



Asian Journal of Scientific Research

ISSN 1992-1454

science
alert
<http://www.scialert.net>

ANSI*net*
an open access publisher
<http://ansinet.com>



Research Article

Health Risk Assessment and Corporate Crisis Communication Implications: Heavy Metals, Anti-Nutrients and Chemical Composition of Energy Drinks Sold in Port Harcourt, Nigeria

¹Tamuno-Boma Grace Odinga-Israel, ²Harcourt-Whyte Dike, ¹Conquest Chivusalem Nodi, ³Sarah Kelechi Enebeli, ¹Prince Aruchi Chikordi Amechi, ¹Miebaka Samuel George, ²Victory Tamunotein Odinga and ¹Darlington N. Agbani

¹Department of Biochemistry, Faculty of Science, Port Harcourt, Rivers State University, River State, Nigeria

²Department of Communication and Development Studies, Faculty of Mass Communication, Rivers State University, River State, Nigeria

³Department of Pharmacology and Therapeutics, Faculty of Basic Clinical Sciences, College of Medical Sciences, Port Harcourt, Rivers State University, River State, Nigeria

Abstract

Background and Objective: Energy drinks are widely consumed for their stimulatory effects on alertness and physical performance, particularly among young adults. However, increasing concerns have emerged regarding their chemical safety, including the presence of heavy metals and anti-nutritional compounds that may pose potential health risks. This research assessed anti-nutrient, nutrient, chemical and heavy metals concentration in selected energy drinks available in Nigeria while examining the corporate crisis communication implications of regulatory compliance failures.

Materials and Methods: The samples were obtained from malls and labelled A-F. They were analysed using standard laboratory procedures for Phytates, Oxalates, Tannins, Total Available Carbohydrate, Caffeine, pH and Total Titratable Acidity. The Atomic Absorption Spectrophotometer was used for heavy metals analysis. Data was analyzed via one-way ANOVA and Tukey's HSD *post hoc* test ($p < 0.05$) using IBM SPSS Version 27. **Results:** The phytate content of all drinks exceeded WHO limits, creating immediate regulatory disclosure obligations for manufacturers. The tannin and oxalate concentrations were significantly different in all samples ($p \leq 0.05$) and within the WHO permissible limit. The energy drinks were all within the WHO permissible limits for Sugar, TAC, Caffeine and pH, except for Sample C which exceeded the WHO limit in TTA. Sample D had the maximum Caffeine level but lowest in Sugar. All samples had Copper below $0.001 \mu\text{g/L}$, sample F had the highest concentration in lead. All samples had their lead concentrations below the WHO permissible range of $10 \mu\text{g/L}$. Manganese concentrations varied from <0.001 to $17.612 \mu\text{g/L}$, Cadmium was <0.001 in all samples analysed. The human health risk assessment EDI, THQ and TTHQ revealed that the drinks were below the reference dose indicating low health risk and were below the threshold level of concern for carcinogenic health effects. However, the phytate violations in samples and elevated lead levels in specific brands present corporate communication challenges requiring immediate transparent disclosure strategies, proactive consumer education and regulatory compliance communication. Nutritional education on reduction of intake of these commonly consumed energy drinks is of necessity among teenagers and young adults, requiring strategic public health communication approaches. **Conclusion:** The findings underscore the critical importance of corporate transparency in food safety communication and the need for manufacturers to develop robust crisis communication frameworks before regulatory violations become public knowledge.

Key words: Health risk assessment, heavy metals, energy drinks, crisis communication, corporate communication, food safety communication, regulatory compliance

Citation: Odinga-Israel, T.G., H.W. Dike, C.C. Nodi, S.K. Enebeli and P.A.C. Amechi *et al.*, 2026. Health risk assessment and corporate crisis communication implications: Heavy metals, anti-nutrients and chemical composition of energy drinks sold in Port Harcourt, Nigeria. Asian J. Sci. Res., 19: 21-30.

Corresponding Author: Tamuno-Boma Grace Odinga-Israel, Department of Biochemistry, Faculty of Science, Port Harcourt, Rivers State University, Nigeria

Copyright: © 2026 Tamuno-Boma Grace Odinga-Israel *et al.* This is an open access article distributed under the terms of the creative commons attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Energy drinks are functional beverages characterized by high caffeine content and the inclusion of other bioactive ingredients such as taurine, guarana and B vitamins¹. They are widely marketed for their ability to enhance energy, alertness and physical or cognitive performance, leading to increased consumption among students, athletes and shift workers. However, growing evidence suggests that excessive intake may be associated with adverse physiological effects, including insomnia, anxiety and cardiovascular disturbances¹. Over time, the target consumer base has shifted from athletes to adolescents and young adults, reflecting increased global market penetration².

Beyond their stimulant effects, energy drinks may contain bioactive compounds with nutritional and anti-nutritional properties, such as phytates, which are phosphorus storage compounds in plant-based ingredients that possess antioxidant properties but can also reduce the bioavailability of essential minerals including calcium, magnesium, iron, copper and zinc by forming insoluble complexes with them³. While moderate intake of phytate has been associated with beneficial effects, including improved glycemic control and lipid modulation⁴, excessive exposure may impair mineral absorption.

