Consumption patterns, perceptions and total carotenoids, iron and zinc contents of yellow flesh cassava

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Abstract. Duah EA, Steiner-Aseidu M, Danquah AO. 2020. Consumption patterns, perceptions, and total carotenoids, iron, and zinc contents of yellow flesh cassava. *Biofarmasi J Nat Prod Biochem* 18: 13-28. The main objective was to investigate consumption patterns of white cassava, knowledge, perceptions, and the nutritional profiles of yellow flesh cassava roots and leaves and their relationship to the recommended daily allowance for vitamin A. Total carotenoids, iron and zinc contents in fresh yellow cassava leaves, roots and products (gari, konkonte, boiled cassava roots, and leaves), antioxidant activity, and the in vitro bioaccessibility of the carotenoids were determined using standard methods. A cross-sectional survey was carried out to identify the consumption patterns of white cassava, the knowledge, and the perception of yellow flesh cassava among Ghanaians. Total carotenoids (T.C), iron (Fe) and zinc (Zn) for fresh roots ranged from 4.73 ± 0.11 to 10.11 ± 0.18 $\mu\text{g/g}$; 87.35 ± 3.18 to 146.25 ± 1.20 $\text{mg}/100\text{g}$; 0.30 ± 0.01 to 1.55 ± 0.07 $\text{mg}/100\text{g}$, respectively. T.C, Fe, and Zn for fresh leaves ranged from 792.93 ± 0.98 to 2649.20 ± 29.10 $\mu\text{g/g}$; 118.35 ± 0.070 to $07182.05 \pm$ $\text{mg}/100\text{g}$; 3.75 ± 0.64 to 15.50 ± 0.14 $\text{mg}/100\text{g}$ respectively. T.C for gari was between 3.21 ± 2.79 and 7.39 ± 1.06 $\mu\text{g/g}$, iron 118.75 ± 0.64 to 181.85 ± 2.05 $\text{mg}/100\text{g}$ and zinc, 0.25 ± 0.07 to 0.80 ± 0.14 $\text{mg}/100\text{g}$. Iron and zinc contents for the konkonte samples ranged from 101.45 ± 0.64 to 116.30 ± 0.14 $\text{mg}/100\text{g}$ and 0.15 ± 0.07 to 0.70 ± 0.01 $\text{mg}/100\text{g}$; however, T.C was not detectable. T.C for boiled roots were between 1.22 ± 0.05 and 2.14 ± 0.11 $\mu\text{g/g}$. Iron content for the samples ranged from 118.75 ± 0.64 to 181.85 ± 2.05 $\text{mg}/100\text{g}$, and for zinc, 0.60 ± 0.01 to 1.30 ± 0.01 $\text{mg}/100\text{g}$. T.C for boiled leaves was between 524.39 ± 9.89 and 1323.5 ± 15.6 $\mu\text{g/g}$, iron; 95.90 ± 0.01 and 148.75 ± 2.76 $\text{mg}/100\text{g}$, and zinc 0.60 ± 0.01 to 1.30 ± 0.01 $\text{mg}/100\text{g}$. In vitro bio-accessibility of carotenoids for boiled roots had the highest of $104.42 \pm 0.88\%$, gari had the highest value of $57.22 \pm 9.01\%$, and boiled leaves $0.28 \pm 0.01\%$. Gari recorded the highest frequency of consumption. 36.6% of the respondents knew yellow flesh cassava. 51.2% were willing to accept yellow flesh cassava. Fermentation, drying, roasting, and boiling retained some carotenoids after processing, but solar drying over a long period completely degraded carotenoids in yellow cassava roots. Cassava leaves had higher retention of carotenoids, but cassava roots had more bio-accessible carotenoids. Carotenoids in yellow flesh cassava leaves had antioxidant properties that have the potential to help combat free radicals in the body. Ghanaians had insufficient knowledge and “willingness to accept” yellow cassava. Yellow cassava will serve as a promising source of provitamin A.

Keywords: Carotenoid, cassava, consumption

INTRODUCTION

Cassava is a relevant root tuber, which is typical food for several populations in the tropical and sub-tropical regions of the world (Bradbury and Holloway, 1988). It is the sixth major staple crop after rice, wheat, maize, Irish potato, and sweet potato globally (FAO 2003). Cassava is a crop that grows on soils with marginal nutrition (Aerni 2006). Cassava roots contain small amounts of zinc, iron, and β -carotene; however, it is the primary essential crop of more than 250 million Africans (Gegios et al. 2010); it also reported that consumers who often eat cassava are at higher risk for malnutrition, especially deficiencies in iron, vitamin-A, and zinc than people who consume other diets, particularly those that are predominantly cereal.

Micronutrient deficiencies are becoming more endemic, specifically in West Africa. The most vulnerable in this population include children, juveniles, women in their reproductive years, breastfeeding mothers, and people who have suffered from war and starvation. Iodine, vitamin A and iron deficiencies are of significant public health importance in several places in Africa and are responsible for the increased mortality and morbidity in children in

Africa (Black et al. 2008). Micronutrient malnutrition, also known as hidden hunger, reduces the productivity rate and income of individuals and governments in Africa. It also decreases psychological development, decreases working capacity, hinders growth, lowers how immune a person is, causes several pregnancy complications, blindness, and goiter, and increases the possibility of mortality (Darnton-Hill et al. 2005).

The National and Regional Estimates of the prevalence of anemia are 65.7% for children between 6-59 months and 42.4% for women between 15-49 years in Ghana, and vitamin A deficiency is also quite high and of public health concern even though various intervention strategies are being used to combat these micronutrient deficiencies. Cassava is very important to the food security status of most Ghanaian households because it is one of the significant staples. It is consumed in various ways such as cooked fresh roots (that include pounded fresh cassava, known as fufu in Ghana), flour (fermented and un-fermented), granulated, roasted cassava (known as gari), fermented pastes, known as agbelima (MoFA 2009).

Bio-fortification is the creation of essential nutrient-dense staple crops using the best traditional propagation

methods and modern biotechnology (Nestel et al. 2006). Biofortification gives a convenient way of getting to people in the rural and remote areas that are malnourished but do not have access to commercially available fortifies (Graham, 1996). Several staple foods are being fortified. These include rice, sweet potato, maize, and cassava. The International Institute of Tropical Agriculture (IITA), with several partners like HarvestPlus over a while, has developed several bio-fortified cassava genotypes popularly known as yellow flesh cassava, which contains predominantly β -carotene, a provitamin A. Yellow flesh cassava proposes to be an avenue to solving micronutrient deficiencies in Africa. The International Institute of Tropical Agriculture (IITA), in conjunction with the CSIR-Crop Research Institute of Ghana, is currently breeding some cassava genotypes in Ghana.

The objectives of the study were to determine micronutrient composition (carotenoids, iron, and zinc) in the yellow flesh cassava genotypes (fresh roots and leaves, boiled leaves and roots, *gari* and *kokonte*), to determine the effect of processing on retention of micronutrient composition (carotenoids, iron, and zinc) in the yellow flesh cassava genotypes, to ascertain the in-vitro bioaccessibility of the carotenoids in cassava products (boiled leaves and roots, *gari* and *kokonte*), to determine antioxidants properties of the carotenoids in yellow flesh cassava genotypes, to assess the consumption patterns of the white cassava and products and as well as perception and knowledge of yellow flesh cassava among consumers of cassava, to determine the contribution of yellow cassava products to the RDA of vitamin A.

MATERIALS AND METHODS

Laboratory study

The laboratory study comprised moisture analysis, total carotenoids, iron and zinc determination, antioxidant activity, and in vitro bio-accessibility of carotenoids.

Sample collection and preparation

Fourteen yellow flesh cassava genotypes were planted by IITA in Crops Research Institute (CRI) at Pokuase in the Greater Accra Region of Ghana. Before processing, moisture contents, total carotenoids, iron, and zinc determination were determined for all fourteen genotypes. Out of these fourteen genotypes, five were selected by IITA to study the effects of processing on the total carotenoid retention, beta carotene concentration, in-vitro bioaccessibility, and iron and zinc concentration of the cassava genotypes. Reasons for the selected five were because previous trials concluded that these genotypes (01, 03, 05, 07, and 15) had sensory and textural characteristics preferred by farmers as well as high contents of total carotenoids. Yellow flesh cassava samples were collected at the Crops Research Institute (CRI) at Pokuase. Samples were processed and bagged in the Nutrition and Food Science Department, Legon University of Ghana.

