Genetic by environment interaction on fresh root yield, dry matter content and total carotene concentration of yellow-fleshed cassava genotypes in five major cassava growing agroecological zones in Nigeria

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ABSTRACT

Eighteen yellow-fleshed cassava genotypes and two released white-fleshed clones (check) were evaluated in five locations representing the major cassava growing agroecological zones of Nigeria to access their performance for fresh root yield, dry matter content, total carotene content and genotypes by environment interaction effects. The aim of the study was to identify stable cassava genotypes that combine high root yield, and high dry matter with high beta carotene content in storage root. The study was conducted in two cropping seasons (2008/2009 and 2009/2010) at Ikenne (humid forest), Ibadan (forest-savanna transition), Ubiaja (sub-humid forest), Mokwa (sub-humid southern-Guinea savanna) and Zaria (moist northern-Guinea savanna). At all locations, the trials were conducted in a randomised complete block design (RCBD) with four replications. The combined analysis of variance showed that fresh root yield (t ha^{-1}), dry matter content (%) and total carotene content (µg g^{-1} fresh weight) was significantly affected ($P < 0.001$) by Genotype (G), Environment E, and G × E interaction. For fresh root yield, the best genotype was IITA TMS I050024 followed by IITA TMS I050998 and IITA TMS I050286. For dry matter content of the storage roots, the genotype IITA TMS 1051570 had the highest score followed by IITA TMS 1051740 and IITA IMS I050998. For total carotene content, the best genotypes across the 10 environments in decreasing order of carotene content were IITA TMS I051601, IITA TMS I050311, IITA TMS I050998 and IITA TMS I050099. When combining fresh root yield and dry matter content (dry yield), the genotypes IITA TMS I050998 and IITA TMS I051740 ranked highest. The Environment effect accounted for most of the variation of the total sum of squares (SS) for fresh root yield (55.0%), dry matter content (42.3%) and dry yield (57.9%). The genotype accounted for most of the SS for total carotene content (67.9%).

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Introduction

Genotype by environment interaction (G × E) is the change in cultivars' relative performance when grown in different environments resulting from the differential response of the genotypes to various edaphic, climatic and biotic factors (Dixon, Asiedu & Haln, 1991). Genotypes refer to the set

of genes possessed by individuals that are important for the expression of traits under investigation. The environment is usually defined as all non-genetic factors that influence expression of traits and includes all biophysical factor, like water, nutrition, temperature and diseases that influence the growth and development of individuals and, thereby, influencing expression of traits (Basford & Cooper, 1998). G × E interaction is a major concern in plant breeding, it reduces progress from selection and it makes cultivar recommendation difficult because the choice of superior cultivars changes with locations (Kang & Magari, 1996). Cassava cultivars often demonstrate specific adaptation due to their high sensitivity to G × E interaction that occurs in both short-term and long-term crop performance trials (Eberhart & Russel, 1966).

Sub-saharan Africa is the world's largest producer of cassava, with 121.4 million tons of fresh storage roots produced in 2010, grown on 11.87 million hectares (FAO, 2011). More than 70 per cent of cassava in Nigeria is processed into 'gari'. Based on the utilisation of cassava in Nigeria, farmers have various preferences for cassava varieties. Currently, most farmers are cultivating white fleshed cassava varieties, although in some locations in the south-east of the country there are white cassava 'gari' coloured yellow with palm oil. In these locations, farmers and consumers already have a favourable view for yellow coloured cassava produce. With yellow flesh cassava genotypes such products will contain beta carotene.