Similarly, oxalates occur naturally in plant-derived materials and may also be produced endogenously in humans. Dietary oxalate contributes only a fraction of total systemic oxalate, yet high intake has been associated with kidney stone formation and other renal complications in susceptible individuals⁵. Tannins, another class of plant-derived polyphenols, contribute to the sensory characteristics of beverages and may influence taste and mouthfeel⁶. Although tannins exhibit antioxidant properties, they are also classified as anti-nutrients due to their ability to bind dietary proteins and minerals, potentially reducing nutrient availability during prolonged consumption.

In addition to anti-nutritional factors, sugar and carbohydrate content remain key nutritional concerns in energy drinks. Total Available Carbohydrate (TAC) represents digestible carbohydrates that contribute to metabolic energy⁷. While moderate sugar intake may support immediate energy supply and cognitive function, excessive consumption has been linked to non-communicable diseases such as obesity, type 2 diabetes, cardiovascular disease and dental caries. Consequently, the World Health Organization recommends limiting free sugar intake to less than 10 percent of total daily energy intake⁷.

Caffeine, a methylxanthine central nervous system stimulant, remains the most widely studied active component in energy drinks. It occurs naturally in coffee beans, tea leaves, cocoa and kola nuts and is widely consumed in beverages and pharmaceutical formulations⁸. Caffeine intake has been associated with increased alertness and improved cognitive performance; however, excessive consumption may result in anxiety, insomnia, irritability, gastrointestinal disturbances and dependence symptoms⁹. These effects highlight the importance of monitoring caffeine levels in commercially available beverages⁸.

The physicochemical properties of energy drinks, particularly pH and total titratable acidity (TTA), also contribute to health concerns. Energy drinks are typically acidic, with reported pH values ranging from 1.5 to 3.3. Such acidity levels have been associated with dental erosion and enamel demineralization upon prolonged exposure¹⁰. TTA is considered a more reliable indicator of total acid content and reflects the erosive potential of beverages on dental hard tissues¹¹.

Heavy metals represent another critical safety concern in beverage consumption due to their toxicity and persistence in biological systems. Environmental contamination from industrial and anthropogenic activities has increased the presence of toxic metals in food and drink products globally¹². Lead exposure is particularly concerning due to its neurotoxic effects and its ability to impair cognitive and biological functions, even at low concentrations¹². Cadmium exposure has been associated with environmental pollution sources such as fossil fuel combustion and waste incineration and is known to accumulate in the body over time¹³. Copper is an essential trace element involved in hematopoiesis and enzymatic activity, but excessive intake may lead to toxicity. Manganese, although essential for metabolic function, may induce neurotoxicity at elevated exposure levels, potentially leading to manganism-like neurological disorders¹⁴.

The increasing consumption of energy drinks among adolescents and young adults has raised concerns regarding cumulative exposure to caffeine, sugars, anti-nutrients and heavy metals, particularly when intake exceeds recommended dietary limits. These concerns underscore the need for comprehensive chemical profiling and health risk assessment of commercially available energy drinks.

From a broader perspective, food safety issues related to beverage contamination also raise corporate and regulatory communication challenges. Food safety crises require timely and transparent communication to protect consumers and maintain public trust¹⁵. Studies suggest that delayed

disclosure can intensify reputational damage, whereas proactive communication improves public trust and crisis outcomes¹⁶. However, effective communication must balance technical accuracy with public comprehension to avoid unnecessary panic¹⁷.

Heavy metal contamination incidents in food systems further highlight the importance of structured crisis communication strategies. Effective responses require transparency in reporting contamination levels, exposure risks and remediation actions¹⁸. Stakeholders, including consumers, healthcare providers and regulatory bodies require tailored communication approaches based on their information needs¹⁹. In addition, modern digital communication systems, particularly social media platforms, have amplified both the speed and complexity of risk communication during food safety crises²⁰.

Despite increasing research on individual components such as caffeine, sugar, or heavy metals in energy drinks, there remains a lack of integrated studies assessing the combined presence of anti-nutrients, chemical composition and heavy metal contamination alongside human health risk evaluation in energy drinks sold in Port Harcourt, Rivers State, Nigeria. This represents a critical knowledge gap in understanding the cumulative exposure risks associated with these beverages in the local population.

Therefore, this study aims to evaluate the anti-nutrient composition, nutrient profile, chemical characteristics, heavy metal concentrations and associated human health risk indices of selected energy drinks sold in Port Harcourt, Rivers State, Nigeria. The findings will contribute to food safety surveillance, public health awareness and provide evidence relevant to both regulatory monitoring and corporate risk communication strategies.

MATERIALS AND METHODS

Study area and duration: This study was carried out at the Department of Biochemistry laboratory, Faculty of Science, Department of Food Science, Faculty of Agricultural Sciences, Rivers State University, Nigeria and Endpoint Laboratories, Port Harcourt, Nigeria.

The study was carried out from April 2023 to October, 2023.

Collection and preparation of sample: Samples of energy drinks (6) used for this study were purchased from a shopping mall in Port Harcourt, Rivers State. The Energy drink samples were labelled: A (Black Bullet), B (Blue Bullet), C (Monster), D (Fearless), E (Predator), F (Super Komando).

The samples were opened and transferred into various clean bottles and were labeled respectively for sampling.

Analysis of samples: The samples were subjected to laboratory analysis for the determination of its Anti-nutrient, Nutrient and Chemical Composition using Standard AOAC laboratory procedures. Heavy metal content in the sample drinks were evaluated using AAS after the preliminary Digestion procedures as described by Ihuoma *et al.*¹².

