptable than TMS 07/0593 and compared favourably with TME 419. GGE biplot was very useful in selecting a broadly adapted variety, a specific variety for target environments and delineating the environments into two mega environments. In improving carotene content of provitamin A cassava, caution should be taken not to have a negative impact on fresh tuber weight and dry matter content. TMS 1368 was the most suitable of the tested cassava varieties that is capable of addressing food security and vitamin A deficiency adequately. Therefore, it should be recommended to farmers for cultivation and consumption in order to improve vitamin A deficiency and enhance food and nutrition security.

Keywords: Cassava (*Manihot esculenta*), phenotypic evaluation, GGE biplot, pro-vitamin A, food security, nutrition security

Cassava (*Manihot esculenta*) is a very important crop to Nigeria. The comparative production advantage of cassava over other staples serves to encourage its cultivation even by the resource poor farmers. Currently, Nigeria is the world's largest producer of cassava with production estimated at 36.8 million tonnes (Sen Nag 2017) with an average yield of 11.7 t/ha (FAOSTAT 2016). Cassava is important in the diet of most of the populations in Nigeria. It is a major source of calories, especially for the poor, and is a relatively dependable crop even in the face of erratic rainfall and poor soils - the consequences of climate change. With this potential, combined with the multifarious uses of cassava in Nigeria, it has a special capacity to bridge the gap in food and nutritional security. However, commonly cultivated local cassava varieties are not only low yielding, but also lacks certain micronutrients. While millions of poor households rely on cassava for half of their daily energy, the crop contains only small amounts of micronutrients such as vitamin A. In recent times, however, the campaign for the cultivation of bio-fortified provitamin A cassava varieties has increased because of their potential in supplying high starch calories in addition to their vitamin A content which hovers around 10 ppm (IITA 2014). Provitamin A cassava supplies micronutrients capable of addressing hidden hunger associated with micronutrient deficiency (vitamin and mineral deficiencies)

which affects over 2 billion people worldwide, causing serious and long-lasting, irreversible health damages (GHI 2014). In meeting the food energy and vitamin A needs of the populace, breeding efforts have led to the release of a number of provitamin A cassava varieties (IITA 2014). A step after the release of a cultivar is evaluation and adaptation of such released cultivars to the local environments. In this regard, genotype x environment (GE) interaction is usually determined. GE is the change in the ranks of genotypes due to the influence of the environment. GE complicates breeding efforts and provides restrictive use of genotypes (Mitrovic et al. 2012). In a bid to select suitable and stable genotypes, stability analysis models such as coefficient of variability, additive main effects multiplicative interaction (Aliyu et al. 2014) and genotype and genotype by environment (GGE) biplot have been used. GGE biplot provides a graphical display of GE interaction across environments based on principal component analysis and helps to identify the ideal genotype and environment (Yayis 2019). This research was conducted to: i) compare the performance of two provitamin A cassava varieties with that of a local variety across diverse agro-ecological zones in Kwara state. ii) determine traits associated with tuber yield for further yield improvement and iii) determine the yield stability of the provitamin A varieties across the agro ecologies using GGE biplots.

Materials and methods

The research was carried out at Erin-Ile, Alapa, Budo-Are and Ilala all in Kwara state, Nigeria (Figure 1). However, the experimental site at Ilala was not accessible during data collection as a result of flood, hence, it was not included in the analysis. Complementary agro-ecologies such as rainforest (Erin-Ile), Southern Guinea Savannahs (Alapa and Budo-Are) were selected. However, although Alapa and Budo Are belong to the same agro-ecology, they differ in their agro-climatic properties. The weather data shows that the annual rainfall at Budo-Are is around half of that at Erin-Ile, with Alapa somewhere between the two. Similarly, the humidity at Alapa, like the rainfall, is somewhere between the values of Erin-Ile and Budo Are. The average temperature values are 23.6°C and 25.5°C for Erin-Ile and Budo-Are respectively, with the average temperature at Alapa being between these values. The experiments were rainfed and established on farmers' fields. Fertiliser was not applied as farmers do not apply fertiliser on cassava because it is expensive. The experimental sites were ploughed, harrowed and ridged. The cassava varieties planted consisted of two provitamin A varieties; namely IITA-TMS-IBA070593 and IITA-TMS-IBA011368 and the national recommended variety TME 419, which are all within a maturity group of 12 months. Stem cutting 25 cm, long with about five to seven nodes, were planted in angular manner at the spacing of 0.9 x 0.9 m. Each row was 90 m long, totalling 100 plants per row. Each plot consisted of three rows. At each locality the experiment was laid out in randomized complete block design in three replicates. Weeds were effectively controlled using pre- and post- emergent herbicides followed by supplementary hand weeding before canopy formation.

