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Research paper

Health Risk and Toxicological Assessment of Some Heavy Metals in Selected Damaged Bouillon Cubes Consumed in Nigeria A Case Study of Funtua, Katsina State

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Abstract

The safety and suitability of food additives for human consumption are largely dependent on their chemical composition.
This study assessed heavy metal contamination in damaged bouillon cubes (Maggi, Knorr, Royco, and Onga) from Funtua LGA using Microwave plasma atomic emission spectrophotometry (MP-AES), and the potential health risks associated with the consumption of these damaged cubes were also evaluated. Concentrations ranged from 2.21–4.24 mg/kg (Cd), 1.01–3.01 mg/kg (Co), 1.01–2.21 mg/kg (Ni), 2.21–6.20 mg/kg (Pb), and 0.21–0.56 mg/kg (Zn), with all except Zn exceeding FAO/WHO limits. Estimated daily intakes(EDIs) for Cd, Co, Ni, and Zn were above USEPA tolerable values, while Hazard quotientsHQs were <1. However, Hazard indices HI exceeded 1 in Maggi and Royco, and Cancer risk (CR) values for all metals were above the USEPA acceptable risk range, indicating possible carcinogenic risk. No significant variation was observed among brands ($p > 0.05$). These findings suggest potential public health hazards from the consumption of damaged bouillon cubes, warranting stricter regulation and monitoring.

Keywords: *Assessment; Bouillon Cubes; Cancer Risk; Estimated Daily Intake; Heavy Metals; Hazard Index; Hazard Quotient.*

1. Introduction

Bouillon cubes are widely used food additives designed to enhance flavor and improve food palatability [1]. In Nigeria, their popularity has grown tremendously, particularly in the context of rapid population growth and increasing demand for affordable, convenient seasonings [2]. The market is currently saturated with several brands, including Maggi Star, Knorr, Royco, and Onga. These products are typically made from dehydrated broth or a mixture of flavoring agents compressed into cube form, though similar formulations also exist in powdered form [3].

However, the issue of damaged bouillon cubes—those that are physically deteriorated, chemically adulterated, and biologically spoiled—has emerged as a potential public health concern. These cubes, often broken, crushed, fragmented, and contaminated with foreign materials, are sometimes discarded as waste products from manufacturing industries. Yet, despite their compromised quality, they still find their way into circulation, raising significant safety questions.

From a global perspective, food safety experts, toxicologists, and nutrition scientists have expressed growing concern about the contamination of widely consumed food products with toxic heavy metals [4]. Bouillon cubes, aside from their naturally high sodium content derived from salt (NaCl) and its associated risk of hypertension and cardiovascular diseases [5], can also serve as potential carriers of heavy metals. These contaminants may be introduced at multiple stages, including raw material sourcing, manufacturing, processing, packaging, or through environmental exposure to polluted air, water, or soil.

The biological implications of heavy metal contamination in food are profound. Metals such as cadmium, cobalt, nickel, lead, and zinc, though in some cases essential at trace levels, become toxic when present in excess. Their bioaccumulation in the human body targets vital organs, leading to adverse outcomes ranging from oxidative stress, organ dysfunction, and metabolic disruption to severe conditions such as cardiovascular disease, neurological impairment, kidney damage, respiratory complications, and carcinogenesis [6]. These outcomes are not only individual health concerns but also broader public health challenges, as heavy metal exposure undermines food security, consumer trust, and healthcare systems.

In sum, while damaged bouillon cubes are uniquely prevalent in Nigeria, the broader phenomenon of heavy metal contamination in low-cost, widely consumed food items is a global issue—particularly in developing regions. The elevated levels of Cd, Ni, and Pb observed in this study are in line with contamination trends noted in spices and instant noodles worldwide. The absence of published research on damaged bouillon cubes worldwide makes this research uniquely novel. Thus, these findings reinforce the global call for stringent food safety monitoring and regulation, especially in products consumed routinely by vulnerable populations.

Ensuring accurate knowledge of heavy metal concentrations in commonly consumed foods is therefore a matter of global health priority[7]. Such knowledge is crucial to balance their dual role as essential micronutrients and potential toxicants, to safeguard public health by minimizing toxic exposures while ensuring adequate nutrient intake [8]. Regular monitoring and surveillance of heavy metals in food products, including bouillon cubes, are essential strategies to mitigate the risk of chronic exposure and its long-term consequences [9]. Furthermore, public awareness and moderation in the use of such damaged cubes are necessary preventive measures to reduce cumulative health risks [10].

