

Original Research Article

Functional properties, hydrogen cyanide and heavy metals assessment of Garri sold in open markets in the three senatorial districts of Cross River State, Nigeria

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Abstract

Purpose: To assess the functional properties, hydrogen cyanide content, and heavy metal concentration of Garri sold in the three Senatorial Districts of Cross River State, Nigeria.

Methods: Twenty-seven Garri samples were collected from three markets in each Senatorial District. Swelling index, water and oil absorption capacities, bulk density, pH, and moisture content were evaluated using standard methods. Hydrogen cyanide and heavy metals (chromium, lead, cadmium, iron, and arsenic) were also analyzed using standard procedures.

Results: Water and oil absorption capacity, swelling index, bulk density, and pH of Garri were within the WHO/FAO permissible limits, while moisture content in all samples exceeded the recommended maximum of 10 % for stored cassava flour. However, hydrogen cyanide levels differed significantly ($p < 0.05$) among the three Senatorial districts, with the lowest mean value recorded in Yakurr location of Central Senatorial District (16.89 ± 0.65 mg/kg) and the highest in Calabar location of the Southern Senatorial District (22.28 ± 0.87 mg/kg). The levels of lead, cadmium, and arsenic were within permissible food safety limits, whereas iron and chromium levels exceeded the allowable limit.

Conclusion: The findings indicate that while Garri sold in Cross River State markets generally meet acceptable functional quality standards, elevated moisture content and significant variation in hydrogen cyanide and chromium levels may pose potential health risks to consumers.

Keywords: Functional properties, Garri, Heavy metal, Hydrogen cyanide, Open market, Senatorial district

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INTRODUCTION

Cassava remains a major food crop in the tropics, with adequate yields even in diverse tropical conditions. It usually yields better than other staple foods including rice, making it a versatile crop serving as a source of calories for

hundreds of millions of people living in the world's hot, tropical climates [1]. As a survival crop, cassava provides more than sixty percent of the day-to-day energy requirement of individuals in tropical Africa and Central America, accounting for more than half of the daily caloric needs after rice and maize [1].

Garri is one of the predominant fermented cassava-based products eaten in the West African sub-region of the world, and over seventy percent of cassava grown in Nigeria is processed into *Garri* [2]. The processing procedures involve peeling the cassava roots, grating the peeled cassava roots, fermenting, dewatering the mash into a wet cake and frying the wet material into gelatinized particles. The gelatinized particles are then allowed to cool by spreading them on a plain surface or mat before final sieving and packaging for marketing and consumption [2]. Due to the mode of storage and marketing of the cassava granules, it can be referred to as a "street food," which is defined as a ready-to-eat food made and/or sold by food merchants, especially in an open space along major roads and public places [3].

Garri can be consumed in different ways, such as cassava jam or soaking in water with beverages and groundnut, mashed beans, or bean cake (*akara*). The main issue of eating *Garri* is the toxicity, which might be linked to inadequate processing of cassava that has been reported to contain cyanogenic glucosides [4]. Hydrogen cyanide, a highly potent poisonous compound produced from the enzymatic degradation of cyanoglycosides, can cause severe cyanide poisoning, including symptoms such as low blood pressure, dizziness, headache, vomiting, diarrhea, cyanosis, twitching, and convulsions [5]. Nevertheless, cyanide concentration has been reported to be greatly decreased following proper processing of cassava to *Garri* [5].

With the growing human population and increasing food insecurity, which have intensified the demand for *Garri*, the current study must investigate the types of heavy metals and hydrogen cyanide present in *Garri*, as well as the pathways through which these contaminants pollute a range of *Garri* products consumed across diverse environmental settings. In Nigeria, particularly in Cross River State, the fermentation period of *Garri* is often shortened to meet growing market demand. The finished products are typically displayed in open buckets or on mats along roadsides at points of sale, where they may be exposed to contamination from passing vehicles. Continuous consumption of such contaminated products may pose significant health risks [4]. Also, *Garri* consumers may be unaware of the chemical and biological dangers related to the chemical elements present in the food. Therefore, it is important to assess the functional properties, hydrogen cyanide and heavy metal concentration of *Garri* sold in open markets in Cross River State, Nigeria.

EXPERIMENTAL

Sample collection

A total of twenty-seven (27) *Garri* samples were randomly collected, comprising three samples from each market across three locations in each of the three study areas (GPS: 4° 45'41" North, 8° 21'53" East). The samples obtained were separately preserved in sealed plastic bags at room temperature (25 ± 3 °C) to avert insect or rodent infestation, as well as spoilage before laboratory analysis.

