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Human Health Risk Assessment of Heavy Metals in Groundnuts (*Arachis hypogaea* L.) Sold in Selected Markets in Port Harcourt Metropolis, Rivers State, Nigeria

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Abstract: *Groundnuts are widely eaten in Nigeria, yet little is known about their heavy metal content or the health risk it may carry for consumers in the Niger Delta. We measured nickel (Ni), cobalt (Co), chromium (Cr), lead (Pb), cadmium (Cd) and arsenic (As) in fresh and roasted groundnuts (Arachis hypogaea L.) from Sangana and Mile 3 markets in Port Harcourt and in roasted homemade samples from a home garden in Rumuekini, collected between August and October 2024. Metals were determined by graphite furnace atomic absorption spectrophotometry after nitric–perchloric acid digestion. Risks to adults (60 kg) and children (15 kg) eating 30 g of groundnuts per day were estimated as estimated daily intake, hazard quotient (HQ), hazard index (HI), cancer risk (CR) and total cancer risk (TCR). Roasted groundnuts from Sangana market had the highest concentrations of As (0.435 ± 0.330 mg/kg), Pb (0.193 ± 0.193 mg/kg) and Cd (0.192 ± 0.180 mg/kg). Arsenic there was significantly higher than in every other group (Tukey–Kramer,* $p < 0.01$*), and Pb exceeded the Codex maximum level for lead in pulses (0.1 mg/kg). No adult HQ reached 1 (As in Sangana roasted: 0.72), and adult HI ranged from 0.027 to 0.857. For children, only As (HQ = 2.9) and HI (3.43) in Sangana roasted groundnuts exceeded unity. TCR fell within* 10^{-6}*–*10^{-4} *for all groups except Sangana roasted (adults* 3.8×10^{-4}*; children* 1.5×10^{-3}*) and Sangana fresh in children (*1.7×10^{-4}*). Arsenic, followed by cadmium, accounted for most of the non-carcinogenic hazard. Given the small sample and the conservative exposure scenario, the results are a screening-level signal rather than proof of harm, but they justify confirmatory sampling of roasted groundnuts at Sangana market and stronger vendor-level monitoring, especially with children in mind.*

Keywords: *groundnut; heavy metals; arsenic; hazard index; cancer risk; food safety; Port Harcourt*

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I. INTRODUCTION

Groundnuts (peanuts) are among the most widely eaten legumes, prized for their protein, oil and micronutrients, and they feature in diets across Africa, Asia and Europe. They can also carry toxic contaminants, notably heavy metals, which reach the food chain through soil, fertilizers, irrigation water, pesticides, atmospheric deposition and processing equipment [1, 2, 3, 4]. Metals such as cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg), chromium (Cr), nickel (Ni), copper (Cu) and zinc (Zn) are of particular concern because they persist in the environment, accumulate in tissues and cause harm when intake is high [5, 6].

Human health risk assessment is the standard way to judge what such contamination means for consumers. It combines hazard identification, exposure assessment, toxicity evaluation and risk characterization. Exposure is usually expressed as the estimated daily intake (EDI) or chronic daily intake, which depends on metal concentration, consumption rate and body weight [7, 8]. Non-carcinogenic risk is judged with the hazard quotient (HQ), where values below 1 are taken to indicate acceptable risk, and with the hazard index (HI), which sums the HQs of several metals [5, 9]. Carcinogenic risk is expressed as incremental lifetime cancer risk, for which values between 10^{-6} and 10^{-4} are generally regarded as the tolerable range [10, 11].

Published surveys show that contamination varies widely between places. In China, notable proportions of peanut samples exceeded limits for Cd, Cr, Ni and Cu [2, 3]. In Africa, legumes sold in Tamale, Ghana, contained As above the FAO/WHO guideline value the authors applied, although the associated cancer risk was low [1], whereas peanuts from Jigjiga, Ethiopia, carried very little of the metals measured [5]. Street-vended foods in Kenya, by contrast, contained alarming levels of Pb, which points to the part that handling and vending conditions can play [12]. Together these reports suggest that environment, agricultural practice and post-harvest handling all shape what ends up in the nut.

