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Research Article

Damian Ndubuisi Njoku, Emmanuel Ukaobasi Mbah*

Assessment of yield components of some cassava (*Manihot esculenta* Crantz) genotypes using multivariate analysis such as path coefficients

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Abstract: Cassava, which is a tropical storage root crop, serves as a veritable source of carbohydrate for people living in Sub-Saharan Africa. It is also an important source of industrial starch, biopolymers, animal feeds and ethanol. However, the genetic improvement of the crop is impeded by dearth in information on its genetic variability. A field experiment was carried out at the National Root Crops Research Institute, Umudike (05° 29′ N; 07° 33′ E; 122 m a.s.l.), Nigeria, aimed at assessing the interrelationship between fresh root yield and thirteen quantitative yield-related characters of twenty-eight (28) newly developed cassava genotypes. The rain-fed experiment was laid out in a randomized complete block design with dual replications in 2016/2017 cropping seasons. The results indicated that the newly developed cassava genotypes [2] NR110315 followed by [20] B1-5 and [1] NR110238 exhibited ($P < 0.05$) highest fresh root yield among the twenty-eight genotypes tested. The fresh root yield of [2] NR110315 (18.77 Mt ha^{-1}) was relatively higher compared with [18] NR050080, which gave the least root yield of 5.38 Mt ha^{-1}. The correlation coefficients obtained from the associations among the variables were positive and exhibited highly significant ($P \leq 0.01$) association, especially between leaf area index (LAI) and root diameter as well as with fresh root yield of cassava. Among the nine variables subjected to the path analysis, LAI, starch content, above ground dry matter (AGDM), weight of fresh marketable roots per plant and root length that contributed positively and directly to higher fresh root yield require greater attention during selection and breeding in cassava studies. The direct effect of the variables indicating their magnitudes in decreasing order showed that LAI exhibited the greatest effect followed by starch content, AGDM, weight of fresh marketable roots plant^{-1}, root length, % cassava bacterial blight incidence and % Cassava mosaic disease incidence, which had the lowest direct effect on root yield of cassava. Cyanide potential exhibited a direct, weak and negative effect on fresh root yield. The results further suggested that cassava improvement could be achieved through these characters that have positive and highly significant magnitude effect on fresh root yield.

Keywords: disease status, correlation, cyanide potential, path analysis, starch content

*** Corresponding author: Emmanuel Ukaobasi Mbah,** Department of Agronomy, College of Crop and Soil Sciences, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria, e-mail: emmaukmbah@ gmail.com, tel: +234 803 460 8421
Damian Ndubuisi Njoku: Cassava Programme, National Root Crops Research Institute, Umudike, Nigeria

1 Introduction

The evaluation of some newly developing cassava (*Manihot esculenta* Crantz) genotypes using appropriate analytical techniques is of immense importance for the present and future agronomic and genetic improvement of cassava in Sub-Saharan Africa (SSA) considering the nature and magnitude of variability existing among cassava genetic materials. Contrary to the path coefficient analysis, the singular use of simple correlation analysis as an instrument in identifying selection indices is insufficient because yields obtained from crops are generally not only quantitative in nature but have complex characteristics. Therefore, it is important to identify traits which are vital for the effective utilization of such materials for improvement purposes of cassava yield.

The path coefficient analysis, which is a standardized partial regression coefficient, indicates the causes of mutual relationships between characters and permits the separation of correlation coefficients into components of direct and indirect effects, hence serve as a veritable instrument in crop selection by elucidating information through direct and indirect pathways leading to the complex plant character following the procedures of Dewey and Lu (1959) in their studies on crested wheatgrass (*Triticum aestivum*), Gravois and McNew (1993) on rice (*Oryza sativa*) and Board et al. (1997) on soybean (*Glycine max*).

Cassava is a staple food crop in Nigeria and the third most important source of calories in the SSA agroeco-region as well as the second most important food crop in terms of global annual production (FAOSTAT 2016). Cassava is gradually gaining importance as an industrial crop, hence can be processed into a wide range of products such as industrial starch, flour, beverages, cassava chips for animal feed and ethanol (Tonukari 2004; Manu-Aduening et al. 2006; Muoneke and Mbah 2007; El-Sharkawy 2012). The fresh young leaves of cassava are eaten as vegetable in some parts of Africa according to Burns et al. (2010). Furthermore, the carbohydrate from the fresh roots of cassava is important in the emerging biofuel industry because of its strong potential as a veritable source of ethanol (Alexandratos 1995; Ziska et al. 2009).

Cassava genotypes are greatly distinguished from each other by their morphological characteristics which include plant height, leaf lobes, stem color, canopy diameter, color of root flesh and root diameter among other growth and reproductive attributes. Studies have shown that cassava can be cultivated during the wet and dry cropping seasons and can be harvested over an extended period of time, hence serves as a classical food security crop in the SSA ecoregions (Ekanayake et al. 1994; DeVries and Toenniessen 2001). According to Alves (2002), Calle et al. (2005) and Dixon et al. (2008), cassava is very tolerant of drought and heat stress and produces well even on marginal soils. They further submitted that access to high-yielding cassava genotypes and an improvement of the production system will invariably result in increased economic benefits to local cassava farmers. Information relating to cassava crop improvement can be enhanced by subjecting the plant growth and yield characters to multivariate analysis.

