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Assessment of the chemical and trace metal composition of dried cassava products from Nigeria

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Abstract

The chemical and trace metal composition of six groups of commercial dried cassava products in Nigeria (*gari*, starch, tapioca, *fufu*, *lafun* and high-quality cassava flour) were evaluated to ascertain quality standard compliance and safety for human consumption. In total, 340 samples of the dried products collected based on their popularity in the Humid forest (92), Derived savannah (234) and Southern Guinea savannah (14) agroecologies were analysed using standard analytical methods. The moisture, cyanogenic potential (CNP), ash and crude fibre content of the samples were significantly different ($P<0.05$). Product type or agroecology of the products did not have a significant influence on the acidity, pH or trace metal (copper (Cu), iron (Fe) and zinc (Zn)) content. Samples from the Humid forest exhibited the highest average moisture (12.80%), pH (6.62), Zn (5.01 mg/kg) and Cu (3.16 mg/kg) content; Southern Guinea savannah samples had the highest CNP (9.06 mg/kg), ash (2.03%) and Fe (35.38 mg/kg) content, while the samples from Derived savannah had the highest starch (61.11%) and crude fibre (2.87%) content. All the parameters analysed were within the FAO/WHO standards for cassava products except for the Fe content which exceeded the threshold limit of 22 mg/kg, suggesting that iron-based processing machines release Fe that contaminate cassava during processing. Therefore, these machines should be made of stainless steel, and processors should adhere to the standard operating procedures that were established by the food regulatory agencies to reduce iron contamination of cassava products.

Keywords: processing, composition, trace metals, standards, cassava products

1. Introduction

Fresh cassava root contains 32-35% carbohydrate, 2-3% protein, 0.1% fat, 1.0% fibre, 0.70-2.50% ash and 75-80% moisture (Oluwole *et al.,* 2004). Because of its high moisture content, cassava root undergoes rapid deterioration within 48 to 72 h if not properly processed (Oyewole and Asagbra, 2003). Hence, there is a need for rapid processing into various products with increased shelf life, and which makes its transportation to urban markets less expensive (Taiwo, 2006). Traditional cassava processing methods involve several unit operations including peeling, fermenting, drying, milling, roasting/toasting, sieving, steaming, pounding and mixing in cold or hot water. Specific combinations of these processes lead to different cassava products with acceptable tastes to a wide range of consumers. These products include *gari*, *fufu*, starch, high quality cassava flour (HQCF) and tapioca among others (Udoro *et al.,* 2008).

However, the quality of the cassava products depends on the management of the handling and processing steps. Irrespective of the processing methods, the most important precaution is strict maintenance of hygiene, especially in relation to water quality, the type of machinery used, storage method applied and time-lag between the period

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of harvesting, processing and consumption of the food (Dziedzoave *et al.,* 2006). The processing of cassava products is often performed manually, mostly by women. Manual processing is labour intensive and time consuming but most smallholder processors lack access to mechanised or other improved processing methods. This is because the improved methods, involving the use of motorised equipment, are expensive and unaffordable to individual smallholders.

The traditional production, processing and handling practices, such as hand-grating, pressing with wood logs and stones, and drying of cassava on the bare floor, mat and rock increase the possibility of contamination (Bolade, 2016). In addition, the use of processing machines made from mild or galvanised iron metal, drying of pre-processed products by the road-side, and display of fully processed products in open containers at point of sale increases the possibility of product contamination either from metals or microorganisms (Bolade, 2016). Food products normally account for a high proportion of trace metal intake in adults and children (Dermience *et al.,* 2017).

Trace metals are very important in human diet for their essential or toxic nature. The copper (Cu), iron (Fe) and zinc (Zn) trace elements for instance are known to be essential and may enter the food materials depending on the varieties, maturity, genetics, and age of the crops, from soil through fertilisation, geographic location, season, water source, or through food handling, processing and cooking (Petry *et al.,* 2016). These metals (Cu, Fe and Zn) are essential for humans, since they play an important role in biological systems, but may produce toxic effects when consumed excessively (Zheng *et al.,* 2007). In humans, excessive dietary intake of Zn can lead to deficiencies in Fe and Cu, nausea, vomiting, fever, headache, tiredness, electrolyte imbalance, anaemia and abdominal pain (Wada, 2004). In addition, the ingestion of Cu and Zn above their safe threshold values can cause neurological impairment, headache and liver disease (US EPA, 2000). The effect of high levels of trace metals in food products is of concern nowadays due to the degree of pollution of food items and their toxic effect on animals and humans. Therefore, this study was aimed at assessing the chemical and trace metal composition of dried cassava products in Nigeria, to ascertain quality standard compliance and safety for human consumption.