This research responds to an identified knowledge gap: despite widespread consumption of bouillon cubes in Nigeria, no prior studies have investigated heavy metal concentrations in damaged bouillon cubes from Funtua. By focusing on cadmium, cobalt, nickel, lead, and zinc levels in leading brands (Maggi Star, Knorr, Royco, and Onga), this study aims to provide critical data that will contribute not only to local risk assessment but also to the global discourse on food safety, toxic metals exposure, and public health protection.

2. Materials and Methods

2.1. Methodology

The chemicals of the highest purity (Analytical grade) were selected for use. Distilled water was used for solution Preparation. Analytical grade reagents and de-ionized water were used throughout the study.

All the glassware and plastic containers used were washed, cleaned, and dried in an oven at 105 °C. All weighing was carried out using an analytical weighing balance [11].

2.2. Description of the study area

The research was conducted in Funtua Local Government, Katsina State, Nigeria. Funtua local government is one of the pioneer local governments in Nigeria, created after the 1976 local governments' reforms. It is the headquarters of the Katsina South district, which consists of eleven local governments: Bakori, Dandume, Faskari, Sabuwa, Kankara, Danja, Malumfashi, Kafur, Musawa, Matazu, and Funtua. The local government covers an area of 448sqkm with population of (NPC,2006) and 570110 according to the 2016 estimate. It is located between latitude 11^{0} 32"N and 7^{0}19"E. It shared a boundary with Giwa local government of Kaduna state to the south, Bakori to the east, Danja to the southwest, Faskari to the northwest, and Dandume to the west(Fig..). The local governments have varying climates with a cool dry season(harmattan) from October to February, a hot dry season from March to May, and a warm wet season from June to September [12].

The economy of Funtua local government in Katsina State is characterized by activities that contribute to heavy metal pollution. Key contributors include agricultural practices that involve the use of fertilizers and Agrochemicals that can pollute the soil and water. Industrial processes, such as the release of untreated effluent and waste management, also play a significant role. Additionally, the release of toxic gas from vehicles along major roads is another significant contributor. These activities can lead to the release of heavy metals like Cd, Co, Ni, Pb, and Zn.

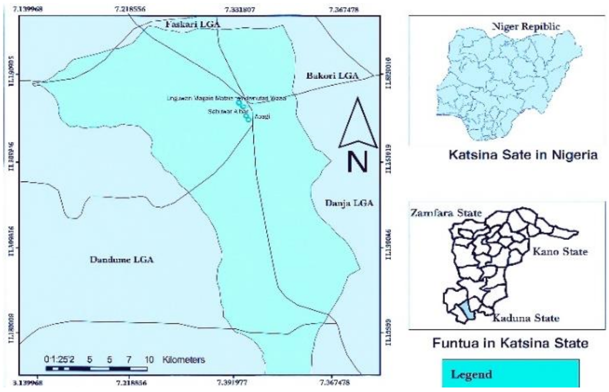

Fig. 1: Map of Katsina State Showing the Study Area (Funtua).

2.3. Sample collection

Four brands of commonly consumed damaged bouillon cubes, Maggi, Knorr cube, Royco, and Onga, were obtained from different locations (Funtua central market, Jabiri, Unguwar Makera along Sokoto Road) based on population density, storage practices, potential contamination sources, and proximity to major roads to achieve good representation in the Funtua local government area of Katsina state, Nigeria, in August 2024. They were transported to the laboratory for preparation.

2.4. Sample digestion

Four brands of damaged bouillon cubes were digested for heavy metal content using a triacid digestion method. Each sample was opened, homogenized, and dried in an oven at 60°C to constant weight. Approximately 2.0 g of the dried sample was accurately weighed into a 100 mL polytetrafluoroethylene (PTFE) digestion tube. A triacid mixture consisting of 2 mL of concentrated nitric acid (HNO_3, ≥ 69%, analytical grade), 10 mL of concentrated hydrochloric acid (HCl, 37%, analytical grade), and 2 mL of concentrated sulfuric acid (H_2SO_4, 98%, analytical grade) was added to each tube.