Therefore, the aim of the present experiment was to investigate the interrelationships between fresh root yield and thirteen quantitative yield related characters of some newly developed cassava genotypes and the extent of their contributions to the fresh storage root yields obtained using the correlation coefficients and the path coefficient analysis.

2 Materials and methods

2.1 Location and environmental condition of the experimental site during the trial

A field experiment was carried out in 2016 and 2017 cropping seasons at National Root Crops Research Institute located in Umudike (coordinates: 07° 33′ E; 05° 29′ N; 122 m a.s.l.). Umudike is situated in the humid tropics of southeastern Nigeria. The experimental site experienced a total annual precipitation of 1,901.80 and 2,526.84 mm, average daily air temperature range of 30.5–34.0°C and 30.0–34.0°C as well as average daily solar radiation hours of 5.36 and 5.70 in 2016 and 2017 cropping seasons, respectively.

2.2 Soil analysis of the experimental site

A composite soil of the experimental site was collected at a depth of 0–25 cm prior to planting and taken to the soil science laboratory for physicochemical analysis according to standard laboratory techniques. The results indicated that the pH (soil:water – 1:2.5) of the soil was 6.10 (McLean, 1982), organic carbon (C) 1.10% obtained by wet oxidation method (Nelson and Sommers 1996), total nitrogen (N) 0.10% by semimicro-Kjedahl digestion method (Bremner 1996), available phosphorous (Av. P) 22.7 mg kg^{-1} by molybdenum blue colorimetry method (Olson and Sommers 1982), while exchangeable calcium (Ca^{2+}), potassium (K^{+}) and magnesium (Mg^{2+}) were obtained by neutral ammonium acetate method (Thomas 1982) which gave 4.0, 5.30 and 1.8 cmol kg^{-1}, respectively. The soil texture was characterized as sandy loam and classified as Ultisol (Paleulstult) according to USDA Soil Classification.

2.3 Experimental materials, treatments and design

The experimental treatments comprised twenty-eight (28) newly developed cassava genotypes (Table 1) sourced from the breeding lines of Cassava programme, National Root Crops Research Institute (NRCRI), Umudike, Nigeria, in collaboration with International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Two promising, identified and released cassava genotypes (NR110223 and B1-5) were used as standard in the study.

The experimental site which had been under fallow for 2 years with *Mimosa invisa*, *Imperata cylindrica*, *Aspilia africana*, *Calopogonium mucunoides* and *Cyperus rotundus* as the predominant weeds was cleared, ploughed, harrowed and 1 m ridges are made with the

Table 1: Description of the 28 cassava genotypes studied for variation and yield parameters

Serial number	Cassava genotype	Origin	Serial number	Cassava genotype	Origin
1	NR 110238	NRCRI	15	NR 110228	NRCRI
2	NR 110315	NRCRI	16	NR 110439	NRCRI
3	NR 110181	NRCRI	17	COB 4-100	NRCRI
4	B1-78	NRCRI	18	NR 050080	NRCRI
6	B4-6	NRCRI	20	B1-5	NRCRI
7	TMS 950211	IITA	21	TMS 961708	IITA
8	NR 090142	NRCRI	22	NR 110178	NRCRI
9	NR 060169	NRCRI	23	B1-117	NRCRI
10	TMS 010354	IITA	24	B1-50	NRCRI
11	NR 050667	NRCRI	25	NR 100486	NRCRI
12	B1-56	NRCRI	26	NR 100449	NRCRI
13	NR 060251	NRCRI	27	COB 5-53	NRCRI
14	NR 110223	NRCRI	28	B1-29	NRCRI

NRCRI, National Root Crops Research Institute, Umudike, Nigeria. IITA, International Institute of Tropical Agriculture, Ibadan, Nigeria.

aid of a tractor before marking into experimental units. The 28 genotype treatments were planted at 100 cm × 100 cm inter- and intrarow spacing into the experimental plots of 5 m × 4 m in a randomized complete block design with dual replications, which was equivalent to a plant population of 10,000 plants ha^{-1}. The plots were manually weeded with hoe at 3 and 8 weeks after planting (WAP), while slashing was carried out at 6 months after planting (MAP) to ensure a weed-free and clean farm. At 8 WAP (after the second weeding operation), inorganic fertilizer (N:P:K, 20:10:10) was applied to treatments at the recommended rate of 400 kg ha^{-1} using the ring method of application to achieve an even distribution of nutrients.

2.4 Data collection

Vegetative and reproductive parameters such as leaf area index (LAI), plant biomass, above ground dry matter (AGDM), cassava mosaic disease (CMD) incidence, cassava bacterial blight (CBB) incidence, cyanide potential, starch content, length of root neck, root diameter, root length, number of marketable roots/plant, weight of marketable roots/plant and fresh root yield (Mt ha^{-1}) were evaluated in all the twenty-eight (28) cassava genotypes under investigation.

CMD and CBB incidence (%) were assessed at 9 MAP) on all the plants in each plot. Disease incidence (%) in the experimental plots was determined according to Fargette et al. (1994) by counting and recording the total number of infected plants in each experimental plot and then estimated as the ratio of total number of infected plants to total number of plants in each experimental plot. Whole cassava plants were used as sampled units, while visual method was employed for the assessment. All the cassava plants in each experimental plot were used to ensure a reliable mean estimate.