Determination of Swelling Index

The estimation of the swelling index was carried out according to the procedures outlined by Bankole and co-workers [6].

Determination of bulk density

Bulk density (BD) of the *Garri* samples was estimated in line with the procedures documented by Onwuka [7].

Determination of water absorption capacity

The water absorption capacity (WAC) was measured as previously described [7].

Determination of oil absorption capacity (OAC)

The method of Onwuka [7] was used for the estimation of OAC.

Determination of pH of *Garri* samples

The pH of the samples was determined following the method described previously [8].

Determination of moisture content

Moisture content was estimated according to the standard methods of Association of Official Analytical Chemists (AOAC) [9].

Hydrogen cyanide determination

The measurement of hydrogen cyanide content was carried out using the modified alkaline picrate method [7].

Determination of heavy metals

The chromium, lead, cadmium, iron, and arsenic analyses were carried out using an atomic absorption spectrophotometer (AAS), and the concentration of each metal was measured from

the calibration curves prepared with their respective standard solutions [9].

Statistical analysis

The data obtained were collated and analyzed using one-way ANOVA with *post hoc* corrected two-tailed *t*-tests in IBM SPSS Statistics software version 22 (SPSS: Statistical Package for the Social Sciences). Results were presented as mean $\pm$ standard deviation, and changes with $p < 0.05$ were regarded as statistically significant.

RESULTS

Functional properties and hydrogen cyanide composition of Garri samples

The water absorption capacity (WAC) and swelling index of the Garri samples obtained within and between the three Senatorial Districts ranged from 4.57 – 5.54 mL/g and 4.18 – 5.89 (v/v), respectively, showing that Garri samples from the Southern and Central senatorial districts had higher values when compared to samples from the Northern senatorial district. Bulk density of Garri samples ranged from 0.56 g/mL to 0.71 g/mL within and between the senatorial districts and the bulk density of samples from the

Southern and Northern Senatorial Districts was significantly higher ($p < 0.05$) compared to samples from the Central senatorial district. The OAC of Garri samples from the three Senatorial Districts showed no significant ($p > 0.05$) changes both within and between the Senatorial Districts.

Furthermore, the pH of the Garri samples varied from 5.39 to 5.64 within and between the Senatorial Districts and the pH value of Garri samples from the Northern Senatorial District increased significantly ($p < 0.05$) compared to those from the Central and Southern Senatorial Districts of the study area. Also, hydrogen cyanide content of Garri samples from the Southern Senatorial District increased significantly ($p < 0.05$) compared to samples from the Central and Northern Senatorial Districts of the state (Tables 1 and 2).

Heavy metals composition of Garri samples

Results of the composition of heavy metals (iron, lead, chromium, arsenic, and cadmium) in Garri sold in open markets within the three Senatorial Districts of Cross River State, Nigeria are presented in Tables 3 and 4.

Table 1: Functional properties and hydrogen cyanide composition of Garri samples within the Senatorial Districts

