

Zinc biofortification on root yield and quality performance of cassava varieties grown in Umudike, southeast Nigeria

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Abstract

A field study was conducted at Michael Okpara University of Agriculture, Umudike (latitude 05° 28' 51'' N, longitude 07° 32' 25'' E, 120 m.a.s.l), Nigeria in 2021/2022 cropping seasons to evaluate the response of cassava (*Manihot esculenta* Crantz) varieties to zinc biofortification. The treatments comprised of all combinations of the three cassava varieties (TME 419, TMS 01/1371, TMS 98/0581) and three zinc rates (0, 5 10 kg/ha) in the form of zinc sulphate ($ZnSO_4 \cdot 7H_2O$) which were fitted into a randomized complete block design with three replications. Results indicated that the varieties were similar values for all the varieties except starch percentage, β -carotene content, root zinc content and zinc recovery efficiency (REzn). The application of zinc induced a positive response of root yield across the cassava varieties. Highest fresh root yield, starch percentage, β -carotene content, root zinc content and zinc recovery efficiency (REzn) were obtained at the application of zinc rate of 10 kg and 5 Kg $ZnSO_4 \cdot 7H_2O$ /ha. However, there was non-significant interaction between variety and Zn application. Root length and weight of marketable roots/plant exhibited positive and significant correlation with root yield of cassava while the regression analysis indicated that the level of contribution of starch yield and weight of marketable roots/plant to fresh root yield was at 28.10 and 3.07 per cent, respectively indicating that yield of the cassava varieties increased positively due to the effect of these variables. The cassava variety (TMS 01/1371) that received 10 kg $ZnSO_4 \cdot 7H_2O \cdot ha^{-1}$ gave the highest fresh root yield closely followed by the interaction between these varieties (TMS 98/0581 and TME 419) and 10 kg $ZnSO_4 \cdot 7H_2O \cdot ha^{-1}$. The least root yield was recorded under TMS 98/0581 \times 0 kg $ZnSO_4 \cdot 7H_2O \cdot ha^{-1}$. The highest zinc uptake in roots, root zinc content and zinc recovery efficiency were recorded under the interaction treatment of cassava variety (TMS 01/1371 \times 5 kg $ZnSO_4 \cdot 7H_2O \cdot ha^{-1}$). Therefore, for increased root yield, TMS 01/1371 \times 10 kg $ZnSO_4 \cdot 7H_2O \cdot ha^{-1}$ can be adjudged to be a viable option while for improved zinc biofortification in cassava roots, TMS 01/1371 \times 5 kg $ZnSO_4 \cdot 7H_2O \cdot ha^{-1}$ may be considered for adoption by farmers in the agro-region.

Key words: Correlation, proximate analysis, root yield, starch, zinc

Introduction

Cassava (*Manihot esculenta* Crantz), a dominant starchy staple in the diet of people in sub-Saharan Africa (Dixon *et al.*, 2008; Maundu *et al.*, 2009) is gaining attention as an industrial crop (Eze and Ugwoke, 2010). The crop is very tolerant of drought, heat stress and produces well even on marginal soils (Muoneke and Mbah, 2007). The nutrient composition of cassava differs depending on varieties and age of the harvested crop, soil conditions and other environmental factors (Manu-Aduening *et al.*, 2006; Adjebeng-Danquah *et al.*, 2016; Njoku and Mbah, 2020). Nigeria produces approximately 45 million tonnes of cassava roots per annum, which is almost 19 % of production in the world (IFAD and FAO, 2005). In Nigeria, cassava production is well-developed and organized, especially in the south and central agro-ecological zones of Nigeria. More than forty (40) cassava varieties have been released in commercial use in Nigeria (Egesi *et al.*, 2004 and Mbah *et al.*, 2019). Cassava is very versatile as a food security crop and its derivatives such as starch have highly diversified industrial applications such as confectioneries, glues, textile, papers, biodegradable products, monosodium glutamate, drugs, ethanol and biofuels (Ziska *et al.*, 2009).

Zinc as a micronutrient is a one of the most important elements required by most field crops as it plays a key role in the production of chlorophyll. Zinc deficiency in soils lead to discoloration of plant leaves and stunted growth in

plants (Panda and Patra, 1999). Zinc acts as a metal component of enzymes and as a functional, structural or regulatory co-factor of a large number of enzymes (Benesi *et al.*, 2004). Studies have shown that the rate of protein synthesis and protein content of zinc-deficient plants can be increased with the application of zinc fertilizer in the soil (Mousavi, 2011). Zinc is an essential component of ribonucleic acid (RNA) polymerase, hence, if removed, the enzyme becomes inactivated (Adeniyi and Ojeniyi, 2005). In cassava, zinc deficiency leads to chlorosis (Panda and Patra, 1999) and it is predominant among plants growing in highly, weathered acid soils and in calcareous soils. Such deficiency can be corrected fairly by the soil application of zinc salts such as zinc sulphate. Zinc plays a crucial role in human growth, development, reproduction and immunity.

