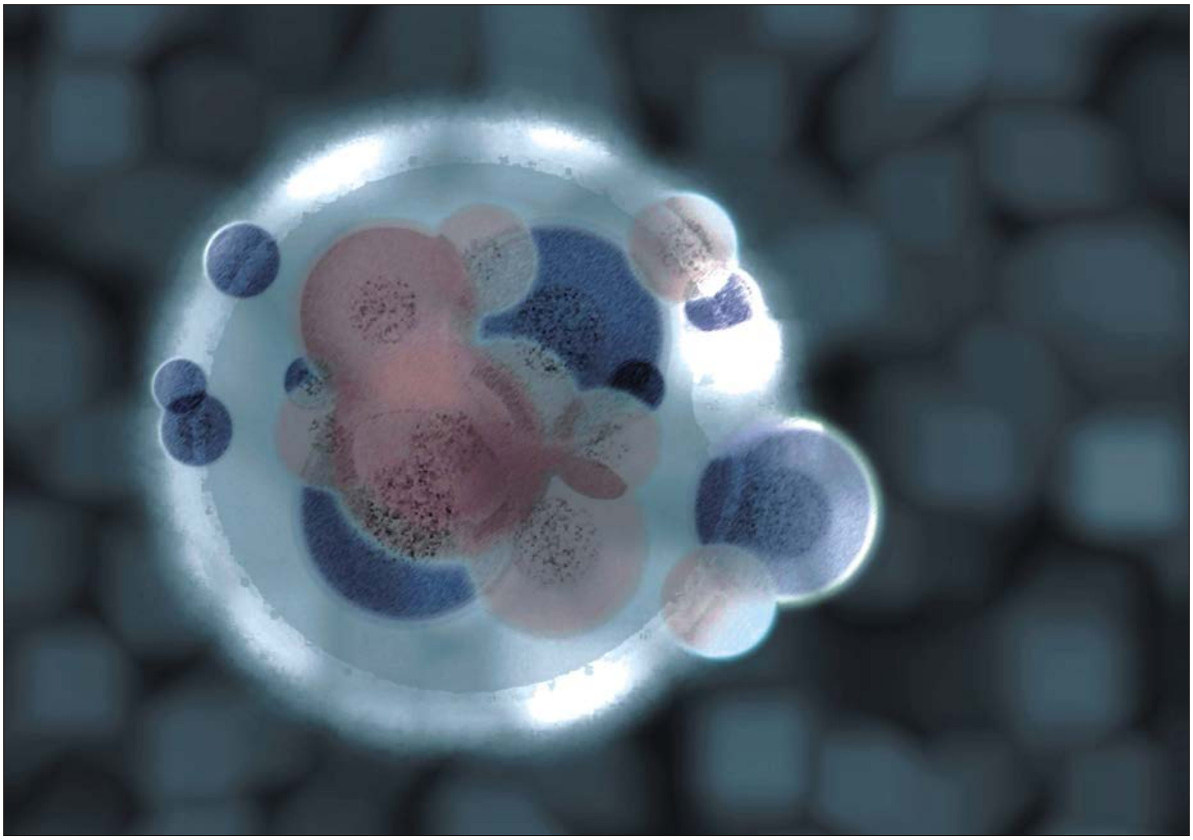

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Trait Association and Path Analysis for Cassava Genotypes in Four Agroecological Zones of Nigeria

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Abstract: The associations among different traits and their direct and indirect influence on yield using the path analysis and correlation procedures were examined in 20 broad-based cassava genotypes to understand how inter-character relationships influences root yield. Field evaluation was carried out in 4 agroecological zones of Nigeria for two cropping seasons. Data were collected on morphological and yield parameters such as plant height, stem girth, canopy volume, shoot weight, leaf size, number of roots, root size and root yield. Results showed that root parameters such as medium-sized roots with correlation coefficient (r) of 0.95, number of roots ($r = 0.91$) and small-sized roots ($r = 0.77$) were highly significantly ($p<0.001$) correlated) with root yield. Path analysis revealed that number of roots had the largest direct effect on root yield with a direct path coefficient effect (P) of 0.61, accounting for 86% of the total direct + indirect effects, followed by number of medium-sized roots ($p = 0.23$), that accounted for 79.2% of the total direct + indirect effects. Small-sized roots had a negative direct effect on root yield ($p = -1.21$) but a positive indirect effect ($p = 1.91$) via number of roots. Number of storage roots and medium-sized roots both contributed the largest influence on storage root yield in cassava. These parameters should, therefore, be considered together while selecting for cassava genotypes with higher storage root yield potentials.