The digestion tubes were sealed and heated on a temperature-controlled digestion block at 135°C for 60 minutes, until the mixtures became clear and uniform. The digests were allowed to cool to room temperature (≈ 30 minutes), then filtered through Whatman No. 42 filter paper into 50 mL acid-washed volumetric flasks, and made up to volume with ultrapure deionized water [13].

2.5. Instrumentation

An Agilent Microwave Plasma–Atomic Emission Spectrometer (MP-AES) equipped with an inert nebulizer and a double-pass glass cyclonic spray chamber was employed for the determination of heavy metals in damaged bouillon cubes. The instrument operates within 4000–6000 K, at a plasma frequency of 2.45 GHz, and a power range of 100–500 W. Calibration was performed using both internal and external standards to correct for matrix effects and ensure analytical accuracy, while blank samples were analyzed for background correction. To ensure reliability, three replicate measurements of each metal were carried out. The MP-AES was selected due to its multi-element capability, high sensitivity, low operational cost, portability, and environmentally friendly characteristics.

Digested samples from four commonly consumed bouillon cube brands in Funtua were transferred into sample cups and positioned on the autosampler tray. After warming up, the solutions were introduced into the nebulizer, producing fine aerosols that entered the spray chamber before being transported to the plasma. In the plasma region, solvent evaporation, vaporization, atomization, and excitation occurred. The excited atoms emitted element-specific wavelengths upon returning to their ground state. These emissions were detected and quantified by the spectrometer, enabling determination of Cd, Co, Ni, Pb, and Zn concentrations in the samples [14].

To ensure accuracy and reliability, the analysis was conducted in triplicate with three concentration measurements taken for each metal in each sample.

Human Health Risk Assessment is used to determine the potential health risk of exposure to heavy metals. It provides vital information for decision-makers to protect their community's health [15]. Both carcinogenic risk, which refers to the possibility that consumption of damaged bouillon cubes may lead to cancer in humans, and non-carcinogenic risk, which refers to the measure of the potential of damaged bouillon cubes to cause harm to human health but not cancer, are estimated by health risk assessment [16].

To estimate the extent of human health concern from the ingestion of metals through consumption of damaged bouillon cubes, the estimated daily intake(EDI), Hazard Quotient(HQ), Hazard Index(HI), and Cancer risk were used based on adult human model toxicological variables provided by [17]

Estimated Daily Intake: is used to evaluate the oral exposure dosage for both the carcinogenic and non-carcinogenic metals during exposure. EDI of heavy metals via consumption of seasoning cubes was determined using the equation below.

$$EDI = \frac{C \times IR}{BW} \text{ [13].} \quad (1)$$

EDI Estimated daily intake, C Concentration of heavy metals in damaged bouillon cubes, BW Average body weight.

Hazard Quotient: is the ratio of the potential exposure to substances and the level at which no adverse effects are expected. It is primarily used by USEPA to assess the health risk of contaminants.

$$HQ = \frac{EDI}{RFDO} \quad (2)$$

[13]. Where EDI = Estimated daily intake, RFDO = Oral reference dose.

Hazard quotient can be determined by the formula

$$HQ = \frac{EFRXEDXFIRXC}{RFDXBWXATC} \times 10^{-3} \quad (3)$$

Where EFR Exposure frequency, ED Exposure duration, FIR=Food ingestion rate, RFD Oral reference dose, BW Body weight, ATC Average lifetime for cancer.

10^{-3} = Conversion factor.

Hazard Quotient less than or equal to 1 indicates that adverse effects are not likely to occur and thus can be considered to have negligible hazard. HQ greater than 1 indicates that adverse health effects are likely to occur.

Hazard Index is the potential human health risk through exposure to multiple heavy metals. It is the summation of the zard quotient of each metal.

$$HI = HQ_1 + HQ_2 + HQ_3 + \ldots\ldots\ldots\ldots\ldots\ldots HQ_n \quad (4)$$

Where n=1,2,3,4……n for each metal.

Cancer Risk Index due to exposure to heavy metals through ingestion of cooking seasoning cubes was determined using equation(5) below.

$$CR = \frac{EDI \times CSF}{BW} \quad (5)$$

Where EDI is the estimated daily intake, CSF is the ingestion cancer slope factor.