Preparation of *gari*

Cassava roots were peeled, washed, and grated. The grated cassava was put into perforated jute bags, fermented for 24 hours, and dewatered. The grated cassava was then sifted over a raft and roasted over minimal heat till crispiness was achieved to avoid loss and degradation of carotenoids in the cassava. Temperature and lighting were not strictly controlled to mimic the garification methods used among *gari* processors in Accra and quantify carotenoids lost during the process. The resulting product, *gari*, was allowed to cool and packaged in an airtight bag, and stored in a cool dark place to help prevent carotenoid loss and degradation.

Preparation of *kokonte*

The cassava roots were harvested from the farm and peeled. The peeled roots were washed and chopped into bigger chunks. The chopped roots were dried evenly in a solar dryer for five days, after which they were milled and packaged in black polythene bags and stored in a cool, dry place for further analysis.

Preparation of boiled roots and leaves

Fresh roots and leaves samples were chopped separately into small pieces, and 5 grams were weighed into a plastic bag, cooked in a stainless-steel pan on an electric cooker for fifteen minutes, and cooled for further analysis.

Determination of moisture content

Moisture content was determined by weighing 2g of the sample (fresh leaves and roots, *gari*, *kokonte*, boiled leaves, and roots separately) and dried in an air oven at a temperature of 105°C for 24 hours. The samples were removed, cooled over a desiccant for 15 minutes, weighed, and the loss in weight of the sample after drying was calculated as percent moisture (AOAC 2005).

Quantification of Beta carotene in yellow cassava genotypes

Beta carotene in yellow cassava genotypes and their products (fresh roots and leaves, *gari*, *kokonte*, boiled leaves, and roots) were assessed using high-performance liquid chromatography (HPLC). Five grams (5g) of each sample was weighed on a digital balance (Professional electronic balance) into a mortar and ground with pyrogallol to prevent oxidation of the carotenoids. The carotenoids were extracted by successive additions of 25 mL of acetone to the weighed sample. The final solution was transferred into a sintered funnel (5 μ m) coupled to a 250 mL Buchner flask and filtered under a vacuum. This procedure was repeated three times, or until the sample became colorless. The obtained extract was transferred to a 500 mL separatory funnel containing 20ml of petroleum ether. The acetone was removed by slowly adding ultrapure water to prevent emulsion formation, and the aqueous phase was discarded. This procedure was repeated four times until no residual solvent remained. The extract was then transferred to a 50 mL volumetric flask through a funnel. The sample was evaporated with a rotary vacuum evaporator to dryness. The concentrate was reconstituted

with 2ml of acetone and put into vials for HPLC analysis (Rodriguez-Amaya and Kimura 2004).

Determination of total carotenoids in fresh yellow cassava roots

The iCheck™ carotene measures total carotenoids in vitamin premix, food, and biological fluids. iCheck Carotene measures the color in the test vial and calculates the total carotenoid content in mg/L. The principle of the method is photometric, and its sample volume per analysis is 400 µL (0.4 mL). It works in a linear range of 0.15-25.0 mg/L. The device's time per report is < 2 min, and its variation is < 10%. iCheck™ carotene has been validated against HPLC (Bioanalyt 2014).

Fresh yellow cassava roots

About 5g of the fresh yellow cassava roots were weighed and ground to a smooth paste to help solubilize all the carotenoids present in the sample and transferred into a falcon tube and made to 25ml mark with distilled water. 0.4ml of the diluted sample was injected into the reagent vial. The vial was vigorously shaken for 10 seconds till the vial's content appeared as one uniform solution. The vial was made to stand still for 5 minutes until the solution in the vial appeared in two distinct phases. The vial with the sample was measured with iCheck™ Carotene earliest 5 minutes and the latest 1 hour after sample injection. The total carotenoid was calculated by multiplying the iCheck™ reading with the dilution factor (Bioanalyt 2014).

Fresh yellow cassava leaves

The procedure was modified for the leaves because they contained excessive amounts of carotenoids, which was above the working range of the check device; thus, 0.5g of the fresh yellow cassava leaves were weighed and ground to a smooth paste and transferred into a falcon tube and made to the 50 ml mark with distilled water. 0.4 ml of the diluted sample was injected into the reagent vial. The vial was vigorously shaken for 10 seconds till the vial's content appeared as one uniform solution. The vial was made to stand still for 5 minutes until the solution in the vial appeared in two distinct phases. The vial with the sample was measured with iCheck™ Carotene earliest 5 minutes and the latest 1 hour after sample injection. The total carotenoid was calculated by multiplying the iCheck™ reading with the dilution factor (Bioanalyt 2014).

Kokonte made from yellow flesh cassava

Two grams (2g) of the sample were weighed and ground to a smooth paste, transferred into a falcon tube, and made a 30 ml mark with distilled water. 0.4 ml of the diluted sample was injected into the reagent vial. The vial was vigorously shaken for 10 seconds until the vial's content appeared as one uniform solution. The vial was made to stand still for 5 minutes until the solution in the vial appeared in two distinct phases. The vial with the sample was measured with iCheck™ Carotene earliest 5 minutes and the latest 1 hour after sample injection. The total carotenoid was calculated by multiplying the iCheck™ reading with the dilution factor (Bioanalyt 2014).

The procedure was modified for kokonte because it had a high swelling capacity, which blocked the syringe during the injection into the vials of the iCheck device.

Yellow cassava gari

The procedure was modified for gari because it had a high swelling capacity which blocked the syringe during the injection into the vials of the iCheck device; thus, two grams (2g) of the sample was weighed and ground to a smooth paste and transferred into a falcon tube and made to 30 ml mark with distilled water. 0.4ml of the diluted sample was injected into the reagent vial. The vial was vigorously shaken for 10 seconds till the content of the vial appeared as one uniform solution, and the vial was made to stand still for 5 minutes until the solution in the vial appeared in two distinct phases. The vial with the sample was measured with iCheck™ carotene earliest 5 minutes and the latest 1 hour after sample injection. The total carotenoid was calculated by multiplying the iCheck™ reading with the dilution factor (Bioanalyt 2014).

Determination of iron and zinc contents

Iron and zinc contents in yellow cassava products (fresh and boiled roots and leaves, gari, and kokonte) were assessed using AOAC (2005) method. Wet digestion was used to digest samples. The weight of 0.1g of each sample (*fresh and boiled roots and leaves, gari, and kokonte*) was digested in 4ml of concentrated sulphuric acid and heated in a fume hood. Ten drops of H₂O₂ were added to the digest and heated from black to dark brown. Six drops of hydrogen peroxide (H₂O₂) were added and heated until the digest was colorless. It was then transferred to a 100 ml volumetric flask and made up to the 100ml mark with deionized water. The wet digest solutions were prepared on the same day for each sample as the check sample and duplicate blanks. The Atomic Absorption Spectrophotometer determined iron and zinc contents (Analyst 400 Perkin Elmer).

Determination of antioxidants properties of carotenoids in yellow flesh cassava

Antioxidant assays were based on measuring the loss of 2, 2-Diphenyl 1, 1-picrylhydrazyl (DPPH) color at 515 nm after reaction with test samples, and the reaction was monitored by a spectrophotometer. The percentage of the DPPH remaining was proportional to the antioxidant concentration of the test samples. One gram (1g) of each sample (*fresh and boiled roots and leaves, gari, and kokonte*) was ground, and carotenoids were extracted using 50ml of 95% methanol as solvent. The solution was filtered using a Whatman filter paper (grade F101 with a pore size of 125mm) till the residue was white. 3ml of the filtrate was added to 3ml of DPPH, vortexed, and allowed to stay in the dark for 30 minutes. The absorbance was read using the Atomic absorption spectrophotometer (T80 UV/VIS spectrophotometer-PG instruments Ltd) using a wavelength of 450nm (Bondet et al. 1997).

Determination of carotenoid retention after processing

For the estimation of true carotenoid retention, the following formula was used:

$$\% \text{ True Retention} = \frac{c_1 \times w_b}{c_2 \times w_{ub}} \times 100$$

Where: c_1 is the carotenoid content in the processed sample, c_2 is the carotenoid content in the fresh (unprocessed) sample, w_b is the weight of the processed sample, and w_{ub} is the weight of the fresh (untreated) sample. Carotenoid content ($\mu\text{g/g}$) was calculated on a dry matter basis for both the processed and unprocessed root samples (Murphy et al. 1975).