2. Materials and methods

Collection of dried cassava products in Nigeria

Dried cassava products (340 samples) traded in Nigeria were collected from both processors and marketers located in three agroecological zones of Nigeria in 2015: Humid forest (92 samples), Derived savannah (234 samples) and Southern Guinea savannah (14 samples). The Derived savannah zone consists of Enugu, Kwara, Oyo and Ogun states; the Humid forest zone Abia, Rivers and some part of Ogun states and the Southern Guinea savannah Kwara State (Figure 1). The average of the annual rainfall, temperatures and relative humidity of each of the Agroecological zones is presented in Table 1. Each (1 kg) of the cassava products collected is representative of the sampling frame, thus, the unequal sampling size. Samples were kept in airtight polypropylene bags at ambient temperature and transported to the laboratory for analyses. The processing methods used for the commercial production of the different dried cassava products are described by Awoyale *et al.* (2017). All the analyses were done in duplicate.

Chemical composition of dried cassava products

Moisture content

The moisture content was determined using the AOAC (2000) method. About 3 g of sample was weighed into a pre-weighed, clean, dried dish, after which the dish was placed in a well-ventilated oven (Draft air Fisher Scientific Isotemp® Oven model 655F, Springfield, MN, USA) maintained at 103±2 °C for 24 h. The loss in weight was recorded as moisture content.

Starch content

The starch content was determined using a colorimetric method by Dubios *et al.* (1956). Hot ethanol was used to extract sugar from the sample. Sample residue was digested with perchloric acid to its monosaccharides for starch estimation. The digest (from residue) was quantified calorimetrically for starch, using phenol sulphuric acid as a colour developing reagent and absorbance read at 490 nm using a spectrophotometer (Spectronic 601, Milton Roy Company, Ivyland, PA, USA).

pH measurement

The pH of the samples was determined by suspending 5 g in deionised water for 5 min at a ratio of 1:5 (w/w) and pH measured using a digital pH meter (Model 720A, Orion Research Inc., Beverly, MA, USA) as reported by Nielsen (2010).

Total titratable acidity content

Acidity of each sample was determined by the titration of 25 ml of the decanted homogenate used for pH determination against 0.1 M NaOH to pH 8.3. The relative amount of lactic acid was calculated as percentage lactic acid on dry matter basis as follows (AOAC, 2000):

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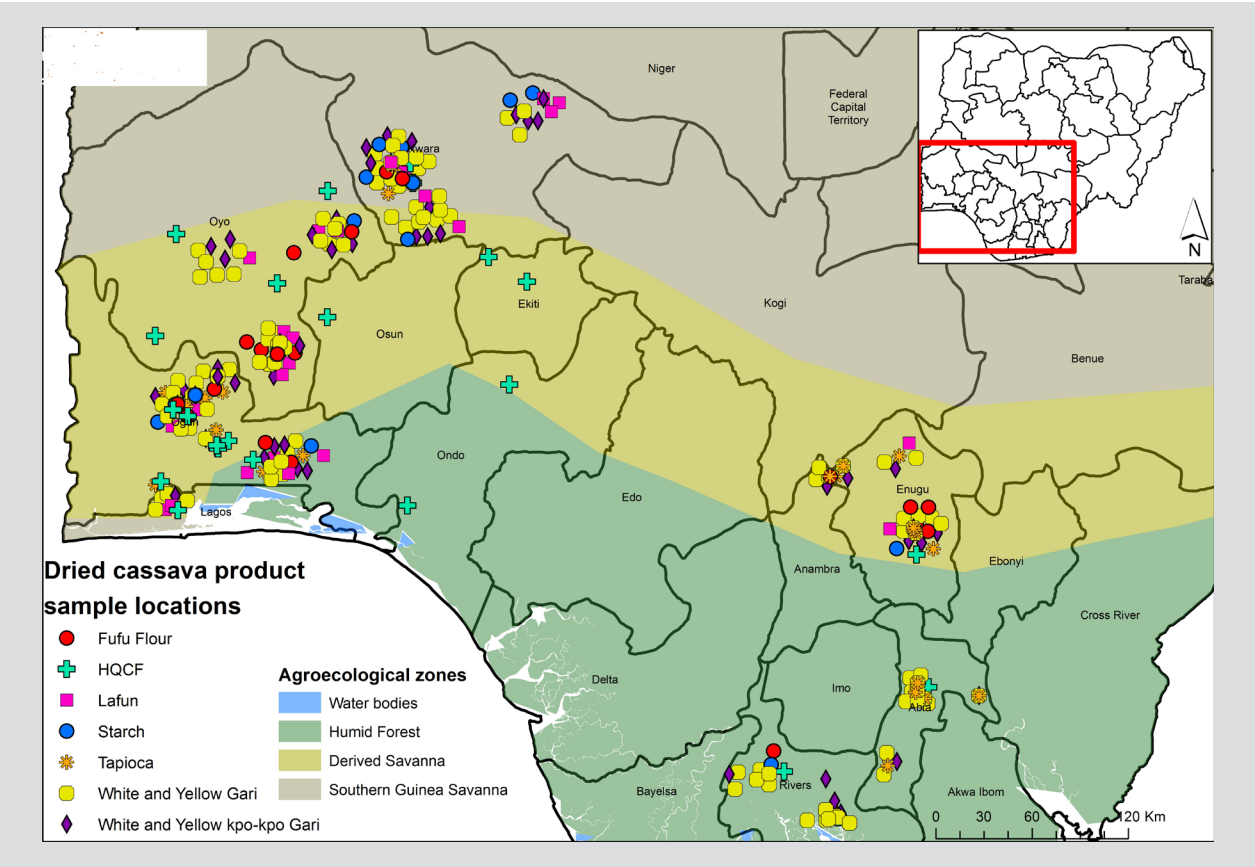

