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Nutritional Composition and Chemical Contaminants in Tapioca Processed Near Gas-Flare Sites in the Niger Delta, Nigeria

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ABSTRACT
This study investigated the influence of gas flaring on selected potentially toxic metals (PTMs) and volatile organic compounds (VOCs) in tapioca processed in flare-impacted environments of the Niger Delta, Nigeria. Samples collected from gas-flaring locations and a non-flare-exposed control site were analyzed for mineral composition, PTMs, proximate properties, cyanide, vitamin C, and VOCs using standard analytical methods. Results showed significant differences in moisture, protein, ash, carbohydrate, cyanide, crude fibre, and vitamin C, while pH showed no significant difference. Mineral concentrations exhibited low variability, with Fe (3.61–4.21 mg/kg), Ca (10.69–12.77 mg/kg), K (14.48–17.93 mg/kg), Na (8.27–10.81 mg/kg), and P (21.21–22.27 mg/kg), showing no consistent elevation in flare-exposed samples. Lead concentrations ranged from 0.07 to 0.11 mg/kg. Lead concentrations near regulatory limits raise concerns about chronic exposure. Mercury was undetectable, whereas arsenic (≤0.01 mg/kg) and nickel (0.08–0.10 mg/kg) were within acceptable safety limits. The concentrations of VOC were below 0.002 mg/kg in each sample. The findings indicate that gas flaring has minimal influence on macro-mineral composition but may contribute to localized lead enrichment, potentially through atmospheric deposition during open-air drying. Controlled drying systems, enhanced environmental monitoring, and further research integrating soil–air–plant interactions and exposure assessment models are recommended to minimize contamination risks.

Keywords: Tapioca, Gas flare sites, Nutritional quality, Potentially toxic metals, Volatile organic compounds

INTRODUCTION

Tapioca is a processed food product obtained from cassava (*Manihot esculenta crantz*), also known as manioc, which is a major staple crop in tropical regions. Cassava is widely consumed in Nigeria and contributes significantly to caloric intake, providing a cheap source of carbohydrates (FAO, 2013). Tapioca production involves grating, fermenting, and drying the cassava starch, after which it is often toasted or further processed into flakes or granules. Nutritionally, cassava-derived products are valued for their high carbohydrate content but are generally low in protein and certain micronutrients (Chauynarong *et al.,* 2009). The method of drying and processing can significantly influence the nutritional profile and safety of tapioca, making the choice of heat source an important factor for consumer health (Otobrise *et al.,* 2024).

The potential contamination of tapioca dried with heat from gas flaring raises serious public health concerns. Potentially toxic metals (PTMs) such as lead, mercury, and arsenic are known to accumulate in the human body and may cause neurological, renal, and cardiovascular disorders (WHO, 2021a, 2021b). Likewise, polycyclic aromatic hydrocarbons (PAHs), such as benzo[a]pyrene are recognized carcinogens, while volatile organic compounds (VOCs) including benzene and toluene have mutagenic and immunotoxic properties (U.S. EPA, 2003, 2005; Emoyan *et al.,* 2015). While cassava and its derivatives play an important role in food security, contamination during processing can offset these benefits, potentially increasing the risk of chronic diseases among consumers. Contamination of garri, tapioca and other cassava based staple foods, could arise from unhygienic drying on floors and roadsides, atmospheric dust and vehicle emissions depositing heavy metals, uptake of metals by cassava from polluted soils and air, contaminated fermentation water, poor processing environments, and smoke and heat exposure during traditional wood-fired roasting by local women processors (Okareh *et al.,* 2021; Enyoh *et al.,* 2023; Uche *et al.,* 2024) This underscores the need for scientific assessment of the nutritional quality and contaminant levels in tapioca dried with heat from gas flaring compared with safer conventional methods.