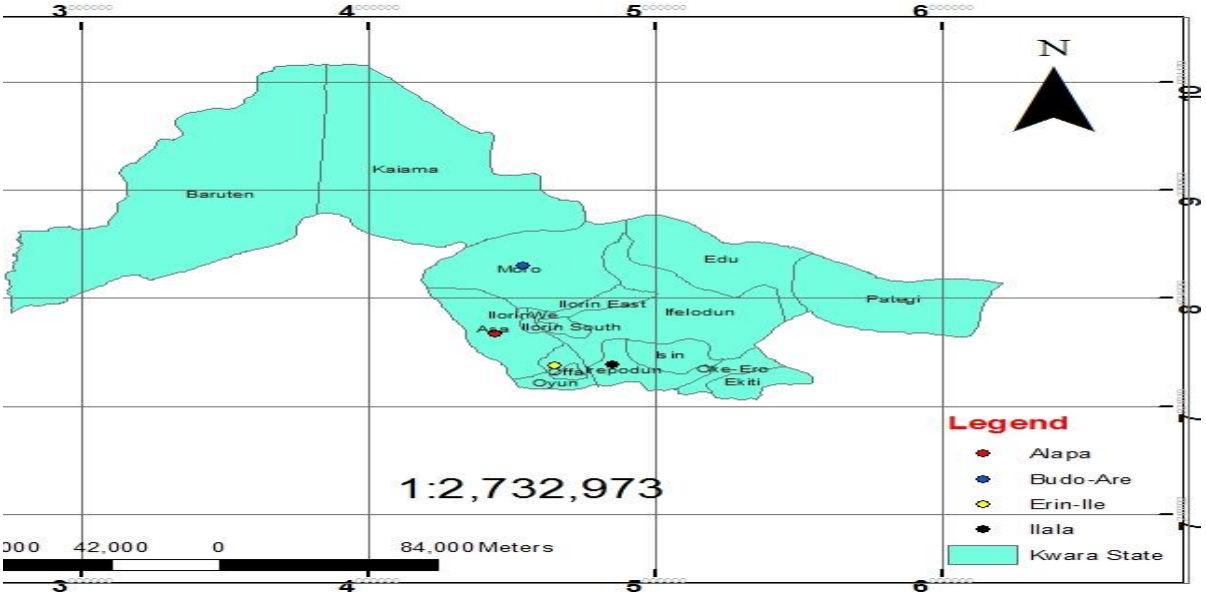

Figure 1: Map of Kwara state showing the local government areas and experimental sites

Data were collected on 20 stands from each of the rows, on plants in the position of multiples of five. All data were collected at harvest, 12 months after planting. Data were collected on the following agronomic traits:

- Plant height (cm) - Height of plants were measured from the base of the plant to the tip of the tallest stem with the aid of a metre rule.
- Number of leaves, number of stems and number of main branches were counted.
- Length of petiole was measured using metre tape from its point of attachment on the stem to the base of the leaf.
- Stem circumference- rope was wound round the middle portion of the stem. The length of rope that went round the stem was marked and placed on metre rule to record the length obtained.

The following stress tolerance traits were measured:

- Stay green was rated on a scale of 1 – 5: 1 = yellow, 3 = green, 5 = very green.
- Pest severity was rated on a scale of 1 – 5: 1 = total infestation, 2 = above 70% infestation, 3 = 50% infestation, 4 = 20% infestation, 5 = no sign of infestation
- Disease severity was rated on a scale of 1 - 5, keeping in mind the common diseases that affect cassava: 1 = total infection, 2 = above 70% infection symptoms, 3 = 50% infection symptoms, 4 = 20% infection symptoms, 5 = no infection symptoms.

The yield parameters measured were:

- Fresh tuber weight (kg) was measured from all harvested roots per plot with a weighing balance.
- Size of tuber was rated on a scale of 1 - 5: 1 = small, 3 = medium, 5 = large
- Number of tubers in each plot.
- Carotene content was determined by cutting a cross sectional area of the tuber, then rated with the aid of a colour chart: 1 = white tuber, 4 = yellow tuber, 7 = deep yellow tuber.
- Fresh shoot weight (kg) is the weight of stems plus weight leaves.
- Total shoot weight: summation of the weight of shoot and weight of tubers.

- Tuber dry matter content: the weight (g) of tubers oven dried to a constant weight.

Harvest index was computed as:

$$\text{Harvest index: } \frac{\text{Fresh tuber weight}}{\text{Total shoot weight}}$$

Analysis of variance was done with SAS version 9.4. Means showing a significant difference were separated by least significant difference (LSD). Chi square was used to test association in categorical data using SPSS. Correlation analysis between traits was also performed. Genotype x genotype x environment (GGE) biplot was used for stability analysis with the aid of GEA-R version 3.4.2. The model for GGE biplot as proposed by Yan (2002) using principal components 1 and 2 is:

$$Z_{ij} - \mu_j = \sum_{k=1}^{n} \lambda_k \alpha_{ik} \gamma_{jk} + \varepsilon_{ij}$$

Where Z_{ij} is the cell mean of genotype *i* in environment j; μ_j is the mean value in environment j; i = 1, · · · g; j = 1, · · · e, g and e being the numbers of genotype and environments respectively; n is the number of principal components used in the model, with n ≤ min (e.g − 1); λ_k scale factor; α_{ik} product of genotypes score; γ_{jk}, an environmental score and ε_{ij} is the error term associated with genotype i in environment j (adapted from Yayis 2019).

Results

Qualitative description, analysis of variance and means of cassava varieties for agronomic traits, stress tolerance and tuber yield

Table 1 shows the morphological characteristics of the cassava varieties cultivated. The petiole colour of provitamin A cassava varieties was between light yellow and light green, while white fleshed cassava had green petiole. The provitamin A cassava varieties had yellow flesh with spreading or umbrella canopy, while the local variety had white flesh and an erect morphology. Table 2 shows that plant heights were significantly different ($P \leq 0.05$) at Erin-Ile, Alapa and across the three locations, while number of stems differed significantly ($P \leq 0.05$) at Budo-Are, Erin-Ile and for the combined analysis. TME 419 was the tallest (204.73 cm), TMS 1368 had the highest number of leaves 42.6, while TMS 07/0593 had the highest number of stems 1.8. Table 3 shows that the number of main branches differed in all locations as well as in the combined analysis ($P \leq 0.05$) and length of petiole differed significantly ($P \leq 0.05$) in two of the three locations and in the combined analysis. Stem circumference was not significantly different between the varieties at any of the sites. Provitamin A cassava varieties TMS 1368 and TMS 07/0593 had the highest number of main branches, 7.21 and 7.63 respectively.