Hazard and cancer indices for adults are often below the usual thresholds, but vulnerable groups, particularly children, can face higher risk, and As and Cd may approach or exceed acceptable cancer-risk levels under high-intake scenarios [7, 9, 11]. Co-contaminants such as aflatoxins and plasticizers may add to the burden [13, 14], and chronic metal exposure is linked with oxidative stress, enzyme disruption and long-term illness [6].

Average consumption may therefore pose little risk in many settings while localized hotspots, often tied to how a product is processed and sold, shift exposure considerably. Region-specific assessments are particularly needed in fast-growing cities where food monitoring is patchy. Groundnuts are widely eaten and sold in several market settings in Port Harcourt, Rivers State, yet data on their metal content and the associated risk are scarce. This study therefore aimed to (i) determine the concentrations of Ni, Co, Cr, Pb, Cd and As in fresh and roasted groundnuts from two Port Harcourt markets and a home garden, (ii) compare them with available international limits, and (iii) estimate the non-carcinogenic and carcinogenic risks to adult and child consumers.

II. MATERIALS AND METHODS

A. Study area

Port Harcourt, the capital of Rivers State, lies in the Niger Delta of southern Nigeria between roughly latitudes 4°42′ and 4°57′ N and longitudes 6°53′ and 7°09′ E [15]. It is a major commercial hub that draws agricultural produce from rural communities and other parts of the country. Sangana Market (4.825° N, 7.020° E) and Mile 3 Market (4.815° N, 7.005° E) were selected because they are heavily patronized and important in the distribution of food commodities, including groundnuts. Roasted groundnuts from a home garden in Rumuekini, Obio/Akpor, were included as a reference and are referred to as homemade samples.

B. Sample collection and preparation

Groundnut samples (*Arachis hypogaea* L.), each weighing 1 kg, were bought at random from different vendors in each market every month from August to October 2024, in both fresh and roasted form. For each market and sample type, material from two sampling points was analyzed, and every sample was digested and read in triplicate, which gave six determinations per market group (n = 6). The homemade groundnuts were grown in the home garden between April and July 2024, processed (roasted) under controlled conditions and analyzed in triplicate (n = 3). All samples were placed in labeled polyethylene zip-lock bags and taken to the Biology Research Laboratory, Ignatius Ajuru University of Education, Rumuolumeni, Port Harcourt.

In the laboratory, samples were washed with tap water and rinsed with deionized water to remove adhering soil and other particles. They were air-dried for 72 h, oven-dried at 70 °C to constant weight and ground to a homogeneous powder in a mortar and pestle, which was washed and rinsed with deionized water between samples to prevent cross-contamination. Each sample type was processed separately and stored in clean, labeled containers until analysis.

C. Digestion and metal determination

Wet digestion followed the standard AOAC procedure [16]. Two grams of each powdered sample were weighed into a 100 mL digestion tube and treated with 10 mL of a freshly prepared mixture of concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a 4:1 (v/v) ratio. The tubes were heated on a hot plate in a fume hood at 80 °C for 30 min and then at 150 °C until dense white fumes appeared and the solution cleared. After cooling, the digests were filtered through Whatman No. 42 paper and made up to 50 mL with deionized water in volumetric flasks. Every sample was digested in triplicate, and reagent blanks were prepared alongside under identical conditions.

Ni, Co, Cr, Pb, Cd and As were determined by graphite furnace atomic absorption spectrophotometry (GFAAS) with element-specific hollow cathode lamps and deuterium background correction. The instrument was calibrated with standard solutions before analysis, and sample readings were corrected against the reagent blanks and converted to mg/kg dry weight.