Gas flaring incompletely combusts hydrocarbons leading to the emission of VOCs such as benzene, a known human carcinogen (Ite and Ibok, 2019). When food products are dried in the path of these emissions, they can act as a sink for these airborne pollutants. Particulate matters laden with HMs can settle on the wet products, while VOCs can be absorbed directly into the food matrix during the heating process. This presents a serious yet understudied pathway for human exposure to toxic substances. Animals and humans are exposed to HMs and VOCs via food, water, and air. This accumulation increases in organisms higher up the food chain—a process known as bioaccumulation and biomagnification, which amplifies toxicity risks (Connell, 1990; Gobas & Morrison, 2000; U.S. EPA, 2010; Newman, 2014). This study aims to evaluate the nutritional composition and concentrations of selected potentially toxic metals and volatile organic compounds in tapioca obtained from gas-flare-impacted locations in the Niger Delta, Nigeria.

MATERIALS AND METHODS

Sample Collection and Preparation

A total of five (5) composite samples were purchased from each sampling location. Each composite is made up of five samples purchased from different individuals at each gas flare site. The samples were purchased from the traders, mostly women, while they were being dried a few meters from the fire emanating from the gas flaring pipes. The five samples purchased from each sampling location were thoroughly mixed to obtain a good blende for analysis. The sampling locations are: Agbara-Otor (5.52265^0N, 6.05828^0E); Eruemukohwarie (5.51602^0N, 5.93848^0E); Otujeremi (5.43508^0N, 5.88419^0E); Ozoro (5.56928^0N, 6.30543^0E) and a control sample from Abraka (5.79024 °N, 6.10473 °E). The latter is not a gas flare site.

Proximate Analysis

Proximate analysis was carried out using standard methods of the Association of Official Analytical Chemists (AOAC, 2019). The parameters determined include moisture content, ash content, crude protein, crude fat, crude fibre, and carbohydrate. Moisture content was determined using the oven-drying method. About 2 g of each sample was weighed into a pre-weighed moisture dish and dried in an oven at 105°C until a constant weight was obtained. Moisture content was calculated using the formula:

$$Moisture\ (\%) = [(W1 - W2) / W1] \times 100$$

Where W1 = initial weight of sample, W2 = final dry weight. Ash content was determined by the muffle furnace technique. Two grams of each sample were incinerated in a muffle furnace at 550 °C for 4 hours. The ash content was calculated using:

$$Ash\ (\%) = (Weight\ of\ ash\ /\ Weight\ of\ sample) \times 100$$

Crude protein was determined using the Kjeldahl method. Nitrogen content was multiplied by a factor of 6.25.

$$Protein\ (\%) = Nitrogen\ (\%) \times 6.25$$

Crude fat was determined using Soxhlet extraction with petroleum ether. Percentage fat was calculated as:

$$Fat\ (\%) = (Weight\ of\ extracted\ fat\ /\ Weight\ of\ sample) \times 100$$

Crude fibre was determined by acid and alkaline digestion, followed by incineration. Percentage fibre was calculated as:

$$Fibre\ (\%) = (Weight\ of\ residue - Weight\ of\ ash)\ /\ Weight\ of\ sample \times 100$$

Carbohydrate content was determined by difference.

$$Carbohydrate\ (\%) = 100 - (\%Moisture + \%Ash + \%Protein + \%Fat + \%Fibre)$$

Analysis of PTMs

The tapioca samples were homogenized and ground for wet digestion. 1.0 g of the ground sample was digested with 10 mL of a mixture of concentrated HNO_3: $HClO_4$ (3:1). The digested samples were filtered (Whatman No. 42) and diluted to 50 mL with deionized water. Iron (Fe), lead (Pb) and calcium (Ca) were analysed using a GBC 932AA atomic absorption spectrophotometer operated with GBC Avanta software. Sodium (Na) and potassium (K) were analysed using a flame photometer.