The LAI of cassava was determined as the ratio of the leaf area of the plant [obtained by measuring the length and broadcast width of the median leaflet and multiplying the product by the total number of the leaflets on the leaf measured, while the total leaf area of the plant was obtained by multiplying the calculated leaf area with the total number of leaves present on the plant according to Ekanayake et al. (1996)] to the area of ground covered by the cassava plant.

At 12 MAP (harvest), three cassava plants were sampled from each experimental unit to reduce bulkiness. They were properly labeled and AGDM of cassava was obtained by cutting the main stem and branches into small pieces and drying the samples in an oven at a temperature of 80°C until a constant weight was obtained and the dry weight was taken with a sensitive balance (Mettler P120).

The cyanide potential (mg kg^{-1} fresh root) and starch content (%) in the roots of the cassava genotypes were analyzed. The measurement of cyanide levels in the fresh roots of cassava was achieved using the alkaline picrate method as outlined by Cooke (1978) and modified by Onwuka (2005). The harvested cassava roots were peeled with a kitchen knife, properly washed to remove dirt and then diced into small chunks. The fresh root chunks were ground in a mortar with the aid of pestle until a homogenized paste was achieved. The homogenized paste samples were oven-dried at 65°C and weighed a number of times until a constant weight was recorded. The flours obtained from the dried paste samples were thoroughly mixed and used to determine cyanide levels in the tested cassava genotypes. According to the laboratory procedure, five grams of each flour sample were added into 50 mL distilled water and left to stand in the dissolved state for 12 h. The samples were filtered and the filtrates obtained were used to determine the cyanide level. Thereafter, 1 g of picrate and 5 g of sodium carbonate (Na_2CO_3) were dissolved in 200 mL of distilled water to give alkaline picrate. Furthermore, 4 mL of alkaline picrate was added to 1 mL of the aqueous extract and the mixture was subjected to incubation in a water bath at a temperature reagent blank containing 1 mL of distilled water and 4 mL of alkaline picrate solution of 50°C for 5 min to enable color development and absorbance. Similarly, a blank reagent containing 4 mL of alkaline picrate solution and 1 mL of distilled water solution was prepared as the standard. The visible absorption of the reaction product (dark red color) was read on the spectrophotometer at 490 nm wavelength against the standard solution. Then, a set of potassium cyanide in serial dilutions was prepared and arranged to correspond with the concentrations of 0.1, 0.2, 0.3, 0.4 and 0.5 $\mu g\,mL^{-1}$. The resulting product solutions were further diluted with 10 mL of water to give the following concentrations: 0.01, 0.02, 0.03, 0.04 and 0.05 $\mu g\,mL^{-1}$. The cyanide levels in the cassava sampled flours were obtained by extrapolation from the standard calibration. The total amount of cyanide in each 100 g of cassava flour sample was calculated with the formula shown below:

$$\text{Cyanide (mg kg}^{-1}) = (\mu\text{g mL}^{-1}\text{ of cyanide level} \times \text{final volume (mL)} \times 10) / \text{Weight of cassava flour sample,} \quad (1)$$

where $\mu g\,mL^{-1}$ of cyanide level is obtained from the standard calibration, final volume – volume of the sample size measured from the filtered extract, weight of sample – weight of the sample extracted.

The starch content in the fresh roots of the cassava genotypes was obtained by washing the dirt out as to secure clean roots. The brown surface layer of the root was peeled with stainless steel knife, and the fresh peeled flesh was washed with portable water to remove dirt and sand particles. The peeled roots were grated and sieved, and the mixture was filtered through a fine mesh (muslin cloth). The filtrate was allowed to settle for 6 h before the supernatant was decanted. Thereafter, the sediment was washed thrice with portable water to obtain a white, odorless and tasteless starch. The wet starch obtained was spread thinly over a black high-density polyethylene in the open air for drying under ambient conditions (28–30°C at 70–80% relative humidity) for a period of 5 h before drying the partially dried starch in an air oven at 60°C until a constant weight was obtained. The properly dried starch cake with a constant weight was milled with a hammer mill to fine particles.

The root neck of cassava (cm) was obtained by measuring the neck collar of the cassava stem base with a meter rule, while root girth (cm) was obtained as the mean value of the girth taken from the top, middle and lower portions of the root with the help of Vernier calipers. The root length of cassava (cm) was obtained with a meter rule as the distance from the lower edge of the root neck to the tip of the root. The number of marketable roots per plot was achieved by counting, while the weight of marketable roots per plot was obtained with the aid of a weighing balance (kg). Fresh root yield ($Mt\,ha^{-1}$) from the net plot was obtained and extrapolated per hectare.

2.5 Statistical analysis

All the field and laboratory data obtained were statistically analyzed according to the procedure for a randomized complete block design with the aid of GenStat Discovery, Edition 4.23 (2007) software package. The significant treatment mean differences were performed with F-tests (LSD) at $P \leq 0.05$ as outlined by Obi (2002). Pearson correlation analysis was performed using the SPSS Ver. 18 (2010) for windows (SPSS Inc., Chicago, IL, USA) to determine the correlation coefficients of cassava fresh root yield to other plant attributes following the procedure outlined by Miller et al. (1958) as well as Singh and Chaudhury (1985):

$$rgXY = \text{GCOV } XY / \sqrt{(\sigma^2 gX)(\sigma^2 gY)} \quad (2)$$

where $rg\,XY$ = genotypic correlation coefficients between plant characters X and Y, GCOV XY = genotypic covariance between plant character X and plant character Y, $\sigma^2\,gX$ and $\sigma^2\,gY$ = genotypic variance for characters X and Y, respectively.