A nationwide food consumption and nutrition survey conducted in Nigeria revealed that 29.5 per cent children under 5 years old were vitamin A deficient (serum retinol < 0.70 µmo l^{-1}) (Maziya-Dixon *et al*., 2006). The proportion of children with vitamin A deficiency differed among agroecological zones with vitamin A deficiency incidence of 31.3 per cent in dry savanna, 24.0 per cent in moist savanna and 29.9 per cent in humid forest (P = 0.001) Beta-carotene is the most potent and most widespread form of provitamin A (Rodriguez-Amaya, 1993). Beta-carotene is the predominant carotenoid in cassava occurring as a mixture of trans- and cis-forms (Rodriguez-Amaya & Kimura, 2001). Structurally, vitamin A (retinol) is essentially one-half of the beta-carotene molecule. Typical white root cassava genotypes contain only small amounts of beta-carotene (Bradbury & Holloway, 1988). However, yellow root cassava contains up to about 100 times as much (McDowell & Oduro, 1983).

In Nigeria, more than 70 per cent of cassava production is processed into 'gari' at the village level. 'Gari' is the principal source of calories for 70 – 80 million Nigerians. The expectations for farmer adoption of yellow fleshed cassava varieties are high because the price premium for yellow gari in Nigeria is 30 – 60 per cent higher than for white 'gari' (Egesi *et al*., 2010). It is, therefore, important to breed and promote yellow fleshed cassava varieties to fight the widespread vitamin A deficiency in Nigeria.

Materials and methods

A set of 18 yellow-fleshed cassava genotypes at the Uniform Yield Trial and two white-fleshed check genotypes were evaluated at five locations representing the major cassava growing agro-ecological zones in Nigeria. These 20 genotypes were cul-

TABLE 1

Characteristics of Locations Where the Trials were Conducted

Location	*Latitude*	*Longitude*	*Maximum temperature (°C)*	*Minimum temperature (°C)*	*Altitude (m asl)*	*Length of growing period (days)*	*Annual rainfall (mm)*	*FAO dominant soil type*	*Agroecological zone*
Ikenne	6.867	3.717	28.2 – 33.4	22.3 – 24.8	44	242	1515	Distric Nitosols	Humid forest
Ibadan	7.388	3.896	27.3 – 33.8	20.7 – 23.1	227	238	1312	Ferric Luvisols	Forest savanna transtition
Mokwa	9.283	5.05	18.1 – 24.6	29.2 – 37.3	132	181	1149	Distric Nitosols	Southern Guinea savanna
Zaria	11.167	7.633	13.9 – 24.3	27.4 – 35.5	687	155	1076	Ferric Luvisols	Northern Guinea savanna
Ubiaja	6.650	6.383	27.1 – 32.6	19.9 – 22.5	285	287	1186	Distric Nitosols	Sub-humid forest

Abbreviation for GGE biplot	*Locations*	*Cropping seasons*
E1	Ibadan	2008 - 2009
E2		2009 - 2010
E3	Ikenne	2008 - 2009
E4		2009 - 2010
E5	Mokwa	2008 - 2009
E6		2009 - 2010
E7	Ubiaja	2008 - 2009
E8		2009 - 2010
E9	Zaria	2008 - 2009
E10		2009 - 2010

tivated for two 12-month cropping seasons 2008/2009 and 2009/2010 at Ibadan (forest-savanna transition), Ikenne (humid forest), Mokwa (southern-Guinea savanna); Ubiaja (sub-humid forest) and Zaria (northern-Guinea savanna) (Table 1).

A randomised complete block design with four replications was used at each location with plants established under rain-fed conditions at 1 m × 1 m spacing on ridges of about 0.3 m high. Each experimental unit was a 6-m × 6 m plot making a total of 36 plants. No fertilizer was applied. Weed control was accomplished manually as deemed necessary. Harvesting was done in all the locations at approximately 12 months after planting for the 2 years. Using a border of 1 m, only the inner plants (maximum of 16 plants) were harvested. The number of plants harvested, number of roots and the weight of the fresh storage roots per plot were recorded. The root dry matter percentage was determined from a random sample of three roots per plot from only two replications. To determine dry matter percentage, a 100-g sample was taken after the three roots were washed and shredded. Samples were oven dried at 70 °C for 48 h. Dry matter percentage (DMC) was calculated by the formula (dry weight/fresh weight) * 100.