Figure 1. Map of Nigeria showing the three agroecological zones where dried cassava products were collected. HQCF = high quality cassava flour.

Table 1. Average annual weather conditions of the agro-ecological zones where samples were collected in the year 2015.

Agroecological zones	Rainfall (mm)	Temperature (°C)	Relative humidity (%)
Derived savannah	1,130.30	30.32	77.30
Humid forest	1,767.74	29.09	84.62
Southern Guinea savannah	781.59	33.48	60.11

$$\% \text{ lactic acid} = \frac{\text{titre value} \times \text{nomality of alkalis}}{\text{weight of sample}} \times 100$$

Cyanogenic potential content

The cyanogenic potential content of the samples was determined using the procedure of Essers *et al.* (1993). The sample (30 g) was homogenised in 250 ml of 0.1 M orthophosphoric acid, the homogenate centrifuged and the supernatant extracted. To get the total cyanogenic potential, 0.1 ml of the extract was treated with linamarin standard. Another assay was run with 0.1 ml of extract, but 0.1 ml of 0.1 M phosphate buffer (pH 6.0) was used to give the non-glucosidic cyanogenic potential. A third assay was then run with 0.6 ml of extract that was added to 3.4 ml of McIlvaine buffer (pH 4.5). It was properly mixed and 0.2 ml of 0.5% chloramine T and 0.8 ml of colour reagent was added to give the free cyanogen. A standard curve was then obtained by plotting absorbance values (y-axis) against standard concentration (x-axis): linamarin = 125 ml/(sample weight×0.01093); non-glucosidic cyanogen = 125 ml/(sample weight×0.03176); free cyanide = 125 ml/(sample weight×0.04151).

Crude fibre content

The crude fibre content of the dried cassava products was determined using the method described by the AOAC (2000). About 5 g (W_0) of each dried cassava product was weighed into a 500 ml flask with the addition of 100 ml of trichloroacetic acid digestion reagent. This was then brought to boiling and refluxed for about 40 min counting from the start of boiling. The flask was then removed from the heater, cooled, then filtered through 15 cm Whatman paper No. 4 (Whatman, Maidstone, UK). The residue was washed with hot water, stirred with a spatula and transferred to a porcelain dish. The sample was dried overnight in the oven at 105 °C. The dried sample was

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transferred to a desiccator and weighed as W_1. It was then burnt in a muffle furnace at 500 °C for 6 h, allowed to cool, and reweighed as W_2.

$$\% \text{ crude fibre} = \frac{W_1 - W_2}{W_0} \times 100$$

W_1 = weight of crucible + fibre + ash;
W_2 = weight of crucible + ash;
W_0 = dry weight of sample.

Ash and trace metal composition

Ash determination

The ash content was determined using the method of the AOAC (2000). It involves burning off moisture and all organic constituents at 600 °C for 5 h in a furnace (VULCAN™ furnace, model 3-1750, Dentsply Ceramco, York, PA, USA) The weight of the residue after incineration was then recorded as the ash content.