D. Health risk assessment

Risk was assessed for adults (60 kg) and children (15 kg) using the US EPA (1989) framework. Daily groundnut intake was assumed to be 30 g for both groups, and risks were calculated from the mean concentration of each sample group. The estimated daily intake (mg kg^{-1} day^{-1}) was calculated as

$$EDI = (C \times IR) / BW$$

where C is the metal concentration (mg/kg), IR is the ingestion rate (0.03 kg/day) and BW is body weight (kg). The non-carcinogenic hazard quotient and hazard index were calculated as

$$HQ_i = EDI_i / RfD_i, \quad HI = \Sigma\, HQ_i \ (i = 1 \text{ to } n)$$

where RfD_i is the oral reference dose of metal i. Cancer risk and total cancer risk were calculated as

$$CR_i = EDI_i \times CSF_i, \quad TCR = \Sigma\, CR_i \ (i = 1 \text{ to } n)$$

where CSF_i is the cancer slope factor of metal *i*. Co was excluded from the cancer-risk calculation because no slope factor is established. Total As was treated as inorganic As, and total Cr was treated as Cr(VI) for the purpose of the slope factor, both of which are conservative assumptions. Risks were interpreted with the usual benchmarks: HQ or HI > 1 indicates potential non-carcinogenic concern; TCR < 10^{-6} is negligible, 10^{-6}–10^{-4} is the tolerable range and > 10^{-4} exceeds the upper bound [10]. Reference doses and slope factors, with their sources, are listed in Table 2.

Table 2. Oral reference doses (RfD) and cancer slope factors (CSF) used in the risk assessment.

Metal	RfD (mg kg^{-1} day^{-1})	Source of RfD	CSF (mg kg^{-1} day^{-1})$^{-1}$	Source of CSF
Ni	0.02	US EPA IRIS [17]	0.84	Literature[b]
Co	0.03	Finley et al. [18]	–	–
Cr	0.003	US EPA IRIS [17], Cr(VI)	0.5	OEHHA [19], Cr(VI)
Pb	0.0035	Literature[b]	0.0085	Literature[b]
Cd	0.001	US EPA IRIS [17], food	0.38	Literature[b]
As	0.0003	US EPA IRIS [17]	1.5	US EPA IRIS [17]

RfD = reference dose; CSF = cancer slope factor. Co was excluded from the carcinogenic risk calculation because no slope factor is established. The Cr values refer to Cr(VI) and were applied to total Cr. [b] Value widely adopted in published food and environmental risk assessments; it is not an US EPA IRIS value.

E. Statistical analysis

Means and standard deviations were calculated from the replicate determinations. Differences among the five sample groups were tested for each metal by one-way analysis of variance (ANOVA) at $\alpha = 0.05$, followed by Tukey–Kramer post hoc comparisons to allow for unequal group sizes [20]. The tests were computed from the group means, standard deviations and sample sizes in Table 1 using SciPy [21]. Risk indices were calculated in R version 4.3.2 [22] with the *dplyr* package [23]. The calculation scripts are available from the corresponding author on request.

III. RESULTS

A. Metal concentrations

Table 1 and Fig. 1 summarize the metal concentrations. Roasted groundnuts from Sangana market had the highest As (0.4349 ± 0.3295 mg/kg), Pb (0.1926 ± 0.1927 mg/kg) and Cd (0.1922 ± 0.1795 mg/kg). Their As content was about 29 times that of fresh groundnuts from the same market (0.0148 ± 0.0148 mg/kg). One-way ANOVA showed significant differences among groups for Co ($F_{4,22} = 9.20$, $p < 0.001$), Cr ($F = 5.43$, $p = 0.003$), Pb ($F = 4.45$, $p = 0.009$), Cd ($F = 4.47$, $p = 0.009$) and As ($F = 8.43$, $p < 0.001$), but not for Ni ($F = 1.46$, $p = 0.248$). Tukey–Kramer comparisons showed that As in Sangana roasted groundnuts was significantly higher than in every other group ($p < 0.01$), Pb was higher than in both Mile 3 groups ($p < 0.05$), and Cd was higher than in Sangana fresh and both Mile 3 groups ($p < 0.05$). Fresh groundnuts from Sangana market had significantly higher Co than all other groups ($p < 0.01$) and higher Cr than the Mile 3 groups ($p < 0.05$). Standard deviations in the Sangana roasted group were about as large as the means, so variation between replicates and sampling points was considerable. Pb in this group (0.1926 mg/kg) exceeded the Codex maximum level for lead in pulses (0.1 mg/kg) [24], the closest applicable category. Codex does not, to our knowledge, set a maximum level for As or Cd in groundnuts, so these metals were judged through the risk indices below. Mile 3 groundnuts and the homemade roasted samples were uniformly low (Ni ≤ 0.0173, Co ≤ 0.0015, Cr ≤ 0.0052 and Pb ≤ 0.0037 mg/kg).