For laboratory determinations of total carotene content (TCC), five medium (500 – 1,000 g) size roots were collected from the harvested roots in two replications. Total carotene was determined by the spectrophotometer method (Rodriguez-Amaga & Kimura, 2004). Total carotene concentration of fresh cassava roots was determined by spectrophotometer within 24 h after harvest. During sample preparation, special care was taken to avoid direct exposure of the storage roots to sunlight, and the lights in the laboratory were protected with UV filters. Samples were covered with aluminum foil when not under processing.

Data collected were statistically analysed using GGE biplot. (Gauch & Zobel, 1996).

Results and discussion

Fresh storage root yield (t ha^{-1})

Fresh storage root yield is a trait that typical demonstrated high G × E interaction effect (Mba & Dixon, 1995). This was observed in the study and emphasizes the importance of multi-environment evaluations of newly developed varieties to identify cassava clones suited for different agroecological zones. The highest average storage root yield per hectare (17.33 t ha^{-1}) was obtained for genotype TMS I050024 and the lowest (8.55 t ha^{-1}) was recorded by the genotype TMS I050099. The overall average root yield among the 20 genotypes across the 10 environments was 12.84 t ha^{-1} (Table 2). The average yields from the study were lower than have been observed in some other cassava yield studies. For example, Maroya & Dixon (1992) observed a range of mean genotypes root yields of 11.47 – 25.14 t ha^{-1} with a grand mean of 18.17 t ha^{-1} in a study of 10 white-fleshed root cassava clones evaluated from 1989 to 1991 in four locations in Benin.

Analysis of variance showed differences among genotypes (G), environments E and for genotype by environment interaction (GE) ($P < 0.00$). These components of variation contributed 6.8 per cent (G), 55.0 per cent (E) and 15.8 per cent (GE) to the total sum of squares (Table 3).

GGE biplot analysis graphically summarises genotype performance in relationship

Table 2

Average Fresh Root Yield (t ha^{-1}), Root Dry Matter (%) and Total Carotene Concentration (µgg^{-1}); for 18 Yellow Fleshed Root and Two Write-Fleshed Root Cassava Genotypes in 10 Environments.

Genotype	*Abbreviation of genotype*	*Fresh root yield (t ha^{-1})*	*Root dry matter content (%)*	*Total carotene concentration (µgg^{-1})*
TMS I050024	G1	17.33a	27.28bcd	2.55ghi
TMS I050286	G2	15.10ab	26.21cde	3.14efghi
TMS I050303	G3	13.17ab	28.36abcd	3.91cde
TMS I050099	G4	8.55c	21.22e	4.86bc
TMS I050311	G5	11.84bc	29.58abcd	5.92ab
TMS I050998	G6	15.86ab	32.32abc	5.20ab
TMS I050741	G7	10.51bc	28.83abcd	3.46defgh
TMS I051274	G8	12.99ab	29.52abcd	3.02efghi
TMS I050231	G9	14.66ab	28.58abcd	3.77de
TME 1	G10	10.13bc	31.37abc	0.98j
TMS I051570	G11	11.40bc	33.51a	2.46hi
TMS I051601	G12	12.21ab	20.89e	5.97a
TMS I050127	G13	11.64bc	29.45abcd	4.49bcd
TMS I050327	G14	13.88ab	26.10cde	4.35bcd
TMS 30572	G15	12.19ab	31.27abc	0.87j
TMS I050128	G16	11.48bc	30.96abc	3.65def
TMS I051740	G17	13.99ab	32.57ab	2.71fg
TMS I051553	G18	13.27ab	30.35abc	3.51defg
TMS I051814	G19	14.34ab	24.98de	2.18i
TMS I050125	G20	12.29ab	31.26abc	4.22bcd
Mean		12.84	28.73	3.56
Std error		3.85	3.78	0.76
CV (%)		29.96	13.17	21.41
LSD (5%)		5.45	5.41	1.01