Trace metal composition

The Fe, Zn and Cu content of the samples were determined using the method described by Jones *et al.* (1990). The samples were ashed at 550 °C, after which the ash was dissolved in 5 ml water and 15 ml HNO_3/HCl (1:3). The minerals were then determined using a Flame Atomic Absorption Spectrophotometer (FAAS; Buck 205 model, Back Scientific, East Norwalk, CT, USA). The detection limits of the minerals using FAAS were found to be 0.072 for Cu, 0.111 for Fe and 0.021 for Zn.

Statistical analysis

Analysis of variance (ANOVA) and separation of the mean values (using Duncan's Multiple Range Test at $P<0.05$) were calculated using SPSS software (version 21.0, IBM Corporation, Armonk, NY, USA).

3. Results and discussion

Chemical composition of dried cassava products

The chemical composition of the dried cassava products is shown in Table 2. The dried cassava products have an average moisture content (MC) of 11.71%, total titratable acidity (TTA) 0.041 g/100 ml, pH 6.11, cyanogenic potential (CNP) 7.20 mg/100 g, ash content 1.20%, starch content 60.53% and crude fibre content 2.68%.

Product type significantly influenced ($P<0.001$) all the chemical parameters of the samples except the TTA, pH and starch content, which were not significantly different among samples ($P>0.05$), while the agroecology had an influence on ash ($P<0.001$) and starch ($P<0.05$) content. Products and agroecology had a significant interactive effect on CNP ($P<0.05$) and starch ($P<0.001$) content, while the effect on the other parameters was not significant ($P>0.05$).

Lower initial MC of a product in storage signifies effectiveness of the drying method, a lower probability of microbial growth and better storage stability (Sanni *et al.,* 2005). This means that products from the Southern Guinea savannah with a mean MC of 10.26% especially the HQCF (10.47%), might store better than those from the Humid forest (12.80% MC). Yellow *kpokpo gari* with MC of 13.40% is particularly prone to low storability. The mean MC (11.71%) of the products was slightly higher than the Standard Organisation of Nigeria (SON) recommendation of 10% as reported by Sanni *et al.* (2005) and FAO/WHO (2006). The lower MC of the products in the Southern Guinea savannah was possibly due to the lower atmospheric humidity in the zone compared with the more humid atmosphere prevalent in the Humid forest. The practice of displaying cassava products in open containers during marketing exposes the products to moisture uptake in a humid environment (Sanni *et al.,* 2008). The use of appropriate packaging materials with a moisture barrier is therefore necessary for the packaging of cassava products to prevent moisture uptake and mould contamination. However, it is very important to note that dehydration of cassava mash during processing accounts for a significant loss in moisture, and depends on temperature, relative humidity and air movement (Raji and Ojediran, 2011). Additionally, Akinoso and Olatunde (2014) reported that an excessive quantity of mash during roasting for *gari* may retard moisture removal while an extended roasting time might influence other quality parameters such as colour, taste and aroma. Thus, the moisture content of the *gari* samples in the present study may be reduced to the stipulated 10% by the Codex, if a specific quantity of cassava mash is roasted at a time (FAO/WHO, 2006).

The TTA was higher in *lafun* (0.063 g/100 ml) and lower in tapioca (0.005 g/100 ml). This is expected as *lafun* is fermented for longer than tapioca. More organic acids were produced during fermentation of *lafun* possibly resulting from increased activities of the fermenting microorganisms at the atmospheric temperature under which fermentation of cassava is carried out (Udoro *et al.,* 2008). This is similar to the observations of Ray and Sivakumar (2009), who reported that during the fermentation process of cassava processing, lactic acid bacteria hydrolyse starch in the cassava into sugar, alcohols and organic acids. The production of organic acids, which increase with fermentation time, leads to an increase in acidity of the sample and a resultant decrease in pH. These researchers, however, pointed out that significant influence of roasting duration on *gari* pH cannot be easily explained.

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Table 2. Chemical composition of dried cassava products in Nigeria.[1,2]