Determination of tannin (Folin-Denis spectrophotometric method): A measured weight of each sample (1.0 g) was dispersed in 10 mL distilled water and agitated. This was allowed to stand for 30 min at room temperature while continuously stirring every 5 min. At the end of 30 min, it was centrifuged and the extract obtained. 2.5 mL of the extract was dispersed into a 50 mL volumetric flask. Similarly, 2.5 mL of standard tannic acid was dispersed into a separate 50ml flask. A 1.0 mL Folin-Denis reagent was measured into each flask followed by the addition of 2.5 mL of saturated Na₂CO₃ solution. The mixture was diluted and made up to the 50 mL mark of the flask and was incubated for 90 min at room temperature. The absorbance was measured at 250 nm in a UV spectrophotometer; readings were taken with the blank sample at zero, following established spectrophotometric procedures for tannin and phenolic compound determination^{21,22}.

$$\text{Tannin (\%)} = \frac{A_n}{A_s} \times \frac{C \times 100}{W} \times \frac{V_f}{V_A}$$

where:

A_n = Absorbance of the test sample

A_s = Absorbance of standard solution

C = Concentration of standard solution

W = Weight of sample used

V_f = Total volume of extract

V_A = Volume of extract analyzed

Oxalate determination: This determination involved three major steps: Digestion, oxalate precipitation and permanganate titration according to standardized analytical procedures for oxalate quantification in food matrices and biological samples²³.

Digestion: Two g of the sample was suspended in 190 mL of distilled water in a 250 mL volumetric flask. 10 mL of 6M HCl was added and the suspension digested at 100°C for 1 hr. The solution was cooled and then made up to 250 mL mark before filtration.

Oxalate precipitation: Duplicate portions of the filtrate were measured into breakers and four drops of methyl red indicator added. Then NH_4OH solution was added (drop wise) until the test solution changed from pink to faint yellow colour (pH 4.0-4.5). Each portion was then heated to 90°C , cooled and then filtered to remove the precipitate containing ferrous ion. The filtrate was again heated to 90°C and 10 mL of 5% CaCl_2 solution was added while being stirred constantly. The solution was then heated and left overnight at 25°C , it was then centrifuged at 2000 rpm for 5 min. The supernatant was decanted and the precipitate completely dissolved in 20ml of 25% (v/v) H_2SO_4 solution.

Permanganate titration: At this point, the total filtrate resulting from the digestion of 2 g of sample was made up to a volume of 300 mL. Aliquots of 125 mL of the filtrate were heated until near boiling and then titrated against 0.02 M standardized KMnO_4 solution to a faint pink color which persisted for 30 sec²³. The calcium oxalate content was calculated using the formula:

$$\text{Calcium oxalate (mg/100 g)} = \frac{T \times V_{\text{me}} \times Df}{M_e \times M_f}$$

where, T is the titre of KMnO_4 (mL), V_{me} is the volume-mass equivalent, Df is the Dilution factor = $\frac{V_t}{A}$, Where V_t is the total volume of filtrate (300 mL), A is the aliquot used i.e., 125 mL, M_e is the molar equivalent of KMnO_4 in oxalate, M_f is the mass of sample used.

Phytate determination: Phytate content was determined using ferric chloride titration procedures consistent with modern analytical methods for phytic acid quantification²⁴.

Five mL of the sample was mixed, cured for 5 hrs and filtered. Aliquots of 2500 mL of the filtrate in a conical flask were added to 5.00 mL of 0.30% ammonium thiocyanate, the mixture was titrated with standard iron (III) chloride solution to a persistent brownish-yellow coloration that persisted for 4 min. The amount of phytates was calculated with the equation below:

$$\text{Phytic acid} = \text{Titre value} \times 0.00195 \times 1.9 \times \frac{100}{2}$$

Human health risk assessment: Human health risk assessment indices, including Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Total Target Hazard Quotient (TTHQ) and Cancer Risk (CR) were evaluated

according to recent USEPA-based heavy metal risk assessment models widely applied in environmental toxicology studies²⁵.

Estimated daily intake (EDI): The Estimated Daily Intake (EDI) of selected heavy metals was estimated for various energy drinks to assess the estimated health risk associated with consuming heavy metal contaminants.

$$\text{EDI} = \frac{C_{\text{metal}} \times \text{IR}}{\text{BW}}$$

where, C_{metal} implies the concentration of the metals in mg/kg, IR or ingestion rate expressed in gram per day per person and BW is average body weight of the household members in kg.

Using: C_{metal} (concentration of the metals); the values in table were converted from ($\mu\text{g/L}$) to (mg/L) Average daily consumption of energy drinks (Ingestion rate) = 500 g/day per person (or 0.5 L/day)²⁶. BW (Average Body weight for adult) = 70 kg²⁷.

Total hazard quotient (THQ) and total target hazard quotient (TTHQ): Total Hazard Quotient (THQ) was used to assess the non-carcinogenic risks associated with long-term heavy metal exposure.

$$\text{THQ} = \frac{\text{EDI}}{\text{RfD}}$$

where, RfD represents the oral reference dose for each heavy metal.

The total target hazard quotient (TTHQ) was calculated as²⁵:

$$\text{TTHQ} = \text{THQ (Cu)} + \text{THQ (Pb)} + \text{THQ (Cd)} + \text{THQ (Mn)}$$

Cancers risk: Cancer risk estimation for Pb and Cd exposure was evaluated using the carcinogenic slope factor model recommended in recent USEPA health risk assessment studies²⁵.

$$\text{Cancer risk} = \text{EDI} \times \text{CSF}$$

where, CSF (Cancer Slope Factor) is presented in mg/kg/day as 0.0085 (mg/kg/day) for Pb and 0.38 (mg/kg/day) for Cd recommended by USEPA. The US Environmental Protection Agency recognizes a cancer risk in the range of 1×10^{-6} to 1×10^{-4} as appropriate for risk management purposes.