Determination of in vitro bio-accessibility of carotenoids in yellow flesh cassava

The method was adapted from Hedre'n et al. (2002) with some modifications. Three grams (3g) of the cassava sample were weighed and ground in a mortar. For the oral phase of the digestion, 0.003grams alpha-amylase was added to 0.005M saline solution (NaCl). About 7.5 ml of the saline solution was added to the sample and sonicated in a water bath at a temperature of 37°C and a pH of 6.8. After 10 minutes, the sample solution was acidified to a pH of 3 using 0.01M HCl to stimulate the gastric phase. 1ml of porcine pepsin (40mg/ml) was added to the sample solution at pH three and incubated for an hour at 37°C, after which pH was brought up to 7 to stimulate the intestinal phase of the digestion. About 4.5 ml of a mixture of porcine pancreatin (4mg/ml) and porcine bile extract (24 mg/ml) was added to the simulated gastric fluid, and 1% (w/v) alpha-tocopherol. The final volume was adjusted to 25ml with a physiological saline solution and incubated in a shaking water bath (100 rpm at 37°C) for two hours. It was then centrifuged at 5,000 g for 45 minutes at 4°C. The supernatant was collected with a plastic pipette into a separatory funnel containing 20 ml of 25% (w/v) NaCl. 20 ml of 95% ethanol and 15 ml of petroleum ether were added and allowed to separate. The solution was washed with water, the organic phase was collected, and the absorbance was read with an Atomic Absorption spectrophotometer at 450nm.

Contribution of yellow cassava to recommended daily allowances for under-five children

The contribution of yellow cassava to the recommended daily allowance for vitamin A was calculated first using a conversion factor of 1 $\mu\text{g/g}$ of beta carotene =3.3IU of vitamin A (Bioanalyt, 2015) to get the amount of vitamin A in the food. After that,

An example of one of the samples is shown below:

1 $\mu\text{g/g}$ of beta carotene in food sample =3.3IU of vitamin A
 3.439 $\mu\text{g/g}$ of food sample =3.3IU *3.439
 = 11.348 IU

Thus if every 1g of food contained 11.34IU of vitamin A, then an allowance of 200IU, which is the upper limit, will be:

=2000/11.35
 =176g of food

Thus, for every 100grams = (2000*100)/176
 =1136.36 IU

To find the %RDA= (1136.36/2000)*100

This was also done using the lower limit and an average to give the final % RDA

Cross-sectional study

A survey was conducted to describe white cassava consumption patterns and the perception and knowledge of participants on yellow flesh cassava. A pretested semi-structured questionnaire was used to interview adult Ghanaians. Data on their socio-demographic characteristics were also collected.

Study area and population

The study area was selected in the Greater Accra region and was chosen for convenience and because the cassava genotypes were planted in Greater Accra. The study population comprised individuals above 18 years of age who consumed cassava. This population was chosen as representative of cassava consumers.

Sample size determination and sampling technique for the survey

Simple random sampling was employed in subject selection for the survey, and a sample size of 287 was used based on the formulae by

$$n_0 = Z^2 pq/E^2$$

n_0 = sample size, Z = confidence interval (1.96), p = α level (0.5), q = 1- p , E = margin of error (0.05) (Cochran 1963).

Data collection

Data were collected on background information, consumption, usage of cassava, knowledge, and the perception of yellow flesh cassava using a pretested questionnaire.

Socio-demographic characteristics

Data were collected on participants' age, marital status, educational level, occupation, residential status, income, and household size.

Consumption and usage of white cassava

Data were collected on the frequency of cassava and cassava products consumed, time of consumption, reasons for cassava consumption, and knowledge of the nutritional value of white cassava.

Knowledge and perception of yellow flesh cassava

Participants were interviewed on knowledge about yellow cassava, source of information about yellow flesh cassava, willingness to accept yellow flesh cassava, and perceived usage of yellow cassava.

Data analyses

The data analysis tools used were Statistical Package for Social Sciences version 16(SPSS), MINITAB version 17, Statistical Analysis System version 9.01 (SAS), and Microsoft Excel.

Laboratory data

Means and standard deviations were computed using Microsoft Excel. Analysis of variance was used to compare means for laboratory analyses.

Survey data

Descriptive statistics were computed using SPSS version 17 for demographic data and consumption patterns of knowledge on yellow cassava. Logistic regression was computed using the Statistical Analysis System version 9.01. Multinomial regression was used, and this provided the opportunity to see the interaction between more than two categories of an outcome (knowledge and "willingness to accept" yellow flesh cassava) and predictors (in this case, selected socio-demographic factors). The socio-demographic factors, education status, marital status, age, and gender were considered independent variables.

Ethical consideration

Ethical clearance was sought from the College of Basic and Applied Science (CBAS) ethical clearance board. Informed consent was also sought from all participants interviewed.

RESULTS AND DISCUSSION

This study was primarily in two sections; laboratory analysis and a survey. The laboratory analysis focused on determining the total carotenoids, iron, and zinc of fourteen yellow flesh cassava genotypes. We also determined the effect of processing on the nutrients and the antioxidant activity of the carotenoids present in the roots and leaves of the selected yellow cassava genotypes. The same analysis was carried out on some selected yellow cassava products (gari, boiled cassava roots, leaves, and kokonte). The breeder's names of the cassava genotypes are in Appendix III. The survey provided information on the consumption patterns of white cassava among Ghanaian consumers and

their willingness to accept the yellow flesh cassava. The survey also determined associations between socio-demographic characteristics and consumption patterns.

Laboratory analysis

Fourteen yellow flesh cassava genotypes were planted by IITA in Crops Research Institute (CRI) at Pokuase in the Greater Accra Region of Ghana. Before processing, moisture contents, total carotenoids, iron, and zinc determination were determined for all fourteen genotypes. Out of these fourteen genotypes, five were selected by IITA to study the effects of processing on the total carotenoid retention, beta carotene concentration, in-vitro bioaccessibility, iron, and zinc concentration of the cassava genotypes. Iron, zinc, and carotenoid contents were reported on a dry matter basis.

Total carotenoids, iron, and zinc contents of fresh yellow cassava roots

Fresh yellow cassava roots had a moisture content between $67.05 \pm 1.09\%$ (sample 08) and $82.123 \pm 0.76\%$ (sample 15) (Table 1). Total carotenoids ranged from $4.73 \pm 0.11 \mu\text{g/g}$ (sample 07) to $10.11 \pm 0.18 \mu\text{g/g}$ (sample 09). Iron content for the samples ranged from 87.35 ± 3.18 to $146.25 \pm 1.20 \text{ mg/100g}$ (samples 06 and 03), and for zinc, 0.30 ± 0.01 to $1.55 \pm 0.07 \text{ mg/100g}$ (samples 06 and 14). There were significant differences among all samples ($p < 0.05$) for dry matter, total carotenoids, iron, and zinc.

Total carotenoids, iron, and zinc contents of fresh yellow cassava leaves

The moisture content was between $56.06 \pm 0.33\%$ (sample 09) and $81.62 \pm 0.52\%$ (sample 10) (Table 2). T.C ranged from $792.93 \pm 0.98 \mu\text{g/g}$ (sample 08) to $2649.20 \pm 29.10 \mu\text{g/g}$ (sample 07). Iron and zinc values ranged between 118.35 ± 0.07 and $182.05 \pm 0.07 \text{ mg/100g}$ (sample 08 and sample 01) and 3.75 ± 0.64 and $15.50 \pm 0.14 \text{ mg/100g}$ (sample 08 and 10). There were significant differences among all samples for each parameter measured ($p < 0.05$).

Table 1. Total carotenoids, iron, and zinc contents of fresh yellow flesh cassava roots (d.m.b)

Sample	Moisture content (%)	Total carotenoid ($\mu\text{g/g}$)	Iron (mg/100g)	Zinc (mg/100g)
01	78.30 ± 0.96^{abc}	7.85 ± 0.07^d	76.10 ± 1.27^g	0.45 ± 0.07^{def}
02	76.17 ± 0.25^{bcde}	4.67 ± 0.03^g	98.70 ± 0.85^d	0.70 ± 0.14^{bcdef}
03	71.60 ± 1.15^{efgh}	5.77 ± 0.07^f	146.25 ± 1.20^a	0.85 ± 0.07^{bcde}
05	68.40 ± 1.74^{gh}	5.69 ± 0.04^f	112.20 ± 0.14^d	0.95 ± 0.07^{bc}
06	79.08 ± 0.32^{abc}	5.02 ± 0.07^g	87.35 ± 3.18^f	0.30 ± 0.01^f
07	76.21 ± 1.04^{bcd}	4.73 ± 0.11^g	111.00 ± 0.42^d	0.60 ± 0.14^{cdef}
08	67.05 ± 1.09^h	6.57 ± 0.28^e	131.05 ± 1.06^b	0.60 ± 0.14^{cdef}
09	75.55 ± 1.99^{cdef}	10.11 ± 0.18^a	88.65 ± 0.21^f	0.40 ± 0.01^{ef}
10	70.22 ± 0.57^{gh}	9.21 ± 0.14^b	121.90 ± 0.01^c	1.05 ± 0.07^{bc}
11	71.39 ± 2.32^{fgh}	6.46 ± 0.04^e	123.85 ± 2.76^c	0.90 ± 0.01^{bcd}
12	72.76 ± 0.42^{defg}	6.43 ± 0.14^e	143.45 ± 2.33^a	0.70 ± 0.28^{bcdef}
13	80.33 ± 0.58^{ab}	8.43 ± 0.07^c	121.55 ± 0.21^c	1.10 ± 0.14^{ab}
14	70.98 ± 0.19^{fgh}	6.16 ± 0.04^f	126.15 ± 0.49^{bc}	1.55 ± 0.07^a
15	82.12 ± 0.76^a	7.69 ± 0.04^d	110.25 ± 0.07^d	0.70 ± 0.01^{bcdef}
P-value	0.00	0.00	0.00	0.00

Note: Means with different superscripts on the same column are significantly different at $P \leq 0.05$.