There is dearth information on the effect of zinc rate on root yield and quality of cassava in degraded ultisols in southeast agro-ecology of Nigeria, hence, a study was undertaken to determine the effect of zinc application rate on root yield and nutritional quality of some cassava varieties.

Materials and Methods

Experimental site

The field experiment was conducted at the Department of Crop and Horticultural Sciences, Michael Okpara University of Agriculture, Umudike located within latitude 05° 28' 51'' N, longitude 07° 32' 25'' E, and at

an elevation of 120 m.a.s.l.) in 2021/2022 cropping seasons. Umudike is in the humid tropics and has a mean rainfall of about 2177 mm with mean air temperature of about 26 °C per annum. The rainfall in the region is bimodal (long rainy season - April to July, short dry season - August, short rainy season - September to October). The dry season is between November and March.

The weather data of the experimental site showed that the total precipitation during the experimental period was 2079.8 mm and 2028.6 mm in 2021 and 2022 cropping seasons, respectively (Table 2). The highest amounts (493.9 mm) and (337.9 mm) were recorded in July (2021) and April (2022), respectively. The minimum air temperature ranged from 23.1 to 29.7 °C while the maximum air temperature ranged from 30 to 35 °C in 2021. In 2022, the lowest minimum air temperature was 21 °C while the highest was 35 °C.

Soil analysis

After land preparation, composite soil samples were collected from the top soil of all the experimental units with the aid of a soil auger at a depth of 0 – 20 cm. A sub-sample was collected and subjected to laboratory analysis for the physical and chemical properties following standard soil laboratory procedures. The physical and chemical analysis of the composite soil of the experimental site in 2021/2022 showed that the soil was sandy loam texturally. The soil pH in water (6.2) was moderately acidic and the soils were low to moderate in nutrient composition with total nitrogen (0.226 g kg⁻¹), available phosphorus (18.9 mg kg⁻¹), organic carbon (1.58 g kg⁻¹) and organic matter (2.64 g kg⁻¹). The exchangeable cation values of potassium, calcium and magnesium were 0.234, 6.40 and 0.80 cmol kg⁻¹, respectively while zinc in soil was 0.37 mg kg⁻¹. The soil of the experimental site was classified as sandy loam Ultisol (paleustalt) (USDA classification).

Experimental design

The treatments consisted of all possible combinations of three rates of zinc (0 kg ha⁻¹, 5.0 kg ha⁻¹, 10.0 kg ha⁻¹) and three cassava varieties [TME 419, TMS 01/1371 (Umucass 38), and TMS 98/0581]. These were laid out as a 3 x 3 factorial arrangement in a randomized complete block design with three replications. The nine (9) treatment combinations were as follows: TME 419 × Zn 0 kg ha⁻¹; TME 419 × Zn 5.0 kg ha⁻¹; TME 419 × Zn 10.0 kg ha⁻¹; TMS 01/1371 × Zn 0 kg ha⁻¹; TMS 01/1371 × Zn 5.0 kg ha⁻¹; TMS 01/1371 × Zn 10.0 kg ha⁻¹; TMS 98/0581 × Zn 0 kg ha⁻¹; TMS 98/0581 × Zn 5.0 kg ha⁻¹; TMS 98/0581 × Zn 10.0 kg ha⁻¹.

Materials

The three cassava varieties used in the study were obtained from the Cassava Programme, National Root Crops Research Institute (NRCRI), Umudike, while the micro nutrient (Zinc) in the form of Zinc sulphate (ZnSO₄•7H₂O) substance was sourced from a reputable Scientific Laboratory (ACONRAWS) in Enugu.

Cultural practices

Each experimental plot size measured 3 × 3 m (9 m²) with 1 m gap as inter-plot and inter-block spacing. Cassava planting was done at 1 m intra- and inter-row spacing, which gave a plant population of 10,000 plants·ha⁻¹. Weed control was done manually with hand-hoe at 4, 8 and 16 weeks after planting (WAP) while slashing was done at 9 months after planting (MAP). Compound fertilizer (N:P:K 15:15:15) was applied at the rate of 400 kg/ha at 6 WAP. The zinc rates were mixed with the fertilizer as per treatments and applied into the designated experimental plots using the ring method.

Data collection

At harvest, the yield parameters assessed from the net plot of 9 m² included root length, root girth, number of roots per plant (marketable and unmarketable), weight of roots per plant (marketable and unmarketable), and fresh root yield (t ha⁻¹). Also, proximate (dry matter, crude fibre, fat, crude protein and carbohydrate), starch content, cyanide potential, beta-carotene and zinc status of the roots from the cassava varieties were carried out.