Key words: Cassava, correlation analysis, traits association, path coefficients, direct and indirect effects

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the most important tropical root crop (Meireles da Silva *et al*., 2003), following closely after maize and sugarcane as the third most important source of calories in the tropics (FAO, 2004). Cassava provides close to 500 calories/day for more than 70 million people (Kawano *et al*., 1998). World cassava production of 192.35 million tonnes (t) in 2003 increased to 203.34 million t in 2005, reflecting a 5.4% increase in world production. Nigeria produced 38.18 million t of fresh roots in 2005, representing 34.8% of Africa's total production and 18.8% of the world's total production (FAOSTAT, 2006). In recent times, there has been a worldwide increase in total land area cropped to cassava. In 2003, an estimated area of 17.6 million ha was cropped to cassava and this increased to 18.7 million ha in 2005, an increase of 5.7%. In 2005, Nigeria cultivated 4.1 million ha to cassava, 66.1% of the total area under cassava cultivation in Africa and 22.1% of the world's total land area cultivated to this crop. Nigeria, therefore, remains the largest producer of cassava in the world with an annual production of over 38 million t of tuberous roots, followed by Brazil with 26.6 million t and Indonesia with 19.5 million t (FAOSTAT, 2006). Despite the increase in production in Nigeria over the years, there has also been a steady decline in yield. An average production of 11.7 t ha^{-1} in 1990 declined to 10.7 t ha^{-1} in 1996 and to 9.3 t ha^{-1} in 2005 (FAO, 2006). This decline in tuber yield in Nigeria has been associated with production constraints, such as unavailability of improved varieties, lack of a well developed market access infrastructure and adequate processing technology, problems of marketing and problems associated with climatic, soil and biotic factors. Genetic improvement aimed at increasing the tuber yield of cassava has become a major focus of international research institutes, such as IITA (1990) and CIAT and also in several regional and national programs where concerted efforts are put in place to develop new improved genotypes that are high yielding with a stable yield across diverse agroecological zones and also resistant to prevalent diseases and pests. Yield is, however, a complex quantitative character controlled by several genes and its improvement depends largely on the functioning and interaction of several physiological components that vary for different genotypes. There is a need to understand the inter-character relationships among genotypes, to identify traits that determine tuber

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yield and to find out the influence of other traits associated with yield. Estimates of phenotypic correlation among characters are useful in planning and evaluating breeding programs (Mahungu, 1983). Mahungu (1983) showed that the number of roots contributed more to the final yield than root size. Naskar *et al.* (1989) reported that tuber length had a positive direct effect on yield. Makame (1995) and Ntawuruhunga *et al.* (2001) established that tuberous root yield was highly correlated with number of tuberous roots/plant, tuberous root size and harvest index. Plant breeders need to ascertain if improvement in one character will simultaneously result in changes in other characters and this could be achieved by estimating inter-character correlations among genotypes. For a better understanding of the association among variables, correlation analysis should be combined with path coefficient analysis. Path analysis is a standardized partial regression that measures the direct influence of one variable over another and permits the separation of the correlation components into direct and indirect effects (Dewey and Lu, 1959). The path analysis procedure has been employed to analyze inter-character associations in several crops, such as sweet potato (Kamalan *et al*., 1978; Naskar *et al*., 1989), yam (Akoroda, 1981) and cassava (Makame, 1995; Ntawuruhunga *et al*., 2001). This study was conducted to examine the associations among different traits and identify characters that are correlated with root yield, also to determine indices that determine yield in cassava.