Table 3

Analysis of Variance and Genotype, Environment and Genotype by Environment Contributions to the Sum of Squares of Fresh Root Yield

	ANOVA table for the fresh root yield					
Source	*DF*	*SS*	*MS*	*F*	*P*	*SS (%)*
Total	799	47268.4				
Geno	19	3254.4	171.3	11.6	<0.001	6.9
Env	9	25981.8	2886.9	195.1	<0.001	55.0
GE	171	7473.5	43.7	2.9	<0.001	15.8
BLK(Env)	30	2122.9	70.8	4.8		
Error	570	8435.7	14.8			

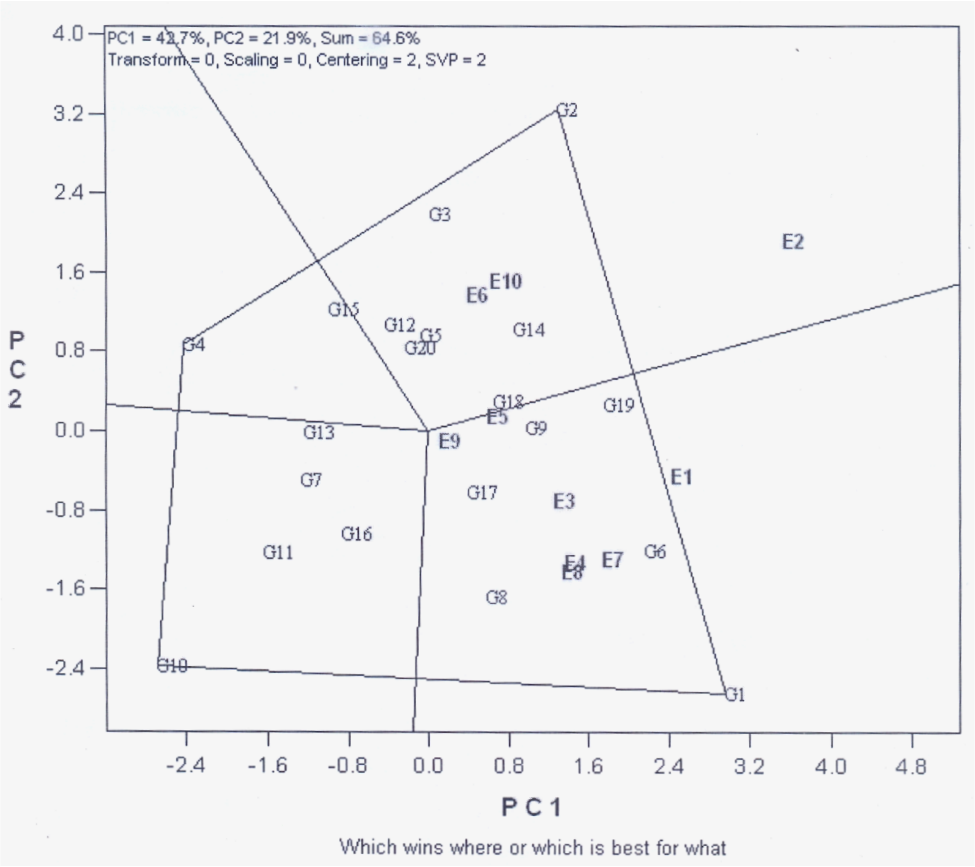

Fig. 1. Mega-environment defined by different winning cassava genotypes tested in 10 environments for the average fresh root yield (t ha^{-1})

to the environments evaluated in the study. Fig. 1 gives a polygon view of GGE biplot showing which genotypes performed best or worse in which environments for fresh root yield (FYLD). The vertex genotypes for FYLD were TMS I050024, TMS I050286, TMS I050099 and TME 1. The other genotypes were located within the polygon and were found less responsive (Weikai, 2006). Environments E1, E3, E4, E5, E7, E8, and E9 fell in the niche where genotype TMS I050024 was the best performer. Environment E2, E6, and E10 fell in the sector with TMS I050099 and TME1 as vertex genotypes.