Table 1. Mean ± SD concentrations of heavy metals (mg/kg dry weight) in groundnuts from markets in Port Harcourt and a home garden, Rivers State, Nigeria.

Sample group	Ni	Co	Cr	Pb	Cd	As
Sangana fresh ($n = 6$)	0.0227 ± 0.0238[a]	0.1279 ± 0.0845[a]	0.0597 ± 0.0373[a]	0.0392 ± 0.0386[ab]	0.0365 ± 0.0188[b]	0.0148 ± 0.0148[b]
Sangana roasted ($n = 6$)	0.0144 ± 0.0016[a]	0.0292 ± 0.0336[b]	0.0451 ± 0.0431[ab]	**0.1926 ± 0.1927**[a]	0.1922 ± 0.1795[a]	**0.4349 ± 0.3295**[a]
Mile 3 fresh ($n = 6$)	0.0173 ± 0.0160[a]	0.0008 ± 0.0006[b]	0.0043 ± 0.0019[b]	0.0037 ± 0.0052[b]	0.0315 ± 0.0057[b]	0.0055 ± 0.0069[b]
Mile 3 roasted ($n = 6$)	0.0093 ± 0.0060[a]	0.0013 ± 0.0018[b]	0.0052 ± 0.0010[b]	0.0017 ± 0.0017[b]	0.0136 ± 0.0086[b]	0.0146 ± 0.0034[b]

Sample group	Ni	Co	Cr	Pb	Cd	As
Homemade roasted (n = 3)	0.0012 ± 0.0004[a]	0.0015 ± 0.0003[b]	0.0027 ± 0.0006[ab]	0.0019 ± 0.0007[ab]	0.0115 ± 0.0071[ab]	0.0158 ± 0.0045[b]
Codex ML (pulses)[c]	–	–	–	0.1	–	–

Values are means ± SD of replicate determinations at two sampling points per market group (n = 6) and at the home garden (n = 3). Within a column, groups sharing a letter do not differ significantly (Tukey–Kramer, p< 0.05; a = highest). Bold values exceed the Codex maximum level for lead in pulses [24]. [c] Closest applicable Codex category; no Codex maximum level for As, Cd, Ni, Co or Cr in groundnuts was identified. – = none.