MATERIALS AND METHODS

Field evaluation of 20 genotypes with broad-based multiple pest resistance was carried out at four different locations in Nigeria for two planting seasons (1999/2000 and 2000/2001). The experimental sites were in Ibadan (forest savanna transition, lat. 7°26′N, long. 3°54′E), Mokwa (southern Guinea savanna, lat. 9°29′N, long. 5°04′E) Zaria, (northern Guinea savanna, lat. 11°11′N, long. 7°38′E) and Mallamadori, (Sudan savanna, lat. 11° 78′N, long. 9° 34′E). The experimental design was a randomized complete block design with four replicates on a plot size of 10×4 m in 4 rows of 10 plants/row. Plants were spaced at 1×1 m on ridges 30 cm high and spaced 1m apart. Planting was done in each location when soil moisture was sufficient to sustain good plant establishment. Soil samples taken from each location were analyzed for soil physical and chemical composition. The fields under natural rainfed conditions were maintained free of weeds with hoes and cutlasses and no fertilizer was applied.

Data on morphological characterization were taken at 3, 6 and 9 Months After Planting (MAP) for parameters that included plant height, stem girth, number of nodes, height at first branching, length of stem with leaves, canopy volume, leaf size and stay-green ability. Harvest data were collected at 12 MAP on a plot basis from 20 plants. The following yield parameters were determined: storage root weight (kg), fresh shoot weight (kg), number of storage roots, number of small roots (size 3), medium roots (size 5) and large roots (size 7). Harvest index and dry matter percentage (DM %) were also determined.

Statistical analysis: All data generated were subjected to Analysis of Variance (ANOVA) using the Generalized Linear Model (GLM) procedures of the statistical analytical system version 9.1 (SAS, 2000). Both genotypes and locations were considered as random factors and the significance of the main effect (genotype) was determined with the appropriate error term. Means with significant differences were separated with Duncan New Multiple Range Test (DNMRT). Phenotypic correlations based on the Pearson's correlation coefficient were calculated using the PROC CORR procedure of SAS. Path-coefficient analysis was done using the procedures of the path analysis program PATHANAL (Akintunde, 2001).

RESULTS

Results of ANOVA for morphological and yield parameters (Table 1) showed that significant ($p<0.01$) mean squares existed among genotypes for most parameters as well as high variability among genotypes as revealed in the range of their mean values and coefficients of variations. Results of correlation analysis, as shown by their coefficients of correlation for storage root yield and shoot parameters (Table 2), revealed that, of all the shoot parameters evaluated in this study, only stay-green ability showed significant ($p<0.05$) correlation ($r = 0.37$) with storage root yield. Significant inter-character correlation, however, existed among the shoot parameters. Plant height was highly significantly ($p<0.001$) correlated with height at first branching ($r = 0.59$); number of nodes was also highly significantly ($p<0.001$) but negatively correlated with plant height ($r = -0.52$); canopy volume showed a highly significant correlation ($p<0.001$) with height with leaf ($r = 0.73$) and was significantly correlated ($p<0.01$) with plant height ($r = 0.56$) and stem girth ($r = 0.50$). Results showed that significant correlation ($p<0.001$) existed between storage yield and most of the yield parameters (Table 3), medium-sized roots had the

Table 1: Phenotypic variability for agronomic traits among 20 cassava genotypes in four locations in Nigeria for two seasons