Table 1: Qualitative description of cassava varieties

Variety	Type	Colour of petiole	Colour of stem	Plant type	Colour of tuber	Colour of flesh
TMS 1368	Provitamin A	Light yellow	Silver	Spreading	Light brown	Yellow
TMS 07/0593	Provitamin A	Light green	Brown	Umbrella	Chocolate	Yellow
TME 419	Non-provitamin A	Green	Green	Erect	Brown	White

Table 2: Means for agronomic traits at each location and across locations

Variety	PLTHT (cm)	NoStem	PLTHT (cm)	NoStem	PLTHT (cm)	NoStem
	Budo-Are		Erin-Ile		Alapa	
TMS -1368	161.95	2.0	176.74	1.3	159.33	1.5
TMS -07/0593	172.86	1.9	164.42	1.7	166.48	1.6
TME 419	170.00	1.3	215.09	1.2	229.10	1.3
LSD	43.63	0.5	23.46	0.3	32.91	0.5
	Combined analysis					
Variety	PLTHT	NoStem	NoL			
TMS -1368	166.01	1.6	42.6			
TMS -07/0593	167.92	1.8	36.8			
TME 419	204.73	1.3	33.6			
LSD	24.48	0.2	8.8			

LSD - least significant difference, PLTHT - plant height, NoStem - number of stems, NoL - number of leaves

Table 3: Means for other agronomic traits at each location and across locations

Variety	NoMBS	StemC (cm)	NoBMS	StemC (cm)	NoBMS	StemC (cm)
	Budo-Are		Erin-Ile		Alapa	
TMS -1368	7.4	7.29	7.2	7.43	7.0	6.76
TMS -07/0593	6.0	7.62	10.3	7.43	6.6	7.00
TME 419	2.4	7.33	3.8	7.57	1.3	8.29
LSD	2.5	1.89	3.4	0.49	1.9	0.93
	Combined analysis					
Variety	NoMBS	StemC	LoPet			
TMS -1368	7.2	7.16	17.47			
TMS -07/0593	7.6	7.35	12.86			
TME 419	2.5	7.73	19.89			
LSD	1.5	0.63	3.21			

LSD - least significant difference, NoMBS - number of main branches, StemC - stem circumference, LoPet - length of petiole

Table 4 shows the results of tests of association between the varieties and tolerance parameters. At Budo-Are, Alapa and overall the two provitamin A varieties differed from the local variety TME 419 for the stay green parameter; TME was usually rated "very green" whereas the other two varieties were usually rated "green". Except at Erin-Ile pest and disease severities were lower for TME 419 than the provitamin A varieties. At all sites TMS 07/0593 and TMS 1368 were yellow fleshed, whereas TME 419 was white fleshed. Tuber size ratings showed a significant difference at Budo-Are with TME producing large tubers and the provitamin A varieties tubers were usually rated as "medium".

Table 5 shows that combined ANOVA for yield and yield parameters varied significantly

among provitamin A cassava varieties TMS 1368 and TMS 07/0593 as well as the local variety (TME 419). Fresh tuber weight, number of tubers and size of tubers differed significantly ($P \leq 0.05$) for combined ANOVA and in at two of the three locations. TME 419 had the highest tuber yield of 30.28 t/ha which was not significantly different from 26.28 t/ha recorded for TMS 1368. Table 6 shows that the combined ANOVA had significant ($P \leq 0.05$) mean square differences for dry matter content and harvest index among the varieties.

Table 4: Test of association between cassava varieties and tolerance parameters as well as yield parameter using chi square

Location	Stay green	Pest severity	Disease severity	Carotene content	Size of tubers
Budo-Are	18.0**	18.0**	9.0**	18.0**	10.8*
Erin-Ile	10.0	5.1	9.0	18.0**	6.8
Alapa	9.0**	9.0**	9.0**	18.0**	9.0
Combined	23.4**	17.9**	25.6**	30.0**	7.1

*,** significantly different at 0.05 and 0.01 respectively

Table 5: Means for yield and yield attributes at each location and across locations

Variety	FTWT (kg)	NoTub	Yield (t/ha)	FTWT (kg)	NoTub	Yield (t/ha)	FTWT (kg)	NoTub	Yield (t/ha)
	Budo-Are			Erin-Ile			Alapa		
TMS -1368	1.54	7.8	22.00	2.21	15.1	31.57	1.78	7.6	25.43
TMS 07/0593	1.45	5.3	20.71	1.27	7.2	18.14	0.86	5.3	12.28
TME 419	1.92	6.7	27.42	2.05	8.3	29.28	2.39	7.1	34.14
LSD	1.01	3.9	1.44	0.67	9.2	9.57	0.61	1.4	8.71

Combined analysis

Variety	FTWT	NoTub	Yield t/ha
TMS -1368	1.84	10.2	26.28
TMS -07/0593	1.19	5.9	17.00
TME 419	2.12	7.4	30.28
LSD	0.44	2.8	6.28

LSD - least significant difference, FTWT -fresh tuber weight, NoTub - number of tubers

Table 6: Means for tuber dry matter content, harvest index and some other parameters at each location and across locations

Variety	DMTu (kg)	TuSwt (kg)	HI	DMTu (kg)	TuSwt (kg)	HI	DMTu (kg)	TuSwt (kg)	HI
	Budo-Are			Erin-Ile			Alapa		
TMS -1368	0.35	3.11	0.50	0.30	3.65	0.62	0.29	2.85	0.63
TMS -07/0593	0.39	2.94	0.47	0.21	2.53	0.49	0.37	2.28	0.35
TME 419	0.48	2.95	0.65	0.73	3.52	0.58	0.51	3.83	0.62
LSD	0.04	1.70	0.09	0.08	0.80	0.17	0.06	1.01	0.14

Combined analysis

Variety	DMTu	TuSwt	HI	FSWT
TMS -1368	0.31	3.20	0.58	1.36
TMS -07/0593	0.32	2.58	0.44	1.39
TME 419	0.58	3.43	0.62	1.32
LSD	0.10	0.70	0.08	0.36

LSD - least significant difference, DMTu - Tuber dry matter content, TuSwt - weight of tuber and shoot, HI - harvest index, FSWT - Fresh shoot weight.