The following toxicological variables, based human adult model of the United States Environmental Protection Agency, were adopted in this research. Lifetime for cancer=54years, exposure duration (ED) = 54years, Adult body weight (BW)= An adult body weight of 65 kg is the standard reference value, consistent with the results reported by [18] in Lagos, Nigeria. exposure frequency=365 days, Average lifetime for cancer(ATn)=54×365, Average intake of bouillon cube=0.01kg. Acceptable cancer risk=1.0×10^{-6} to 1.0×10^{-4}, Cd cancer slope factor=6.3, Pb=0.0085, Ni=0.91. Rfd for the metals under study Cd(0.001), Pb(0.004), Zn(0.3), Ni(0.02) and Co(0.004)[19]

In the absence of nationally representative dietary intake data for damaged bouillon cube consumption in Nigeria, a value of 10g/day was adopted based on typical estimated usage frequency in local households, through interviews with consumers.

2.6. Statistical analysis

The mean concentrations of the heavy metals in some brands of damaged bouillon cubes were analyzed statistically using IBM SPSS 23.0. Analysis of variance (ANOVA) conducted on the heavy metals ' concentrations in the damaged bouillon cubes investigated did not reveal any significant differences, as P-values were greater than 0.05, implying that the results are not statistically significant.

Table 1: Results of Statistical Analysis (ANOVA).

Groups	Count	Sum	Average	Variance		
Maggi	4	11.53	2.8825	3.273025		
Knorr Cube	4	8.66	2.165	1.843366667		
Royco	4	10.43	2.6075	6.056025		
Onga	4	7.14	1.785	0.4099		
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.81165	3	0.937216667	0.323671574	0.808248074	3.490294821
Within Groups	34.74695	12	2.895579167			
Total	37.5586	15				

SS=sum of squares, df= degree of freedom, F= Fisher statistic, Fcrit=Fisher Critical value, P-Value= probability value.

3. Results

Table 2: The Mean Concentrations of Some Heavy Metals(Mg/Kg) in the Analyzed Damaged Bouillon Cubes Obtained from Funtua Local Government Area with Their Standard Deviations

Metals	Cd	Co	Ni	Pb	Zn
Maggi Star	2.21±0.01	3.01±0.01	1.01±0.01	5.3±0.01	0.56±0.01
Knorr Cube	2.32±0.01	1.01±0.01	1.31±0.01	4.02±0.01	0.41±0.01
Royco	4.24±0.01	1.01±0.01	2.21±0.01	6.2±0.01	0.51±0.01
Onga	3.61±0.01	2.4±0.01	1.52±0.01	2.21±0.01	0.21±0.01

Table 3: Estimated Daily Intakes of Some Heavy Metals in the Analyzed Damaged Bouillon Cubes Obtained from Funtua

Metals	Cd	Co	Ni	Pb	Zn
Maggi Star	0.34	0.463	0.16	0.82	0.09
Knorr Cube	0.36	0.16	0.21	0.62	0.063
Royco	0.652	0.16	0.34	0.93	0.08
Onga	0.56	0.37	0.23	0.34	0.094
Rfd	0.001	0.004	0.02	0.004	0.3

Table 4: The Values of Hazard Quotients and Hazard Indices of Some Heavy Metals in Analyzed Damaged Bouillon Cubes from Funtua

Metals	Cd	Co	Ni	Pb	Zn	HI
Maggi Star	0.3	0.47	0.0078	0.20	0.29	1.31
Knorr Cube	0.36	0.16	0.01	0.155	0.0021	0.69
Royco	0.65	0.16	0.017	0.24	0.0026	1.07
Onga	0.56	0.12	0.012	0.085	0.00011	0.78

Table 5: The Numerical Values of Carcinogenic Risks of Some Heavy Metals in the Analyzed Damaged Bouillon Cubes Obtained from Funtua

Metals	Cd	Co	Ni	Pb	Zn
Maggi Star	$3.3X10^{-2}$	NA	$2.32X10^{-3}$	$1.11X10^{-3}$	NA
Knorr Cube	$3.5X10^{-2}$	NA	$2.94X10^{-3}$	$8.1078X10^{-3}$	NA
Royco	$6.32X10^{-2}$	NA	$4.76X10^{-3}$	$1.216X10^{-4}$	NA
Onga	$5.43X10^{-2}$	NA	$3.22X10^{-3}$	$4.45X10^{-5}$	NA

NA= Not Available.