				Mean squares	
Character	Mean±SE	Range	CV (%)	B/w clones (df = 19)	Error (df=430)
Plant height	114.71±1.50	55.33 - 290.11	32.8	3490.56***	235.21
Stem with leaves	38.06±0.75	4.33 - 210.22	49.4	798.77***	157.47
Stem girth	1.79±0.01	0.92 - 3.31	17.2	0.33***	0.04
Leaf size	100.79±1.73	24.57 - 262.31	42.9	2067.62***	530.95
Stay-green	4.33±0.03	2.67 - 5.00	17.4	0.36***	0.17
Stands at harvest	14.86±0.29	0.00 - 20.00	48.1	69.65***	23.52
Number of roots	4.81±0.10	0.33 - 30.00	53.1	20.52***	2.79
Size 3 roots	2.97±0.07	0.00 - 18.00	60.2	12.35***	1.66
Size 5 roots	1.52±0.05	0.00 - 8.00	76.2	2.30***	0.36
Size 7 roots	0.33±0.02	0.36 - 4.00	86.0	0.18***	0.09
Yield (t ha^{-1})	11.9±0.40	0.00 - 45.00	83.4	184.94***	12.35
Shoot weight	1.54±0.03	0.26 - 2.0	50.9	10.09***	57.62
Harvest index (HI)	0.50±0.01	0.05 - 0.93	28.7	0.07***	0.01
Root dry matter (%)	29.59±0.28	10.65 - 45.20	23.6	152.94***	17.60
CMDS	1.36±0.03	1.00 - 4.00	51.4	7.32***	0.12

*** Significant level at $p<0.001$. CMDS = Cassava mosaic disease severity score

Table 2: Correlation coefficients between storage root yield and shoot parameters

	Yld	Stem no	IstBrHt	Totalht	Htwtlf	Stgirth	Canvol	Lfsize	stagrn
Yld	1	0.088	-0.038	-0.294	-0.058	-0.034	-0.204	-0.066	0.369*
StemNo		1	-0.090	-0.109	0.053	-0.310	-0.068	0.112	0.446**
IstBrHt			1	0.594***	0.354*	0.242	0.176	-0.043	-0.382*
Totalht				1	0.579	0.457*	0.559**	-0.160	-0.261
Htwtlf					1	0.246	0.737***	-0.452*	0.120
Stgirth						1	0.497**	0.049	0.109
Canvol							1	-0.481	0.160
Lfsize								1	0.090
stagrn									1

*,**, *** significant level at $p<0.05$, 0.01 and 0.001, respectively. Yld = storage root yield in t ha^{-1}, Stem no = Stem Number, IstBrHt = Height to first branching, Totalht = Plant height, Htwtlf = length of shoot with leaf, Stgirth = stem girth, Lfsize = Leaf size (cm^2), Canvol = Canopy volume estimated using formula for calculating volume of a cone ($1/3*22/7*r^2*$ h),stagrn = Stay-green ability using a scale of 1-5, where 1 = Complete defoliation and candle stick appearance and 5 = full canopy with high leaf turgidity

Table 3: Correlation coefficients between root yield, root parameters and other traits

	Yld	NoHav	RtNo	Size3	Size5	Size7	Shtwt	HI	DM
Yld	1	0.811***	0.911***	0.765***	0.946***	0.567***	0.446**	0.742***	0.312
NoHav		1	0.875***	0.820***	0.790***	0.343*	0.646***	0.486**	0.351
RtNo			1	0.952***	0.882***	0.344	0.624***	0.589***	0.291
Size3				1	0.701***	0.154	0.657	0.445**	0.244
Size5					1	0.476**	0.455**	0.691***	0.310
Size7						1	0.107	0.443**	0.138
Shtwt							1	0.076	-0.184
HI								1	0.279
DM									1

*,**, *** significant level at $p<0.05$, 0.01 and 0.001, respectively. Yld = Storage root yield in t ha^{-1}, DM = dry matter content, RtNo = Root number, NoHav = Number of stands harvested, Shtwt = shoot weight (kg), HI = Harvest index, size 3 = Small-sized roots, size 5 = Medium-sized roots, size 7= Large-sized roots