Table 2. Total carotenoids, iron, and zinc contents of fresh yellow cassava leaves (d.m.b)

Sample	Moisture content (%)	Total carotenoids (µg/g)	Iron (mg/100g)	Zinc (mg/100g)
01	63.65±0.89cde	2224.51±2.84b	182.05±0.07a	6.85±0.07h
02	63.65±0.89ef	2223.80±28.90b	147.20±0.28ab	8.95±0.07def
03	61.82±0.31f	862.20±21.50g	177.3±46.60a	7.80±0.70gh
05	70.69±0.55b	2034.74±8.23c	147.6±25.00ab	13.42±0.16bc
06	69.70±0.49b	1798.76±2.76d	163.85±1.34f	8.55±0.07efg
07	67.37±0.58bcd	2649.20±29.10a	181.55±0.63d	4.25±0.21i
08	61.01±1.43f	792.93±0.98g	118.35±0.07b	3.75±0.64i
09	56.05±0.32g	2593.90±101.80a	181.75±0.64a	12.75±0.07c
10	81.62±0.52a	2312.53±12.56b	143.40±0.14ab	15.50±0.14a
11	60.79±1.40f	991.85±8.86f	165.25±0.35ab	9.75±0.07d
12	68.21±1.40bc	2042.74±1.86c	152.90±0.14ab	8.25±0.07fg
13	62.60±0.45ef	1810.28±4.86d	174.40±0.42ab	7.50±0.28gh
14	65.92±0.10cde	1171.15±0.95e	168.10±0.14ab	9.40±0.01de
15	64.12±1.05def	1133.16±1.92e	129.65±0.21ab	14.30±0.14b
P-value	0.00	0.00	0.00	0.00

Note: Means with different superscripts on the same column are significantly different at $P \leq 0.05$

Total antioxidant activity of fresh yellow cassava roots and leaves

The overall antioxidant activity of fresh roots (Table 3) ranged from non-detectable (ND) to $86.28 \pm 0.10\%$ (sample 02). Fresh leaves had total antioxidant activity between $17.39 \pm 0.10\%$ for (sample 03) and $70.96 \pm 0.10\%$ (for sample 12). The antioxidant activity was also expressed in Alpha-Tocopherol units. For fresh leaves, antioxidant activity ranged from 13.64 ± 0.05 Alpha Tocopherol units (sample 12) to 38.81 ± 0.05 Alpha Tocopherol units (sample 03). For cassava roots, values ranged between ND to 8.53 ± 0.05 Alpha Tocopherol units (sample 02). There were significant differences among all samples for each parameter measured ($p < 0.05$).

Total carotenoids, iron, and zinc contents of yellow flesh cassava products

Five out of the fourteen genotypes were selected based on farmer preferences and previous trials by IITA to study further the effect of processing on total carotenoids, iron and zinc content, antioxidant activity, in-vitro bioaccessibility, and beta-carotene concentration. The selected genotypes were 01, 03, 05, 07, and 15 were made into gari, kokonte, boiled, and boiled leaves.

Total carotenoids, iron, and zinc contents of yellow flesh gari

Dry matter content was between $94.74 \pm 0.07\%$ and $97.12 \pm 0.09\%$ for samples 05 and 07, respectively. Total carotenoids were between 7.39 ± 1.06 µg/g (sample 07) and 3.21 ± 2.79 µg/g (sample 05). Iron content for the samples ranged from 118.75 ± 0.64 to 181.85 ± 2.05 mg/100 g (samples 07 and 15), and for zinc, 0.25 ± 0.07 to 0.80 ± 0.14 (samples 01 and 15). There were significant differences among all samples ($p < 0.05$) for dry matter, total carotenoids, iron, and zinc (Table 4).

The nutrient profile of yellow flesh kokonte

Table 5 shows the Total carotenoids, iron, and zinc contents of *kokonte*. Moisture content ranged from $11.30 \pm 0.15\%$ (sample 07) to $13.79 \pm 0.46\%$ (sample 05). Dry matter content ranged between $86.21 \pm 0.46\%$ (sample 05) and $88.56 \pm 0.28\%$ for sample 01. Iron content ranged from 101.45 ± 0.64 to 116.30 ± 0.14 mg/100 g (samples 01 and 07) and for zinc, 0.15 ± 0.07 to 0.70 ± 0.01 mg/100 g (samples 07 and 03). Total carotenoids were not detectable (ND) in all *kokonte* samples. There were significant differences among all samples ($p < 0.05$) for dry matter, total carotenoids, iron, and zinc.

Total carotenoids, iron, and zinc contents of boiled yellow flesh cassava roots

Dry matter content was between $23.20 \pm 0.60\%$ (sample 05) and $30.58 \pm 0.81\%$ (sample 07). Moisture content ranged between $69.43 \pm 0.81\%$ (sample 07) and $76.80 \pm 0.60\%$ (sample 05) (Table 6). Total carotenoids were between 1.22 ± 0.05 µg/g (samples 05) and 2.14 ± 0.11 µg/g (sample 15). Iron content for the samples ranged from 118.75 ± 0.64 to 181.85 ± 2.05 mg/100 g (samples 07 and 15), and for zinc, 0.60 ± 0.00 to 1.30 ± 0.00 (samples 07 and 03). There were significant differences among all samples for each parameter measured ($p < 0.05$).

Total carotenoids, iron, and zinc contents of boiled yellow flesh cassava leaves

Samples recorded moisture content of between $72.00 \pm 2.97\%$ (sample 15) and $77.80 \pm 0.28\%$ (sample 03) (Table 7). Dry matter content ranged between $28.00 \pm 2.97\%$ (sample 15) and $22.200 \pm 0.28\%$ (sample 03). Total carotenoids were between 524.39 ± 9.89 µg/g (sample 07) and 1323.5 ± 15.6 µg/g (sample 03). Iron values were between 95.90 ± 0.01 mg/100g for sample 05 and 148.75 ± 2.76 mg/100g for sample 15. Zinc values 0.60 ± 0.01 mg/100 g for sample 07 and 1.30 ± 0.01 mg/100 g for sample 03 respectively. There were significant differences among all samples ($p < 0.05$) (Table 8).

Table 3. Total antioxidant activity of fresh yellow cassava roots and leaves (d.m.b)

Sample	Fresh roots (%)	Fresh roots (AT units)	Fresh leaves (%)	Fresh leaves (AT units)
01	81.85±0.10 ^a	8.53±0.05 ^a	62.45 ±0.10 ^b	17.64 ±0.05 ^m
02	86.28±0.10 ^b	6.44±0.05 ^b	51.03±0.01 ^e	23.00±0.01 ^j
03	*ND ^c	*ND ^c	17.39±0.10 ⁿ	38.81±0.05 ^a
05	*ND ^c	*ND ^c	26.31±0.27 ^m	34.61±0.13 ^b
06	*ND ^c	*ND ^c	50.44±0.21 ^f	23.28±0.10 ⁱ
07	*ND ^c	*ND ^c	41.63±0.01 ^j	27.42±0.01 ^e
08	*ND ^c	*ND ^c	37.67±0.27 ^l	29.28±0.13 ^c
09	*ND ^c	*ND ^c	57.13± 0.10 ^d	20.14±0.05 ^k
10	*ND ^c	*ND ^c	48.20±0.01 ^g	24.33±0.01 ^h
11	*ND ^c	*ND ^c	44.47±0.01 ^h	26.08±0.01 ^g
12	*ND ^c	*ND ^c	70.96±0.10 ^a	13.64±0.05 ⁿ
13	*ND ^c	*ND ^c	38.97±0.18 ^k	28.67±0.08 ^d
14	*ND ^c	*ND ^c	43.64±0.10 ⁱ	26.47±0.05 ^f
15	*ND ^c	*ND ^c	59.85±0.20 ⁱ	18.86±0.10 ^l
P-value	0.00	0.00	0.00	0.00

Note: *ND means not detectable; means with different superscripts on the same column are significantly different at $P \leq 0.05$. AT-alpha-tocopherol units