4. Discussion

4.1. Cadmium (Cd)

As shown in Table 2, cadmium concentrations in the damaged bouillon cubes ranged from 2.21 ± 0.01 to 4.24 ± 0.01 mg/kg, with the highest value in Onga and the lowest in Maggi. According to the ANOVA results (Table 1), these variations were not statistically significant. However, all measured levels exceeded the permissible limit of 0.3 mg/kg set by [20], indicating potential health concerns.

Elevated cadmium levels may result from the use of Cd-containing equipment, leaching from packaging, or atmospheric deposition during poor storage conditions [21]. Cadmium is classified as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC) and is known to bioaccumulate in the liver, kidneys, bones, and placenta, causing oxidative stress, mitochondrial dysfunction, and epigenetic DNA changes [22]. These findings aligned with those of [8], who reported 4.24 ± 0.38 mg/kg Cd in intact bouillon cubes from Aba, and [23], who found 3.63 ± 0.03 mg/kg in undamaged samples from Nasarawa.

4.2. Cobalt (Co)

Cobalt concentrations were 3.01 ± 0.01 mg/kg in Maggi, 2.40 ± 0.01 mg/kg in Onga, and 1.01 ± 0.01 mg/kg in both Knorr and Royco(Table 2). ANOVA results in Table 1) showed no significant differences among the brands. All values were below the permissible limit of 3.5 mg/kg [20], indicating minimal risk under current exposure levels. However, chronic intake near the threshold may result in cumulative toxicity.

Contamination sources may include environmental deposition or contact with cobalt-based materials during storage [2]. Compared to [24], who reported 0.001 ± 0.001 mg/kg Co in intact Maggi Star cubes from Lagos, levels in this study were substantially higher. Although cobalt is essential for hematopoiesis, DNA synthesis, and energy metabolism, excessive exposure is associated with neurotoxicity, cardiovascular disease, thyroid dysfunction, and hematological abnormalities [25].

4.3. Nickel (Ni)

Nickel concentrations followed the trend: Royco (2.21 ± 0.01 mg/kg) > Onga (1.52 ± 0.01) > Knorr (1.31 ± 0.01) > Maggi (1.01 ± 0.01). ANOVA results (Table 1) indicated no significant variation among the brands. All values exceeded the 0.1 mg/kg permissible limit [20], and therefore might pose potential health risks.

Contamination may originate from nickel-based processing equipment, leaching from storage containers, or environmental dust [15]. Nickel disrupts enzyme activities by displacing essential metals, leading to biochemical dysfunction. Long-term exposure is associated with kidney failure, cardiovascular disease, hemorrhage, and cancer [26]. Although the levels found here were lower than the 4.03 ± 0.3 mg/kg reported by [15] in Delta State, the elevated Ni in damaged cubes may have resulted from dust, moisture, or compromised packaging, pointing to post-production contamination as a key factor.

4.4. Lead (Pb)

Lead concentrations ranged from 2.2 ± 0.01 mg/kg (Onga) to 6.2 ± 0.01 mg/kg (Royco). Maggi and Royco exceeded the 5.0 mg/kg limit [20], while Knorr and Onga remained within safe levels. ANOVA (Table 1) showed no statistically significant difference among brands.

Elevated Pb levels could be due to lead-based processing tools, leaching from packaging, or atmospheric contamination [27]. Lead is one of the most toxic heavy metals, linked to neurological disorders, infertility, kidney cancer, cardiovascular disease, and joint pain [28]. This study is not in agreement with [29], who reported Pb levels below detection limits in Nigerian bouillon cubes.

4.5. Zinc (Zn)

Zinc levels in all the samples were below the 5 mg/kg permissible limit of [20], indicating minimal contamination risk. The low levels may be due to naturally low zinc content of raw materials, coupled with the use of zinc-free packaging materials that minimize leaching [31]. Table 1 ANOVA results indicated that there was no significant variation in zinc concentrations among the analyzed damaged bouillon cubes.

Zinc is essential for immune function and enzymatic processes, but excessive intake causes gastrointestinal distress, kidney and liver failure[31], and impaired absorption of other trace elements such as copper and iron [32]. The findings were consistent with [1], who reported 0.53 mg/kg Zn in fresh bouillon cubes from Southern Nigeria, and [24], who reported 0.643 ± 0.082 mg/kg in Maggi Star from Lagos State.

Due to the lack of global studies on damaged bouillon cubes, this research provides novel insights into the contamination risks associated with damaged packaging.