Relationship between cassava traits

Table 7 shows the combined Spearman's correlation between traits. While fresh tuber weight (FTWT) was significantly ($P \leq 0.05$) and positively correlated with plant height (PLTH), length of petiole (LoPet), number of tubers (NoTub) and size of tubers (SoTub), it was significantly ($P \leq 0.05$) and negatively correlated with number of stems (NoStem) and number of main branches (NoBMS). Carotene content (was significantly ($P \leq 0.05$) and positively correlated with NoStem, NoMBS as well as stay-green (Staygn), and significantly ($P \leq 0.05$) and negatively with PLTH, LoPet, pest severity (PestSER), SoTub and tuber dry matter content (DMTu). Tuber dry matter content was significantly ($P \leq 0.05$) and positively correlated with FTWT, SoTub, PLTH, LoPet and disease severity (DisSER), and significantly ($P \leq 0.05$) but negatively correlated with number of leaves (NoL) and NoBMS. PestSER was significantly ($P \leq 0.05$) and positively correlated with DisSER but negatively correlated with NoTub and CaroC. Stay-green was significantly ($P \leq 0.05$) and negatively correlated with PestSER and DisSER.

Table 7: Combined Spearman's correlation matrix for agronomic traits, stress tolerance characteristics and yield parameters across the three experimental locations

	PLTHT	NoL	NoStem	NoBMS	LoPet	Staygn	PestSER	DisSER	FTWT	NoTub	SoTub	CaroC	FSWT	DMTu	TuSwt
PLTHT	1	0.15	-0.27	-0.55**	0.48*	-0.12	-0.04	0.11	0.71**	0.41*	0.63**	-0.38*	0.67**	0.55**	0.85**
NoL		1	-0.07	0.30	-0.09	-0.19	-0.18	-0.34*	0.31	0.47*	0.03	0.17	0.22	-0.41*	0.32
NoStem			1	0.38*	-0.17	0.02	-0.18	0.00	-0.47*	-0.23	-0.55**	0.52*	0.28	-0.34	-0.22
NoBMS				1	-0.59**	0.25	-0.29	-0.56**	-0.45*	0.08	-0.50*	0.55**	0.00	-0.83**	-0.30
LoPet					1	-0.38*	0.41*	0.62**	0.55**	0.24	0.34	-0.49*	0.31	0.52*	0.54**
Staygn						1	-0.59**	-0.43*	-0.22	0.02	0.08	0.41*	0.02	-0.05	-0.13
PestSER							1	0.74**	0.02	-0.39*	-0.08	-0.52*	-0.26	0.14	-0.12
DisSER								1	0.18	-0.44*	-0.08	-0.33	-0.09	0.43*	0.04
FTWT									1	0.64**	0.67**	-0.36	0.32	0.37*	0.88**
NoTub										1	0.53**	-0.06	0.39*	-0.09	0.67**
SoTub											1	-0.40*	0.19	0.49*	0.57**
CaroC												1	0.15	-0.57**	-0.22
FSWT													1	0.12	0.71**
DMTu														1	0.33
TuSwt															1

*,** significantly different at 0.05 and 0.01 respectively. PLTHT - plant height, NoL - number of leaves, NoStem - number of stems, NoMBS - number of main branches, LoPet - length of petiole, Staygn - stay green, PestSER - pest severity, DisSER - disease severity, FTWT - fresh tuber weight, NoTub - number of tubers, CaroC - carotene content, SoTub - size of tuber, FSWT - fresh shoot weight, DMTu - tuber dry matter content, TuSwt - weight of tuber and shoot.

GGE biplot analysis for tuber yield, carotene content and other yield Parameters

Principal component axes 1 and 2 accounted for 83.55% and 16.45% respectively for fresh tuber weight (Figure 2). PC I and P C II for other traits are 94.15%; 5.86% for dry matter content, 77.31%; 22.7% for harvest index, and 89.77%; 10.23% for number of main branches (data not shown).

With regards to which won where or what for the best varieties in the test environments for fresh tuber yield (Figure 3) and carotene content of tubers (Figure 4), TMS 1368 was the best provitamin A cassava at Erin-Ile while TMS 07/0593 and TME 419 were good for Alapa and Budo-Are. There was close affinity between Alapa and Budo-Are for carotene content. A similar trend was observed for dry matter content. TMS 1368 was best for harvest index at Alapa and Budo-Are. In terms of number of main branches, TMS 1368 was best for Erin-Ile and Alapa (data not shown).