Grouping	N	Moisture (%)	TTA (g/100 ml)	pH	CNP (mg HCN/kg)	Ash (%)	Starch (%)	Crude fibre (%)
Tapioca	40	12.55±1.93^{a}	0.005±0.00^{b}	7.14±0.70^{a}	5.60±2.88e	0.73±0.98^{d}	62.62±16.64^{a}	2.22±0.94^{d}
White *kpokpo gari*	46	11.50±3.01^{b}	0.042±0.03^{ab}	6.26±0.77^{a}	8.77±1.63^{a}	1.56±0.52^{a}	61.53±12.29^{a}	2.41±0.79^{cd}
Yellow *kpokpo gari*	10	13.40±2.42^{a}	0.021±0.02^{ab}	6.52±0.82^{a}	7.18±1.72^{bd}	1.43±0.26^{ab}	53.60±7.46^{c}	4.36±3.12^{a}
Yellow *gari*	43	12.96±2.81^{a}	0.060±0.31^{a}	6.14±0.70^{a}	6.65±2.34^{d}	1.30±0.42^{b}	59.92±15.74^{ab}	3.17±1.00^{b}
White *gari*	102	10.94±3.09^{ab}	0.047±0.03^{ab}	5.73±0.72^{a}	7.93±2.31^{b}	1.34±0.41^{b}	59.98±14.04^{ab}	2.93±0.82^{bc}
Fufu powder	15	12.50±2.40^{a}	0.029±0.03^{ab}	6.24±0.86^{a}	5.14±2.49e	0.66±0.37^{d}	60.58±17.36^{ab}	1.95±0.29^{d}
Lafun	29	10.93±2.35^{bc}	0.063±0.04^{a}	5.67±0.77^{a}	7.00±2.57^{cd}	1.59±0.72^{a}	55.60±19.26^{bc}	2.61±0.60^{b-d}
Starch	15	12.63±1.70^{a}	0.031±0.03^{ab}	6.13±1.23^{a}	6.76±2.37^{d}	0.57±0.19^{d}	63.75±12.36^{a}	2.00±1.40^{d}
HQCF	25	10.42±2.30^{c}	0.041±0.03^{ab}	6.27±1.05^{a}	7.75±2.428^{ab}	1.06±0.49^{c}	65.17±11.78^{a}	2.99±0.95^{bc}
States in Nigeria								
Enugu	47	14.31±1.60^{a}	0.022±0.02^{c}	6.19±0.76^{b}	5.62±3.16^{c}	1.02±0.73^{bc}	55.90±14.00^{c}	2.83±1.23^{ab}
Abia	32	13.28±3.14^{b}	0.020±0.02^{c}	6.74±0.55^{a}	5.54±3.96^{c}	1.10±0.75^{bc}	46.65±13.94^{d}	3.05±0.74^{a}
River	36	13.15±2.26^{b}	0.075±0.34^{a}	6.40±0.78^{b}	7.78±1.98^{a}	0.96±0.52^{c}	64.08±8.63^{b}	2.51±0.69^{bc}
Kwara	63	10.93±1.77^{c}	0.057±0.03^{ab}	5.07±0.62^{b}	8.16±2.08^{a}	1.45±0.61^{a}	65.05±15.07^{ab}	2.19±0.79^{c}
Oyo	75	10.29±3.06^{d}	0.041±0.03^{bc}	6.10±0.73^{b}	7.19±1.74^{b}	1.37±0.59^{a}	55.19±11.22^{c}	3.28±1.59^{a}
Ogun	87	10.94±2.34^{c}	0.033±0.03^{bc}	6.49±0.87^{b}	7.72±2.08^{a}	1.12±0.55^{b}	68.04±14.71^{a}	2.31±0.87^{c}
Agroecological zones in Nigeria								
Derived savannah	234	11.36±2.79^{b}	0.039±0.03^{a}	5.99±0.88^{a}	7.18±2.40^{b}	1.23±0.61^{b}	60.92±14.75^{a}	2.87±1.38^{a}
Humid forest	92	12.80±2.72^{a}	0.041±0.21^{a}	6.62±0.76^{a}	6.94±3.05^{b}	1.00±0.61^{c}	59.92±16.05^{a}	2.57±0.82^{ab}
Southern Guinea savannah	14	10.26±1.71^{c}	0.075±0.04^{a}	4.83±0.34^{a}	9.06±1.27^{a}	2.03±0.56^{a}	58.00±10.88^{a}	2.24±0.72^{b}
Mean		11.71	0.041	6.11	7.2	1.2	60.53	2.68
Interactions								
Product		***	NS	NS	***	***	NS	***
States		***	NS	NS	***	NS	***	**
Agroecological zones		NS	NS	NS	NS	***	*	NS
Product × states		***	NS	NS	***	***	***	**
Products × agroecological zones		NS	NS	NS	*	NS	***	NS
Agroecological zones × states		NS	NS	NS	NS	**	NS	NS

[1] TTA = total titratable acidity; CNP = cyanogenic potential; HQCF = high quality cassava flour; HCN = hydrogen cyanide.
[2] *** $P<0.001$; ** $P<0.01$; * $P<0.05$; NS = not significant; means with different superscript on the same column are significantly different at $P\leq0.05$.