The significance of the correlations was tested by the t-test according to Vencovsky and Barriga (1992), with n-2 degrees of freedom, where n is the total number of observations. The correlation coefficients were further partitioned into direct and indirect effects of the characters (independent variables of the regression model) on fresh root yield (dependent variables) using the path analysis, which is a standard selection criterion that measures the magnitude and directions of multiple effects on root yield as described by Dewey and Lu (1959), Togay et al. (2008) and Hailegebrial et al. (2015). The path coefficients are standardized partial-regression coefficients obtained from equations, where the yield-related variables are expressed as deviations from the means in units of standard deviation (Steel et al. 1997). The letter R represents the residual factors that influenced fresh storage root yield complex in cassava. A path diagram indicating the relationships of the cause and effect (Figure 1) exhibited that lines with double arrows indicated the interrelationships among the variable characters as measured by the correlation coefficients, while lines with single arrows indicated the direct effects on fresh root yield as measured by the path coefficients.

The direct and indirect effects of the independent characters on fresh root yield of cassava were estimated based on the formula:

$$r_{ij} = p_{ij} + \sum r_{ik} \cdot p_{kj}, \tag{3}$$

where r_{ij} = mutual association between the independent characters (i) and dependent characters – fresh root yield (j) as measured by the correlation coefficients, p_{ij} = components of direct effects of the independent characters (i) on the dependent characters – fresh root yield (j), $\Sigma r_{ik} \cdot p_{kj}$ = summation of components of indirect effect of a given independent character (i) on the dependent characters – fresh root yield (j) via all other k-independent characters.

The residual effects were estimated with the formula:

$$\text{Residual effects } (R) = [1-(P_1 r_{16} + P_2 r_{26} + P_3 r_{36} + P_4 r_{46} + P_5 r_{56} + P_6 r_{66} + P_7 r_{76} + P_8 r_{86})] \cdot 100 \tag{4}$$

3 Results and discussion

The results from the analysis of variance (Table 2) indicated that cassava genotypes significantly ($P < 0.05$) affected all the tested variables (LAI at 12 MAP, plant biomass, CMD incidence, CBB incidence, cyanide potential, starch content, length of root neck, root diameter, root length, number of marketable roots per plot, weight of marketable roots per plot and total fresh root yield [Mt ha^{-1}]).

Among the cassava genotypes, LAI at 12 MAP and plant biomass ranged from 2.22 [21] (TMS 961708) to 7.26 [20] (B1-5) and 300 [20] (B1-5) to 665 [22] (NR110178) kg per plant, respectively, while CMD and CBB incidence ranged from 5.0% [6] (B4-6) to 70.0% and 26.0% to 85.0%, respectively. The cassava genotype [10] (TMS 010354) exhibited the highest CMD incidence which was higher by 92.9% relative to the lowest disease incidence recorded in [20] B1-5 cassava genotype, while [4] B1-78 had the lowest CBB incidence percentage, which was lower by 69.4% relative to the highest CBB disease incidence recorded in [25] NR100486 and [26] NR100449 cassava genotypes. Furthermore, the disease incidence across all the tested cassava genotypes was relatively low; an indication of resistance level exhibited due to the