Senatorial District	Sample locations	WAC (mL/g)	OAC (mL/g)	BD (g/mL)	SI (v/v)	pH	HCN (Mg/kg)	Moisture content (%)
Southern	Akamkpa	5.54 $\pm$ 0.31	1.64 $\pm$ 0.05	0.71 $\pm$ 0.01	4.99 $\pm$ 0.25	5.62 $\pm$ 0.05	17.34 $\pm$ 0.68	13.90 $\pm$ 0.58
	Adim	5.00 $\pm$ 0.18	1.58 $\pm$ 0.08	0.67 $\pm$ 0.01	5.37 $\pm$ 0.21	5.53 $\pm$ 0.08	17.72 $\pm$ 1.08	13.87 $\pm$ 0.58
	Calabar	5.22 $\pm$ 0.31	1.59 $\pm$ 0.04	0.57 $\pm$ 0.0 ^a	5.51 $\pm$ 0.17	5.39 $\pm$ 0.06 [*]	22.28 $\pm$ 0.87 ^{*a}	13.67 $\pm$ 0.66
[*] = $p < 0.05$ vs Akampka; ^a = $p < 0.05$ vs Adim								
Central	Yakurr	4.94 $\pm$ 0.04	1.63 $\pm$ 0.04	0.56 $\pm$ 0.01	5.58 $\pm$ 0.10	5.44 $\pm$ 0.05	16.89 $\pm$ 0.65	13.74 $\pm$ 0.80
	Ikom	5.15 $\pm$ 0.12	1.61 $\pm$ 0.05	0.61 $\pm$ 0.01 [*]	5.89 $\pm$ 0.10 [*]	5.72 $\pm$ 0.01 [*]	15.95 $\pm$ 0.53	11.93 $\pm$ 0.61 [*]
	Obubra	5.05 $\pm$ 0.07	1.50 $\pm$ 0.03	0.57 $\pm$ 0.01 ^a	5.58 $\pm$ 0.08 ^a	5.70 $\pm$ 0.03 [*]	14.87 $\pm$ 0.21 [*]	12.10 $\pm$ 0.15
[*] = $p < 0.05$ vs Yakurr; ^a = $p < 0.05$ vs Ikom								
Northern	Mbube	4.84 $\pm$ 0.22	1.43 $\pm$ 0.11	0.65 $\pm$ 0.02	4.92 $\pm$ 0.10	5.94 $\pm$ 0.06	13.63 $\pm$ 0.27	12.25 $\pm$ 0.62
	Okuku	4.50 $\pm$ 0.10	1.69 $\pm$ 0.06 [*]	0.61 $\pm$ 0.0 [*]	4.71 $\pm$ 0.27	5.56 $\pm$ 0.07 [*]	18.73 $\pm$ 1.03 [*]	16.39 $\pm$ 0.42 [*]
	Utuguan	4.36 $\pm$ 0.12 [*]	1.66 $\pm$ 0.07	0.64 $\pm$ 0.01	4.18 $\pm$ 0.14 [*]	5.43 $\pm$ 0.05 [*]	18.40 $\pm$ 0.82 [*]	12.48 $\pm$ 0.81 ^a
[*] = $p < 0.05$ vs Mbube; ^a = $p < 0.05$ vs Okuku								

WAC: water absorption capacity; OAC: Oil absorption capacity; BD: bulk density; SI: swelling index; HCN: hydrogen cyanide

Table 2: Functional properties and hydrogen cyanide composition of Garri samples between the Senatorial Districts

Senatorial district	WAC (g/ml)	OAC (g/ml)	BD (g/ml)	SI (v/v)	pH	HCN (mk/kg)	Moisture content (%)
Southern	5.25 $\pm$ 0.13	1.60 $\pm$ 0.03	0.65 $\pm$ 0.02	5.29 $\pm$ 0.13	5.51 $\pm$ 0.04	19.12 $\pm$ 0.66	13.81 $\pm$ 0.34
Central	5.05 $\pm$ 0.05	1.58 $\pm$ 0.03	0.58 $\pm$ 0.01 [*]	5.68 $\pm$ 0.06 [*]	5.62 $\pm$ 0.03	15.90 $\pm$ 0.32 [*]	12.59 $\pm$ 0.36 [*]
Northern	4.57 $\pm$ 0.10 ^{*a}	1.59 $\pm$ 0.05	0.64 $\pm$ 0.01 ^a	4.61 $\pm$ 0.12 ^{*a}	5.64 $\pm$ 0.05 [*]	16.92 $\pm$ 0.63 [*]	13.71 $\pm$ 0.51

Values are expressed as mean $\pm$ SEM, n = 27. ^{*} = significantly different from South at $p < 0.05$; ^a = significantly different from Central at $p < 0.05$; WAC: water absorption capacity; OAC: Oil absorption capacity; BD: bulk density; SI: swelling index; HCN: hydrogen cyanide

The iron concentration of *Garri* samples obtained from the Southern Senatorial District ranged from 4.74 mg/kg to 7.18 mg/kg. The *Garri* samples from Calabar location (7.18 ± 0.77 mg/kg) recorded the highest iron content within the Southern Senatorial District, while the iron content of the samples from all the locations within the Central and Northern Senatorial districts was not significantly ($p > 0.05$) different. However, between the senatorial districts, the concentration of iron in all the *Garri* samples showed no significant ($p > 0.05$) changes in their values. Concentrations of lead in *Garri* samples obtained within the Southern Senatorial districts varied from 0.05 mg/kg to 0.07 mg/kg, with samples from Calabar location (0.07 ± 0.01 mg/kg) having a significantly ($p < 0.05$) higher lead level within the Southern Senatorial district, compared to other samples. The lead value of the samples obtained from Obubra location in the Central Senatorial district increased significantly ($p < 0.05$) compared to those from Yakurr and Ikom locations. However, the lead content of *Garri* samples from the three locations in the Northern Senatorial district was not significantly ($p > 0.05$) different from each other. However, between the three senatorial districts, the lead value in all the *Garri* samples showed no significant ($p > 0.05$) variation in their values. In addition, the chromium concentration of *Garri* samples from Obubra location increased