Similarly, higher acidity was found in *lafun* (0.075 g/100 ml) produced in the Southern Guinea savannah zone, compared to the other fermented products (0.039 g/100 ml) from the Derived savannah zone. The TTA of all the products was below the Codex and SON standard of 1 g/100 ml for cassava products (FAO/WHO, 2006; Sanni *et al.,* 2005). Tapioca (7.14) had a higher pH value and *lafun* (5.67) had the lowest. These results are similar to results obtained by other researchers (Oduro *et al.,* 2000; Udoro *et al.,* 2008). Products (6.62) from the Humid forest zone are higher in pH and those (5.99) from the Derived savannah are lower. The high pH of the products from the Humid forest zone might be attributed to shorter fermentation times and the consumer preference for unfermented products in the area.

The cassava cyanide disease network reported that cyanide is very poisonous because it binds cytochrome oxidase and stops its action in the electron transport chain, which is a key energy conversion process in the body, and that excess cyanide content in cassava products could have deleterious effects on consumers. Such effects may include acute intoxication with symptoms of dizziness, headache, stomach pains, vomiting and diarrhoea (CCDN, 2011). The CNP content of the products ranged from 5.14 to 8.77

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mg hydrogen cyanide (HCN)/kg, with white *kpokpo gari* having the highest value and *fufu* powder the lowest. The low cyanide content of the *fufu* powder agreed with the observation of Onwuka and Ogbogu (2007), who reported that soaking cassava roots coupled with fermentation is more effective than fermentation alone in the reduction of cyanide in cassava products. Southern Guinea savannah products (9.06 mg HCN/kg) were higher in CNP, while those (6.94 mg HCN/kg) from the Humid forest were lower. It was reported by Maziya-Dixon *et al.* (2007) that the safe levels of cyanide for both human and animal consumption have not been synchronised by scientists and international regulatory agencies. But, the SON standard for hydrogen cyanide (10 mg HCN/kg) in cassava products agrees with that of the 3rd session of the FAO/WHO Food Standards Program Codex Committee on Contaminants in Foods, which concluded that a level of up to 10 mg HCN/kg in edible cassava flour (CAC, 2013) was not associated with acute toxicity. Also, in line with this conclusion, the Joint FAO/WHO Food Standards Programme (JECFA, 2009) has set the tolerable limit for hydrogen cyanide in food as 10 mg/kg. By implication, all the products are safe for human consumption from the stand point of CNP being less than 10 mg/kg. However, the variation in the CNP content of the products from the different agroecological zones might be due to differences in cassava varieties, locations and processing methods.

The products (60.92%) from the Derived savannah have the highest starch content and those (58.00%) of the Southern Guinea savannah the lowest. Starch was highest in HQCF (65.17%) and lowest in yellow *kpokpo gari* (53.60%). The low starch content in the Southern Guinea savannah products could be attributed to the starch content of varieties of cassava preferred in the zone and the activities of microorganisms, which might have converted the starch into organic acids (Liaud *et al.*, 2015), resulting in the low starch content. This observation agrees with that of Ray and Sivakumar (2009). The variation in the starch content of the products from the agroecological zones might be due to differences in cassava varieties adopted, processing methods and age at harvest.

Crude fibre is a measure of the quantity of indigestible cellulose, pentosans, lignin, and other components of this type in foods. Fibre has little food value but provides the bulk necessary for proper peristaltic action in the intestinal tract (Food Science, 2008). The crude fibre content of the products ranged between 1.95 and 4.36%, with yellow *kpokpo gari* having the highest value and *fufu* powder the lowest. Derived savannah products (2.87%) are higher in crude fibre, while those (2.24%) of the Southern Guinea savannah are lower. This implied that the crude fibre content of *fufu* powder is lower compared to the Codex stipulated standard of 2%, while that of the yellow *kpokpo gari* is higher (FAO/WHO, 2006). The low crude fibre content in the *fufu* powder may be attributed to the wet sieving step in *fufu* processing that eliminates most of the fibre in cassava (Etudaiye *et al.,* 2012). Additionally, the softening of the fibrous tissue of the cassava root through the activities of microorganisms during submerged fermentation in the production of *fufu* may have contributed to the low crude fibre content of the *fufu* powder (Falade and Akingbala, 2010). However, the variation in the crude fibre content of the products from the different agroecological zones might be due to differences in cassava varieties, age at harvest, processing methods and other factors.