Table 4. Total carotenoids, iron, and zinc contents of yellow flesh gari (d.m.b)

Sample	Moisture content (%)	Dry matter (%)	Total carotenoids (g/100g)	Iron (mg/100g)	Zinc (mg/100g)
01	3.36±0.11 ^c	96.64±0.12 ^b	7.37±0.51 ^a	143.40±0.57 ^c	0.25±0.07 ^b
03	3.19±0.02 ^c	96.81±0.02 ^b	6.00±0.45 ^{ab}	156.10±1.13 ^b	1.10±0.14 ^a
05	5.25±0.07 ^a	94.75±0.07 ^d	3.21±2.79 ^b	125.50±0.28 ^d	0.80±0.01 ^a
07	2.88±0.09 ^d	97.12±0.09 ^a	7.39±1.06 ^a	118.75±0.64 ^e	0.35±0.07 ^b
15	4.01±0.08 ^b	95.99±0.08 ^c	6.96±0.33 ^a	181.85±2.05 ^a	0.80±0.14 ^a
P-value	0.00	0.00	0.00	0.00	0.00

Note: P-value <0.05; Means that do not share a letter are significantly different

Table 5. Total carotenoids, iron, and zinc contents of yellow flesh kokonte (d.m.b)

Sample	Moisture content (%)	Dry matter (%)	Total carotenoids (µg/g)	Iron (mg/100g)	Zinc (mg/100g)
01	11.44±0.28 ^b	88.56±0.28 ^a	ND*	101.45±0.64 ^c	0.30±0.01 ^c
03	11.71±0.145 ^b	88.29±0.15 ^a	ND*	113.35±0.21 ^b	0.70±0.01 ^a
05	13.80±0.46 ^a	86.21±0.46 ^b	ND*	112.10±0.42 ^b	0.50±0.01 ^c
07	11.53±0.11 ^b	88.46±0.11 ^a	ND*	116.30±0.14 ^a	0.15±0.07 ^b
15	11.30±0.152 ^b	88.70±0.15 ^a	ND*	116.40 ±0.00 ^a	0.15±0.07 ^c
P-value	0.00	0.00	0.00	0.00	0.00

Table 6. Total carotenoids, iron, and zinc contents of boiled yellow flesh cassava roots (d.m.b)

Sample	Moisture content (%)	Dry matter (%)	Total carotenoids (µg/g)	Zinc (mg/100g)	Iron (mg/100g)
01	71.60±1.09 ^b	28.40±1.09 ^a	2.12±0.163 ^a	0.65±0.07 ^a	143.40±0.57 ^c
03	70.90±1.09 ^b	29.10±1.09 ^a	1.35±0.05 ^b	1.30±0.01 ^{ab}	156.10±1.13 ^b
05	76.80±0.60 ^a	23.20±0.60 ^b	1.22±0.05 ^b	1.15±0.21 ^{bc}	125.50±0.28 ^d
07	69.43±0.81 ^b	30.57±0.81 ^a	2.07±0.05 ^a	0.60±0.01 ^c	118.75±0.64 ^e
15	72.59±0.52 ^b	27.41±0.52 ^a	2.14±0.11 ^a	0.80±0.01 ^c	181.85±2.05 ^a
P-value	0.00	0.00	0.00	0.00	0.00

Note: *ND means not detectable; means with different superscripts on the same column are significantly different at $P \leq 0.05$.

Table 7: Total carotenoids, iron, and zinc content of boiled yellow flesh cassava leaves (d.m.b)

Sample	Moisture content (%)	Dry matter (%)	Total carotenoids (µg/g)	Iron (mg/100g)	Zinc (mg/100g)
01	72.40±1.27 ^a	27.60±1.27 ^a	633.23±3.62 ^c	14.80± 0.14 ^d	0.65±0.07 ^c
03	77.80±0.28 ^a	22.20±0.28 ^a	1323.50±15.60 ^a	148.25±0.07 ^b	1.30±0.01 ^c
05	75.55±0.35 ^a	24.85±0.35 ^a	662.40±44.10 ^c	95.90±0.01 ^c	1.15±0.21 ^{ab}
07	72.95±1.06 ^a	27.05±1.06 ^a	524.39±9.89 ^d	113.10±1.13 ^a	0.60±0.01 ^a
15	72.00±2.97 ^a	28.00 ±2.97 ^a	1194.79±10.01 ^b	148.75±2.76 ^a	0.80±0.01 ^{bc}
P-value	0.00	0.00	0.00	0.00	0.00

Note: Means with different superscripts on the same column are significantly different at $P \leq 0.05$.

Table 8. Beta carotene in selected fresh yellow cassava and their products (d.m.b)

Sample	Fresh cassava roots ($\mu\text{g}/100\text{g}$)	Boiled Cassava roots ($\mu\text{g}/100\text{g}$)	Gari ($\mu\text{g}/100\text{g}$)	Kokonte ($\mu\text{g}/100\text{g}$)	Fresh cassava leaves ($\mu\text{g}/100\text{g}$)	Boiled cassava leaves ($\mu\text{g}/100\text{g}$)
01	343.99	79.05	0.54	*ND	691.86	12.78
03	72.26	40.13	3.02	*ND	*ND	417.85
05	6.74	14.88	ND	3.94	1911.91	1875.15
07	20.24	104.99	0.10	*ND	1213.78	1190.45
15	160.04	21.42	1.65	*ND	97.47	95.60

Note: *ND means not detectable

Total antioxidant activity of yellow flesh cassava products

Total antioxidant activity for boiled roots, *kokonte*, and *gari* were not detectable. For boiled leaves, values ranged between not detectable and $97.52 \pm 0.47\%$. There was a significant difference among all samples ($p < 0.05$) (Table 9). The antioxidant activity was also expressed in Alpha-Tocopherol units. For boiled leaves, antioxidant activity ranged from 1.17 ± 0.22 to 6.94 ± 0.05 Alpha Tocopherol units. There was a significant difference among all samples ($p < 0.05$) (Table 10).

Total carotenoid retention in yellow cassava products after processing

Table 11 shows carotenoid retention in yellow cassava products after processing. *Gari* had retention between $33.88 \pm 1.73\%$ and $61.15 \pm 0.01\%$ for samples 05 and 07,

respectively. Carotenoid retention in boiled roots was between $23.47 \pm 1.32\%$ (sample 03) and $43.89 \pm 0.01\%$ (sample 07). Boiled leaves showed retention of between $19.79 \pm 0.16\%$ and $153.52 \pm 2.02\%$. There was a significant difference among all samples ($p < 0.05$).

Effect of processing and variety on total carotenoids, iron and zinc contents of yellow flesh cassava

Cassava processing had a significant effect on dry matter and the total carotenoids ($p < 0.05$) but had no significant effect on iron and zinc contents ($p < 0.25$), as presented in (Table 12). The type of cultivar, on the other hand (Table 13), had a significant effect ($p < 0.05$) on the dry matter, iron, and zinc contents but had no significant effect on the total carotenoids ($p > 0.05$).

Table 9. Total antioxidant activity (%) of yellow flesh cassava products

Sample	Boiled roots	Boiled leaves	Kokonte	Gari
01	*ND	90.36 ± 0.10^a	*ND	*ND
03	*ND	96.03 ± 0.72^b	*ND	*ND
05	*ND	0.00 ± 0.01^c	*ND	*ND
07	*ND	97.51 ± 0.45^d	*ND	*ND
15	*ND	85.26 ± 0.03^e	*ND	*ND
P-value	0.00	0.00		0.00

Note: *ND means not detectable; means with different superscripts on the same column are significantly different at $P \leq 0.05$.

Table 10. Total antioxidant activity in yellow cassava products in alpha-tocopherol units

Sample	Boiled leaves	Boiled roots	Kokonte	Gari
01	4.53 ± 0.05^b	*ND	*ND	*ND
03	1.86 ± 0.34^c	*ND	*ND	*ND
05	*ND ^e	*ND	*ND	*ND
07	1.17 ± 0.22^d	*ND	*ND	*ND
15	6.94 ± 0.05^a	*ND	*ND	*ND
P-value	0.00	0.00	0.00	0.00

Note: *ND means not detectable; means with different superscripts on the same column are significantly different at $P \leq 0.05$.

Table 11. Total carotenoid retention (%) in yellow cassava products after processing

Sample code	Boiled roots	Gari	Kokonte	Boiled leaves
01	26.96 ± 1.79	39.08 ± 0.43	*ND	28.47 ± 0.20
03	23.48 ± 1.32	39.85 ± 0.82	*ND	153.52 ± 2.02
05	21.44 ± 1.09	33.88 ± 1.73	*ND	32.56 ± 2.30
07	43.89 ± 0.01	61.15 ± 0.01	*ND	19.79 ± 0.16
15	27.77 ± 1.55	35.17 ± 0.19	*ND	105.44 ± 0.70

Note: *ND means not detectable; means with different superscripts on the same column are significantly different at $P \leq 0.05$.