Nutritional composition

The crude fibre of fresh cassava root samples was determined by the Wende method according to James (1995). The fat content of fresh cassava root samples was determined using solvent extraction in a Soxhlet apparatus as described by Onwuka (2018). Crude protein of the cassava root sample was determined using the Kjeldahl method as described by Chang (2003). The carbohydrate content of the cassava fresh root sample was calculated following the method described by James (1995). The energy value was estimated using Atwater factors according to Onwuka (2005). β-carotene content was determined using the spectrophotometric method (Onwuka, 2005). The amount of cyanide in the flour obtained from the fresh roots of the cassava varieties was determined using the alkaline picrate procedure outlined by Cooke (1978) and modified by Onwuka (2005).

The starch content was obtained following the procedure outlined by Moorthy (1991). Determining zinc content in cassava root was obtained using the dry ash extraction method (Shuman, 1985). The Zn uptake of the root was estimated as the product of zinc concentration and root dry matter (mg·kg⁻¹) (Zhu *et al.*, 2001). Zinc recovery efficiency was estimated as zinc content with zinc application minus root zinc content without zinc application divided by the amount of zinc applied to the crop and it is expressed in percentage.

Statistical analysis

The variable data collected were analyzed for variance using Genstat Discovery 14th Edition statistical software package following the procedure for a factorial experiment in a randomized complete block design. The differences in means were performed with F-tests (LSD) at P≤0.05. Pearson's correlation was carried out using SPSS 25 Regression analysis was used to test associations between root yield and zinc rate with linear model. Also,

between root yield and dry matter content, as well as between root yield and root zinc content, using a non-linear model (Jandel, 1992).

Results

The root yield and yield components of cassava showed that variety has no significant ($p > 0.05$) effect on cassava root yield and yield components (root diameter, root length, weight of unmarketable roots/plants, weight of marketable roots/plant and fresh root yield) (Table 1). Zinc sulphate (ZnSO_4) application rate showed significant ($p > 0.05$) effect on all the tested variables while the interaction between variety and zinc rate had no significant effect on the root yield and yield components of cassava. The application of 10 kg ha^{-1} of ZnSO_4 had the highest root diameter and weight of marketable roots/plant which was comparable with $5 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ application. Furthermore, fresh root yield of cassava (21.60 t ha^{-1}) increased by 33.3 and 29.2 % relative to the applications of 5 and $0.0 \text{ kg ZnSO}_4 \text{ ha}^{-1}$, respectively.

Variety and ZnSO_4 application rate as well as their interactions significantly affected root zinc uptake, root zinc content, and zinc recovery efficiency of cassava. The cassava variety "TMS 01/1371" had the highest amount of root zinc uptake and zinc recovery efficiency which was similar with TMS 98/0581 and TMS 419, respectively. TMS 98/0581 exhibited the highest root zinc content closely followed by TMS 01/1371 but at par with TMS 01/1371.

The application of $10 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ had the highest root zinc uptake which was at par with ZnSO_4 application rate at 5 kg ha^{-1} while 0 kg rate had the least uptake. However, the application of $5 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ had the highest root zinc content which was comparable with plants treated $10 \text{ kg ZnSO}_4 \text{ ha}^{-1}$. Zn recovery efficiency was similar across all varieties. The interaction between cassava variety and zinc rate indicated that TMS 01/1371 treated with $5 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ had the highest root zinc uptake, root zinc content and zinc recovery efficiency.

The proximate composition of fresh root yield of cassava indicated that variety irrespective of zinc rate significantly ($P < 0.05$) affected dry matter, crude fibre, fat, energy value, β -Carotene and starch yield but had no effect on carbohydrate (Table 2). Conversely, except dry matter, crude fibre and crude protein, ZnSO_4 rate significantly affected all the other variables (crude fibre, fat, and energy value) irrespective of cassava variety. The interaction between variety and ZnSO_4 rate had no significant ($P > 0.05$) effect on all the variables except fat, and energy value. The cassava variety TMS 01/1371 had the highest dry matter and crude fibre but at par with TMS 419 and TMS 98/0581, respectively while TMS 98/0581 cassava variety had highest fat (0.76 %). It also had the highest energy value (148.7 Kcal.) but comparable with TMS 01/1371.

The application of $10 \text{ kg zinc per ha}$ gave the highest amount of fat while 5 kg zinc per ha gave the highest carbohydrate. It also had the highest energy value but at par with 0 kg ZnSO_4 rate. The significant interaction

between variety and zinc rate showed that fat content was highest in TMS 419 treated with $10 \text{ kg ZnSO}_4 \text{ ha}^{-1}$. TMS 01/1371 variety treated with $10 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ had the highest energy value. Variety and ZnSO_4 application rate significantly ($P < 0.05$) affected starch yield and β -carotene content but not with cyanide potential. The cassava variety TMS 98/0381 gave the highest starch yield which similar with TMS 419. β -carotene content was highest in TMS 98/0581 which was not significantly higher than TMS 01/1371. The application of $5 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ gave the highest starch content and starch yield but at par with $0 \text{ kg ZnSO}_4 \text{ ha}^{-1}$. Plants treated with $10 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ had the highest β -carotene content which was significantly higher than untreated plants.