The ash content is a measure of the total amount of minerals present within a food, whereas the mineral content is a measure of the amount of specific inorganic components present within a food, such as Fe, Cu, Zn, Ca, Na and K. The determination of these parameters in food is important for nutritional labelling, quality, microbiological stability, nutrition and processing among others (McClements, 2005). The ash content was higher in *lafun* (1.59%) and lower in cassava starch (0.57%). In terms of agroecology, products from the Southern Guinea savannah have the highest ash content (2.03%) compared with products (1.00%) from the Humid forest. Ash content is a reflection of the mineral status, even though high ash content may indicate high contamination of the product (Baah *et al.,* 2009). The high ash content may imply that products from the Southern Guinea savannah, and particularly *lafun,* might have been contaminated with foreign particles or trace metals from processing machines, especially the cassava grater, and during drying (Otutu *et al.,* 2013). However, the ash content of all the products are within the Codex regulatory standards of 1.5% (CAC, 2013; Sanni *et al.,* 2005), except for the ash content of *lafun* and white *kpokpo gari* that were slightly higher.

Trace metal composition of dried cassava products

Knowledge of the concentration and type of specific metals present in food products is often important in the food industry. Trace metals such as Fe, Zn and Cu are involved in the function of several enzymes and are essential for maintaining health throughout life (Institute of Medicine, Food and Nutrition Board, 2001). This is because these metals are naturally present in foodstuffs and are nutritionally important to humans, but toxic when consumed in excess. The deficiencies of these metals constitute the largest nutrition and health problem to populations in developed and developing countries (Olivares *et al.*, 2004). Additionally, body mass index has been reported to be negatively correlated with Zn in blood, Cu in plasma and Fe in urine (Błażewicz *et al.*, 2013). Thus, assessing the level of these metals (Fe, Zn and Cu) in dried cassava products available in Nigeria is very important to ascertain their health risk.

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The mean of the trace metal composition of the dried cassava products are Fe 29.16 mg/kg, Cu 2.67 mg/kg and Zn 4.55 mg/kg (Table 3). The product type and origin (state and agroecology) had no significant effect (P>0.05) on trace metal content. Cassava products (35.38 mg/kg) made in the Southern Guinea savannah had the highest Fe content and those (28.75 mg/kg) from Derived savannah the lowest. Among these products, cassava starch (34.60 mg/kg) had the highest Fe content and HQCF (13.56 mg/kg) the lowest (Table 3). The high Fe content of products produced from the Southern Guinea savannah could have resulted from the mild steel-constructed cassava grating machine used for cassava processing and the widespread practice of drying the products in the sun and in places where vehicular traffic is heavy (Bolade, 2016). The Fe content of all the products except that of the HQCF was above the recommended maximum limit (22 mg/kg) stipulated by SON (FAO/WHO, 2006; Sanni *et al.,* 2005). The low Fe content of the HQCF may be attributed to strict adherence to standard operating procedures, non-exposure to environmental pollutions during marketing and the use of stainless-steel machines for processing. Hence, it would be necessary for processors of cassava to replace processing machines made with galvanised or mild steel with machines made with stainless steel to reduce Fe contamination of the processed products through machine corrosion, and as well adhere strictly to the standard operating procedure to produce the cassava products in Nigeria. However, Fe content of between 24 and 40 mg/kg was reported for *gari* collected from Port Harcourt, Rivers State, Nigeria (Dibofori-Orji and Edori, 2015). The high Fe content in the *gari* was attributed to unhygienic practices including atmospheric exposure of the food by food vendors during marketing. Bolade (2016) reported lower range of values (1.04-1.61 mg/kg) for the Fe content of road side, sundried fermented cassava mash. This may be attributed to reduced vehicular traffic along this road, and the differences in processing.

Table 3. Essential mineral composition of dried cassava products.[1,2]