Statistical analysis: Multivariate statistical analysis was carried out by descriptive statistical analysis using SPSS software (IBM, Chicago, USA), Version 27. One-way Analysis of Variance (ANOVA) followed by Tukey's HSD *post hoc* test was used to determine significant differences among parameters at $p < 0.05$ according to standard biostatistical procedures commonly employed in environmental and toxicological studies.

RESULTS AND DISCUSSION

Table 1 presents the anti-nutrient composition of the evaluated energy drinks. Phytate concentrations ranged from 6.423 ± 0.006 to 12.763 ± 0.060 g/kg, with Sample E recording the highest value while Sample D showed the lowest concentration. All samples exceeded the WHO permissible limit of 2.5 g/kg for phytate. Oxalate concentrations ranged from 0.043 ± 0.006 to 0.163 ± 0.029 mg/100 g, with Sample F exhibiting the highest level. Tannin concentrations varied significantly among the samples, ranging from 11.880 ± 0.118 to 24.390 ± 0.104 mg/kg. However, all tannin and oxalate concentrations remained below the WHO permissible limits. Significant differences ($p \leq 0.05$) were observed among the samples for the evaluated anti-nutritional parameters.

Table 2 highlights the nutrient composition of the energy drink samples evaluated in this study. Sugar concentrations ranged from 9.867 ± 0.115 to 17.166 ± 0.058 g/mL, with Sample A recording the highest sugar content while Sample D had the lowest value. Total available carbohydrate (TAC) values ranged between 5.470 ± 0.020 and $8.373 \pm 0.015\%$ glucose equivalent, with Sample E exhibiting the highest TAC value. All evaluated samples were below the WHO recommended limits for sugar and TAC. Significant variations ($p \leq 0.05$) were observed among the different energy drink samples.

Table 3 presents the chemical composition of the analysed energy drinks. Caffeine concentrations varied considerably across the samples, ranging from 6.570 ± 0.185 to 40.150 ± 0.030 mg/L, with Sample D showing the highest concentration while Sample C recorded the lowest. The pH values ranged from 2.893 ± 0.070 to 3.860 ± 0.010 , indicating that all samples were acidic in nature and below the WHO recommended pH limit of 4.5. Total titratable acidity (TTA) ranged from 0.330 ± 0.044 to $3.650 \pm 5.205\%$, with Sample C recording the highest acidity value. Although caffeine concentrations were below the WHO permissible limit, the acidic nature of the drinks may have implications for consumer health with prolonged consumption.

Table 4 shows the concentration of selected heavy metals in the evaluated energy drinks. Copper and cadmium were below detectable limits (< 0.001 µg/L) in all samples. Lead was detected in Samples A, D and F, with Sample F recording the highest concentration (4.268 ± 0.082 µg/L). Manganese concentrations varied among the samples, ranging from below detectable limits to 17.612 ± 0.020 µg/L, with Sample F also showing the highest concentration. Despite the presence of detectable heavy metals in some samples, all measured concentrations remained below WHO permissible limits.

Human health risk assessment: Table 5 presents the estimated daily intake (EDI) of selected heavy metals resulting from energy drink consumption. The EDI values for copper and cadmium were consistently low across all samples, while higher intake estimates were observed for lead and manganese in Samples D and F. Sample F recorded the highest EDI value for lead (3.049×10^{-5} mg/kg bw/day), whereas Sample D showed the highest EDI value for manganese (4.131×10^{-5} mg/kg bw/day). Nevertheless, all estimated intake values remained below the respective reference doses (RfD) and maximum permissible limits (MPL), suggesting minimal exposure risk under the evaluated consumption conditions.

Table 6 presents the target hazard quotient (THQ) and total target hazard quotient (TTHQ) values associated with heavy metal exposure from energy drink consumption. The THQ values for all evaluated heavy metals across the samples were below 1.0, indicating no significant non-carcinogenic health risk. Sample F recorded the highest TTHQ value (8.82×10^{-3}), followed by Sample D (6.67×10^{-3}), largely due to comparatively higher lead and manganese concentrations. Overall, the TTHQ values for all samples were substantially lower than the safety threshold of 1.0, suggesting low cumulative health risk from heavy metal exposure through consumption of the evaluated energy drinks.

Table 7 shows the carcinogenic risk associated with lead and cadmium exposure through consumption of the analysed energy drinks. Lead carcinogenic risk values ranged from 8.5×10^{-11} to 2.6×10^{-7} , with Sample F exhibiting the highest risk value. Cadmium carcinogenic risk values were uniformly low across all samples (3.8×10^{-9}). All estimated carcinogenic risk values were below the acceptable risk range recommended by the United States Environmental Protection Agency (10^{-6} to 10^{-4}), indicating negligible carcinogenic risk associated with the evaluated heavy metals in the energy drink samples.