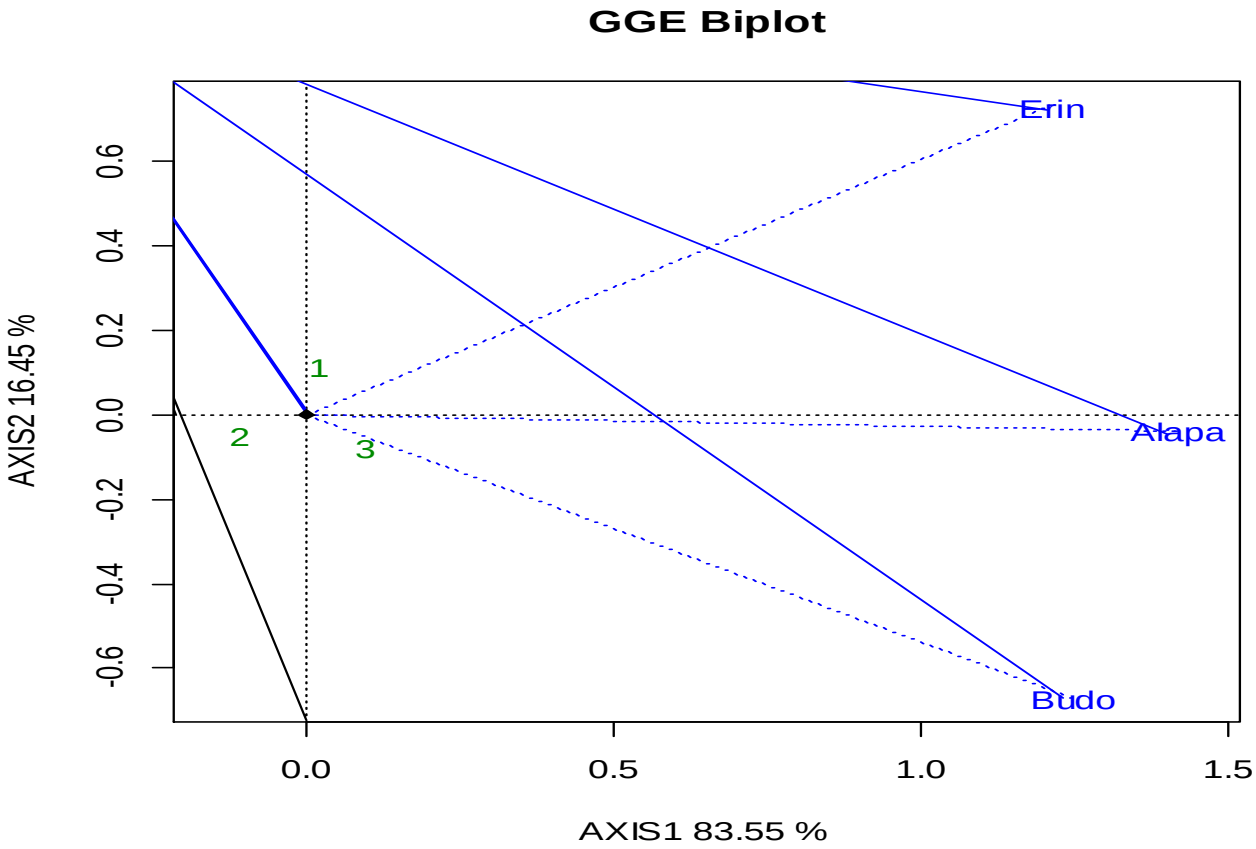

Figure 2: GGE biplot for cassava varieties showing relationship between genotype and environment for fresh tuber weight.
Variety: 1 = TMS 1368 2 = TMS 07/0593 3 = TME 419

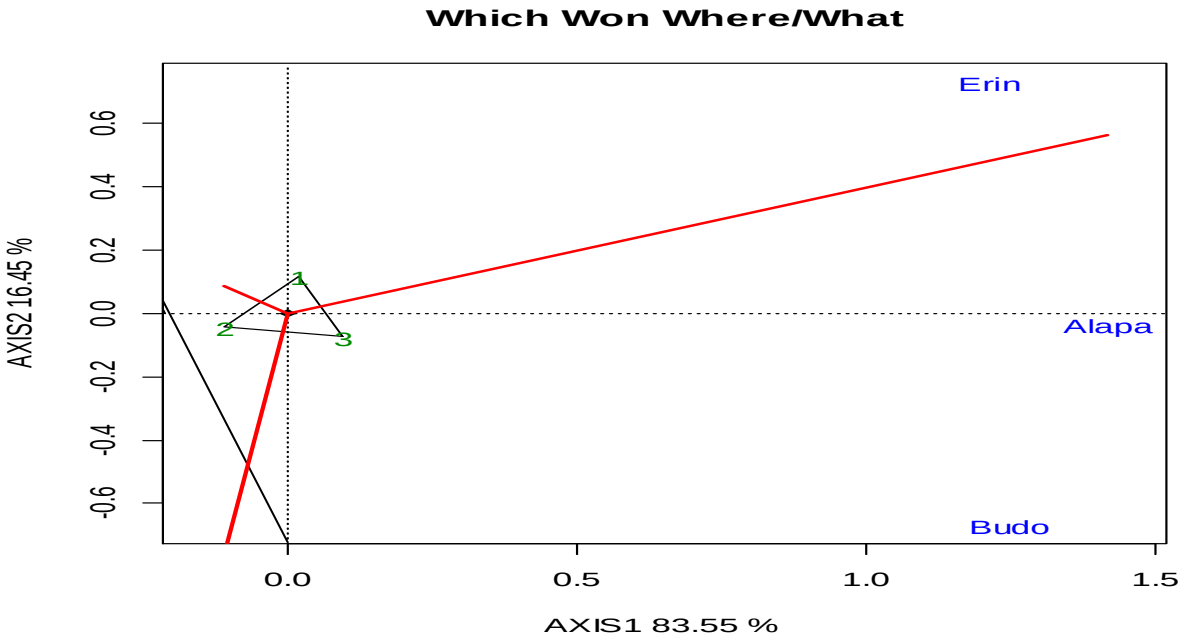

Figure 3: Which won where/what for cassava varieties showing relationship between genotype and environment for fresh tuber weight.
Variety: 1 = TMS 1368 2 = TMS 07/0593 3 = TME 419