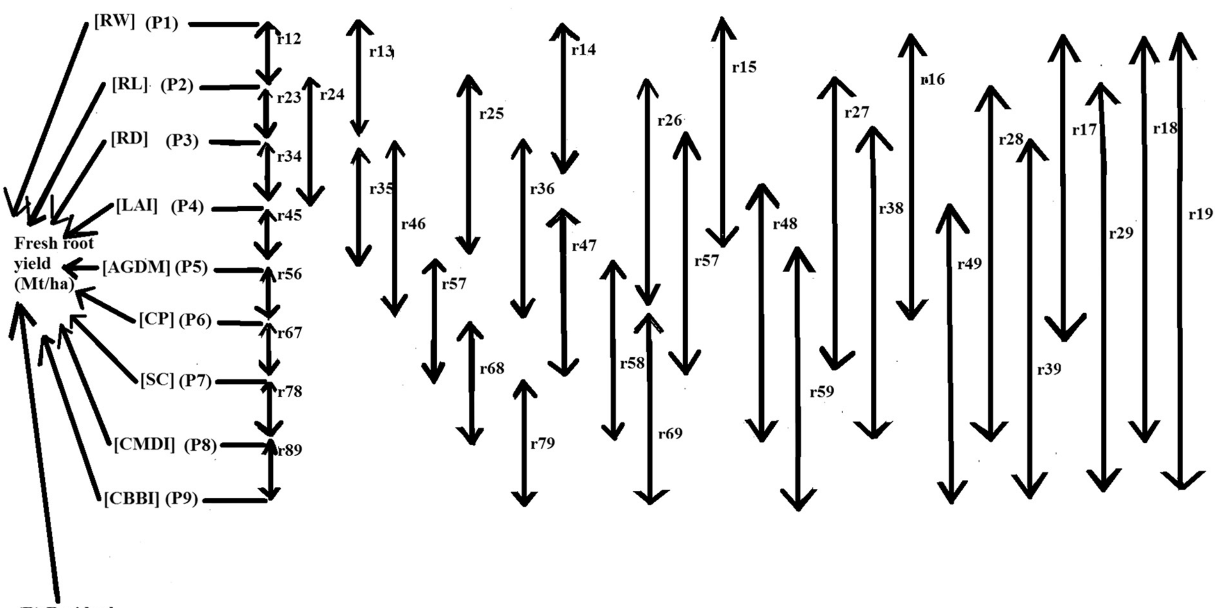

Figure 1: Nature of casual of variables for the path coefficients analysis in twenty-eight cassava genotypes. Residual factor (R), unilateral pathway (P1–P9), values of correction coefficients ($r_{12} - r_{89}$) as obtained from mutual associations between variables of cassava genotypes. Double arrowed lines ($\longleftrightarrow$) denote mutual associations as measured by correction coefficients. Single arrowed lines ($\longleftarrow$) denote direct influence and measured by the path coefficients analysis. Abbreviations: RW, root weight/plot (kg); RL, root length (cm); RD, root diameter (cm), LAI, leaf area intex; AGDM, above ground dry matter (g); CP, cyanide potential (mg/kg fresh root); SC, starch content (%); CMDI, cassava mosaic disease incidence (%); CBB, cassava bacteria blight incidence (%).

Table 2: Multivariate assessment of twelve (12) characters of twenty-eight (28) cassava genotypes in Umudike, Nigeria

Cassava genotypes	LAI (12 MAP)	Plant biomass (kg)	CMD incidence (%)	CBB incidence (%)	Cyanide potential (mg kg^{-1} fresh root)	Starch (%)	Length of root neck (cm)	Root diameter (cm)	Root length (cm)	No. of marketable roots plot^{-1}	Weight of marketable roots (kg plot^{-1})	Total fresh root yield (Mt ha^{-1})
NR110238	5.77	540	62.5	60.0	64.24	22.37	21.80	6.70	15.50	48.0	26.60	16.45
NR110315	4.39	500	14.0	80.0	59.04	19.45	15.70	3.85	21.60	41.5	32.60	18.77
NR110181	6.16	575	49.5	42.5	60.18	17.44	20.70	5.55	16.95	45.5	22.55	12.62
B1-78	4.75	550	30.0	26.0	52.28	16.20	11.55	4.90	10.35	31.0	19.50	10.58
NR110084	3.54	500	18.0	55.0	61.25	23.13	13.80	5.30	10.95	24.0	27.10	14.23
B4-6	3.99	450	5.0	82.5	61.23	21.04	23.00	5.55	15.20	64.0	23.20	12.65
TMS950211	2.43	450	45.0	52.5	51.03	18.43	18.05	4.90	15.00	18.0	15.20	8.55
NRO90142	3.73	475	11.0	57.5	77.23	22.32	15.00	5.30	17.50	44.0	25.50	13.80
NR060169	4.54	465	12.5	75.0	66.51	23.16	21.25	4.55	22.55	42.0	24.50	12.75
TMS010354	5.36	475	70.0	68.5	78.33	20.66	15.00	5.05	14.30	22.5	15.35	9.68
NR050667	3.03	565	16.0	35.0	49.24	23.05	28.00	4.80	24.00	31.0	14.10	7.98
B1-56	3.61	525	42.5	50.0	70.13	18.90	23.05	5.30	8.55	27.5	21.20	13.45
NR060251	5.81	410	32.5	65.0	73.14	18.11	14.05	5.70	12.75	24.5	15.80	9.25
NR110223	6.12	575	14.0	50.0	43.25	19.25	19.75	4.85	10.50	28.0	19.00	12.20
NR110228	3.05	500	15.0	60.0	81.42	21.12	19.80	5.40	13.60	54.0	21.15	11.40
NR110439	2.44	565	57.0	60.0	82.05	24.17	15.50	5.35	14.95	32.5	25.80	14.00
COB4-100	3.81	500	30.0	50.0	70.14	20.32	17.00	4.30	21.00	23.5	12.95	7.88
NR050080	5.09	545	15.0	65.0	58.64	25.11	16.45	5.50	23.60	27.5	9.65	5.38
NR100297	6.14	615	60.0	68.5	60.52	22.03	24.00	5.00	20.85	21.5	22.80	11.73

Cassava genotypes	LAI (12 MAP¹)	Plant biomass (kg)	CMD incidence at 9 MAP (%)	CBBincidence at 9 MAP (%)	Cyanide potential (mg kg^{-1} fresh root)	Starch (%)	Length of root neck (cm)	Root diameter (cm)	Root length (cm)	No. of marketable roots plot^{-1}	Weight of marketable roots (kg plot^{-1})	Total fresh root yield (Mt ha^{-1})
B1-5	7.26	300	15.0	80.0	36.235	22.16	8.55	5.10	10.55	34.5	16.90	17.60
TMS961708	2.22	415	17.5	42.5	81.050	28.05	16.70	5.10	17.55	30.5	14.10	9.43
NR110178	3.97	665	17.5	60.0	74.615	18.66	20.20	10.50	10.80	12.0	12.20	7.25
B1-117	3.53	400	27.5	75.0	43.015	21.26	22.00	5.65	21.90	22.5	23.00	13.58
B1-50	3.87	360	25.0	75.0	44.245	19.23	11.10	5.00	16.55	16.0	13.00	8.00
NR100486	4.11	450	27.5	85.0	48.880	20.31	17.65	5.85	19.30	25.5	16.00	9.00
NR100449	3.84	500	16.0	85.0	39.100	16.95	15.10	5.40	14.65	15.5	9.60	5.60
COB5-53	3.20	550	25.0	57.5	41.010	16.65	18.35	3.85	24.10	29.0	15.60	10.60
B1-29	3.61	420	17.5	65.0	86.110	16.44	11.05	4.70	11.50	30.0	14.75	8.40