Table 12. Statistical effect of processing on total carotenoids, iron and zinc contents of yellow flesh cassava

Sample	Mean total carotenoids($\mu\text{g/g}$)	Mean dry matter (%)	Mean iron (mg/100g)	Mean zinc (mg/100g)
Fresh roots	6.40 ^c	37.52 ^c	114.18 ^a	0.78 ^a
Gari	6.20 ^c	96.26 ^a	145.12 ^a	0.66 ^a
Kokonte	0.00 ^c	88.05 ^b	111.92 ^a	0.36 ^a
Boiled roots	1.80 ^c	27.70 ^d	104.20 ^a	0.90 ^a
Boiled leaves	867.70 ^b	26.18 ^d	104.20 ^a	0.90 ^a
Fresh leaves	1780.80 ^a	33.99 ^{cd}	159.52 ^a	9.36 ^a
P-Value	0.01	0.01	0.25	0.25

Note: Means with different superscripts on the same column are significantly different at $P \leq 0.05$.

Table 13. Statistical effect of cultivar on total carotenoids, iron and zinc contents of yellow flesh cassava

Cultivar	Mean total carotenoids (%)	Mean dry matter (%)	Mean iron (mg/100g)	Mean zinc (mg/100g)
01	442.90a	53.14b	88.8b	1.53a
03	338.80a	54.11b	148.24a	2.18a
05	416.80a	51.88b	114.87ab	2.99a
07	491.00a	53.58b	125.63ab	1.09a
15	361.30a	62.52a	141.16a	1.86a
P-value	0.74	0.03	0.00	0.00

Note: Means with different superscripts on the same column are significantly different at $P \leq 0.05$.

Effects of processing and cultivar on antioxidant activity of yellow flesh cassava

Processing and cultivar significantly affected the antioxidant activity of yellow flesh cassava (p-value 0.0001) (Tables 14 and 15).

Contribution of yellow flesh cassava to RDA of vitamin A for under-5 children

The percentage of recommended daily allowance (RDA) met for vitamin A per 100 grams of fresh yellow cassava for children under five years was between 1.39% (sample 05) and 70.95% for sample 01. The percent RDA was between 3.07% and 21.66% for boiled roots for samples 05 and 07, respectively. *Kokonte* had an RDA of between *ND* to 0.81%; fresh leaves reported values between 20.11% and 394.39% for samples 15 and 05, respectively. Boiled leaves also had values between 2.64% for sample 01 and 245.56% for sample 05 (Figure 1).

Figure 1. Contribution of yellow flesh cassava to recommended daily allowance (RDA) of vitamin A for children under-5

Comparison of *icheck*^{TM} carotene and spectrophotometric method for carotenoid determination

The spectrophotometric method for determining total carotenoids compared to the *icheck*^{TM} carotene method for fresh roots and gari. Regression (R^2) of 96.49% and 95.31% were obtained (Figures 2 and 3).

Table 14. Statistical effects of processing on antioxidant activity of yellow flesh cassava

Treatment	Mean total antioxidant activity (%)
Fresh roots	16.37 ^c
Gari	0.00 ^d
Kokonte	0.00 ^d
Boiled roots	0.00 ^d
Boiled leaves	37.88 ^b
Fresh leaves	73.83 ^a
P-value	0.01

Note: Means with different superscripts on the same column are significantly different at $P \leq 0.05$.

Table 15. Statistical effect of cultivar on antioxidant activity of yellow flesh cassava

Cultivar	Mean total antioxidant activity (%)
01	43.99 ^a
03	21.27 ^b
05	4.93 ^c
07	26.09 ^b
15	23.79 ^b
P-value	0.01

Note: Means with different superscripts on the same column are significantly different at $P \leq 0.05$.

Figure 2. Relationship between iCheck™ carotene and spectrophotometric method (*Gari*)

In vitro bio-accessibility of carotenoids in yellow flesh cassava

Table 16 shows the *in vitro* bio-accessibility of boiled yellow cassava roots, *gari*, and boiled yellow cassava leaves. *In vitro* bio-accessibility of carotenoids for boiled roots ranged between not detectable to $104.42 \pm 0.88\%$, and for *gari*, values ranged between not detectable (ND) to $57.22 \pm 9.01\%$. Values ranged between not detectable (ND) to $0.28 \pm 0.01\%$ for boiled leaves. There was a significant difference between all samples ($P < 0.000$).

Effect of processing and cultivar on the in vitro bio-accessibility of carotenoids

Processing significantly affected the *in vitro* bio-accessibility of the carotenoids, with a *p*-value of 0.0299. The cultivar, however, did not have a significant effect on the *in vitro* bioaccessibility of carotenoids present in the yellow flesh cassava genotypes (Tables 17 and 18).

Survey on consumption patterns of cassava

This section of the results describes the consumption patterns of cassava and then probes into the attitudes toward the adoption of yellow flesh cassava in the Ghanaian diets.

Socio-demographic characteristics of the study population

The socio-demographic characteristics of respondents are presented in Table 19. Two hundred and eighty-seven (287) respondents were interviewed for the survey, 135(47%) being males and 152(53%) females.

Consumption patterns of white cassava

Cassava product consumption patterns data indicated that *gari* had the highest frequency of consumption, followed by other cassava products, cassava dough, *kokonte*, boiled cassava, and, lastly, boiled leaves (Figure 4).

Reasons for cassava consumption among Ghanaians

Reasons given for the consumption of cassava included it being a staple food, affordable, available, and having lots of uses. Other purposes stated were that cassava could be used as a source of nutrients and easy to prepare. The frequencies of responses are shown in Figure 5.

Figure 3. Relationship between iCheck™ carotene and spectrophotometric method (Fresh roots)

Knowledge of the nutritional value of white and yellow flesh cassava

The survey also showed that 70.4% of respondents knew the nutritional value of white cassava. Out of this population, 63.9% knew white cassava to be a major source of macronutrients, but only 6.5% of this same population knew it to be a source of micronutrients. 36.6% of the respondents knew about yellow flesh cassava, and 13% of this population knew its nutritive value as it is a source of carbohydrates and vitamin A (Figure 6).

Table 16. *In-vitro* bio-accessibility (%) of carotenoids in yellow flesh cassava

Sample	Boiled roots	Gari	Boiled leaves
01	$21.49 \pm 3.53b$	NDc	$0.28 \pm 0.01a$
03	$4.10 \pm 1.42c$	$29.25 \pm 0.49b$	$0.04 \pm 0.01d$
05	NDc	$57.22 \pm 9.01a$	NDc
07	NDc	$0.617 \pm 0.01c$	$0.13 \pm 0.01b$
15	$104.42 \pm 0.88a$	NDc	$0.08 \pm 0.01c$
P-Value	0.00	0.00	0.00

Note: Means that do not share a letter are significantly different

Table 17. Effect of processing on the *in vitro* bioaccessibility of carotenoids

Sample	Mean (%) in <i>in vitro</i> bio-accessibility
Gari	26.000a
Boiled roots	17.416c
Boiled leaves	0.104b
P-Value	0.03

Note: Means that do not share a letter are significantly different

Table 18. Effect of cultivar on the *in vitro* bioaccessibility of carotenoids

Sample	Mean % in <i>in vitro</i> bio-accessibility
01	7.25b
03	11.13ab
05	19.07ab
07	0.25b
15	34.83a
P-Value	0.07

Note: Means that do not share a letter are significantly different

Table 19. Socio-demographic characteristics of the study population (N=287)

Variable	n (%)
Age (years)	
18-39	262(94)
40-59	19 (4)
Above 60	6(1.9)
Sex	
Male	135(47)
Female	152(53)
Marital status	
Single	224(78)
Married/Cohabiting	50(17.4)
Divorced	8(2.8)
Widow	5(1.7)
Educational level	
No formal education	8 (2.8)
Primary/JHS/ middle school	53(18.5)
SHS/secondary	30(10.5)
Post-secondary	33(11.5)
Tertiary	163(56.8)
Occupation	
Student	131(45.6)
Fixed income	64(22.3)
*Non-fixed income	77(26.2)
Average monthly income (GHC)	
0-100	104(36.2)
100-1000	143(49.8)
1000-2000	14(4.9)
2000 and above	26(9.1)
Number of households with children under 15 years	
Yes	170(59.2)
No	117(40.8)
Residential status	
Own house	57(19.9)
Family house	105(36.6)
Rented house	104(36.2)
Company/mission house	2(0.7)
Government house	12(4.2)
Caretaker	4(1.4)
Squatter	3(1.0)

Note: *Non fixed income-(beautician, carpentry, caterer, Craftsmanship, driver, hairdressing, marketer, self-employed, sound engineer, steel bender, petty trading, farming, dressmaking)

Figure 4. Consumption frequency of cassava products. Note: other cassava products (fufu, fried cassava balls, and chips, tapioca, yakeyake)

Acceptability of yellow flesh cassava

Of the total population, 51.2% were willing to accept yellow flesh cassava. The reasons given for "willingness to accept" were diet diversity and curiosity. The unwillingness to accept yellow flesh cassava was due to a lack of knowledge about the yellow cassava (Figure 7).