4.6. Health risk assessment

The Estimated Daily Intake (EDI) is a key index for assessing potential health risks from dietary exposure to heavy metals [17]. In this study, the EDI values for all analyzed metals except Zn exceeded their respective oral reference doses (Table 3), suggesting possible long-term health implications.

To further evaluate non-carcinogenic effects, Hazard Quotient (HQ) and Hazard Index (HI) were applied. HQ assesses the risk from a single element, while HI reflects cumulative exposure. According to international guidelines, HQ < 1 implies no appreciable risk, whereas HI > 1 indicates potential for adverse health outcomes [17].

The HQ values for all metals were below 1 (Table 4), suggesting limited immediate health risks such as respiratory, reproductive, or neurological impairment. However, HI values varied across brands. Knorr and Onga had HI values below 1, indicating negligible cumulative risk. In contrast, Maggi and Royco exceeded the threshold, implying that chronic consumption may increase the risk of carcinogenic and systemic effects, including neurotoxicity, cardiovascular disorders, renal impairment, and reproductive dysfunction [33].

4.7. Cancer Risk Assessment(CR)

The Cancer Risk (CR) index estimates the probability of developing cancer from long-term exposure to carcinogenic substances. According to international guidelines, CR values below 1.0×10^{-6} are considered negligible, while values above 1.0×10^{-4} indicate a significant risk to human health [17].

As shown in Table 5, the CR values for cadmium (Cd), nickel (Ni), and lead (Pb) in the damaged bouillon cubes exceeded the acceptable range (1.0×10^{-6} to 1.0×10^{-4}), suggesting that regular consumption could considerably elevate lifetime cancer risk. This is consistent with the known carcinogenicity of these metals: Cd is classified by IARC as a Group 1 human carcinogen, linked to lung, prostate, and kidney cancers [34]; Ni exposure has been associated with lung, nasal, and kidney cancers [35]; and Pb is a probable carcinogen and neurotoxin, implicated in brain, kidney, and lung cancer [33].

These findings highlight the potential public health risk posed by long-term exposure to heavy metals through the consumption of contaminated bouillon cubes.

5. Conclusion

The study assessed Cd, Co, Ni, Pb, and Zn levels in damaged bouillon cubes consumed in Funtua. Cd, Ni, and Pb exceeded FAO/WHO limits, while Co and Zn remained within safe ranges. Estimated daily intake (EDI) values indicated that, except Zn, all metals surpassed their oral reference doses, posing potential exposure risks. Although individual hazard quotients (HQ) were below 1, suggesting limited immediate effects, hazard index (HI) values varied by brand: Knorr and Onga were within safe limits, whereas Maggi Star and Royco exceeded 1, indicating possible non-carcinogenic risks. Cancer risk (CR) values for Cd, Ni, and Pb were above the USEPA's acceptable range, pointing to potential long-term carcinogenic concerns. These damaged bouillon cubes were unsafe for consumption. These results

underscore the public health risks of consuming damaged bouillon cubes and emphasize the need for stricter monitoring, regulatory action, and consumer awareness.
As such, the following were recommended:
Strict compliance with the permissible limits of heavy metals in food, as set by SON, NAFDAC, Codex Alimentarius, FAO/WHO, and USEPA, should be enforced.
National food safety standards should be reviewed and updated to specifically cover the monitoring of damaged or expired bouillon cubes.
Routine inspection of bouillon cubes in open markets, retail shops, and storage facilities should be carried out.
Random laboratory testing of bouillon cubes for heavy metals such as cadmium, lead, and arsenic should be conducted.
The sale of damaged, expired, or improperly stored bouillon cubes should be prohibited.
Clear labeling requirements, indicating safe storage conditions and shelf life, should be made mandatory.
Public awareness campaigns should be launched to educate consumers on the health risks associated with the consumption of damaged bouillon cubes.
Training on proper storage and handling should be provided to food vendors and retailers.
Further research should be supported to investigate the pathways of heavy metal contamination in bouillon cubes (manufacturing, packaging, transportation, or storage).
Other toxic elements, such as mercury and arsenic, which were not covered in this research, should be investigated.
Stronger enforcement powers should be given to NAFDAC and SON to penalize manufacturers, distributors, and retailers involved in the circulation of substandard or damaged bouillon cubes.

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Conflict of Interest

The Authors have declared that no conflict of interest exists.

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