Root dry matter content (%)

The average storage root dry matter content ranged from 20.9 per cent to 33.5 per cent (Table 2). The grand mean for root dry matter content was 28.7 per cent. These results were similar to those reported in other studies of yellow flesh genotypes (IITA, 1987; Ssenmakula & Dixon, 2007). The analysis of variance revealed highly significant differences ($P < 0.001$) among genotypes, environments and for genotype by

environment interaction. The highest dry matter was obtained for the genotype TMS 1051570 (33.5%) followed by TMS I051740 (32.6%) and TMS I050998 (32.3%), respectively. The lowest dry matter was registered by the genotype TMS I051601 (20.9%). Ssemakula & Dixon (2007) stated that cassava varieties with 30 per cent and above are said to have high dry matter content. In the study, six of the 18 yellow fleshed root cassava genotypes (TMS I050998, TMS I051570, TMS I050128, TMS I051740, TMS 1553 and TMS I050125) together with the two white- root genotypes used as checks (TMS I30572 and TMEB 1) had high dry matter content (Table 2). These findings show that yellow-fleshed cassava genotypes can have relatively high dry matter (IITA, 1987). G, E and GE for the storage root dry matter content contributed 23.80 per cent, 42.30 per cent and 19.10 per cent, respectively, to the total sum of squares (Table 4).

For the GGE biplot analysis, the PC1 and PC2 together explained 71.2 per cent of the total variation. Fig. 2 gives a polygon view of the GGE biplot for DMC, showing which genotypes performed best in which environments. The vertex genotypes for DMC were TMS I051570, TMS I051740, TMS I050741, TMS I050099, TMS I051601 and TMS I050327. All 14 other genotypes located within the polygon were found less responsive. Two mage environments were usefully defined. The first mega environment was the winning-niche of genotype G11 made of E2, E3, E7, E8, E9, and E10. The second mega environment fell in the sector with genotype G17 made of environments E2, E4, E5, and E6 (Fig. 2).

Total carotene concentration in fresh storage roots

The average total carotene concentration ($\mu g g^{-1}$ fresh weight) of the 18 yellow-fleshed and two white-fleshed cassava genotypes in each of the 10 environments range from 0.6 to 8.5 $\mu g g^{-1}$ fresh weight (Table 2). The overall mean for total carotene concentration was 3.55 $\mu g g^{-1}$. There were highly significant differences among genotypes, environments and genotype by environment interaction with each component contributing 67.9 per cent, 6.7 per cent and 14.8 per cent, respectively, to the total sum of squares

Table 4

Analysis of Variance and Genotype, Environment and Genotype by Environment Contributions to the Sum of Squares of Dry Matter Content (%)

	ANOVA table for the dry matter content					
Source	*DF*	*SS*	*MS*	*F*	*P*	*SS (%)*
Total	399	19072.3				
Geno	19	4543.9	239.1	16.7	< 0.001	23.8
Env	9	8075.8	897.3	62.6	< 0.001	42.3
GE	171	3640.5	21.3	1.5	< 0.001	19.1
BLK(Env)	10	90.1	9.0	6.0		
Error	190	2721.9	14.3			