Pearson's correlation analysis showed that root length and weight of marketable roots/plant had positive and significant correlation with root yield of cassava with correlation coefficients (r) of 0.64 and 0.73, respectively (Table 3). Weight of marketable roots/plant indicated significant and positive relationship with root length ($r = 0.62$) and root diameter ($r = 0.42$), respectively. Conversely, dry matter content had highly significant and positive correlation with carbohydrate ($r = 0.96$) and starch content ($r = 0.98$) while zinc uptake also exhibited significant and positive correlation with crude fibre ($r = 0.41$). The other variables exhibited different strengths of associations amongst themselves.

The results from the multiple linear regression analysis of fresh root yield to some growth and yield components of cassava (Table 4) indicated a significant model summary in which out of the eight (8) variables in the analysis, starch yield ($b = 0.980$, $t = 28.102$, $P \leq 0.000$), weight of marketable roots/plant ($b = 0.103$, $t = 3.073$, $P \leq 0.007$) exhibited significant and positive relationship with fresh root yield of cassava (Table 4). The level of contribution of starch yield and weight of marketable roots/plant to root yield was at 28.10 and 3.073 per cent, respectively, which implied that root yield of the cassava varieties increased positively due to the effect of these variables.

The multiple linear regression analysis indicated a significant model summary. The analysis showed that starch yield had a positive effect on fresh root yield of cassava ($B = 0.980$, $S.E = 0.064$, $P = < 0.001$). Regression analysis of root yield on growth and yield components also showed that weight of marketable roots per plant followed by number of marketable roots per plant, Zinc uptake in root and dry matter content were important characters that affected fresh root yield. Therefore, these variables accounted for 98 per cent of the variations in fresh root yield of cassava.

Zn uptake per 100 g fresh root yield showed positive and significant ($b = 0.063$, $t = 2.204$, $P \leq 0.004$) effect on fresh root yield of cassava and that 2.2 per cent of the variation in root yields explained by zinc uptake. Furthermore, there was a negative but slightly significant ($b = -0.0099$, $t = -2.893$, $P \leq 0.010$) effect between number of marketable roots/plant and root yield, which implied that number of marketable roots were reduced during root formation which allowed for weightier root bulking thereby

increasing root yield. The other predictors (length of root, dry matter content and carbohydrate) had no significant effect on root yield of cassava varieties.

Discussion

This study had demonstrated that zinc application influenced cassava root yield and its quality. Varietal differences were not observed on yield and yield components. This was contrary to the view of Apea-Bah *et al.* (2011) on the effect of genotypic difference on cassava yield components. The results further showed that favorable pH and more nutrient content in the soil increased the rooting system and invariably crop yield. The findings corroborate reports by Howeler (2002), Fergeria *et al.* (2010) and Janket *et al.* (2018) in foliar application of 2% ZnSO₄·7H₂O micronutrient to cassava genotypes compared to fertilizer application alone. It indicates that zinc is an essential element in many enzymatic reactions including dehydrogenases and proteinases that aid molecular configurations between enzymes and substrates. Similar responses in cassava root yield to zinc application have earlier been reported by Ali and Elkader (2014), and positive response in tuber yield of potato have been documented by Mousavi *et al.* (2007), Ahmed *et al.* (2011) and Panitnok *et al.* (2013) suggesting that differences among genotypes might be due to differences in plant characteristics, which influenced their genetic responses to zinc application.

The response of variety to proximate composition of the cassava emphasized the dynamics of micronutrient deficiency in the soils. These observations aligned with previous findings studies by Kennedy and Meyers (2005) and Taylor *et al.* (2016) on iron and zinc in which the estimated average requirement (EAR) for the zinc micronutrient for non-modified cassava storage roots was only 8 and 14 % EAR zinc for 1-6-year-old children and non-lactating, non-pregnant West African women, respectively. Furthermore, Okwuonu *et al.* (2021) reported positive effects of biofortification of cassava with zinc to address the deficiency of the micronutrient in the diet of the people in the region. The correlation findings showed that root length and weight of marketable roots/plant had positive and significant association with root yield of cassava. Similarly, Muluaem (2012) reported positive and significant correlation between root length of cassava, weight of marketable roots/plant and fresh weight of roots. Also, Ugwu *et al.* (2020) indicated significant and positive correlation between the amount of zinc extracted from the soil and plant uptake of zinc, which may be due to zinc transformation and availability in soils. Furthermore, Pearson's correlations between root yield of cassava and other yield components such as weight of marketable roots and length of roots indicated highly significant and positive according to Mbah *et al.* (2019) in the works on twenty-eight high- and low-cyanide cassava genotypes.