Table 2: Continued

Cassava genotypes	LAI (12 MAP¹)	Plant biomass (kg)	CMD incidence at 9 MAP (%)	CBBincidence at 9 MAP (%)	Cyanide potential (mg kg^{-1} fresh root)	Starch (%)	Length of root neck (cm)	Root diameter (cm)	Root length (cm)	No. of marketable roots plot^{-1}	Weight of marketable roots (kg plot^{-1})	Total fresh root yield (Mt ha^{-1})
Grand Mean	4.26	494	28.1	61.7	61.216	20.57	17.65	5.32	16.31	30.9	19.50	11.17
SED	1.373	81.676	12.788	17.232	0.052	0.795	3.019	0.914	3.323	10.029	16.90	3.141
LSD $_{(0.05)}$	2.817	167.6	26.24	35.36	0.1064	1.631	6.196	1.875	6.819	20.58	12.497	6.444
F Pr.	0.078*	0.053*	<0.001***	0.136*	<0.001***	<0.001***	<0.001***	0.001**	<0.001***	0.003**	0.035*	0.016*

Data analyzed with least squares means and means separated with LSD. ns, *, ** and *** stand for nonsignificant at the 0.05 probability level, significant at the 0.05, 0.01 and 0.001 probability level, respectively. WAP, weeks after planting, CMB, cassava mosaic disease, CBB, cassava bacterial blight. MAP, months after planting, CMB, cassava mosaic disease, CBB, cassava bacterial blight. *$P \le 0.05$, **$P \le 0.01$, ns. nonsignificant

genetic make-up of the individual genotypes. The findings corroborate similar results by Okonkwo (2002) on cassava response to biotic stress, Egesi et al. (2004) on CMD-resistant varieties, Sayre et al. (2011) on biofortification of cassava studies and Odedina et al. (2015) on poultry manure and time of harvest effect on cassava as well as Pipatsitee et al. (2019) on the growth performance of cassava in response to water-deficit stress in Thailand in which they highlighted that growth, disease resistance and yield performance of cassava can be attributed to strong influence by a number of factors such as the genetic constituent of the crop, nutrient status of the soil and environmental conditions under which the root crop was grown. The results further revealed that [28] B1-29 exhibited the highest cyanide potential (86.11 mg kg^{-1}), while [20] B1-5 had the least amount of cyanide potential (36.24 mg kg^{-1}) in its fresh root yield compared with the other cassava genotypes. These levels of cyanide potential recorded among the newly developed cassava genotypes were considered moderately at the same level relative to other previously released cassava genotypes in Nigeria as reported by Githunguri et al. (2004), Dada and Oworu (2010), Okpara et al. (2014) and Ashok et al. (2019).

The starch content varied from 16.20 to 28.05% on genotypes [4] B1-78 and [21] TMS961708, respectively, with a grand mean of 20.57%. The great variations recorded from the findings on this quantitative variable corroborate similar studies by Perez et al. (2001), Ceballos et al. (2004), Tonukari (2004), Ntawuruhunga and Dixon (2010), Vanderschuren and Zhang (2011) as well as Ebah-Djedji et al. (2012) in their various studies who submitted that the starch content in cassava genotypes is not only influenced by environmental factors and physiological status of the crop but also served as one of the principle characters required in the development and improvement of cassava genotypes for the domestic and industrial uses. The length of the root neck, root diameter and root length ranged from 8.55 to 28.00 cm, 3.65 to 6.70 cm and 8.55 to 24.10 cm, respectively, with [11] NR050667, [1] NR110238 and [27] COB 5-53 cassava genotypes exhibiting the longest root neck, thickest root diameter and longest root, respectively, compared with the other cassava genotypes.

The cassava genotype, [6] B4-6 closely followed by [15] NR110228, exhibited the highest number of fresh roots per plot relative to the other genotypes evaluated in the study. The weight of marketable fresh roots of the genotypes varied significantly (P < 0.05) with [2] NR110315 as the weightiest among the genotypes, while [26] NR100449 had the least fresh root weight. The same trend was recorded under total fresh root yield (Mt ha^{-1}) with [2] NR110315 closely followed by [20] B1-5 and [1] NR110238 exhibiting the highest root yield compared with other genotypes studied. Among the highest yielder, [2] NR110315 gave higher total fresh root yield by 5.75 and 12.36% relative to [20] B1-5 and [1] NR110238, respectively, while the same yield was also higher by 71.34% relative to the least yielder [18] (NR050080) that gave 5.38 Mt ha^{-1} total fresh root yield. Similar studies by Eke-Okoro (2000) on some cassava varieties, Carsky and Toukourou (2005) in Southern Benin, West Africa, on fertilizer application on cassava, Elegba et al. (2013) on five cassava accessions, Njoku et al. (2014) in their works on the identification of pro-vitamin A cassava varieties in Nigeria, Danquah et al. (2016) in the Guinea Savannah ecology of Ghana reported significantly high root yield in cassava at 12 MAP, Adjebeng-Danquah et al. (2016) on genotypic diversity of some cassava genotypes in the Guinea Savannah ecology of Ghana, Warunyu et al. (2019) on four contrasting cassava morphotypes in Thailand and Badewa et al. (2019) on ten parental yellow-fleshed root cassava genotypes in the Guinea Savannah agroecological zone of Nigeria which was not only due to the genetic make-up of the cultivars but also environmental factors under which the crops were grown.