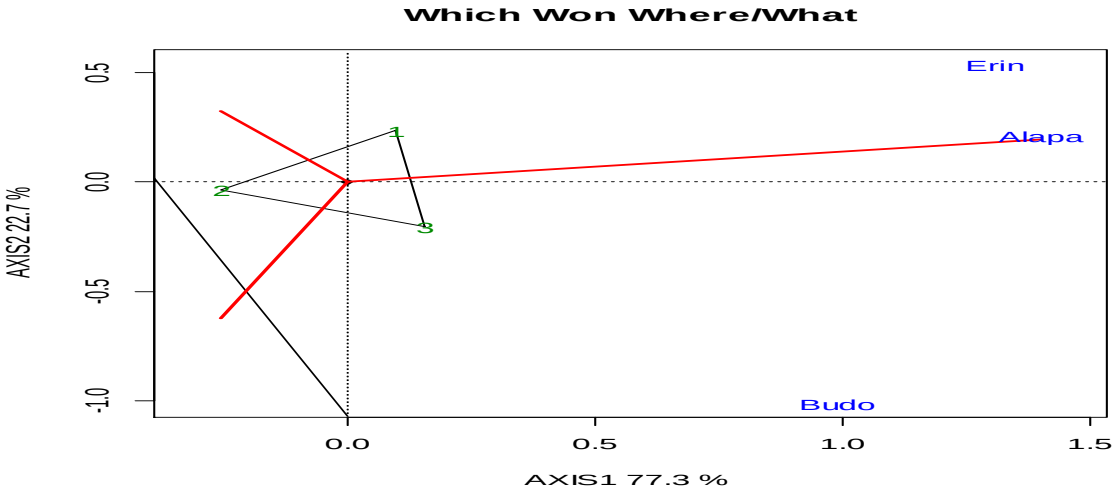

Figure 4: Which won where/what for cassava varieties showing relationship between genotype and environment for number of main branches.
Variety: 1 = TMS 1368 2 = TMS 07/0593 3 = TME 419

Figure 5 shows comparison between mean and stability for fresh tuber yield, carotene content. Generally, all the varieties were stable with TMS 07/0593 having the least PC II score being the most stable and also with the least mean for fresh tuber yield. TMS 1368 and TME 419, having the highest PC II score had the highest mean fresh tuber yield and were also stable. All the three varieties had low PC II scores for carotene content, dry matter content, harvest index and number of main branches (data not shown).

Figures 6-7 show the discriminatory potential and representativeness of the

experimental sites. In terms of fresh tuber weight, Alapa had the least angle with average environmental axis (AEA) and the longest vector; while Erin-Ile and Budo-Are had the widest angle to AEA. All the three environments have long vectors (Figure 6). While Budo-Are was closest to AEA with regards to dry matter content (Figure 7), it was widest with respect to harvest index. Alapa had the least angle with AEA for harvest index and number of main branches (data not shown).

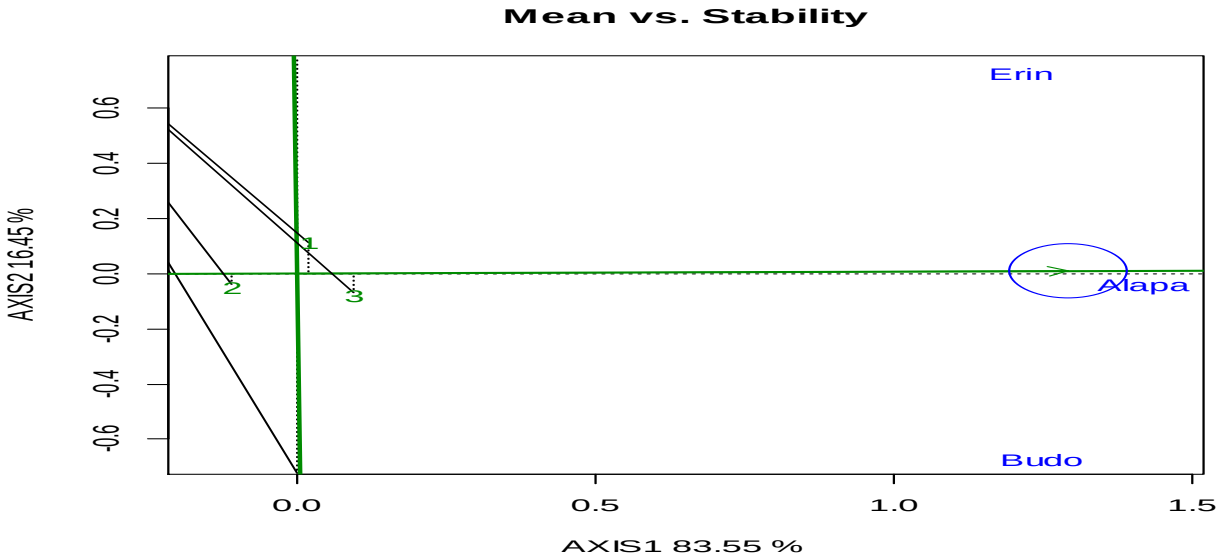

Figure 5: Mean vs stability for cassava varieties showing relationship between genotype and environment for fresh tuber weight.
Variety: 1 = TMS 1368 2 = TMS 07/0593 3 = TME 419