Conclusion

This study had exhibited that the application of zinc sulphate (ZnSO₄·7H₂O) in the soil induced a positive response of root yield in the cassava. Fresh root yield, starch percentage, β-carotene content, root zinc content and zinc recovery efficiency (REzn) increased with ZnSO₄·7H₂O application over Control. The highest root yield was recorded on those treated with 10 kg ZnSO₄·7H₂O·ha⁻¹. The cassava variety (TMS 01/1371) that received 10 kg ZnSO₄·7H₂O·ha⁻¹ gave the highest fresh root yield closely followed by TMS 98/0581 and TME 419 that also received 10 kg ZnSO₄·7H₂O·ha⁻¹ while TMS 98/0581 × 0 kg ZnSO₄·7H₂O·ha⁻¹ had the least root yield. However, the highest zinc uptake in roots, root zinc content and zinc recovery efficiency were recorded under the interaction treatment of cassava variety (TMS 01/1371 × 5 kg ZnSO₄·7H₂O·ha⁻¹). Therefore, for increased root yield, TMS 01/1371 × 10 kg ZnSO₄·7H₂O·ha⁻¹ can be adjudged to be a viable option while for improved zinc biofortification in cassava roots, TMS 01/1371 × 5 kg ZnSO₄·7H₂O·ha⁻¹ may be considered for farmers in the agro-eco-region to adopt.

Declaration and Conflicts of Interests:

We hereby declare that we are the authors of the submitted manuscript and that the manuscript is our original work which has not been published in any other journal and has not been submitted anywhere for publication and there are no conflicts of interests. You are very free to edit the manuscript to suit the requirements of your reputable Journal.

References

- Adeniyi, N.O. and Ojeniyi, S.O. (2005). Effect of poultry manure, NPK 15-15-15 and combination of their reduced levels on maize growth and soil chemical properties. *Nigerian Journal of Soil Science*, 15: 34-41. Doi:10.4314/njss.v15i1.37444.
- Adjebeng-Danquah, J., Gracen, V.E., Offei, S.K., Asante, I.K., Manu-Aduening, J. (2016). Agronomic performance and genotypic diversity for morphological traits among cassava genotypes in the guinea savannah ecology of Ghana. *Journal of Crop Science and Biotechnology*, 19(1): 99–108.
- Ahmed A.A., Abd EL-Baky, M.M.H., Zaki, M.F. and Abd EL-ALal, F.S. (2011). Effect of folia application of active yeast extract and zinc on growth, yield and quantity of potato plant (*Solanum tuberosum* L). *Journal of Applied Science and Research*, 7(12): 2479-2488.
- Ali, R.A.M. and Elkader, D.Y. (2014). Influence of application System of k₂SO₄ and foliar application of micronutrient mixture of cassava grown in sandy soil.

Table 1: Root yield, yield components, zinc concentration in root, zinc content and zinc recovery efficiency of cassava as influenced by variety and zinc rate in 2021/2022 cropping seasons in Umudike, Nigeria

Treatment	Root diameter (cm)	Root length (cm)	Weight of unmarketable roots/plants (kg)	Weight of marketable roots/plants (kg)	Fresh root yield (t/ha)	Zn uptake in root (mg 100 g ⁻¹)	Root zinc content (mg 100 g ⁻¹)	Zinc recovery efficiency (%)
Variety (V)								
TME 419	6.39	28.5	0.42	1.79	19.08	0.788	0.2909	0.59
TMS 01/1371	6.90	29.0	0.55	1.80	17.46	0.864	0.3314	1.02
TMS 98/0581	6.64	32.8	0.82	1.94	19.44	0.841	0.3317	0.36
LSD _(0.05)	ns	ns	ns	ns	ns	0.03194	0.0319	0.542
Zinc rate (Z) (kg/ha)								
0	5.85	17.6	0.21	1.405	15.30	0.763	0.2772	0.01
5	6.61	37.9	0.92	2.020	19.09	0.859	0.3516	1.49
10	7.46	34.8	0.65	2.108	21.60	0.862	0.3252	0.48
LSD _(0.05)	1.296	9.25	0.530	0.2661	2.149	0.0319	0.0319	ns
V × Z (Interaction)								
TME 419 × 0	5.94	15.5	0.12	2.07	17.22	0.827	0.2534	0.01
TME 419 × 5	6.75	31.0	0.47	1.42	18.78	0.757	0.3174	1.28
TME 419 × 10	6.48	39.0	0.67	1.88	21.23	0.780	0.3020	0.49
TMS 01/1371 × 0	6.55	15.3	0.29	1.43	12.67	0.747	0.2714	0.00
TMS 01/1371 × 5	6.55	35.7	1.04	1.85	17.52	0.940	0.3982	2.54
TMS 01/1371 × 10	7.61	36.0	0.31	2.12	22.19	0.907	0.3245	0.53
TMS 98/0581 × 0	5.06	22.0	0.23	1.37	16.00	0.847	0.3067	0.00
TMS 98/0581 × 5	6.55	47.0	1.27	2.33	20.96	0.843	0.3391	0.65
TMS 98/0581 × 10	8.30	29.5	0.97	2.14	21.37	0.833	0.3492	0.42
LSD _(0.05)	ns	ns	ns	ns	ns	0.0553	0.0553	0.938