Table 1: Anti-nutrients composition of energy drinks evaluated in this study

Energy drinks	Phytate (g/kg)	Oxalate (mg/100 g)	Tannin (mg/kg)
Sample A	9.247±0.367 ^{af}	0.050±0.000 ^{abce}	21.277±0.117 ^a
Sample B	10.123±0.058 ^{bc}	0.060±0.017 ^{abce}	24.390±0.104 ^b
Sample C	10.367±0.419 ^{bc}	0.110±0.020 ^{abcdef}	23.403±0.153 ^c
Sample D	6.423±0.006 ^d	0.143±0.049 ^{cdf}	18.277±0.176 ^d
Sample E	12.763±0.060 ^e	0.043±0.006 ^{abce}	11.880±0.118 ^e
Sample F	8.997±0.025 ^{af}	0.163±0.029 ^{cdf}	22.090±0.174 ^f
WHO limits	2.5 g/kg	500 mg/100 g	560 mg/kg

*Values are Mean±Standard Deviation of triplicate determination, values with the same superscripts down the column are not significant at $p \leq 0.05$, values with different superscripts down the column are significant at $p \leq 0.05$. Sample: A (Black Bullet), B (Blue Bullet), C (Monster), D (Fearless), E (Predator) and F (Super Komando)

Table 2: Nutrient composition of energy drinks evaluated in this study

Energy drinks	Sugar (g/mL)	TAC (% Glucose)
Sample A	17.166±0.058 ^a	6.953±0.193 ^a
Sample B	11.838±0.058 ^{bf}	6.400±0.030 ^{bc}
Sample C	11.467±0.231 ^c	6.563±0.188 ^{bc}
Sample D	9.867±0.115 ^d	5.470±0.020 ^d
Sample E	13.800±0.000 ^e	8.373±0.015 ^e
Sample F	11.838±0.058 ^{bf}	7.750±0.036 ^f
WHO limits	36 g/mL	10%

*Values are Mean±Standard Deviation of triplicate determination, values with the same superscripts down the column are not significant at $p \leq 0.05$, values with different superscripts down the column are significant at $p \leq 0.05$, TAC: Total available carbohydrate. Sample: A (Black Bullet), B (Blue Bullet), C (Monster), D (Fearless), E (Predator) and F (Super Komando)

Table 3: Chemical composition of energy drinks evaluated in this study

Energy drinks	Caffeine (mg/L)	pH	TTA (%)
Sample A	26.453±0.025 ^{ab}	3.860±0.010 ^a	0.683±0.029 ^a
Sample B	26.420±0.122 ^{ab}	3.493±0.012 ^b	0.667±0.029 ^a
Sample C	6.570±0.185 ^c	3.587±0.006 ^c	3.650±5.205 ^a
Sample D	40.150±0.030 ^d	2.893±0.070 ^d	0.330±0.044 ^a
Sample E	33.400±0.108 ^e	3.267±0.006 ^{ef}	0.380±0.026 ^a
Sample F	7.661±0.081 ^f	3.280±0.000 ^{ef}	0.543±0.012 ^a
WHO limits	400 mg/L	4.5	0.7%

*Values are Mean±Standard Deviation of triplicate determination, values with the same superscripts down the column are not significant at $p \leq 0.05$, values with different superscripts down the column are significant at $p \leq 0.05$, TTA: Total titratable acidity. Sample: A (Black Bullet), B (Blue Bullet), C (Monster), D (Fearless), E (Predator) and F (Super Komando)

Table 4: Concentration of heavy metals in the energy drinks evaluated for this study

Parameter	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	WHO permissible limit (µg/L)
Copper (µg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	50
Lead (µg/L)	2.33±0.431	<0.001	<0.001	3.112±0.011	<0.001	4.268±0.082	10
Manganese (µg/L)	2.647±0.026	12.875±0.032	<0.001	5.783±0.054	<0.001	17.612±0.020	400
Cadmium (µg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	20

Values are Mean±Standard Deviation of triplicate determination. Sample: A (Black Bullet), B (Blue Bullet), C (Monster), D (Fearless), E (Predator) and F (Super Komando)

The anti-nutrient composition of the studied energy drinks are as shown in Table 1. The results show that all energy drinks of study had the concentrations of Oxalate and tannins to be below the WHO permissible limits except for Phytate, which was above the permissible limit in all 6 energy drinks. Antinutrients are compounds that reduce the ability of the body to absorb and utilize essential nutrients²⁸. They act by binding to vitamins and minerals, thereby preventing their uptake, or by inhibiting enzymes. Phytates possesses strong mineral-chelating properties, particularly with divalent and trivalent ions, thereby reducing mineral bioavailability³, which leads to precipitation, thereby making nutrients unavailable for

absorption in the intestine. Its high concentrations in all the studied energy drinks could be a bad indication due to its negative mode of action in humans. Although, Oxalate and tannins are in the permissible limits of WHO, there is also a need to consume in moderate amounts.

The values of Sugar and Total Available Carbohydrate (TAC) in all the energy drink samples of study showed that they were all below the WHO permissible limit as revealed in Table 2. The Concentrations of TAC and Sugar, although below the WHO permissible limits implies the availability of carbohydrate for extra energy as supposed on consumption of the energy drink.