Pearson's correlation analysis (Table 3) indicated that fresh root yield of cassava exhibited positive and highly significant ($P \leq 0.01$) correlation with LAI with correlation coefficients (r) of 0.51. Furthermore, the results indicated that the root weight per plot showed highly significant ($P \leq 0.01$) and positive correlations with root length ($r = 0.60$), root diameter and LAI ($r = 0.68$) as well as between AGDM and cyanide potential with $r = 0.52$. The other variables exhibited nonsignificant ($P \geq 0.05$) correlation among themselves. The findings corroborate similar studies at different locations by Adeniji et al. (2011) in Northern Nigeria, Mulualem and Dagne (2013) in Ethiopia, Kundy et al. (2014a) in southern Tanzania, Okpara et al. (2014) in southeastern Nigeria, Babu et al. (2017) in India, Adu et al. (2018) on eight cassava genotypes in Ghana and Warunyu et al. (2019) in Thailand on relationships between cassava yield components which indicated significant and positive correlations among the yield characters; an indication that the yield indices especially LAI, AGDM, cyanide potential, root diameter, root length and root weight at genotypic level contributed significantly, hence could serve as veritable information tool during the selection of cassava characters for fresh root yield improvement.

The path coefficient analysis (Table 4) of nine plant variables (weight of marketable roots per plot [kg], root

Table 3: Pearson's correlation matrix between variables of twenty-eight (28) cassava genotypes in Umudike, Nigeria

Variables	Total fresh root yield (Mt ha^{-1})	Root weight (kg plot^{-1})	Root length (cm)	Root diameter (cm)	LAI (12 WAP)	AGDM (g)	Cyanide potential (mg kg^{-1} fresh root)	Starch (%)	CMD incidence at 9 MAP (%)	CBB incidence at 9 MAP (%)
Total fresh root yield (Mt ha^{-1})	1	0.34 ^{ns}	0.29^{ns}	0.26^{ns}	0.51**	0.15^{ns}	−0.07^{ns}	0.20^{ns}	0.04^{ns}	0.11^{ns}
Root weight (kg plot^{-1})		1	0.60**	−0.05^{ns}	0.19^{ns}	−0.22^{ns}	−0.18^{ns}	0.27^{ns}	−0.04^{ns}	0.13^{ns}
Root length (cm)			1	−0.19^{ns}	0.13^{ns}	−0.19^{ns}	−0.05^{ns}	0.35^{ns}	−0.09^{ns}	0.12v
Root diameter (cm)				1	0.68**	0.12^{ns}	0.04^{ns}	0.04^{ns}	0.07^{ns}	0.23^{ns}
LAI (12 WAP)					1	0.11^{ns}	−0.01^{ns}	−0.07^{ns}	0.09^{ns}	0.15^{ns}
AGDM (g)						1	0.52**	0.23^{ns}	0.27^{ns}	−0.20^{ns}
Cyanide potential (mg kg^{-1} fresh root)							1	0.36^{ns}	0.17^{ns}	−0.17^{ns}
Starch (%)								1	−0.08^{ns}	−0.06^{ns}
CMD$^{\pm}$ incidence at 9 MAP (%)									1	−0.16^{ns}
CBB‡ incidence at 9 MAP (%)										1

WAP, weeks after planting, MAP, months after planting, CMB, cassava mosaic disease, CBB, cassava bacterial blight. *, $P \leq 0.05$, **, $P \leq 0.01$,^{ns}, nonsignificant.

Table 4: Path coefficient analysis indicating direct and indirect effects and correlation coefficients of nine plant characters of twenty-eight (28) cassava genotypes on fresh root yield in Umudike, Nigeria