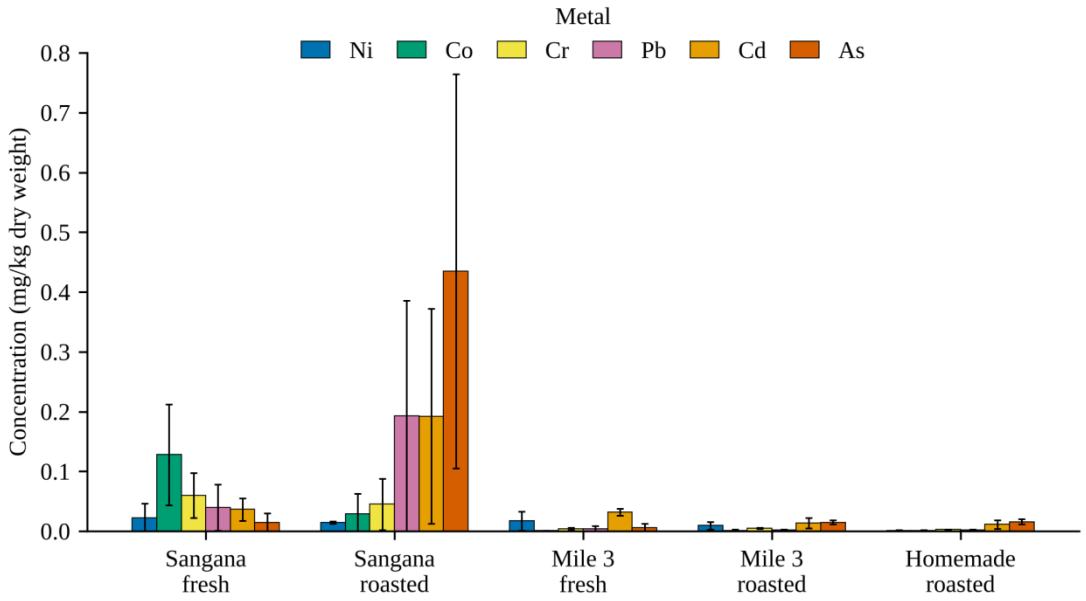


Fig. 1. Mean concentrations of heavy metals in groundnuts from Port Harcourt markets and a home garden (mg/kg dry weight). Error bars show ± SD; lower bars are truncated at zero.

B. Non-carcinogenic risk

Estimated daily intakes, hazard quotients and cancer risks for each metal are given in Table 3, and the hazard and total cancer indices for each group in Table 4. For adults, no individual HQ reached 1. The highest was As in Sangana roasted groundnuts (0.72), followed by Cd (0.096) in the same group. Adult HI ranged from 0.027 in Mile 3 fresh to 0.857 in Sangana roasted, where As supplied 85% of the total. Cd was the leading contributor in Mile 3 fresh groundnuts (59%), and As led in the roasted groups from Mile 3 and the home garden (75–80%).

Because children weigh less, the same concentrations produced hazard quotients four times higher. Only As in Sangana roasted groundnuts exceeded 1 (HQ = 2.9), giving a child HI of 3.43 (Fig. 2). Child HI in the other groups remained below 1, from 0.106 (Mile 3 fresh) to 0.245 (Sangana fresh).

Table 3. Estimated daily intake (EDI, μg kg^{-1} day^{-1}), hazard quotient (HQ) and cancer risk (CR) for each metal in groundnuts for adult (60 kg) and child (15 kg) consumers eating 30 g per day.

Metal	Adult EDI	Adult HQ	Adult CR	Child EDI	Child HQ	Child CR
Sangana fresh						
Ni	0.011	<0.001	9.5×10^{-6}	0.045	0.0023	3.8×10^{-5}
Co	0.064	0.0021	–	0.26	0.0085	–
Cr	0.030	0.0100	1.5×10^{-5}	0.12	0.040	6.0×10^{-5}
Pb	0.020	0.0056	1.7×10^{-7}	0.078	0.022	6.7×10^{-7}
Cd	0.018	0.018	6.9×10^{-6}	0.073	0.073	2.8×10^{-5}
As	0.0074	0.025	1.1×10^{-5}	0.030	0.099	4.4×10^{-5}
Sangana roasted						
Ni	0.0072	<0.001	6.0×10^{-6}	0.029	0.0014	2.4×10^{-5}
Co	0.015	<0.001	–	0.058	0.0019	–
Cr	0.023	0.0075	1.1×10^{-5}	0.090	0.030	4.5×10^{-5}