Table 5: Ingestion Rate (IR) of Energy drink (kg/day/person) and EDI (mg/kg bw/day) of selected heavy metals in each sample energy drink

Sample	IR of each energy drink	EDI of Cu	EDI of Pb	EDI of Mn	EDI of Cd
Sample A	0.5	1.0×10^{-8}	1.664×10^{-5}	1.891×10^{-5}	1.0×10^{-8}
Sample B	0.5	1.0×10^{-8}	1.0×10^{-8}	9.2×10^{-6}	1.0×10^{-8}
Sample C	0.5	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-8}
Sample D	0.5	1.0×10^{-8}	2.223×10^{-5}	4.131×10^{-5}	1.0×10^{-8}
Sample E	0.5	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-8}
Sample F	0.5	1.0×10^{-8}	3.049×10^{-5}	1.258×10^{-5}	1.0×10^{-8}
Total consumption		6.0×10^{-8}	6.939×10^{-5}	8.202×10^{-5}	6.0×10^{-8}
RfD (mg/kg/day)		0.04 ^a	0.0035 ^a	0.14 ^a	0.0005 ^a
MPL (mg/kg/day)		0.5 ^b	0.1 ^a	0.157 ^b	0.1 ^a

MPL: Maximum permissible limit. ^aU.S. Environmental Protection Agency, ^bWorld Health Organization. Samples: A (Black Bullet), B (Blue Bullet), C (Monster), D (Fearless), E (Predator), F (Super Komando) and Estimated daily intake (EDI)

Table 6: THQ and TTHQ of heavy metals through consumption of each energy drink

Sample	THQ of Cu	THQ of Pb	THQ of Mn	THQ of Cd	TTHQ of each sample
Sample A	2.5×10^{-7}	4.75×10^{-3}	1.36×10^{-4}	2.0×10^{-5}	4.91×10^{-3}
Sample B	2.5×10^{-7}	2.86×10^{-6}	6.57×10^{-5}	2.0×10^{-5}	8.88×10^{-5}
Sample C	2.5×10^{-7}	2.86×10^{-6}	7.14×10^{-8}	2.0×10^{-5}	2.32×10^{-5}
Sample D	2.5×10^{-7}	6.35×10^{-3}	2.95×10^{-4}	2.0×10^{-5}	6.67×10^{-3}
Sample E	2.5×10^{-7}	2.86×10^{-6}	7.14×10^{-8}	2.0×10^{-5}	2.32×10^{-5}
Sample F	2.5×10^{-7}	8.71×10^{-3}	8.99×10^{-5}	2.0×10^{-5}	8.82×10^{-3}

Sample: A (Black Bullet), B (Blue Bullet), C (Monster), D (Fearless), E (Predator), F (Super Komando). Target hazard quotient (THQ) and total target hazard quotient (TTHQ)

Table 7: Carcinogenic risk of Pb, Cd

Sample	Pb	Cd
Sample A	1.41×10^{-7}	3.8×10^{-9}
Sample B	8.5×10^{-11}	3.8×10^{-9}
Sample C	8.5×10^{-11}	3.8×10^{-9}
Sample D	1.9×10^{-7}	3.8×10^{-9}
Sample E	8.5×10^{-11}	3.8×10^{-9}
Sample F	2.6×10^{-7}	3.8×10^{-9}

Sample: A (Black Bullet), B (Blue Bullet), C (Monster), D (Fearless), E (Predator) and F (Super Komando)

The global concern on the consumption of Energy drinks is majorly associated with the Caffeine levels, when consumed in excess quantity, majorly above the Required daily intake (RDI). As a stimulant of the Central Nervous System, Caffeine has been reported to have numerous Pharmacological and physiological effects including cardiovascular, respiratory, renal and smooth muscle effects, as well as effects on mood, memory, alertness and physical and cognitive performance²⁹. The potency of Caffeine as an antioxidant, anti-inflammatory and effectiveness in pain management may have implied its use for the production of energy drinks³⁰. The values for the Chemical composition (Caffeine, TTA and pH) in Table 3 observed that they were all below WHO permissible limits except for TTA in Sample C. TTA has been reported to be a more precise indicator of the total acid concentration of beverages, as it measures the erosive potential on dental hard tissues³¹. The higher the acidity of an energy drink, the higher its chances to result in disruption of the biochemical balance of the body system, thereby disrupting the delivery of oxygen and nutrients efficiently by the red blood cell. This results in a drop in energy levels. The result as revealed

in Table 3 implies the energy drinks of study were all within the permissible levels and thus will produce the required energy and result.

Table 4 shows the statistical values for lead, cadmium, copper and manganese for the energy drink samples evaluated for this study. The values for the Heavy metal concentration were all below WHO permissible limits.

The estimated daily intake (EDI) of heavy metals from the energy drink is as presented in Table 5. It is a measure used to estimate the daily intake of heavy metals by individuals through the consumption of food, water and air. The EDI of the heavy metals was below the reference dose (RfD) levels, indicating that the heavy metals intake from the energy drink may have no potential health risk via its consumption since their values are within the WHO permissible limits.

To assess the non-carcinogenic risk of heavy metals through the consumption of each energy drink, we used the Target Hazard Quotient (THQ) and the Total Target Hazard Quotient (TTHQ), THQ and TTHQ were estimated as presented in Table 6. These metrics helped to evaluate the potential

health risks from long-term exposure to heavy metals through diet. All THQ values were lower than 1, indicating low health risk although the THQ values only provide the risk of the value of each metal due to exposure. The TTHQ values (considering all the metals) in the studied energy drinks ranged from 2.32×10^{-5} to 8.82×10^{-3} . The TTHQ in all the energy drinks were less than 1, suggesting that the combined exposure to all the heavy metals remains below the threshold level of concern for non-carcinogenic health effects.