highest correlation coefficients with storage root yield (r = 0.95), followed by number of roots harvested (r = 0.91), number of stands harvested (r = 0.81), small-sized roots (r = 0.77), harvest index (r = 0.74). Shoot weight had the lowest correlation coefficient (r = 0.45) of all the parameters that showed a significant correlated response with storage root yield. The significant positive correlation between storage root yield and other yield-related traits indicate the possibility of improving these traits in a breeding programme. The positive association between root yield and Harvest Index has also been confirmed by Birader *et al.* (1978) Kamalan *et al.* (1978) Kawano, (1978) and Radhakrishnan and Gopakumar (1984). Harvest Index and number of storage roots also showed a strong positive correlation with storage root yield and have been confirmed as good indicators of yield in cassava (Lian, 1985). Although dry matter showed no significant correlation with storage root yield, it is assumed to be one of the most important storage root components. Ntawuruhunga (1992) and Kawano *et al.* (1998) reported that selection for dry matter content could be conducted without any serious effect on other yield components.

Results in this study showed that storage root yield was not significantly correlated with dry matter. There were also significant inter-character correlations among

Table 4: Calculated direct and indirect path coefficients for storage root yield and five yield-related parameters

No of storage root vs. root yield	
Direct effect of Rtno on Yield	0.612
Indirect effect of Rtno on yield via Size3	-0.441
Indirect effect of Rtno on yield via Size5	0.121
Indirect effect of Rtno on yield via Size7	0.285
Indirect effect of Rtno on yield via HI	0.137
Total indirect effects	0.102
Total (direct + indirect) effect	0.713
Small-sized roots vs. root yield	
Direct effect of Size3 on yield	-1.219
Indirect effect of Size3 on yield via Rtno	1.907
Indirect effect of Size3 on yield via Size5	-1.253
Indirect effect of Size3 on yield via Size7	-0.202
Indirect effect of Size3 on yield via HI	0.012
Total indirect effects	0.464
Total (direct + indirect) effect	-0.291
Medium-sized roots vs. root yield	
Direct effect of Size5 on yield	0.229
Indirect effect of Size5 on yield via Rtno	0.838
Indirect effect of Size5 on yield via Size3	-1.012
Indirect effect of Size5 on yield via Size7	0.037
Indirect effect of Size5 on yield via HI	0.167
Total indirect effects	0.030
Total (direct + indirect) effect	0.289
Large-sized roots vs. root yield	
Direct effect of Size7 on yield	0.171
Indirect effect of Size7 on yield via Rtno	0.388
Indirect effect of Size7 on yield via Size3	-0.302
Indirect effect of Size7 on yield via Size5	-0.056
Indirect effect of Size7 on yield via HI	0.092
Total indirect effects	0.121
Total (direct + indirect) effect	0.291
Harvest index vs. root yield	
Direct effect of HI on yield	0.152
Indirect effect of HI on yield via Rtno	0.252
Indirect effect of HI on yield via Size3	-0.263
Indirect effect of HI on yield via Size5	-0.123
Indirect effect of HI on yield via Size7	0.016
Total indirect effects	-0.118
Total (direct + indirect) effect	-0.084
R^2	0.92

many of the root parameters. Number of stands harvested was significantly correlated with number of roots, root size, shoot weight and harvest index. Number of roots also was significantly correlated with all categories of root size, shoot weight and harvest index. Shoot weight was significantly correlated with storage root yield and other yield-related parameters, including number of stands harvested, number of roots and number of medium-sized roots. Harvest index also showed a significant correlation with storage root yield and all other root parameters, except shoot weight and dry matter. Results of the path analysis procedure (Table 4) showed that the five variables in the path analysis together accounted for up to 92% of the total observed variability in root yield indicated by the coefficient of determination (R^2). Storage root number contributed the highest direct effect (P) on storage root yield (0.61) and this accounted for 86% of the total direct + indirect effect. The positive direct effect of number of roots on storage root yield was influenced by positive indirect effects via large-sized roots (p = 0.29), harvest index (p = 0.14) and medium-sized roots (p = 0.12) and also by negative indirect effect via small sized roots (p = -0.44). The second largest direct effect (p = 0.23) was observed for medium-sized roots, representing (79.2%) of total direct + indirect effect (p = 0.29). Large-sized roots had the third largest direct effect on storage root yield (p = 0.17), contributing 58.7% of the total direct + indirect effect. Harvest index also had a high direct effect on yield (p = 0.15) and a high indirect effect (p = 0.25) on storage root yield via number of roots. Small-sized roots showed a high negative direct effect (p = -1.22) on storage root yield and a positive indirect effect on storage root yield via number of roots (p = 1.91).