Table 2: Proximate composition, starch content, starch yield, cyanide content and β-carotene content of fresh root yield of cassava as influenced by variety and zinc rate in 2021/2022 cropping seasons in Umudike, Nigeria

Treatment	Dry matter (g)	Crude fibre	Fat (%)	Crude protein (%)	Carbohydrate	Energy value (Kcal)	Starch content (%)	Starch yield (%)	Cyanide potential (mg kg ⁻¹)	β-Carotene content (μg/g)
Variety (V)										
TME 419	38.81	1.496	0.583	1.756	31.62	138.7	30.80	9.19	30.53	5.61
TMS 01/1371	40.89	1.628	0.531	1.792	32.51	142.0	31.53	8.70	29.52	7.02
TMS 98/0581	35.22	1.570	0.760	2.047	33.42	148.7	32.60	10.41	28.10	7.95
LSD _(0.05)	2.218	0.0813	0.179	ns	ns	9.58	ns	1.278	ns	1.981
Zinc rate (Z) (kg/ha)										
0	37.29	1.542	0.569	2.004	32.88	144.7	32.10	7.96	28.35	5.57
5	38.24	1.614	0.546	1.863	35.17	153.0	34.08	11.14	27.87	7.30
10	39.40	1.537	0.760	1.727	29.50	131.7	28.74	9.20	31.93	7.72
LSD _(0.05)	ns	ns	0.1792	ns	2.268	9.58	2.457	1.278	ns	1.981
V × Z (Interaction)										
TME 419 × 0	37.54	1.487	0.533	2.073	31.69	139.9	30.74	8.34	28.29	4.81
TME 419 × 5	40.01	1.550	0.567	1.747	34.57	150.4	33.19	10.47	30.72	4.72
TME 419 × 10	34.33	1.450	0.650	1.447	28.58	143.2	28.48	8.74	32.57	7.32
TMS 01/1371 × 0	38.41	1.573	0.627	1.840	32.56	124.4	31.89	6.39	28.52	6.18
TMS 01/1371 × 5	42.36	1.710	0.523	1.820	36.58	158.3	35.56	11.08	27.00	7.89
TMS 01/1371 × 10	33.39	1.600	0.443	1.717	28.39	144.9	27.13	8.63	33.04	7.01
TMS 98/0581 × 0	40.48	1.567	0.547	2.100	34.39	126.0	33.68	9.14	28.23	5.72
TMS 98/0581 × 5	40.30	1.583	0.547	2.023	34.36	150.4	35.50	11.88	25.89	9.31
TMS 98/0581 × 10	37.41	1.560	0.187	2.017	31.53	150.9	30.61	10.23	30.18	8.82
LSD _(0.05)	ns	ns	0.3103	ns	ns	16.59	ns	ns	ns	ns

*. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Table 4. Regression estimates of fresh root yield of cassava on some growth and yield components of cassava as influenced by variety and zinc rate in 2021/2022 cropping seasons in Umudike, Nigeria

	Unstandardized		Standardized	T	Sig.
	Coefficients		Coefficients		
	B	S.E	Beta	Probability	
Length of roots (cm)	0.011	0.010	0.032	1.049	0.308
Number of marketable roots/plant	-0.054	0.019	-0.099	-2.893	0.010
Weight of marketable roots/plant (kg)	0.516	0.168	0.103	3.073	0.007
Zinc concentration in root (mg/100g)	2.646	1.200	0.063	2.204	0.041
Dry matter content (g)	-0.595	0.345	-0.547	-1.724	0.102
Carbohydrate (%)	>-0.451	0.353	-0.411	-1.278	0.217
Starch yield (t/ha)	1.792	0.064	0.980	28.102	0.000

Dependent Variable: Root yield (t/ha), S.E: Standard error of means, P<0.001***: Significant at 0.001, P<0.01*: Significant at 0.01, R = 0.994, R² = 0.988, Adjusted R² = 0.982.