Individual AccuStandard single-element atomic absorption standards were used for the preparation of calibration solutions for Fe, Pb and Ca. The nominal stock concentration was 1,000 mg/L for each standard. Sodium and potassium were calibrated using appropriate sodium and potassium standards compatible with the flame photometer. Working standards were prepared by suitable dilution, and reagent blanks were included in the analytical sequence. The AccuStandard reference standards used for the five analytes were Fe (AA27N-1), Pb (AA29N-1), K (AA43N-1), Ca (AA09N-5) and Na (AA54N-1). The Fe, Pb and Ca standards were used for AAS calibration, while the K and Na standards were intended for flame-photometer calibration. Provisional blank-based estimates were calculated using Limit of Detection = 3s and Limit of Quantification = 10s, where *s* represents the sample standard deviation of replicate blank concentration readings.

Analysis of VOCs

VOC extraction was performed using Headspace Solid Phase Micro extraction (HS-SPM). 5 g of dried tapioca was placed in a 20 mL headspace vial. The vial was sealed with a polytetrafluoroethylene (PTFE) septum and incubated at 60°C for 30 minutes. A 100 µm polydimethylsiloxane (PDMS) fiber was exposed to the headspace for 30 minutes. The adsorbed VOCs were thermally desorbed into a Gas Chromatograph-Mass Spectrometer (GC-MS) system (Model: [Orbitrap Exploris GC MS], Manufacturer: [Thermo Fisher Scientific]). Column: HP-5MS capillary column (30 m × 0.25 mm × 0.25 µm). Carrier gas: Nitrogen at 1.0 mL/min. Oven temperature program: Initial at 40°C (held 2 min), ramped to 200°C at 10°C/min, then to 280°C at 5°C/min. MS conditions: Electron impact ionization at 70 eV, scan range m/z 35–500. Identification of VOCs was done by matching mass spectra with the NIST/EPA/NIH mass spectral library, and quantification was based on peak areas using external standards for selected target VOCs (e.g., benzene, toluene, ethylbenzene, xylene, formaldehyde, acetaldehyde, etc.).

Quality Control and Assurance

All glassware and containers were pre-cleaned with 10% HNO_3 and rinsed with deionized water.

Reagent blanks, matrix spikes, and duplicate samples were run in each batch. Recovery rates for PTMs ranged from 85% to 110%; method detection limits (MDLs) were established in accordance with USEPA Method 6020A for metals and EPA 8260B for VOCs. All analyses were performed in triplicates and results expressed as mean ± standard deviation for each analysis.

Statistical Analysis

Data analysis was performed using Microsoft Excel for mean and standard deviation. The study had one categorical independent factor (sample source) with five levels (A, B, C, D, E-Control) and one continuous dependent variable per test e.g., moisture (%), Fe (mg/kg) etc. One-way analysis of variance at 5% significance level and Post-Hoc Tukey HSD were used to compare the properties of the different tapioca samples.

RESULTS AND DISCUSSION

The proximate composition of the tapioca samples expressed on wet-weight basis is shown on table 1.

Table 1: Proximate Composition of Tapioca Samples

Parameters	A	B	C	D	E (Control)
pH	6.40±0.08	6.30±0.16	6.43±0.12	6.60±0.00	6.50±0.00
Moisture content (%)	6.10±0.08	6.40±0.08	7.60±0.00	5.27±0.02	8.40±0.08
Protein content (%)	0.11±0.00	0.15±0.01	0.21±0.01	0.14±0.01	0.20±0.02
Ash content (%)	1.08±0.03	1.21±0.01	1.10±0.01	1.10±0.04	1.24±0.00
Crude fat (%)	0.90±0.08	1.00±0.08	1.10±0.08	1.20±0.00	0.90±0.00
Crude fibre (%)	11.34±0.03	12.12±0.07	11.80±0.08	10.75±0.04	13.16±0.04
Carbohydrate content (%)	80.47±0.06	79.12±0.10	78.19±0.08	75.80±0.11	81.84±0.03

The pH values ranged from 6.30 to 6.60. The values reflects minimal variation among the samples, suggesting uniformity in acidity irrespective of exposure conditions. Cassava products typically exhibit mildly acidic to near neutral pH depending on the extent of fermentation and processing methods. The values obtained in this study suggest that the tapioca underwent limited fermentation prior to drying, or that fermentation acids were reduced during processing. They also indicate that gas flaring–associated drying conditions did not significantly influence the acidity profile of the tapioca. The results align with reported literature values for non-fermented or mildly processed cassava products and suggest that the physicochemical integrity of the samples with respect to acidity was maintained (Sule *et al.,* 2017; Bakwanamaha *et al.,* 2026).