Metal	Adult EDI	Adult HQ	Adult CR	Child EDI	Child HQ	Child CR
Pb	0.096	0.028	8.2×10^{-7}	0.39	0.11	3.3×10^{-6}
Cd	0.096	0.096	3.7×10^{-5}	0.38	0.38	1.5×10^{-4}
As	0.22	0.72	3.3×10^{-4}	0.87	2.9	1.3×10^{-3}
Mile 3 fresh						
Ni	0.0086	<0.001	7.3×10^{-6}	0.035	0.0017	2.9×10^{-5}
Co	0.00040	<0.001	–	0.0016	<0.001	–
Cr	0.0021	<0.001	1.1×10^{-6}	0.0086	0.0029	4.3×10^{-6}
Pb	0.0019	<0.001	1.6×10^{-8}	0.0074	0.0021	6.3×10^{-8}
Cd	0.016	0.016	6.0×10^{-6}	0.063	0.063	2.4×10^{-5}
As	0.0027	0.0092	4.1×10^{-6}	0.011	0.037	1.6×10^{-5}
Mile 3 roasted						
Ni	0.0046	<0.001	3.9×10^{-6}	0.019	<0.001	1.6×10^{-5}
Co	0.00065	<0.001	–	0.0026	<0.001	–
Cr	0.0026	<0.001	1.3×10^{-6}	0.010	0.0035	5.2×10^{-6}
Pb	0.00085	<0.001	7.2×10^{-9}	0.0034	<0.001	2.9×10^{-8}
Cd	0.0068	0.0068	2.6×10^{-6}	0.027	0.027	1.0×10^{-5}
As	0.0073	0.024	1.1×10^{-5}	0.029	0.097	4.4×10^{-5}
Homemade roasted						
Ni	0.00060	<0.001	5.0×10^{-7}	0.0024	<0.001	2.0×10^{-6}
Co	0.00075	<0.001	–	0.0030	<0.001	–
Cr	0.0014	<0.001	6.8×10^{-7}	0.0054	0.0018	2.7×10^{-6}
Pb	0.00095	<0.001	8.1×10^{-9}	0.0038	0.0011	3.2×10^{-8}
Cd	0.0057	0.0057	2.2×10^{-6}	0.023	0.023	8.7×10^{-6}
As	0.0079	0.026	1.2×10^{-5}	0.032	0.11	4.7×10^{-5}

HQ = EDI/RfD; CR = EDI × CSF; – = no slope factor for Co. Calculations used the mean concentrations in Table 1.

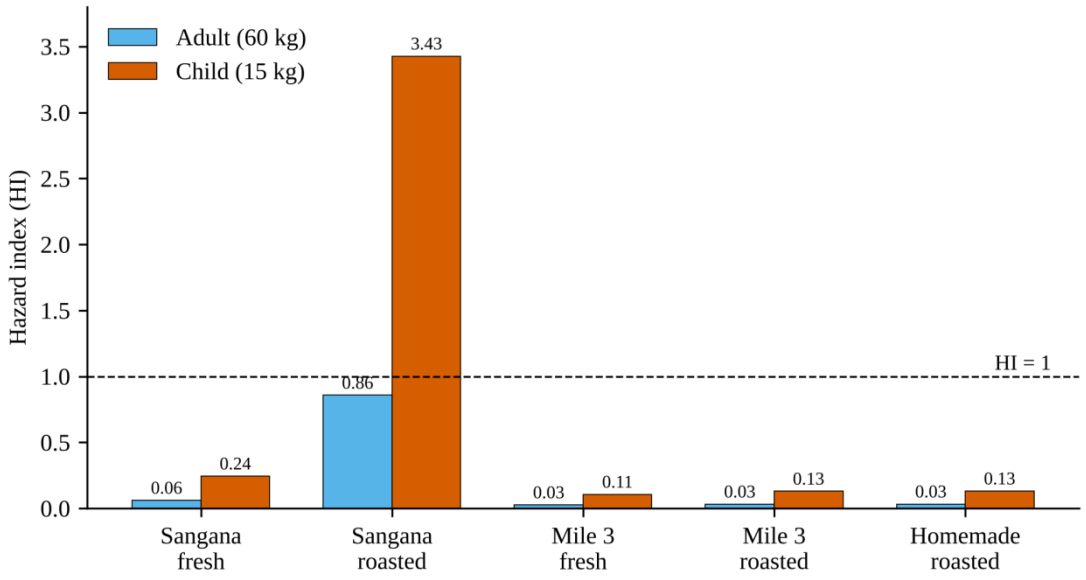


Fig. 2. Hazard index (HI) of heavy metals in groundnuts for adult (60 kg) and child (15 kg) consumers eating 30 g per day. The dashed line marks HI = 1.