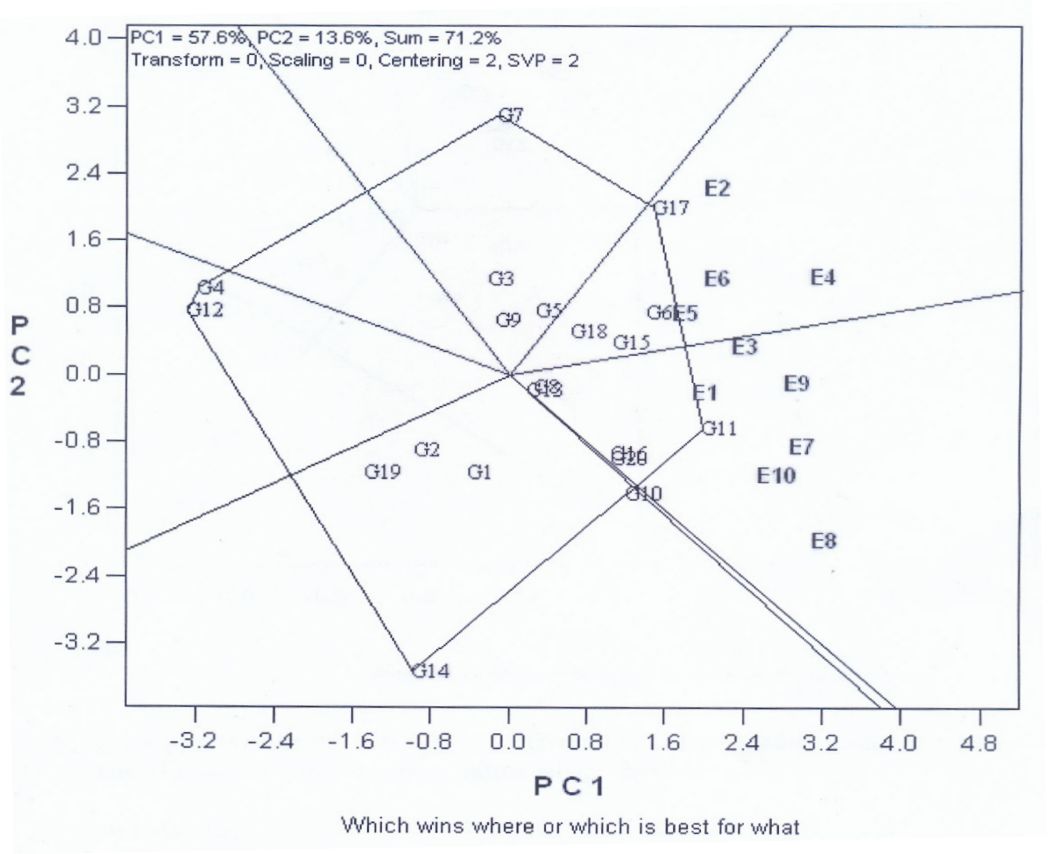

Fig. 2: Mega-environment defined by different winning cassava genotypes tested in 10 environments for the average root dry matter content (%).

TABLE 5

Analysis of Variance and Genotype, Environment and Genotype by Environment Contributions to the Sum of Squares of Total Carotene Concentration ($\mu g g^{-1}$ Fresh Weight)

	ANOVA table for the total carotene concentration					
Source	*DF*	*SS*	*MS*	*F*	*P*	*SS (%)*
TOTAL	398	1086.6				
GENO	19	738.1	38.8	66.9	< 0.001	67.9
ENV	9	73.1	8.1	14.0	< 0.001	6.7
GE	171	160.7	0.9	1.6	< 0.001	14.8
BLK(ENV)	10	4.9	0.5	0.8		
ERROR	189	109.7	0.6			

(Table 5).

In the GGE biplot analysis, the first and second principal components together explained 89.7 per cent of the total variation. Genotype G12 recorded the highest value of total carotene concentration. It was followed in the same group by G5 and G6. Genotype G15 and G10 (the white-fleshed checks) had the lowest total carotene concentration. The most stable genotype for total carotene concentration was G14. A polygon view of the GGE biplot (Fig. 3) showed which genotypes performed best in which environments. The vertex genotypes for total carotene concentration were G12, G5, G15 and G10. Two mega environments were defined. The first mega environment included E1, E2, E3, E9 and E10 with the winning-niche occupied by genotype G12. The second mega environment was genotype G5 and comprised environments E4, E5, E6, E7 and E8.