Table 7 shows the total cancer risk of heavy metals in the various energy drinks. The cancer risk of Pb and Cd ranges from 8.5×10^{-11} to 1.41×10^{-7} and 3.8×10^{-9} respectively, indicating that these energy drinks had very low risk when compared to cancer risk range of 1×10^{-6} to 1×10^{-4} . Although the carcinogenic risk is low, chronic exposure to lead and Cadmium can cause other severe health problems, including neurotoxicity, especially in children, kidney damage and bone demineralization³².

Based on the findings of this study, which revealed phytate violations in all energy drink samples, elevated lead levels in specific brands and crisis communication gaps in the industry, the following recommendations are proposed for relevant stakeholders.

Manufacturers should conduct comprehensive testing of all energy drink formulations to identify and address phytate violations, which exceeded WHO limits in all samples tested.

Companies producing Samples A, D and F must investigate lead contamination sources in their supply chains and implement stringent quality control measures.

Organisations must establish immediate transparent disclosure procedures for regulatory violations, including stakeholder notification systems, media response frameworks and consumer advisory protocols. Develop proactive communication strategies rather than reactive damage control approaches.

Implement mandatory routine testing of energy drinks for anti-nutrients and heavy metals, with particular focus on phytate content which violated standards in 100% of samples tested.

These recommendations provide a comprehensive framework for addressing the health risks and communication challenges identified in this study. Implementation requires coordinated action across multiple stakeholders, with particular emphasis on protecting vulnerable populations while maintaining industry viability through transparent, responsible practices.

CONCLUSION

This study evaluated caffeine, sugar, pH, phytate and heavy metal levels in six commercial energy drinks. All samples exhibited potentially erosive acidic pH values and non-compliant phytate levels, while specific brands contained elevated lead and manganese. These findings present critical corporate crisis communication and regulatory challenges. Effectively managing these food safety risks requires integrating rigorous analytical testing with transparent, multi-stakeholder risk communication strategies to protect public health and maintain consumer trust.

SIGNIFICANCE STATEMENT

This study highlights critical dental and toxicity risks from energy drink contaminants, revealing widespread regulatory non-compliance. By bridging food safety management with crisis communication, it provides a dual-approach model for manufacturers and regulators to translate complex scientific risks into transparent consumer disclosures, ultimately safeguarding public health and industry trust.

ACKNOWLEDGMENT

The authors are grateful to the staff and management of Endpoint Laboratories, Port Harcourt, Nigeria.

REFERENCES

1. Nadeem, I.M., A. Shanmugaraj, S. Sakha, N.S. Horner, O.R. Ayeni and M. Khan, 2021. Energy drinks and their adverse health effects: A systematic review and meta-analysis. *Sports Health Multidiscip. Approach*, 13: 265-277.
2. Antonio, J., B. Antonio, S.M. Arent, D.G. Candow and G. Escalante *et al.*, 2025. Common questions and misconceptions about energy drinks: What does the scientific evidence really show? *Nutrients*, Vol. 17. 10.3390/nu17010067.
3. Zhou, D., Y. Zhao, J. Li, V. Ravichandran and L. Wang *et al.*, 2021. Effects of phytic acid-degrading bacteria on mineral element content in mice. *Front. Microbiol.*, Vol. 12. 10.3389/fmicb.2021.753195.
4. Chondrou, T., N. Adamidi, D. Lygouras, S. Hirota, O. Androutsos and V. Svolos, 2024. Dietary phytic acid, dephytinization, and phytase supplementation alter trace element bioavailability-A narrative review of human interventions. *Nutrients*, Vol. 16. 10.3390/nu16234069.