Table 3. Matrix of Pearson's correlation of fresh root yield and growth, yield components of cassava as influenced by variety and zinc rate in 2021/2022 cropping seasons in Umudike, Nigeria

	-Root yield (t/ha)	Root length (cm)	Root diameter (cm)	Weight of marketable roots/plant (t/ha)	Dry matter (g)	Crude fibre (%)	Carbohydrate (%)	Starch (mg/100 g)	Hydrogen cyanide (mg/kg)	Zinc conc. in root (mg/100g)
Root length (cm)	0.64**									
Root diameter (cm)	0.33	.320								
Weight of marketable roots/plant (t/ha)	0.732**	0.616**	0.415*	1.00						
Dry matter (g)	-0.468*	-0.050	-0.288	-0.143	1.00					
Crude fibre (%)	-0.108	0.176	0.277	0.155	0.328	1.00				
Carbohydrate (%)	-0.454*	-0.028	-0.281	-0.127	0.996**	0.315	1.00			
Starch (mg/100 g)	-0.460*	-0.045	-0.307	-0.139	0.985**	0.248	0.986**	1.00		
Hydrogen cyanide (mg/kg)	0.343	-0.007	0.256	0.160	-0.407*	-0.357	-0.378	-0.323	1.00	
Zinc concentration in root (mg/100 g)	0.198	0.285	0.010	0.151	0.137	0.406*	0.143	0.076	-0.089	1.00

Alexandria Science Exchange Journal, 35(4): 315 - 324.

Apea-Bah, F., Oduro, I., Ellis, W. and Safo-Kantanka, E. (2011). *World Journal of Dairy and Food Sciences*, 6(1):43-54.

Benesi, I.R.M., Labuschagne, M., Dixon, A.G.O. and Mahungu, N.M. (2004). Stability of native starch quality parameters, starch extraction and root dry matter of cassava genotypes in different environments. *Journal of the Science of Food and Agriculture*, 84 (11): 1381- 1388. Doi: 10.1002/jsfa.1734.

Chang, S.K.C. (2003). *Protein Analysis. In: Food Analysis*, Nielsen, S.S. (Ed.). Kluwer Academic Plenum Publisher, New York.

Cooke, R.D. (1978). An enzymatic assay for the total cyanide content of cassava (*Manihot esculanta* Crantz). *Journal of Science Food and Agriculture*, 29: 345-352.

Dixon, A. G. O., Akoroda, M. O., Okechukwu, R. U., Ogbe, F., Iona, P., Sanni, L. O. (2008). Fast track participatory approach to release of elite cassava genotypes for various uses in Nigeria's cassava economy. *Euphytica*, 160: 1-13.

Egesi, C.N., Ogbe F.O., Dixon A.G.O., Akoroda M.O., Ukpabi, U.J., Eke Okoro O.N. (2004). Multi-locational trials of cassava mosaic disease resistant varieties.

Umudike, Nigeria: National Root Crops Research Institute (NRCRI), Annual Report, p.53.

Eze, S.C. and Ugwoke, K.I. (2010). Evaluation of Different Stem Portions of Cassava (*Manihot esculenta*) in the Management of its Establishment and Yield. *Research Journal of Agriculture and Biological Sciences*, 6(2): 181-185.

Fergeria, N.K., Baliger, V.C. and Jones, C. A. (2010). *Growth and Mineral Nutrition of Field Crops*. CRC Press, Florida.

Howeler, C.H. (2002). Cassava mineral nutrition and fertilization. In: Hillocks, R. J., Thresh, M. J. and Bellotic, A. C. (eds.). *Cassava, Biology, Production and Utilization*. CAB International Wallingford p. 115-147.

IFAD and FAO. (2005). A review of cassava on Africa with country case studies on Nigeria, Ghana, the United Republic of Tanzania, Uganda and Benin. Proceeding of the validation forum on the Global Cassava Development Strategy. 2 FA, Rom.

James, C.S., (1995). *Analytical Chemistry of Foods*. (1st Edn.) Chapman and Hall, New York, Pages: 178

Jandel TBLCURVE. (1992). *Jandel Scientific Table Curve. Curve fitting software*. Corte Madera, California, USA.

Janket, A., Vorasoot, N., Kesmala, T. and Jogloy, S. (2018). Influence of zinc, copper and manganese on dry matter yield and physiological traits of three cassava genotypes grown on soil micronutrient