Moisture content is a critical quality parameter in dried food products, as it significantly influences shelf life, microbial stability, texture, and overall storage characteristics. The results indicate that the moisture levels of the tapioca fall within a relatively low range (5.27–8.4%), which is generally desirable for dried cassava products. From a storage standpoint, the moisture levels recorded in this study indicate that the tapioca possess favorable storage characteristics and are less likely to support microbial spoilage. The observed values also fall within acceptable moisture ranges commonly reported for dried cassava products in food quality studies (SON, 1988; Sanni *et al.,* 2005; Bamgbose *et al.,* 2011).

The protein content of tapioca was generally low across all samples, ranging from 0.11% to 0.21%. The low protein levels observed are consistent with the inherent nutritional characteristics of cassava roots, which are known to contain minimal protein compared with other staple crops. During processing, particularly drying and heat exposure, minor losses in protein content may occur due to thermal denaturation or structural changes in nitrogenous compounds. However, the small differences observed between the exposed samples and the control suggest that the heat associated with gas flaring did not significantly degrade the protein fraction of the tapioca.

The ash content of the tapioca ranged from 1.08% to 1.24%. The results fall within the typical range reported for processed cassava products in the literature (Sanni *et al.,* 2005; Chisenga *et al.,* 2019). Overall, the samples possess a relatively stable mineral composition, and the drying conditions did not significantly affect the total inorganic content of the samples when compared with the control.

The crude fibre content of the samples ranged from 10.75% to 13.16%. The slightly higher fibre content observed in the control sample compared with some of the exposed samples may be attributed to minor processing variations or natural differences in cassava root composition. However, the relatively narrow range observed suggests that the drying conditions associated with gas flaring did not significantly alter the crude fibre content of the tapioca.

The carbohydrate content of the samples ranged from 75.80% to 81.84%. Comparison between the exposed samples and the control sample suggests that the drying conditions associated with gas flaring did not significantly affect the carbohydrate composition of the tapioca. Carbohydrates, particularly starch, are relatively stable during moderate heat processing and are less susceptible to degradation compared with heat-sensitive nutrients such as certain vitamins. Consequently, the thermal conditions associated with drying are unlikely to cause substantial reductions in carbohydrate content.

The result of the one-way ANOVA and Post-Hoc HSD tests on the proximate analysis data are shown on table 2.

Table 2: One-way ANOVA and Post-Hoc HSD Results

Property	F-statistic	p-value	Decision at p<0.05	HSD
pH	2.568	0.1030	a	-
Moisture	750.039	(<0.0001)	b	0.2100
Protein	37.929	0.000005	b	0.0318
Ash	18.767	0.000121	b	0.0787
Crude fat	8.500	0.00290		
Crude fibre	531.574	(<0.0001)	b	0.1820
Carbohydrate	1605.100	(<0.0001)	b	0.8470

a = no significant difference between values across a row; b = significant difference exists between values across a row

There were five tapioca samples and three replicate measurements per sample. The degree of freedom between the five samples is 4, the degree of freedom within the fifteen replicates is 10; giving a total degree of freedom of 14. One-way ANOVA revealed significant differences ($p<0.05$) in moisture, protein, ash, crude fat, crude fibre and carbohydrate across samples, while pH showed no significant difference ($F=2.57$, $p=0.103$). Tukey's HSD post-hoc test showed that control sample E had significantly lower moisture and fibre and higher carbohydrate than market samples A-D, indicating superior drying and processing. Sample D showed significantly higher moisture (8.4%) and fibre (13.16%) and lower carbohydrate (75.80%), suggesting poor drying and inadequate sieving.

Concentration levels of the PTMs are presented on table 3 below.