significantly ($p < 0.05$), compared to those from other locations in the three Senatorial districts. However, the *Garri* sample from Mbube axis recorded the lowest (0.12 ± 0.02 mg/kg) chromium concentration. The concentration of chromium in the *Garri* samples obtained between the three Senatorial districts varied from 0.17 mg/kg to 0.28 mg/kg, with samples from the Central Senatorial district (0.28 ± 0.05 mg/kg) having a significantly ($p < 0.05$) higher value compared to samples obtained from the Southern (0.21 ± 0.02 mg/kg) and Northern Senatorial districts (0.17 ± 0.01 mg/kg).

Furthermore, the concentration of arsenic in the *Garri* samples obtained from the three locations within each Senatorial district of the State showed no significant ($p > 0.05$) changes. However, the concentration of arsenic in the *Garri* samples between the three Senatorial districts varied from 0.03 mg/kg to 0.04 mg/kg. The arsenic concentration of *Garri* from Southern and Northern Senatorial districts had the same value (0.04 ± 0.01 mg/kg) and was significantly ($p < 0.05$) higher compared to those from the Central Senatorial district (0.03 ± 0.01 mg/kg). Similarly, cadmium concentration in the *Garri* samples from the Southern senatorial districts was significantly higher ($p < 0.05$) compared to those from the Central and Northern Senatorial districts.

Table 3: Heavy metals composition of *Garri* samples within the three Senatorial Districts of Cross River State, Nigeria

Senatorial District	Sample locations	Iron (mg/kg)	Lead (mg/kg)	Chromium (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)
South	Akamkpa	4.74 ± 0.35	0.05 ± 0.01	0.26 ± 0.05	0.04 ± 0.01	0.05 ± 0.01
	Adim	5.22 ± 0.31	0.06 ± 0.01	0.14 ± 0.04	0.05 ± 0.01	0.04 ± 0.01
	Calabar	$7.18 \pm 0.77^{*,a}$	$0.07 \pm 0.01^{*,a}$	0.22 ± 0.03	0.04 ± 0.01	0.05 ± 0.01
* = $p < 0.05$ vs Akamkpa; ^a = $p < 0.05$ vs Adim						
Central	Yakurr	5.62 ± 0.29	0.04 ± 0.01	0.15 ± 0.03	0.03 ± 0.01	0.03 ± 0.01
	Ikom	5.32 ± 0.14	0.05 ± 0.01	0.16 ± 0.04	0.03 ± 0.01	0.03 ± 0.02
	Obubra	5.48 ± 0.26	$0.07 \pm 0.01^{*,a}$	$0.54 \pm 0.12^{*,a}$	0.03 ± 0.01	0.03 ± 0.01
* = $p < 0.05$ vs Yakurr; ^a = $p < 0.05$ vs Ikom						
North	Mbube	5.58 ± 0.21	0.05 ± 0.01	0.12 ± 0.02	0.04 ± 0.01	0.03 ± 0.01
	Okuku	6.43 ± 0.59	0.07 ± 0.01	$0.22 \pm 0.01^*$	0.04 ± 0.01	$0.05 \pm 0.01^*$
	Utuguan	6.68 ± 0.56	0.06 ± 0.01	$0.19 \pm 0.03^*$	0.04 ± 0.01	0.03 ± 0.01^a
* = $p < 0.05$ vs Mbube; ^a = $p < 0.05$ vs Okuku						

Values are expressed as mean $\pm$ SEM, n = 27

Table 4: Heavy metals composition of *Garri* samples sold between the three Senatorial Districts of Cross River State, Nigeria

Senatorial District	Iron (mg/kg)	Lead (mg/kg)	Chromium (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)
South	5.71 ± 0.35	0.06 ± 0.01	0.21 ± 0.02	0.04 ± 0.01	0.05 ± 0.01
Central	5.47 ± 0.14	0.06 ± 0.01	0.28 ± 0.05	$0.03 \pm 0.01^*$	$0.03 \pm 0.01^*$
North	6.23 ± 0.29	0.06 ± 0.01	0.17 ± 0.01^a	0.04 ± 0.01^a	$0.04 \pm 0.01^{*,a}$
WHO/FAO permissible limits	0.21	0.20	0.10	0.20	0.20
Codex tolerable limits	----	0.1–1.5	----	----	0.05–1.0