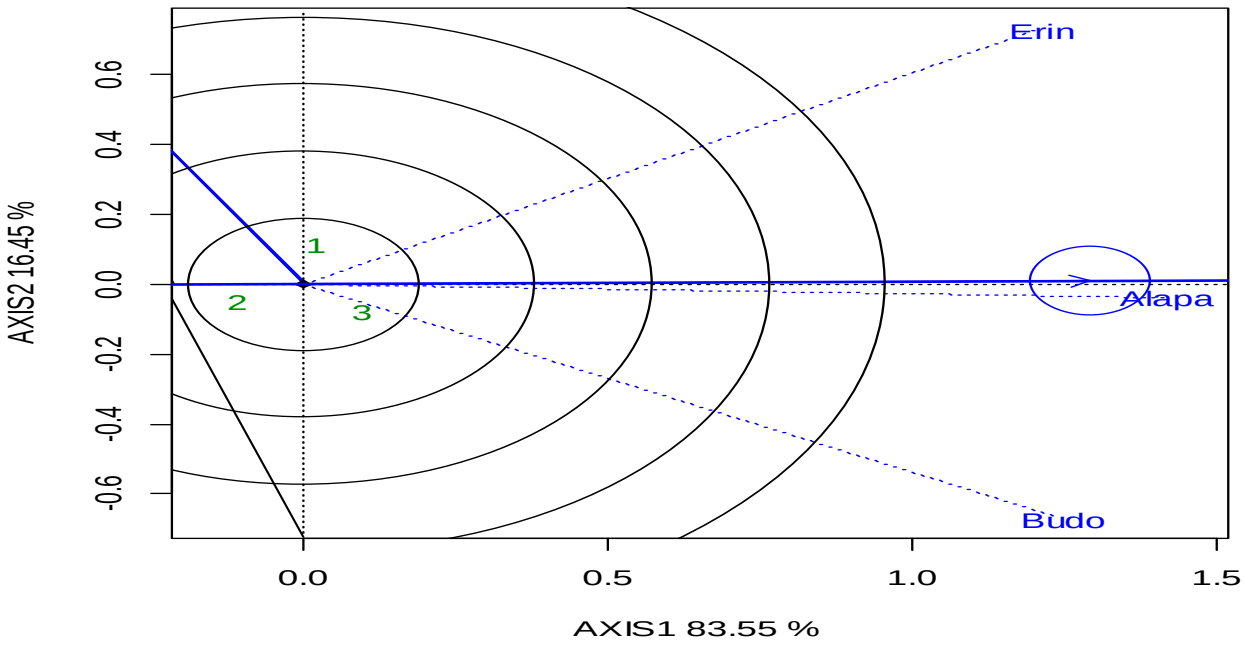

Figure 6: Discriminatory ability vs representativeness for cassava varieties showing relationship between genotype and environment for fresh tuber weight.
Variety: 1 = TMS 1368 2 = TMS 07/0593 3 = TME 419

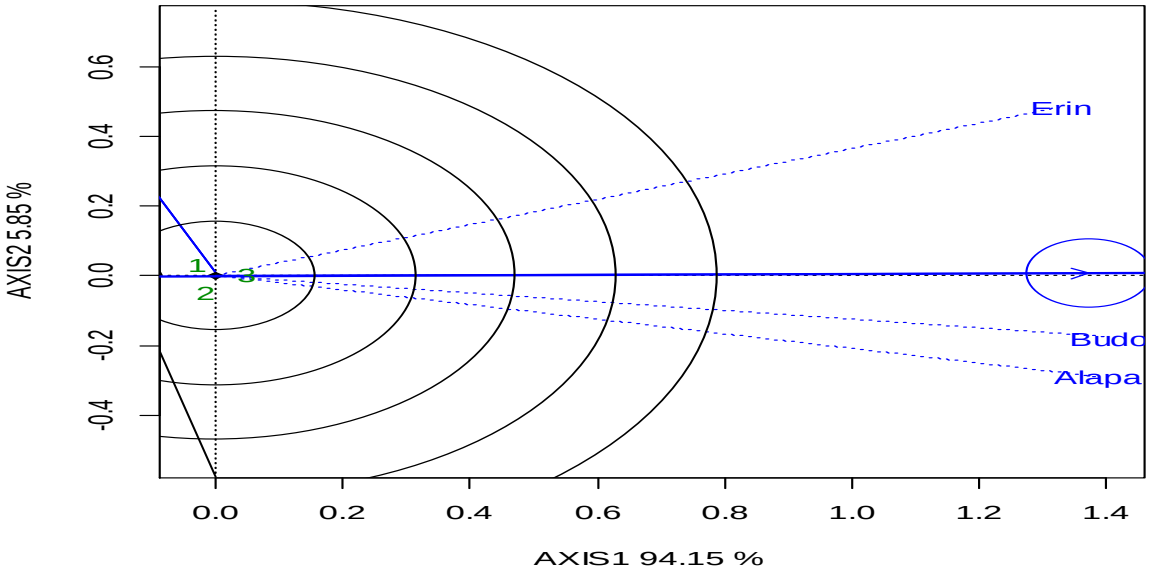

Figure 7: Discriminatory ability vs representativeness for cassava varieties showing relationship between genotype and environment for dry matter content.
Variety: 1 = TMS 1368 2 = TMS 07/0593 3 = TME 419

Index selection

Table 8 shows the indices upon which selection was based. TMS 1368 had highest multiplicative index score (3.04) and thus ranked as the best variety.

Table 8: Selection indices based on multiplicative index

Selection traits	TMS 1368	TMS 07/0593	TME 419
Fresh tuber weight	1.84	1.19	2.12
Carotene content	5.33	5.67	1.00
Dry matter content	0.31	0.32	0.58
Multiplicative index score	3.04	2.16	1.23

Discussion

Identifying suitable crop varieties for cultivation by farmers involves extensive procedures. There is usually the need to establish the variability among the varieties, determine the association between secondary traits and yield and also, test the varieties in multiple environments in order to determine their stability. G x E analysis geared towards establishing the stability of identified varieties is important in a crop like cassava in order to aid broad and specific adaptation necessary in their adoption and use. GGE biplot is a roburst tool in stability studies as it gives graphical display of phenotypic stability across loacations and helps identification of best genotypes on site basis (Oliveira et al. 2019). Cultivation of provitamin A cassava is uncommon in the study area but farmers exhibited great willingness to cultivate them (Yusuf et al. 2020). The need therefore to recommend the most suitably adapted cultivars to farmers is essential in order to enhance continued adoption.

Comparative analysis of provitamin A cassava

Morphologically, provitamin A cassava varieties have yellow flesh as a result of their carotene content (IITA 2014). Cassava varieties have differing potentials to tap

sunlight for photosynthesis, which is necessary in the production of photosynthate at the sink. TME 419 can tap light energy at higher height, being the tallest, while TMS 1368 had the highest photosynthetic apparatus (leaves), implying higher potential for photosynthesis and transfer assimilate to the sink, and hence higher tuber yield (Anuradha et al. 2017). Different studies have associated increased plant height with increase in yield in different crops like soybean (Lawal et al. 2020a) and maize (Ajala et al. 2018). Farmers cultivate cassava not only for tubers, but also for stem cuttings which are used as planting material. TMS 1368 and TMS 07/0593 produced a high number of plantable stems, implying abundance of planting materials and high tendency of earning more from the sales of their stems. Biotic and abiotic stress are the major impediment to crop growth. Loss of greenness in leaves (stay green) is associated with environmental stress such as drought and low soil nitrogen. TMS 1368 and TMS 07/0593 retained their stay green until harvest, implying higher potential to withstand environmental stress and hence, assimilate in the sink which is translatable to higher tuber yield (Anuradha et al. 2017). TMS 07/0593 shows the highest symptoms for pest and disease attack, which are major causes of low yield (Aderolu et al. 2018).