Table 3: Concentrations of Essential Elements and PTMs in Tapioca Samples

Metals (mg/Kg)	A	B	C	D	E (Control)
Fe	3.61±0.38	4.21±0.19	3.99±0.04	3.78±0.16	4.02±0.07
Ca	11.14±0.59	11.55±0.25	12.77±0.27	10.69±0.23	11.47±0.70
K	15.86±0.37	15.24±0.31	14.48±0.48	17.67±0.58	17.93±0.46
Na	8.27±0.27	9.78±0.59	10.11±0.50	10.81±0.19	10.38±0.34
P	21.40±0.38	21.75±0.24	21.57±0.79	21.21±0.56	22.27±0.30
Pb	0.09±0.01	0.11±0.01	0.11±0.00	0.09±0.01	0.07±0.01
Hg	___	___	___	___	___
As	___	___	0.01±0.00	0.01±0.00	0.01±0.00
Ni	0.10±0.00	0.09±0.00	0.10±0.02	0.09±0.00	0.08±0.00

Iron concentrations ranged from 3.61 mg/kg to 4.21 mg/kg; while Calcium levels ranged from 10.69 mg/kg to 12.77 mg/kg. The World Health Organization does not specify a strict maximum permissible limit for iron and calcium in food at low concentrations because they nutritionally required and not classified as toxic metals under normal dietary exposure. The concentrations of Fe and Ca observed in this study fall within levels commonly reported for plant based food materials and do not indicate excessive accumulation Alamu *et al.,* 2015; Chisenga *et al.,* 2019). Furthermore, the similarity between the Fe and Ca concentrations of the control sample (4.02 and 11.47 mg/kg respectively) and the ones exposed to gas flare, suggests that gas flaring may not be a major contributing factor to increased levels of Fe or Ca in the tapioca samples.

The concentrations of Potassium (14.48 – 17.93 mg/Kg), Sodium (8.27 -10.81 mg/Kg) and Phosphorus (21.21 – 22.27 mg/Kg) in this study are consistent with the known mineral composition of cassava products (Adepoju *et al.,* 2010; Otobrise *et al.,* 2024). The World Health Organization provides dietary intake recommendations for K, Na and P, but does not establish maximum permissible contamination limits in foods, as they are not classified as toxic metals under normal dietary conditions. The K, Na and P concentrations in the samples were within nutritionally appropriate ranges and show no evidence of contamination due to gas flaring.

Lead concentrations ranged from 0.07 mg/kg to 0.11 mg/kg. The highest concentrations were observed in Samples B and C (0.11 mg/kg), while the lowest concentration was recorded in the control sample (0.07 mg/kg). Lead is a potentially toxic metal even at low concentrations. Chronic exposure to it can cause neurotoxicity, kidney dysfunction, and hematological disorders (WHO, 2021). The World Health Organization and the Codex Alimentarius Commission recommend a maximum limit of 0.10 mg/kg for lead in cereals and cereal-based foods, which serves as a reference for food safety evaluation. Samples B and C slightly exceeded the WHO/FAO maximum limit (0.11 mg/kg > 0.10 mg/kg). Samples A, D, and E had Pb levels that were below the permissible threshold. The elevated levels in Samples B and C may be attributed to environmental contamination resulting from gas flaring activities. Gas flaring in the Niger Delta releases particulate matter containing trace metals, including lead, which can deposit on agricultural soils and be absorbed by crops. Additional contributions may arise from the use of metallic processing equipment or drying surfaces contaminated with lead-containing particulates.

Mercury levels in the samples were below the detection limit. The data indicate that most of the samples contained arsenic at very low levels (0.01 mg/kg). While Samples A and B had arsenic below the detection limit; samples C – E had values well below the WHO/FAO maximum permissible limit (0.10 mg/kg), suggesting no immediate health risk from arsenic exposure through consumption of these cassava flakes.