C. Carcinogenic risk

For adults, TCR was within the tolerable range (1.5×10^{-5} to 4.3×10^{-5}) in all groups except Sangana roasted groundnuts, where it reached 3.8×10^{-4}, and As alone contributed 3.3×10^{-4} of this (Table 4). For children, TCR was 6.1×10^{-5} to 7.5×10^{-5} in the homemade and Mile 3 groups, 1.7×10^{-4} in Sangana fresh and

1.5×10^{-3} in Sangana roasted, so two groups exceeded the 10^{-4} upper bound. Arsenic dominated TCR in the roasted groups (59–86% in adults), but not in the fresh ones. In Sangana fresh groundnuts, Cr (35%) and Ni (22%) together outweighed As (26%), and in Mile 3 fresh groundnuts Ni (39%) and Cd (32%) did.

Table 4. Hazard index (HI), total cancer risk (TCR) and main contributors to HI for adult and child consumers of groundnuts.

Sample group	Adult HI	Child HI	Adult TCR	Child TCR	Main contributors to HI
Sangana fresh	0.0612	0.245	4.3×10^{-5}	**1.7×10^{-4}**	As (40%), Cd (30%)
Sangana roasted	0.857	**3.43**	**3.8×10^{-4}**	**1.5×10^{-3}**	As (85%), Cd (11%)
Mile 3 fresh	0.0266	0.106	1.8×10^{-5}	7.4×10^{-5}	Cd (59%), As (34%)
Mile 3 roasted	0.0325	0.130	1.9×10^{-5}	7.5×10^{-5}	As (75%), Cd (21%)
Homemade roasted	0.0329	0.131	1.5×10^{-5}	6.1×10^{-5}	As (80%), Cd (17%)

HI = sum of HQ values; TCR = sum of CR values (As, Cd, Cr, Ni, Pb). Bold values exceed 1 (HI) or 10^{-4} (TCR). Percentages are the share of each metal in the HI and are the same for adults and children.

IV. DISCUSSION

A. Contamination pattern

The picture that emerges is one of a single hotspot rather than general contamination. Groundnuts from Mile 3 Market and the home garden carried low and similar amounts of all six metals, and none was elevated. Levels of this order resemble those reported for peanuts in Ethiopia [5] and for nuts in Poland [25]. Roasted groundnuts from Sangana market stand apart.

The comparison between fresh and roasted groundnuts from the same market is informative. At Sangana, roasting was accompanied by a roughly 29-fold rise in As, a five-fold rise in Pb and a five-fold rise in Cd, whereas at Mile 3 the difference between fresh and roasted samples was small. This pattern points to the roasting and vending stage rather than the raw nuts as the likelier source of the excess, which is in line with the Kenyan finding that vending practices shape Pb contamination [12]. Plausible contributors include the roasting medium (for example, sand reused many times), fuel and ash, contaminated equipment and roadside dust, but none of these was measured here, so they remain hypotheses. Fresh groundnuts from Sangana also had the highest Co and Cr, which suggests that the supply chain or storage at that market may differ from the others. Because these are means from few samples with large standard deviations, the size of the Sangana excess is uncertain even though its direction is clear.