Number of tubers and size of tubers are good yield indices. TMS 1368 with fresh tuber yield of 26.28 t/ha was comparable with TME 419, the nationally recommended cassava variety before the need for provitamin A cassava. Provitamin A cassava varieties were however, lower in dry matter content. Fresh tuber weight was directly linked with plant height, length of petiole, number and size of tubers and could be indexed in future, for further improvement of the yield of provitamin A cassava. Profuse stem production and branching were detrimental to fresh tuber weight. Possibilities exist for carotene content to be enhanced by improving stay green, number of stems and main branches. There seems to be a drag effect between carotene content and tuber yield as a result of their inverse relationship. Carotene content had inverse correlations with pest severity and dry matter content. This calls for caution as possibilities exist in lowering tuber yield, dry matter content and pest severity in the cause of improving carotene content of provitamin A cassava. More so, pest invasion results in disease attack, which can both be minimized through improvement of stay-green.

Cross over effects, which change the ranking of cassava varieties as a result of the influence of the environment were obvious and this limits blanket recommendation of a variety across all environments, hence, there are usually target varieties for target environments (Mitrovic et al. 2012).

Stability analysis on provitamin A cassava using GGE biplots

GGE biplot is a useful statistical tool which provides a graphical illustration of which-won-where or the best variety, best location, mega locations, specific adaption, cross over effect etc (Negash et al. 2017). Principal components 1 and 2 adequately approximated the contribution of variety, the environment and their interaction for fresh tuber weight, carotene content, dry matter content, harvest index and number of main branches. The which-won-where in GGE biplot is likened to a "pair-wise comparison".

Which won where/what

There is no universal best variety that combine fresh tuber weight, carotene content, dry matter content, harvest index and number of main branches. For fresh tuber weight, TMS 1368, TMS 07/0593 and TME 419 were the vertex varieties. According to Badu-Apraku et al. (2011), the vertex varieties are usually the highest yielding. TMS 1368 is the best and most adapted variety for Erin-Ile. TME 419 is adapted to Alapa and Budo-Are. The triangular

view classified the environments into two mega environments. The perpendicular lines passed through the origin of the biplot and partitioned the triangle into sections. Erin-Ile standing alone and high and Budo-Are and Alapa with close affinity. There was reversal of ranking of the environments for harvest index and with TME 419 taking the lead. Number of main branches followed a similar trend to fresh tuber weight. TMS 1368 was consistently adapted to Erin-Ile for most traits, while TME 419 was adapted to Budo-Are and Alapa. Similar reports on mega environments and 'which won where' had been reported for cashew (Aliyu et al. 2014), common bean (Negash et al. 2017), cassava (Peprah et al. 2020) and forage grasses (Lawal et al 2020b). More so, as reflected by low percentage variability accounted for by the second principal component, all the varieties are stable for fresh tuber weight, carotene content and other traits.

Discriminability and representativeness

The average environment axis (AEA) represents the main line running through the average environment, denoted by a small circle at the centre and biplot origin. The average environment captured the mean coordinates of the three test environments. The minimal the angle between a test environment and AEA, the more such an environment can represent other test environments (Yan and Tinker 2006). From the foregoing, for fresh tuber weight, Alapa is most representative of the other environments while Erin-Ile and Budo-Are are the least representative of other test environments. All the three environments were also discriminatory. Generally adapted varieties are selected at test environment(s) that are discriminating and representative (Peprah et al. 2020; Lawal et al. 2020b). Hence, Alapa is a good test environment where generally adapted varieties can be chosen, and the generally adapted variety is TME 419, the nationally recommended variety. On the other hand, specifically adapted varieties for a target environment can be chosen from a discriminating test environment that is non-representative provided that the target environment is sub zoomed into mega environments (Yan and Tinker 2006). Thus, Erin-Ile was valuable in selecting TMS 1368 as the most suitable and adapted variety in that ecology. Environments with short vectors are non-discriminating and non-informative, thus less useful (Yan and Tinker 2006). In this study, all the environments were discriminating. The centre of the concentric circles is the ideal environment, which is most discriminating and most representative (Peprah et al. 2020). In reality, an ideal environment is non-existent but a reference point. Thus, the ideal test environment is Alapa, it is where the best variety is selected. Yan (2002), noted that good test environments should bear high PC1 scores, that is most discriminating varieties, and close to zero for PC2 scores that is most representative of an average environment. For carotene content and number of main branches, the test environments were discriminating and hence, non-informative. Whereas, for dry matter content, Budo-Are was most representative with TME 419 being the generally adapted variety. With regards to harvest index, Alapa is most representative and discriminating with TMS 1368 being the most adapted variety.

The outcome of selection matrix considering multiple traits ranked TMS 1368 as the best variety.

Conclusion and recommendations

Wide genetic variation existed among the cassava varieties, suggestive of possibilities of improving them. There is need to take caution when improving carotene content of provitamin A cassava in order to avoid losing out on fresh tuber weight and dry matter content. TMS 1368 was better yielding and adaptable than TMS 07/0593 and compared favourably with TME 419. GGE biplot was very useful in selecting broadly

adapted variety, target variety for target environments and delineating the environments into two mega environments. TME 419 was generally most adapted to Kwara State while TMS 1368 is specifically adapted to Erin-Ile. TMS 1368 is the most suitable cassava variety capable of addressing food security and vitamin A deficiency adequately and therefore should be the recommended variety to the farmers.

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