Nickel concentrations ranged from 0.08 mg/kg to 0.10 mg/kg. It is a non-essential trace element that can pose health risks at elevated concentrations, including dermatitis, respiratory effects, and systemic toxicity upon chronic exposure. While the World Health Organization does not establish a universal maximum limit for nickel in all foods, Joint FAO/WHO Expert Committee on Food Additives (JECFA) suggest that concentrations up to 0.20–0.50 mg/kg in general foodstuffs are considered within safe limits for human consumption. Comparison of the measured concentrations with recommended reference ranges indicates that all samples are well below the upper safe limit. The slightly higher concentrations in Samples A and C relative to the control sample may reflect minor variations in soil composition or environmental deposition; however, the differences are minimal and do not suggest significant contamination from gas flaring.

The result of the one-way ANOVA and Post-Hoc HSD tests on the metals analysis data are shown on table 4.

Table 4: One-way ANOVA and Post-Hoc HSD Results

Elements	F-statistic	p-value	Decision at p<0.05	HSD
Fe	2.51	0.1080	a	-
Ca	5.86	0.0107	b	1.4880
K	22.90	<0.0001	b	1.4710
Na	11.49	0.0009	b	1.3300
P	1.33	0.3250	a	1.6320
Pb	5.18	0.0160	b	0.0310
Ni	2.03	0.1660	a	0.0277

a = no significant difference between values across a row; b = significant difference exists between values across a row

The one-way ANOVA results show that measured values of Ca, K, Na and Pb differed significantly among the five tapioca samples at the 5% significance level. Results for Fe, P and Ni showed no statistically significant difference. Post-hoc Tukey HSD test against control sample revealed that the strongest separation is for K and Na, the concentrations of the control sample for both were among the highest. For toxic metals, Pb and Ni, values are low (0.06 -0.12 mg/Kg).

However, Pb shows that sample E is significantly cleaner than B and C.

Fifty VOCs were analysed for in the five tapioca samples. Individual compounds recorded <0.002 mg/kg, as shown on table 5. No differences were apparent between the samples, including the control. The uniform absence of reported concentrations of VOCs suggests that none of the listed compounds was detected at a quantifiable concentration under the analytical conditions employed. Sample preparation and detection limits of the equipment used played a major role in the results on table 5.