- deficiencies. *Pakistan Journal of Botany*, 50(5): 1719-1725.
- Kennedy, E. and Meyers, L. (2005).** Dietary Reference Intakes: Development and uses for assessment of micronutrient status of women – A global perspective. *American Journal of Clinical Nutrition*, 81 (5): 11945-11978. Doi:10.1093/ajcn/81.5.1194.
- Manu-Aduening, J., Lamboll, J.A., Mensah, A., Lamptey, J.N., Moses, E., Dankyi, A.A. and Gibson, R.W (2006).** Development of Superior Cassava Cultivars in Ghana by Farmers and Scientist: The Process Adopted Outcome, Contributions and Changed Roles of Different Stakeholders. Pages 433-444.
- Maundu, P. Achigan-Dako, E. and Morimoto, (2009).** Biodiversity of African vegetables. In: African indigenous vegetables. In: Agriculture (Schackleton, M., Pasaiuni, M.W.). Earthscan publishers in association with the International Institute for Environment and Development, London Pp 68 and 69.
- Mbah, E.U., Nwankwo, B.C., Njoku, D.N. and Gore, M.A. (2019).** Genotypic evaluation of twenty-eight high- and low-cyanide cassava in low-land tropics, southeast Nigeria. *Heliyon*, 5: e01855.
- Moorthy, S.N. (1991).** Extraction of starches from tuber crops using ammonia. *Chemistry, Carbohydrate Polymers*, 16: 391-398.
- Mousavi, S.R., Galavi, M. and Ahmadvan, G. (2007).** Effect of zinc and manganese folia application on yield quality and enrichment on potato (*Solanum tuberosum* L.). *Asian Journal of Plant Science*, 6(8): 1256-1260.
- Mousavi, S.R. (2011).** Zinc in crop production and Interaction with phosphorous. *Australian Journal of basic and applied sciences*, 5(9): 1503-1509.
- Mulualem, T. (2012).** Cassava (*Manihot esculenta* Crantz) Varieties and Harvesting Stages Influenced Yield and Yield Related Components. *Journal of Natural Sciences Research*, 2(10): 122 -128.
- Muoneke, C.O. and Mbah, E.U. (2007).** Productivity of Cassava/Okra Intercropping System as Influenced by Okra Planting Density. *African Journal of Agricultural Research*, 2(5): 223- 231
- Njoku, D.A. and Mbah, E.U. (2020).** Assessment of yield components of some cassava (*Manihot esculenta* Crantz) genotypes using multivariate analysis such as path coefficients. *Open Agriculture*, 5: 516–528.
- Okwuonu, I.C., Narayanan, N.N., Egesi, C.N. and Taylor, N.J. (2021).** Opportunities and challenges for biofortification of cassava to address iron and zinc deficiency in Nigeria. *Global Food Security*, (28):1-9.
- Onwuka, G. I. (2005).** *Food analysis and instrumentation*. Theory and practice. Naphthali Print Lagos, Nigeria. Pp. 133-137.
- Onwuka, G. I. (2018).** *Food analysis and instrumentation*. Revised Edition. Theory and practices. Naphtali Print Lagos, Nigeria.
- Panda, S.P., Prasad, K.V.S.K. and Shanida, P. (1999).** Concerted action of antioxidant enzymes and curtailed growth under zinc toxicity in Brassica Juncea Environ. Exp. Bot., 42: 1-10
- Panitnok, K., Chaisri, S., Sarobol, Ed., Ngamprasitthi, S., Chaisir, P., Changlek, P. and Thongluang, P. (2013).** The combination effects of zinc, magnesium, sulphur foliar fertilizer management on cassava growth and yield grown on Map Bon, coarse-loamy variant soil. *Procedia-Social and Behavirol Sciences*, 91(2): 288-293.
- Shafiq, T., Yasmin, H., Shah, Z.A., Nosheen, A., Ahmad, P., Kaushik, P. and Ahmad, A. (2022).** Titanium oxide and zinc oxide nanopaticles in combination with cadmiun tolerant *Bacillus pumilus* ameliorates the cadmium toxicity in maize. *Antioxidants*, 11: 2156. doi.org/10.3390/antiox14030316.
- Shuman, L.M. (1985).** *Fractionation Method for Soil Micronutrients*. Soil Science, 140: 11-22. <http://dx.doi.org/10.1097/00010694-198507000-00003>.
- Surleva, A., Zaharia, M., Ion, L., Gradinaru, R.V., Drochioiu, G. and Mangalagiu, I. (2013)** Ninhydrin-Based Spectrophotometric Assays of Trace Cyanide. *Acta Chemica IASI*, 21: 57-70. <http://dx.doi.org/10.2478/achi-2013-0006>.
- Taylor, N.J., Narayanan, N., Beyene, G., Chauhan, R.D., Gaitan-Solis, E., Siritunga, D., Grusak, M.A., Anderson, P. (2016).** Iron and zinc biofortification of cassava storage roots to nutritionally significant levels. *Vitro Cell Development Biology*, 52: S38–S38.
- Ugwu, C.C., Asawalam, D.O., Eteng, E.U., Ano, A.O. (2020).** Determination of Zinc Requirement of Cassava (*Manihot esculenta* Crantz) in Soils Derived from Coastal Plain Sands of South Eastern Nigeria. *International Journal of Research Studies in Science, Engineering and Technology*, 7 (2): 7-22.
- Ziska, L., Runion, G.B., Tomecek, M., Prior, S.A., Torbet, H.A. and Sicher, R. (2009).** An Evaluation of Cassava, Sweet Potato and Field Corn as Potential Carbohydrate Sources for Bioethanol Production in Alabama and Maryland. *Biomass and Bioenergy*, 33:1503-1508.
- Zhu, Y.G., Smith, S.E. and Smith, F.A. (2001).** Zinc (Zn)-phosphorus (P) interactions in two cultivars of spring wheat (*Triticum aestivum* L.) differing in P uptake efficiency. *Ann. Bot.*, 88: 941–945