Values are expressed as mean $\pm$ SEM, n = 27; * = significantly different from South at $p < 0.05$; a = significantly different from Central at $p < 0.05$

DISCUSSION

Cassava granules remain the most desired cassava product due to their affordability, availability, convenience in preparation and transportation, as well as less perishability. The activities of nutrients in the diet during manufacturing, storing, as well as packaging, which affect food quality and satisfactoriness, are reported to be governed by functional properties [6]. The functional properties of *Garri* samples within and between the three Senatorial districts agree with the previous study [10] for traditionally prepared cassava granules but are lower than the results obtained in the recent study [11] for *Garri* fortified with soybean flour. The variations in the functional properties observed in these studies could be due to the energy content of *Garri* [10], since carbohydrates are known to significantly influence the functional properties of foods.

Findings from this study revealed significant variations in the WAC, BD, SI, as well as pH of the *Garri* samples. However, the significantly higher water absorption capacity of *Garri* samples from Southern and Central Senatorial districts may be attributed to a short fermentation period, which may influence the starch content in the *Garri* samples. *Garri* samples from the Southern and Central Senatorial districts may have a short fermentation period; hence, they are not typically sour, which is a quality of *Garri* that is properly fermented. Also, the high bulk density of the Southern and Northern districts *Garri* samples could be linked to the short fermentation period of the cassava granules, which is responsible for a high content of starch. The size of the particles of the cassava granules may also be responsible for the variation in the bulk density. Generally, BD (0.58 – 0.65 g/mL) of *Garri* samples recorded in this study was lower than the 0.82 - 0.84 g/cm³ values reported in a previous study [12] for *Garri* samples from various processing factories in Southwest Nigeria. Swelling index measures the hydration capacity, and it was observed that significant variations occurred among the samples in the study areas. The result of the swelling index of the present study was higher than the value (3.8 %) reported by Adewole and co-workers [10] for traditionally prepared cassava granules. Fermentation period, species of cassava and processing procedures may have contributed to the variations in the swelling index.

Significant variation occurs in the moisture content of *Garri* samples within and between the Senatorial Districts. The moisture content of all *Garri* samples in this study was above the

stipulated regulated standard for *Garri* (10 %), though some samples fell within the safe limit (12 % - 13 %) reported previously [2]. From the present study, *Garri* sold along Central senatorial districts, specifically Ikom markets, recorded the least moisture content, compared to those from Southern and Northern Senatorial districts, and this could be attributed to the processing procedures and species of cassava. This implies that *Garri* samples from the Southern and Northern senatorial districts may have lower shelf life, thereby being susceptible to spoilage, if stored for longer period. Results from a previous study showed that *Garri* with moisture level lower than 13 % is highly resistant to moisture-related spoilage [10]. This suggests a good shelf life for *Garri* from the Central senatorial districts, as the decreased moisture levels could delay the progression of microbes, as well as deterring the breakdown of inherent elements in cassava.

The hydrogen cyanide content of *Garri* samples within and between the study areas was higher than the levels reported in a recent study [13] for *Garri* from different sources and exceeded the World Health Organization (WHO) recommended safe intake of 10 mg HCN/kg body weight for cyanide-containing foods for humans and animals. This suggests that local cassava producers in Cross River State may not be employing optimal processing practices, raising a public health concern. The elevated cyanide levels may be attributed to the shortened fermentation period, as it has been reported that longer fermentation periods, typically 2–3 days, significantly reduce cyanide concentrations [13]. However, the short fermentation period assumed to be employed by the *Garri* producers in the study area could be linked to the constant high demand for *Garri*, as the food is one of the most consumed foodstuffs in the state, causing some marketable hubs to hastily process *Garri* without adequate fermentation and processing practices, leading to an increase in cyanide concentration. Moreover, good *Garri* processing methods, such as sun drying and proper frying, have been reported to considerably reduce the residual cyanide concentration in foods [14].

The high cyanide content observed in the present study could cause a severe health-related challenge to humans. Experimental studies have shown that continued contact with cyanide at low levels leads to increased blood cyanide concentration, triggering symptoms including nausea and emesis, dizziness, headache, tachypnea, uneasiness, tiredness, while paralysis, nerve injuries, myxedema, and spontaneous abortion have been reported in severe cases [4]. Acute exposure can be fatal,

while long-lasting effects have been accompanied by goiter, as well as nerve damage [4]. These findings highlight the urgent need for relevant agencies to raise awareness among *Garri* producers in Cross River State about proper processing methods to safeguard consumer health.