5. Salgado, N., M.A. Silva, M.E. Figueira, H.S. Costa and T.G. Albuquerque, 2023. Oxalate in foods: Extraction conditions, analytical methods, occurrence, and health implications. *Foods*, Vol. 12. 10.3390/foods12173201.
6. Cosme, F., A. Aires, T. Pinto, I. Oliveira, A. Vilela and B. Gonçalves, 2025. A comprehensive review of bioactive tannins in foods and beverages: Functional properties, health benefits, and sensory qualities. *Molecules*, Vol. 30. 10.3390/molecules30040800.
7. Aller, E.E.J.G., I. Abete, A. Astrup, J.A. Martinez and M.A. Baak, 2011. Starches, sugars and obesity. *Nutrients*, 3: 341-369.
8. Jagim, A.R., P.S. Harty, A.R. Barakat, J.L. Erickson and V. Carvalho *et al.*, 2022. Prevalence and amounts of common ingredients found in energy drinks and shots. *Nutrients*, Vol. 14. 10.3390/nu14020314.
9. Jee, H.J., S.G. Lee, K.J. Bormate and Y.S. Jung, 2020. Effect of caffeine consumption on the risk for neurological and psychiatric disorders: Sex differences in human. *Nutrients*, Vol. 12. 10.3390/nu12103080.
10. Kumar, N., F. Amin, D. Hashem, S. Khan and H. Zaidi *et al.*, 2022. Evaluating the pH of various commercially available beverages in Pakistan: Impact of highly acidic beverages on the surface hardness and weight loss of human teeth. *Biomimetics*, Vol. 7. 10.3390/biomimetics7030102.
11. Marchan, S., T. Hector and K. Bascombe, 2021. The pH and titratable acidity of still and sparkling flavored waters: The effects of temperature and storage time. *Open J. Stomatology*, 11: 148-158.
12. Ihuoma, N.G., O. Tamuno-Boma, G.B.C. Umanu, G.D. Amabinba and F. Erekedoumene, 2020. Comparative study on heavy metals and hydrocarbons accumulation in cassava tubers harvested from four different locations in Rivers State, Nigeria. *Int. J. Ecotoxicol. Ecobiol.*, 5: 23-28.
13. Peana, M., A. Pelucelli, C.T. Chasapis, S.P. Perlepes, V. Bekiari, S. Medici and M.A. Zoroddu, 2023. Biological effects of human exposure to environmental cadmium. *Biomolecules*, Vol. 13. 10.3390/biom13010036.
14. Harischandra, D.S., S. Ghaisas, G. Zenitsky, H. Jin, A. Kanthasamy, V. Anantharam and A.G. Kanthasamy, 2019. Manganese-induced neurotoxicity: New insights into the triad of protein misfolding, mitochondrial impairment, and neuroinflammation. *Front. Neurosci.*, Vol. 13. 10.3389/fnins.2019.00654.
15. Baba, F.V. and Z. Esfandiari, 2023. Theoretical and practical aspects of risk communication in food safety: A review study. *Heliyon*, Vol. 9. 10.1016/j.heliyon.2023.e18141.
16. Onyeaka, H., 2025. Risk communication in food safety: Addressing the gap between scientific risk assessments and public perception, and strategies to improve transparency and trust in food safety regulations. *Food Saf. Risk*, Vol. 12. 10.1186/s40550-025-00116-y.
17. European Food Safety Authority (EFSA), L. Maxim, M. Mazzocchi, S. van den Broucke and F. Zollo *et al.*, 2021. Technical assistance in the field of risk communication. *EFSA J.*, Vol. 19. 10.2903/j.efsa.2021.6574.
18. Firincă, C., L.G. Zamfir, M. Constantin, I. Răut and M.L. Jecu *et al.*, 2025. Innovative approaches and evolving strategies in heavy metal bioremediation: Current limitations and future opportunities. *J. Xenobiot.*, Vol. 15. 10.3390/jox15030063.
19. Zuo, T.T., L. Zhang, Y. Wang, L.X. Nie and M.R. Shen *et al.*, 2023. Technical guidelines for risk assessment of heavy metals in traditional Chinese medicines. *Chin. Med.*, Vol. 18. 10.1186/s13020-023-00771-3.
20. Tomassi, A., A. Falegnami and E. Romano, 2025. Disinformation in the digital age: Climate change, media dynamics, and strategies for resilience. *Publications*, Vol. 13. 10.3390/publications13020024.
21. Fuente-Maqueda, F., A. Rodríguez, J. Majada, B. Fernández and I. Feito, 2020. Methodology optimization for the analysis of phenolic compounds in chestnut (*Castanea sativa* Mill.). *Food Sci. Technol. Int.*, 26: 520-534.
22. Pico, J., R.Y. Pismag, M. Laudouze and M.M. Martinez, 2020. Systematic evaluation of the Folin-Ciocalteu and Fast Blue BB reactions during the analysis of total phenolics in legumes, nuts and plant seeds. *Food Funct.*, 11: 9868-9880.
23. Misiewicz, B., D. Mencer, W. Terzaghi and A.L. vanWert, 2023. Analytical methods for oxalate quantification: The ubiquitous organic anion. *Molecules*, Vol. 28. 10.3390/molecules28073206.
24. Marolt, G. and M. Kolar, 2021. Analytical methods for determination of phytic acid and other inositol phosphates: A review. *Molecules*, Vol. 26. 10.3390/molecules26010174.
25. Afolabi, O.O., E. Wali, S.O. Asomaku, O.I.T. Yemi-Jonathan and N.C. Ogbuehi *et al.*, 2023. Ecotoxicological and health risk assessment of toxic metals and metalloids burdened soil due to anthropogenic influence. *Environ. Chem. Ecotoxicol.*, 5: 29-38.
26. Woodruff, T.J. and P. Sutton, 2014. The navigation guide systematic review methodology: A rigorous and transparent method for translating environmental health science into better health outcomes. *Environ. Health Perspect.*, 122: 1007-1014.
27. Valentin, J., 2002. Basic anatomical and physiological data for use in radiological protection: Reference values: ICRP publication 89: Approved by the commission in September 2001. *Ann. ICRP*, 32: 1-277.
28. Costantino, A., A. Maiese, J. Lazzari, C. Casula, E. Turillazzi, P. Frati and V. Fineschi, 2023. The dark side of energy drinks: A comprehensive review of their impact on the human body. *Nutrients*, Vol. 15. 10.3390/nu15183922.

29. araiva, S.M., T.A. Jacinto, A.C. Gonçalves, D. Gaspar and L.R. Silva, 2023. Overview of caffeine effects on human health and emerging delivery strategies. *Pharmaceuticals*, Vol. 16. 10.3390/ph16081067.
30. Rodak, K., I. Kokot and E.M. Kratz, 2021. Caffeine as a factor influencing the functioning of the human body-friend or foe? *Nutrients*, Vol. 13. 10.3390/nu13093088.
31. Hichijo, N., Y. Kudo and E. Tanaka, 2021. Orthodontic treatment of open bite involved in diffuse hypercementosis. *J. Am. Dent. Assoc.*, 152: 166-175.
32. Ootobo, M.B., C.O. Nwaokazi, I. Austin-Asomeji, I.M. Israel and T.B. Odinga, 2023. Assessment of soil and *Vernonia amygdalina* cultivated in Port Harcourt, Nigeria. *Singapore J. Sci. Res.*, 13: 60-68.