Characters	Direct effects	Root weight (kg plot^{-1})	Root length (cm)	Root diameter (cm)	LAI (12 WAP)	AGDM (g)	Cyanide potential (mg kg^{-1} fresh root)	Starch content (%)	CMDincidence at 9 MAP (%)	CBB incidence at 9 MAP (%)	Correlation coefficients (r^2)
Root weight (kg plot^{-1})	**0.129**	—[a]	0.077	−0.006	0.024	−0.029	−0.022	0.035	0.006	0.017	0.336 ^{ns}
Root length (cm)	**0.062**	0.368	—	−0.011	0.008	−0.012	−0.003	0.021	−0.006	0.007	0.291^{ns}
Root diameter (cm)	**−0.139**	0.007	−0.026	—	−0.095	−0.017	−0.006	−0.006	−0.010	−0.031	0.257^{ns}
LAI (12 WAP)	**0.549**	0.104	0.070	0.373	—	0.060	−0.002	−0.039	0.051	−0.084	0.505**
AGDM (g)	**0.210**	−0.046	−0.039	0.025	0.002	—	0.109	0.047	0.057	−0.041	0.146^{ns}
Cyanide potential (mg kg^{-1} fresh root)	**−0.218**	0.038	0.012	−0.009	−0.001	−0.113	—	−0.079	−0.037	−0.037	−0.067^{ns}
Starch content (%)	**0.228**	0.062	0.079	0.010	−0.016	0.052	0.083	—	−0.017	−0.014	0.203^{ns}
CMD incidence at 9 MAP (%)	**0.021**	−0.001	−0.001	0.001	0.002	0.057	0.004	−0.002	—	−0.003	0.044^{ns}
CBB incidence at 9 MAP (%)	**0.059**	0.008	0.007	0.013	0.009	−0.012	−0.010	−0.004	−0.009	—	0.114^{ns}
Residual											**0.773**

WAP, weeks after planting, MAP, months after planting, CMB, cassava mosaic disease, CBB cassava bacterial blight. Values highlighted are direct effects of plant characters on fresh root yield of cassava (Mt ha^{-1}) while the off-diagonal values are indirect effects of nine plant characters via the specific correlation coefficients path. *, $P \leq 0.05$, **, $P \leq 0.01$, ns, nonsignificant.
[a] Dashes indicate no values because the representative values are shown in the highlighted column indicating direct effects.

length [cm], root diameter [cm], LAI at 12 MAP, AGDM [g plant^{-1}], cyanide potential [mg fresh root^{-1}], starch content [%], CMD incidence [%] at 9 MAP and CBB incidence [%] at 9 MAP), which on examination indicated the direct and indirect effects of the variables on fresh root yield of cassava. LAI exhibited highly significant, positive and direct effect on fresh root yield with the correlation coefficient (r^2) of 0.505 relative to the direct effects of the other variables. The mean sequence of the positive and direct effect of the variables on fresh root yield of cassava was in the order: LAI > starch content > AGDM > weight of fresh marketable roots per plant > root length > % CBB incidence > % CMD incidence, while the cyanide potential and root diameter had a direct but weak and negative effect on fresh root yield. This suggests that the selection through these characters with positive and greater magnitudes could be effective in identifying genotypes with high root yield. The weight of fresh marketable roots per plant had weak, positive and indirect effect on root yield through root length and LAI, while the root diameter positively impacted on root yield indirectly via LAI. AGDM exhibited a weak, negative and indirect effect on fresh root yield through the cyanide potential. The other variables had a negligible indirect but largely negative effect on fresh root yield. These are good attributes that could be subjected to further studies aimed at enhancing fresh root yield of cassava genotypes before releasing them to farmers in the local region of southeastern Nigeria.

The residual effect determines how best the casual factors accounted for variability of the fresh root yield of cassava. Its estimate (0.773) indicated that the nine plant characters only explained 22.7% of the total variations in the fresh root yield of cassava. The findings further showed that the level of determination was low, an indication that some other factors (77.3%) that were not considered into account need to be included in the result study analysis as to account appropriately for the total degree of variations of fresh root yield of the cassava genotypes. Further examination of the partitioning into direct and indirect effects indicated that LAI, starch content and AGDM exerted the greatest direct and indirect effect on fresh root yield of cassava. Hence, they can be assumed to be important criteria that could be used in selecting desirable characters for the genetic improvement of cassava. The findings were in consonance with different investigations on cassava in varied tropical locations conducted by Ntawuruhunga et al. (2001) on ten cassava genotypes in low-, mid- and high-altitude locations in Uganda, Mulualem and Dagne (2013) on eleven cassava genotypes in three locations of southern Ethiopia, Kundy et al. (2014b) on twelve cassava genotypes in three locations of Southern Tanzania, Okpara et al. (2014) on thirty-eight (38) high- and low-cyanide cassava genotypes in the lowland plains of southeast Nigeria, Babu Rao et al. (2015) on seventy-seven (77) cassava genotypes in the eastern coastal plains of India, Akpan and Udoh (2017) on five cassava genotypes in the Cross River flood plains, Nigeria, Kumba et al. (2019) on 102 cassava accessions in the lowland Southern Sierra Leone as well as Diniz and Oliveira (2019) on eight hundred and fourteen (814) cassava accessions in two environments in Brazil in which they have recorded significant and positive relationships between the fresh root yield of cassava and some yield characters such as LAI, starch content, AGDM, root length and weight of fresh root yield per plant. These intrinsically useful genetic criteria invariably demand significant attention in cassava development and improvement during the selection aimed at increased fresh root yield and starch content in the field crop.

4 Conclusion

The correlation coefficients from the analysis indicated the associations among the characters and their direct and indirect effects on fresh root yield of the newly developed cassava genotypes, while the results from the path coefficient analysis showed that premium should be placed on these agronomic characters (LAI at 12 MAP, starch content, AGDM, weight of fresh marketable roots per plant, root length, per cent CBB incidence, per cent CMD incidence, cyanide potential and root diameter) for effective selection strategies aimed at higher fresh root yield of cassava and to improve the development of new genotypes characterized by high productivity.

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