Conclusion

Despite the fact that the yellow-fleshed cassava genotypes used in the study had low total carotene concentration (TCC), there was significant variation among genotypes, environments and genotype by environment interaction. This was true for fresh storage root yield, dry matter content and the total carotene concentration. For fresh root yield, the best genotypes across the 10 environments were TMS I050024, TMS

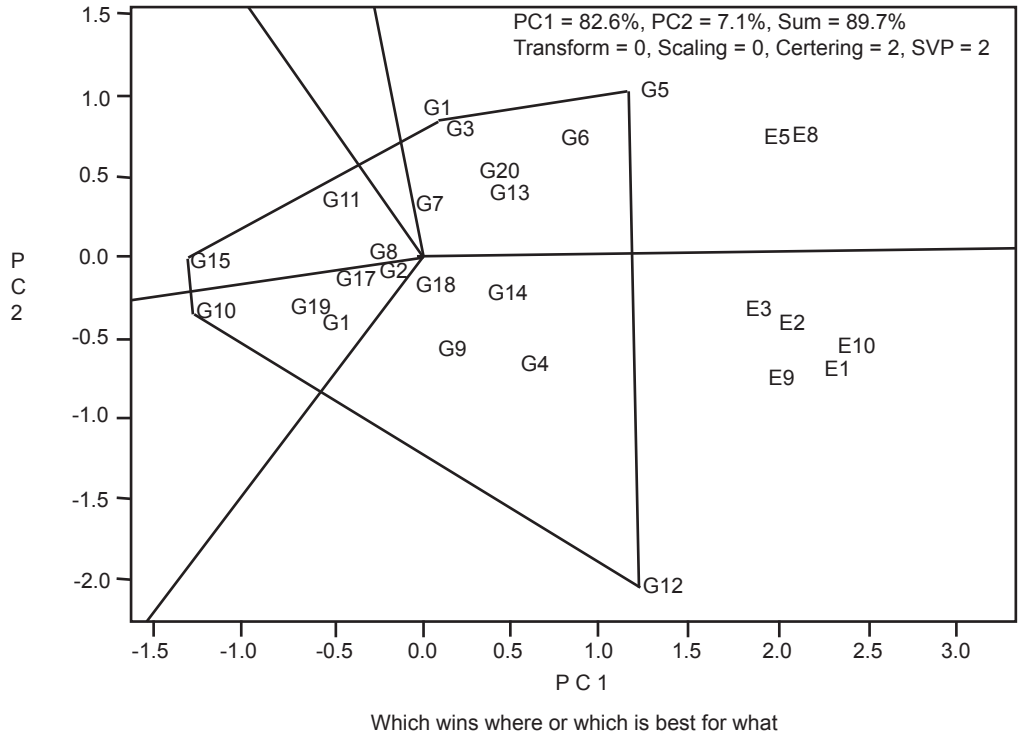

Fig. 3. Mega-environment defined by different winning cassava genotypes tested in 10 environments for total carotene concentration (μgg^{-1} fresh weight).

I050998,TMS I050024286, TMS I050321 and TMS I051814. The high performance for dry matter content of yellow-fleshed `genotypes was recorded across the 10 environments for genotypes TMS I051570, TMS I051740, TMS I050998, TMS I050125, TMS I050128 and TMS I051553. When combining the fresh yield and the dry matter content, the first five performing yellow-fleshed genotypes were TMS I050024998, TMS I051740, TMS I050024, TMS I051553 and TMS I050231. For TCC, the best genotypes across the 10 environments were TMS I051601, TMS I050311 and TMS I050998. These results showed that the clone TMS I050998 was the best for the three treatments evaluated in this trial.

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