B. Health risk in context

Under the exposure scenario used, adult consumers faced no appreciable non-carcinogenic hazard from any group, since all HQ and HI values were below 1. The cancer-risk picture was less comfortable. Adult TCR for Sangana roasted groundnuts (3.8×10^{-4}) lay above the 10^{-4} bound, a value comparable with the 95th-percentile arsenic risk reported for walnuts in Iran (3.1×10^{-4}) [26] and with the Cd-related risk in seeds from Gansu, China, which was reported to be just above 10^{-4} [11]. Studies in Ghana, Ethiopia, Poland and China generally found HI below 1 and cancer risk within acceptable limits for nuts and legumes [1, 3, 5, 25], so a child HI of 3.43 for one product is unusual among nut studies. It is closer to values reported for other Nigerian food crops, such as those from the Ishiagu mining area, where Cd and Pb pushed hazard quotients above 1 [27].

Children were consistently more exposed. The fourfold difference between age groups is a direct result of body weight, because intake was held at 30 g per day for both. That assumption is probably generous for a 15 kg child, so the child values are best read as an upper bound. The same applies to the child CR and TCR values, which were calculated from the daily intake in the same way as the adult values and therefore do not represent a true lifetime exposure of a child. Even so, the direction of the finding agrees with earlier work showing that children can exceed hazard thresholds under high nut intake [9].

C. Limitations

Several limitations should be kept in view. The number of samples is small, concentrations were highly variable within groups, and sampling covered one season and two markets, so the results cannot be generalized to all groundnuts sold in Port Harcourt. Concentrations are expressed on a dry-weight basis, whereas limits and actual intake relate to the fresh or as-sold product, which means risk may be slightly overstated. Total As was treated as inorganic As and total Cr as Cr(VI), and oral slope factors for Cd and Ni are less firmly established than that for As, so TCR may be overestimated for the groups in which these metals contribute most; arsenic alone, however, accounted for 86% of the adult TCR in Sangana roasted groundnuts. The 30 g daily intake is an assumption rather than a measured consumption rate, and no uncertainty was propagated through the risk calculation. Codex sets no maximum level for As or Cd in groundnuts, so only Pb could be compared with a limit, and then only against the pulses category. The ANOVA and Tukey–Kramer tests assume independent

observations and similar variances; neither is fully met here, because replicates from one sampling point are not independent and variances differ markedly among groups, so the *p*-values should be read as indicative. Finally, the Co reference dose used (0.03 mg kg^{-1} day^{-1}) [18] is a hundred times higher than the US EPA provisional value (0.0003 mg kg^{-1} day^{-1}). With the provisional value, the child HI for Sangana fresh groundnuts would rise to about 1.09, although the findings for Sangana roasted groundnuts would not change.

V. CONCLUSIONS AND RECOMMENDATIONS

Groundnuts from Mile 3 Market and the home garden contained low concentrations of Ni, Co, Cr, Pb, Cd and As, and the risk they posed under the assumed exposure was within accepted bounds. Roasted groundnuts from Sangana Market were the exception: As was significantly higher than in every other group, Pb exceeded the Codex lead limit for pulses, and the resulting HI (3.43) and TCR (1.5×10^{-3}) for children, and TCR (3.8×10^{-4}) for adults, exceeded the usual thresholds. The much lower values in fresh groundnuts from the same market suggest that contamination was introduced during roasting or vending rather than inherited from the raw nuts. Arsenic was the dominant driver of non-carcinogenic risk, followed by cadmium.

These findings are a screening-level warning and call for confirmation rather than alarm. We recommend repeat sampling of roasted groundnuts at Sangana Market covering more vendors and seasons, with speciation of As and analysis of the roasting medium, fuel and equipment to identify the source. Food safety authorities should include roasted groundnuts in routine monitoring against national and Codex limits, vendors should be advised on clean roasting media and handling, and caregivers should be cautioned about frequent feeding of this product to young children until the results are confirmed.

DECLARATIONS

Ethics approval: not applicable; no human or animal subjects were involved. **Funding:** this research received no external funding. **Conflict of interest:** the authors declare no conflict of interest. **Data availability:** the data supporting the findings are available from the corresponding author on request.

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