The result of pH analysis in our findings agrees with that of previous finding [15]. The pH is a vital index influencing the mobility, bioavailability, and buildup of chemical elements in food, with lower pH (acidic) conditions generally increasing the risk of contamination. All heavy metal concentrations of *Garri* samples in the present study were within the WHO permissible limit except in the case of iron and chromium, whose values were higher than the 0.21 and 0.10 mg/kg limits set by WHO/FAO for iron and chromium in food, respectively. Also, samples from the Southern senatorial district recorded a significantly higher heavy metal concentrations compared to those from the Northern and Central senatorial districts and this may be linked to the lower pH values and higher moisture content recorded in the *Garri* from the Southern senatorial districts, as chemical elements like lead, cadmium and copper have been reported to be more easily released from uptake by crops in acidic environment (pH 3 – 5) compared to neutral or alkaline conditions [15]. Also, the high concentration of the heavy metals in the *Garri* samples from the Southern senatorial district may be linked to unhygienic practices, including atmospheric exposure of the cassava granules by food vendors during the packaging and marketing processes. In addition, Calabar metropolis, which is a major area in the Southern senatorial district of Cross River State, is associated with heavy industrial and commercial activities, as the area houses most active agencies of both the State and Federal governments and this may contribute to the presence of these chemical elements in the *Garri* samples sold in the area.

The levels of heavy metals revealed in our findings agree with those of the previous study [16]. Though the harmful effects of these heavy metals are enormous, some of them have been reported to possess some beneficial properties; for instance, metals such as iron have been implicated in food supplements, particularly for women of reproductive age, as well as with children [17]. Also, iron is associated with numerous biochemical processes, such as hemoglobin, oxygen transportation, as well as synthesis of enzymes [17]. Nevertheless, some heavy metals are poisonous in both low and high concentrations, as well as with long-term contact

and they show the capacity to move and concentrate in various organs, resulting in numerous public health concerns [16]. For example, lead affects the regular action of enzymes and is associated with carcinogenesis, mutagenesis, and teratogenesis in experimental animals [18]. The toxic effects of arsenic are typically determined by its ability to bind with the sulfhydryl groups of proteins and enzymes and to interfere with phosphorus-dependent biological reactions [16]. Long-term exposure to arsenic can disrupt cardiovascular and reproductive system functions and may contribute to the development of cancer or diabetes [18]. Consequently, individuals consuming *Garri* contaminated with heavy metals are at risk of adverse health effects, which can include immunological, neurological, reproductive, developmental, and carcinogenic outcomes.

Following the results of the present study, which revealed high concentrations of hydrogen cyanide and heavy metals in the *Garri* samples sold in the study area, mostly in the Southern senatorial district, there is a need for public health guidelines and enactment of proper processing practices regarding the preparation, handling and vending of cassava and its products. Furthermore, *Garri* producers and vendors should be adequately educated, monitored, and potentially licensed by food regulatory agencies before selling to the public, to protect the health of the large and growing population of *Garri* consumers, as well as future generations. Implementing these measures would help ensure the safety of *Garri* as a staple food in Nigerian households, particularly among low-income populations that rely heavily on the product for daily sustenance.

CONCLUSION

The results of this study indicate that chemical and environmental contaminants in market areas significantly contribute to the hydrogen cyanide and heavy metal contamination of *Garri* sold across the study area.

DECLARATIONS

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Ethical approval

Not applicable.

Use of Artificial intelligence/Large language models

The authors declare that neither Generative artificial intelligence (AI) nor AI-assisted technologies were used in writing the manuscript.

Availability of data

The datasets used/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent of publication

Not applicable, as human subjects were not used.

Conflict of interests

No conflict of interest is associated with this work.

Contribution of authors

We declare that this work was done by the author(s) listed in this article, and all liabilities pertaining to claims relating to the content of this article will be borne by the authors. Conceptualization and design: Margaret A. Agiang and Obazi A. Oham; Acquisition, analysis, and interpretation of data: Margaret A. Agiang, Obazi A. Oham, Aniekeme N. Inyang, John E. Mgbang, Nzem C Chidubem; Drafting, revision, and resources: Obazi A. Oham, Aniekeme N. Inyang, Josephine E. Egbung, John E. Mgbang, Ediye O. Ottoho, and Ude C. Sunday. All the authors read the manuscript and the authors' list and consented to the publication.

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