Perceived usage of yellow flesh cassava

Some of the respondents (64.3%) perceived that yellow flesh cassava could be used for *gari*, cassava dough, starch, and other cassava products that white cassava is being used for. The remaining 35.7% did not know what yellow flesh cassava could be used for (Figure 8).

Figure 5. Reasons for cassava

Figure 6. Knowledge of yellow flesh cassava

Figure 7. Acceptability of yellow flesh cassava

Figure 8. Perceived usage of yellow flesh cassava

Predictors of knowledge and willingness to accept yellow flesh cassava

Results of the logistic regression (Table 20) indicate that compared to people between 18-39 years (the reference category), those aged between 40 to above 59 were four times more likely to have knowledge about yellow flesh cassava. Married people were two times more likely to “willingly accept” yellow flesh cassava.

Discussion

Nutrient profiles of yellow flesh cassava roots and leaves

Moisture content is an essential factor in the storage of cassava and its products; very high levels greater than 12% are reported, which allows for microbial growth (Padonou et al. 2010). Low levels are more favorable because they give a relatively longer shelf life (Harris and Koomson 2011). Fresh yellow cassava roots had a moisture content between (67.053±1.09) and (82.123 ±0.76) % and dry matter content of (17.877±0.760) and (32.947±1.09) %. The United States Department of Agriculture (2009)

reported 45.9 to 85.3% for moisture content and (29.8 to 39.3%) dry matter content for yellow flesh cassava roots (Zvinavashe et al. 2011) reported moisture content for cassava roots to be between 60.3% to 87.1%. Chávez et al. (2008) and (Teye et al. 2011) also recorded values ranging from 29.8% to 40.7%, with an average of 34.5% for dry matter content. The moisture content of between 57.5 and 54.8 % for yellow flesh cassava roots was reported by (Ceballos et al. 2013), and 69.1±4.17% was reported by (Maziya-Dixon and Dixon, 2015). The moisture content of the leaves was between 56.06±0.33% and 81.62±0.52%, as reported by (Wobeto et al. 2006). The moisture content of 64.8 to 88.6% was also reported by (USDA 2009). This trend from the various studies generally indicates that yellow flesh cassava is very susceptible to post-harvest deterioration and therefore needs to be processed immediately after harvesting. However, (Morante et al. 2010) reported that the presence of the beta carotene trait, which has an oxidative nature, influences the reduction of the deterioration of harvested cassava roots.

Total carotenoids ranged from 792.93±0.98 µg/g and 2649.20±29.10 µg/g for fresh leaves and between 4.73±0.11 µg/g and 10.11±0.18 µg/g for fresh roots. This is in agreement with reports by (Vimala et al. 2008), who reported a total of 3.6-6.4µg/g (fresh weight.) carotenoids for yellow flesh cassava roots. Iglesias et al. (1997) also reported 7.7 to 46.9 mg/g (dry matter basis) for yellow flesh cassava roots, similar to results by (Omodamiro et al. 2012) and (Esuma et al. 2012). Total carotenoid content differences could result from factors such as variety, stage of maturity, geographic site of production, part of the plant which is used, conditions during planting, post-harvest handling, processing, and storage conditions (Rodriguez-Amaya and Kimura 2004).

Table 20. Predictors of Knowledge and ‘willingness to accept’ Yellow Flesh Cassava (N=284)

Variable	Knowledge of yellow flesh cassava O.R(C.I)	Willingness to accept yellow cassava O.R(C.I)
Age		
18-39	1.00	1.00
18-39 versus 40-59	4.44(1.63-12.07)*	2.18(0.81-5.92)
18-39 versus above 60	4.09(0.74-22.80)	0.50(0.09-2.80)
Gender		
Male	1.00	1.00
Male versus female	0.72(0.45-1.12)	0.65(0.41-1.04)
Marital Status		
Single	1.00	1.00
Single versus Married	1.81(0.95-3.47)	2.49(1.26-4.94)*
Single versus Cohabiting	1.38(0.23-8.44)	3.38(0.67-17.09)
Single versus Divorced	2.07(0.50-8.51)	0.281(0.03-2.56)
Single versus Widow	3.10(0.51-18.98)	0.75(0.12-4.58)
Educational status		
No formal education	1.00	1.00
No formal education versus up to middle school	2.98(0.64-13.88)	1.94(0.43-8.70)
No formal education versus secondary	1.11(0.22-5.54)	1.50(0.31-7.19)
No formal education versus Post-secondary	0.56(0.11-2.86)	0.52(0.11-2.51)
No formal education versus Tertiary	0.65(0.15-2.82)	0.90(0.21-3.70)

Note: Reference category * means p-value<0.05

Iron and zinc contents in yellow flesh cassava were reported by (Wobeto et al. 2006) to be between 20.29-22.5 mg/100g and 4.20-5.16 mg/100g. (Umuhozi et al., 2014) also reported 5.9 to 7.62 mg/100g for zinc and iron of 21.5-27.8 mg/100g. These reported values from the literature are lower than the results from the study with iron (87.35 ± 3.18 to 146.25 ± 1.20 mg/100g) and higher for (zinc) 0.30 ± 0.00 to 1.55 ± 0.07 mg/100g for fresh yellow cassava roots. Iron (23.0-27.8 mg/100g) and zinc contents (6.4-7.6 mg/100g) were reported in fresh cassava leaves (Umuhozi et al. 2014), and (Balal et al. 2013) reported iron contents of 7.4 mg/100g for fresh white cassava leaves. According to (Graham and Rosser 2000) and (Hess et al. 2005), Cassava roots with provitamin A carotenoids have a mutually stimulating effect on iron and zinc, which could have accounted for the higher iron and zinc contents in the study. Fresh leaves, on the other hand, contained 118.35 ± 0.07 and 182.05 ± 0.07 mg/100g (iron) and 3.75 ± 0.64 and 15.50 ± 0.14 mg/100g (zinc). The pH of the soil where the cassava was planted also has a high impact on Fe and Zn contents in the roots (Bortey-Sam et al., 2015).

Effect of processing on total carotenoids, iron, and zinc contents of yellow cassava Cassava must be modified into different products to promote a good shelf life, improve transportation and marketing, decrease cyanide content and improve acceptability (Nyirenda et al. 2011). Cassava products include *gari*, *kokonte*, cassava dough, and *fufu*, among others. Cassava processing methods involve many operations that are done in various phases. Such activities are taking off the peels, cutting them into chips or slices, mashing, milling into finer particle sizes, and grating, among others (FAO 2001).

Carotenoids are highly unsaturated and therefore are more susceptible to isomerization and be oxidation (Rodriguez-Amaya 2002). This occurs when carotenoids are exposed to heat, acids, and light (Maziya-Dixon et al., 2015). Carotenoid loss happens during processing through peeling, isomerization, and enzymatic or non-enzymatic oxidation (Rodriguez-Amaya et al. 1997).

Gari is a moisture-free, brittle but tender, creamy-white, grainy, and fermented food made from cassava (James et al. 2012). It is the most popular form of processed cassava presently eaten in West Africa (Ukenye et al., 2013). Drying causes a reduction in moisture, volume, and cyanide content of roots, thereby prolonging product shelf life (Westby 2002). Osunde and Fadeyibi (2011) reported that the moisture content of gari for safe storage should be below 12.7%, and their findings agree with the results, which reported moisture content of 2.88 ± 0.09 to $5.25 \pm 0.07\%$. The total carotenoid from the study was similar to findings from (Maziya-Dixon et al. 2015) for gari, who reported total carotenoid content of 3.11-15.9 µg/g. Iron content for the boiled leaves samples was not significantly different from that of the fresh leaves and was not affected much by the processing. Fermentation, a process used in making gari, is also one of the oldest and most important traditional food processing and preservation techniques (Cardoso et al. 2005). Fermentation is reported by (Achinewhu et al. 1998) to enhance the nutrient content

of foods through the biosynthesis of vitamins, fiber digestibility as well as enhancing micronutrient bioavailability. This could have accounted for the high carotenoid content in the yellow cassava gari, as well as iron and zinc contents. The observed increase in total carotenoid concentration after processing into gari, according to (Rodriguez-Amaya 2004), could be because carotenoids in processed foods can be obtained more quickly than with those in an uncooked form where the provitamin A are shielded and/or in combination with other food compounds that hinder solvent entry and extraction. The higher amounts may also result from unaccounted losses of moisture and solids, which would increase the retention and the total carotenoid per unit weight of the processed food (Maziya-Dixon et al., 2015).