Products	N	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)
Tapioca	40	29.69±31.70^{a}	2.79±3.30^{ab}	4.61±5.81^{ab}
White *kpokpo gari*	46	30.52±32.44^{a}	2.67±8.10^{ab}	4.46±4.99^{ab}
Yellow *kpokpo gari*	10	28.28±37.15^{a}	5.15±15.01^{a}	4.58±5.27^{ab}
Yellow *gari*	43	31.92±36.24^{a}	3.31±7.74^{ab}	5.43±6.12^{ab}
White *gari*	102	30.29±33.51^{a}	2.69±5.94^{ab}	4.46±5.19^{ab}
Fufu	15	27.90±30.41^{a}	2.34±3.06^{b}	3.42±3.88^{b}
Lafun	29	30.41±32.67^{a}	1.94±2.54^{b}	6.14±10.16^{a}
Starch	15	34.60±39.24^{a}	1.38±2.01^{b}	3.72±4.25^{ab}
HQCF	25	13.56±27.27^{b}	2.28±4.28^{b}	3.48±4.85^{ab}
States in Nigeria				
Enugu	47	32.30±34.20^{a}	3.22±3.52^{a}	5.54±5.92^{ab}
Abia	32	32.91±35.07^{a}	3.18±3.36^{a}	6.02±6.82^{a}
River	36	28.37±29.51^{a}	3.11±3.31^{a}	4.80±6.12^{ab}
Kwara	63	32.15±34.74^{a}	2.68±10.78^{a}	4.33±4.78^{ab}
Oyo	75	28.01±35.46^{a}	1.31±73.48^{a}	4.12±7.04^{b}
Ogun	87	25.10±30.15^{a}	3.15±6.00^{a}	3.91±4.50^{b}
Agroecological zones in Nigeria				
Derived savannah	234	28.75±33.60^{a}	2.60±7.01^{ab}	4.29±5.68^{a}
Humid forest	92	29.24±31.71^{a}	3.16±3.63^{a}	5.01±6.07^{a}
Southern Guinea savannah	14	35.38±38.18^{a}	0.57±0.64^{b}	4.84±5.37^{a}
Mean		29.16	2.67	4.55
Interactions				
Product		NS	NS	NS
States		NS	NS	NS
Agroecological zones		NS	NS	NS
Product × states		NS	NS	NS
Products × agroecological zones		NS	NS	NS
Agroecological zones × states		NS	NS	NS

[1] Fe = iron; Cu = copper; Zn = zinc; HQCF = high quality cassava flour; NS = not significant.

[2] Means with different superscript on the same column are significantly different at P≤0.05.

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The Cu content of the products ranged from 1.38 to 5.15 mg/kg, and the Zn content between 3.42 mg/kg and 6.14 mg/kg. Yellow *kpokpo gari* has the highest Cu content and cassava starch the lowest. The Zn content was higher in *lafun* and lower in *fufu* powder (Table 3). Awoyale *et al.* (2018) reported the range of values for the Cu content of Liberia *gari* to be 0.70 to 1.25 mg/kg, while the Zn content ranged from 3.50 to 7.85 mg/kg. The Cu content of Liberia *gari* is lower compared to that of the present study. Adebayo-Oyetoro *et al.* (2013) reported a higher range of values for the Cu content of *lafun* (21-28 mg/kg) available in Ogun and Oyo state markets, while lower values (0.59-0.72 mg/kg) were reported by Bolade (2016) for fermented cassava mash dried along the roadside. Furthermore, the Zn content of the tapioca (5 mg/kg) reported in this study is lower compared to that of the sundried locally produced fermented cassava mash reported by Bolade (2016). This may be associated with the differences in processing methods. Products (3.16 mg/kg) from the Humid forest have higher Cu content compared to those (0.57 mg/kg) from the Southern Guinea savannah zone with the lowest. Products (5.01 mg/kg) from the Humid forest have higher Zn content than products (4.29 mg/kg) from the Derived savannah. The higher Cu content of yellow *kpokpo gari* and Zn of *lafun* may also be attributed to the machine corrosion and drying in locations with heavy vehicular movement (Harrison *et al.*, 1981). Additionally, the lower values of these metals in cassava starch and *fufu* powder could be evidence that the grating step, which is less used in these products than *gari*, was mostly responsible for the high heavy metal contamination in *gari* from the predominately mild, steel-made machines. It could also be indicative of the use of stainless-steel machines by processors (factories) from the formal sector mostly involved in the processing of these two products unlike *gari* that is mostly produced by small-scale processors. Nevertheless, the Cu and Zn content of the products were below the maximum limit of 20 and 50 mg/kg, respectively, recommended by the food regulatory agencies in Nigeria (Sanni *et al.,* 2005). The products also comply with the WHO/FAO recommended maximum limit for Cu (40 mg/kg) and Zn (60 mg/kg) in crop plants (WHO/FAO, 2007) and are therefore safe for consumption.

4. Conclusions

This study showed that some chemical constituents of cassava products differ among products (moisture, CNP, ash and crude fibre) while others did not (TTA, pH, crude fibre, starch and heavy metals). Similarly, the ash and starch content of the investigated cassava products differ by agroecology. The levels of chemical constituents and trace metals, mainly Fe, Cu and Zn, were within the SON and FAO/WHO standards for cassava products except for the Fe content, which did not conform to set standards. Hence, for the purposes of food regulation, surveillance and export, the introduction of traceability steps for all metals and certification of origin of all foods when trading might not be unrealistic. Additionally, since cassava products have been noted to be hygroscopic, processors in the Humid forest must pay attention to proper packaging, selecting moisture impermeable packaging materials and packaging the cassava products soon after production.

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Conflict of interest

The authors report no conflict of interest.

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