DISCUSSION

Significant variability that existed among cassava genotypes for most parameters evaluated as indicated in the range of mean values, coefficients of variability and mean squares, can be explored in improving the crop. The lack of correlation between storage root yield and shoot parameters showed that shoot characters cannot be used directly as indicators of root yield in cassava. Root parameters with significant phenotypic correlation indicate a strong influence on root yield. Mahungu (1983) also noted that number of tuberous roots contributed more to the final yield in cassava while Makame (1995) ascertained that root size, harvest index and number of storage roots per plant were the three most important traits having the highest direct influence on root yield in cassava and therefore regarded as the most reliable components of yield determination. Medium-sized roots showed the highest correlation coefficient with root yield, indicating that this character has a higher influence on root yield than other characters that were correlated with yield. Therefore, this character should be given higher consideration when selecting indices towards increasing root yield in cassava. These would invariably lead to an improvement in root yield (Naskar *et al.*, 1989; Varma and Rai, 1993). Negative correlations between yield components in crop plants have been reported to create obstacles to yield improvement (Adams, 1976). The negative direct effects obtained from path analysis for small-sized roots indicate that, despite being significantly correlated with root yield, a preponderance of small roots over large roots will have a negative effect on final root yield. An increase in the number of tubers without a corresponding increase in tuber size will not increase tuber yield. Breeding efforts should, therefore, focus on increasing the root size while increasing the number of roots. This study provides strong evidence that number and size of roots, especially the bigger roots, are important factors contributing to yield enhancement in cassava. These parameters should, be given a higher priority when selecting for higher yield in cassava. Yield increase has been found to be mainly due to increases in both numbers of storage roots and individual root weight (Kasele, 1983) with storage root number being more closely correlated with root dry weight than with the individual weight of storage roots.

The significant positive phenotypic correlations which other parameters, such as number of stands, small-sized roots, large-sized roots and harvest index, have on root yield indicate that these parameters are also important contributors to yield, although their influence on final yield is not as large as the influence of number of roots and medium-sized roots, as also reported by Makame (1995). Harvest index was correlated with root yield in this study, as reported by Radhakrishnan and Gopakumar (1984) and Ntawuruhunga *et al.* (2001). However, when harvest index is considered as a selection index, a standard yield level should be introduced and genotypes that exceed such standard yield levels with preferable harvest index values should be selected, as noted by Tan (1987). Dry matter was not correlated with storage root yield, indicating that dry matter is not an important indicator of storage root yield in cassava, as reported by several researchers (Ntawuruhunga, 1992; Varma and Rai, 1993; Makame, 1995; Ntawuruhunga *et al.*, 2001). Path-coefficient analysis revealed that the direct and indirect effects of number of roots, small, medium and large-sized roots and harvest index explained about 92% of the total variation for tuber yield, with number of roots contributing the highest direct effect on storage root yield. Similar findings were made by Ntawuruhunga *et al.* (2001). The positive direct effect of number of storage roots on storage root yield was influenced by indirect effects via the number of large-sized roots and harvest index and negatively influenced by the number of small-sized roots. A detailed study of the relationships obtained by path analysis showed that the relationship between storage root yield and its components are similar to those obtained through correlation analysis. Number of roots followed by medium-sized roots had the highest direct effects on storage root yield from path analysis. Medium-sized roots followed by number of roots had the highest correlation coefficient values from correlation analysis.

In conclusion, the number of storage roots and number of medium-sized roots were found to contribute the largest influence on storage root yield in cassava. Both parameters should be considered together while selecting for cassava genotypes with higher potentials for storage root yield.

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