Boiling has been implicated in losses of certain micronutrients in food, including iron, copper, and zinc (Ahenkora et al. 1996). Boiled roots have lower total carotenoid concentration than that in gari, even though some studies have reported that boiling retains more carotenoids than the roasting (Iglesias et al. 1997; Chavez et al. 2005). This could be because wet heat treatments are more destructive to nutrients than dry heat treatments. Boiled leaves also had a reduction in total carotenoids; however, the location of carotenoids in the leaves makes them more protected from heat than the roots (Coleman et al. 2010).

Drying in a solar dryer can appreciably reduce losses of carotenoids by protecting the food from direct sunlight. However, this depends on the length of the drying period. Longer drying periods in the solar dryer after five days degrade the carotenoids instead of being protective (Rodriguez-Amaya and Kimura 2004). Vimala et al. (2011) also reported that the drastic reduction of carotenoids in this process might be due to the destructive effect of sunlight on the stability of carotenoids. *Kokonte* used in the study was solar-dried during the rainy season, which elongated the drying period to 7 days. This could have accounted for the degradation of the carotenoids, making it not detectable. The cultivar or genotype of cassava also affected the total carotenoid content after processing (Iglesias et al. 1997).

Factors affecting carotenoid retention

Nutrient retention is defined as the measure of the number of nutrients left in processed food concerning the nutrient originally present in the raw food (USDA 2009). Smolin et al. (2003) report that the time, method, and temperature for cooking are some factors that affect nutrient retention. The retention of carotenoids also decreased with longer processing time and after a higher processing temperature, also when food is blended (Rodriguez-Amaya 2002). *Gari* had the highest retention of the carotenoids for the products made from the roots. The carotenoid loss during gari processing was much lower in yellow gari. On the other hand, boiled roots retained the lower amounts of carotenoids, while *kokonte* retained no carotenoids at all after processing. Boiled leaves retained the highest amounts of carotenoids after processing. Carotenoids in green leafy vegetables are

located in the chloroplasts and also bound to protein complexes, which protect the carotenoid, thus giving room for more retention (Canene-Adams and Erdman 2009). Carotenoids in the roots, however, are within membranes of large proteins, which are crystalline. These membranes are easily broken on exposure to heat, making them more liable for the carotenoids to be lost (Serrano et al. 2005). Retention varies between 10% for cassava products processed to a greater extent to 87% for boiling (Maziya-Dixon et al. 2000; Thakkar et al. 2009). This was in agreement with the findings from the study.

In vitro bio-accessibility of carotenoids in yellow cassava

Processing methods using heat are said to enhance the bio-accessibility of beta carotene by unbinding the matrix, thus facilitating its assimilation (Veda et al. 2006). Carotenoids present in green leafy vegetables are located in the chloroplasts and form bonds to protein complexes, which are not easily digestible. On the other hand, carotenoids in the roots are within membranes of large proteins, which are crystalline, making them more available (Canene-Adams and Erdman 2009). This could explain why cassava root products were more bio-accessible than the leaves. Inhibitors such as gels and cellulose fiber inhibit absorption by sustaining bile salts and preventing micelle formation, which will aid at the point of absorption (Serrano et al. 2005). In vitro bioaccessibility of the carotenoids was comparable to studies reported by Failla et al. (2009).

Contribution of yellow flesh cassava to RDA of vitamin A under-5 children

Boiled roots contributed between 4 and 21% of the RDA for children less than five years, and the boiled leaves contributed between 2.6 to 386% of the RDA for every 100 grams of food consumed, which showed more potential to meet the RDA. Gari and kokonte, however, provided less than 1% of the RDA for every 100 grams of cassava. A greater amount of the food must be consumed to meet a more significant amount of the RDA. Notwithstanding, a positive outcome of some contribution to RDA implies that processors should put some viable measures to help reduce carotenoid losses in these products, especially in gari, because it is the most frequently consumed cassava food.

Effect of processing and cultivar on antioxidant activity of carotenoids

Processing methods such as dehydration, blanching, and canning also affect the antioxidant property of the carotenoids of some dietary plants (Van Het Hof et al. 2000). Vegetables, such as carrots, mushrooms, peppers, potatoes, sweet potatoes, cabbage, and tomatoes, increase their antioxidant activity when these vegetables are boiled or steamed (Halvorsen et al. 2006). Antioxidant activity of the cassava leaves also showed similar trends of increasing after boiling. However, the antioxidant activity of the roots was destroyed after processing.

Comparison of icheck and spectrophotometric method for carotenoid determination

The study showed that the icheck method for carotenoid determination was highly comparable to the spectrophotometric method, with regression (R^2) of 95.3% and 96.68%, respectively. This was comparable to the regression results (Islam and Schweigert, 2015) that compared the two methods using carotenoids from egg yolk. This comparison was made to validate the accuracy of total carotenoid content in this study because a quite recent method of carotenoid analysis was used.

Socio-demographic characteristics

The majority of the study participants were between 18-39 years. This population represents the highly reproductive part of the population who are also vulnerable to vitamin A deficiency (WHO 2001). The majority of the participants had up to tertiary education. However, their level of education did not predict the corresponding level of knowledge about yellow flesh cassava. Again, most of the population had children less than 15 years in their households, another vulnerable group to vitamin A deficiency (West 2002). This suggests an early adaptation to yellow cassava would be a good step in curbing the prevalence of vitamin A deficiency.

Consumption patterns of white cassava

Participants between 18 - 39 years consumed gari and boiled leaves the least. Gari has a longer shelf life and thus may be a factor in it being the most consumed food for that population. Onyemauwa (2010) also reported gari to be the highest consumed cassava product making it a more viable vehicle for introducing yellow cassava to the Ghanaian populace. However, for the participants between 40-59 years, the most consumed cassava foods were other cassava products, including fufu. Fufu is known to be more energy-dense because of the addition of cocoyam, plantain, or yam. This age group preferred more energy-dense foods probably because of their family size and economic status.

Acceptability of yellow flesh cassava

Nutrition education is a vital tool in communicating biofortified crops' nutritional and health benefits and an important factor affecting the acceptability of bio-fortified crops (Tanumihardjo 2008). Chowdhury et al. (2011) reported that mothers in Uganda easily adopted bio-fortified foods after receiving nutrition education. From the present study, most of the consumers who took part in the survey were not willing to accept yellow flesh cassava because they did not know about it, which is similar to studies on the acceptability of bio-fortified foods. Consumer preferences for bio-fortified foods have also been influenced by providing nutritional information in Ghana (De Groote et al. 2010). When given the same information on the willingness to pay for orange sweet potato, orange maize, and yellow cassava, research showed that consumers liked the organoleptic traits of the biofortified crops and were more likely to pay more money for high provitamin A genotypes than for white genotypes.

(Oparinde et al. 2012, Chowdhury et al. 2011; Meenakshi et al. 2012).

Determinants of knowledge and willingness to accept yellow flesh cassava

Socio-economic characteristics of poor consumers, such as their income, amount of land owned, age, education level, household size, and the number of young minors they have in their household, might play a vital role in the success of a bio-fortification program (Etumnu 2016). The study showed that socio-demographic characteristics such as age and marriage significantly affected a person's knowledge and willingness to accept yellow cassava.

Limitations of the study

Although iron and zinc values were very high, their bioavailability was not estimated and thus was not compared to the recommended daily allowances (RDA). RDA for vitamin A could not be computed after the in vitro bio-accessibility of carotenoids because of the unavailability of an HPLC to quantify beta-carotenes at the time of the study. Micellization efficiency was not computed for this study's in vitro bio-accessibility model; thus, the bioavailability could not be calculated.

Conclusion

Fermentation, drying, roasting, and boiling retained some carotenoids after processing, but solar drying over a long time completely degraded carotenoids in yellow cassava. Cassava leaves had higher retention of carotenoids, but cassava roots were more bioaccessible. Carotenoids in yellow flesh cassava had antioxidant properties and thus had the potential to help combat free radicals in the body. The antioxidant activity in the yellow flesh cassava roots was destroyed after processing into gari, kokonte, and boiled roots but was higher in leaves after boiling. Yellow cassava would provide a viable source of provitamin A. The knowledge and "willingness to accept" yellow cassava was low among Ghanaians in the Greater Accra region.

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