Table 5: Concentrations of VOCs in tapioca samples

VOCs (mg/Kg)	A	B	C	D	E (Control)
Dichlorodifluoromethane	<0.002	<0.002	<0.002	<0.002	<0.002
Chloromethane	<0.002	<0.002	<0.002	<0.002	<0.002
Vinyl chloride	<0.002	<0.002	<0.002	<0.002	<0.002
Chloroethane	<0.002	<0.002	<0.002	<0.002	<0.002
Trichlorofluoromethane	<0.002	<0.002	<0.002	<0.002	<0.002
1,1-Dichloroethylene	<0.002	<0.002	<0.002	<0.002	<0.002
Methylene Chloride	<0.002	<0.002	<0.002	<0.002	<0.002
Trans-1,2-Dichlorothylene	<0.002	<0.002	<0.002	<0.002	<0.002
Tert-Butyl Methyl Ether	<0.002	<0.002	<0.002	<0.002	<0.002
1,1-Dichloroethane	<0.002	<0.002	<0.002	<0.002	<0.002
Diisoropropyl Ether	<0.002	<0.002	<0.002	<0.002	<0.002
2,2-Dichloropropane	<0.002	<0.002	<0.002	<0.002	<0.002
Cis-1,2-Dichloroethylene	<0.002	<0.002	<0.002	<0.002	<0.002
Chloroform	<0.002	<0.002	<0.002	<0.002	<0.002
1,1,1-Trichloroethane	<0.002	<0.002	<0.002	<0.002	<0.002
Carbon Tetrachloride	<0.002	<0.002	<0.002	<0.002	<0.002
Benzene	<0.002	<0.002	<0.002	<0.002	<0.002
1,2-Dichloropropane	<0.002	<0.002	<0.002	<0.002	<0.002
Bromodichloromethane	<0.002	<0.002	<0.002	<0.002	<0.002
Toluene	<0.002	<0.002	<0.002	<0.002	<0.002
1,2,2-Trichloroethane	<0.002	<0.002	<0.002	<0.002	<0.002
Tetrachloroethylene	<0.002	<0.002	<0.002	<0.002	<0.002
1,3-Dichloropropane	<0.002	<0.002	<0.002	<0.002	<0.002
Dibromochloromethane	<0.002	<0.002	<0.002	<0.002	<0.002
1,2-Dibromoethane	<0.002	<0.002	<0.002	<0.002	<0.002
Chlorobenzene	<0.002	<0.002	<0.002	<0.002	<0.002
Ethylbenzene	<0.002	<0.002	<0.002	<0.002	<0.002
m-Xylene	<0.002	<0.002	<0.002	<0.002	<0.002
p-Xylene	<0.002	<0.002	<0.002	<0.002	<0.002
o-Xylene	<0.002	<0.002	<0.002	<0.002	<0.002
isopropylbenzene	<0.002	<0.002	<0.002	<0.002	<0.002
Bromobenzene	<0.002	<0.002	<0.002	<0.002	<0.002
1,1,2,2-Tetrachloroethane	<0.002	<0.002	<0.002	<0.002	<0.002
n-Propylbenzene	<0.002	<0.002	<0.002	<0.002	<0.002
2-Chlorotoluene	<0.002	<0.002	<0.002	<0.002	<0.002
1,3,5-Trimethylbenzene	<0.002	<0.002	<0.002	<0.002	<0.002
4-Chlorotoluene	<0.002	<0.002	<0.002	<0.002	<0.002
tert-Butylbenzene	<0.002	<0.002	<0.002	<0.002	<0.002
1,2,4-Trimethylbenzene	<0.002	<0.002	<0.002	<0.002	<0.002
sec-Butylbenzene	<0.002	<0.002	<0.002	<0.002	<0.002
1,3-Dichlorobenzene	<0.002	<0.002	<0.002	<0.002	<0.002
p-Isopropyltoluene	<0.002	<0.002	<0.002	<0.002	<0.002
1,4-Dichlorobenzene	<0.002	<0.002	<0.002	<0.002	<0.002
n-Butylbenzene	<0.002	<0.002	<0.002	<0.002	<0.002
1,2-Dichlorobenzene	<0.002	<0.002	<0.002	<0.002	<0.002
1,2-Dibromo-3-	<0.002	<0.002	<0.002	<0.002	<0.002
1,2,4-Trichlorobenzene	<0.002	<0.002	<0.002	<0.002	<0.002
Hexachlorobutadiene	<0.002	<0.002	<0.002	<0.002	<0.002
Napthalene	<0.002	<0.002	<0.002	<0.002	<0.002
1,2,3-Trichlorobenzene	<0.002	<0.002	<0.002	<0.002	<0.002
Total VOCs	<0.002	<0.002	<0.002	<0.002	<0.002

Conclusion

The findings of this study revealed that tapioca dried under conditions associated with gas flaring exhibited detectable levels of both essential mineral elements and trace PTMs. However, the concentrations of toxic metals such as lead, arsenic, and nickel were relatively low, while mercury was not detected. This suggests that the drying conditions associated with gas flaring did not result in significant heavy metal contamination of the tapioca analyzed. Proximate analysis further revealed that the tapioca samples maintained the characteristic nutritional composition typical of cassava products. The samples contained moderate moisture levels suitable for storage, high carbohydrate content as the primary energy source, and measurable amounts of dietary fibre and mineral residues. Protein and vitamin C levels remained relatively low, which is consistent with the inherent nutritional profile of cassava and the effects of processing. The study demonstrates that while environmental conditions such as gas flaring may influence certain processing parameters, the tapioca analyzed did not show extreme levels of contamination or significant deterioration in nutritional quality. The authors acknowledge uncertainty concerning processing exposure, sampling representativeness, analytical detection limits and food-safety interpretation. Hence, further studies that will take into cognizance improved sampling, validated contaminant analysis and appropriate dietary exposure assessment, could be undertaken to amplify the findings of this research.

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