

Assessment of the Risk of Heavy Metals Contamination in Infant Formulas and Children Food Products Available in Gusau, Zamfara State, Nigeria

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ABSTRACT

Infants and children are highly susceptible to contaminated foods, evaluating the presence of toxic metals in commercial infant formulas and children food products is prerequisite to ensuring good and safe nutrition for infants and children. The study was conducted to determine the concentration of selected heavy metals in infant formulas and children food products sold in Gusau, Zamfara State Nigeria. The concentrations of Cd, Co, As, Pb, Cr and Al in infant formulas and children food products were analyzed using Microplasma atomic emission spectrophotometer (MP-AES). The mean concentrations of Cd, Co, As, Pb, Cr and Al in infant formula samples were 2.500, 0.859, 0.796, 0.563, 0.484 and 1.641 $\mu\text{g/g}$, respectively. The concentrations of metals in children food products were in the decreasing order of Al > Cd > Cr > Pb > As > Co. The calculated EWI (estimated weekly intakes) for all the analyzed metals in the samples were within the PTWI (provisional tolerated weekly intakes) values established by FAO/WHO. The THQ values of Cd, As, Pb, and Al were greater than the threshold value of 1. This implies that the infant formulas marketed at the time of this study in the area have likelihood to induce non-carcinogenic health risk over long term consumption. Based on CR values established in this study, Cd, As, Cr and to some extent Pb have values above 10^{-6} . Thus, making them unfit for human consumption and demonstrating potential health risk to infants. Therefore, monitoring and evaluation of manufacturing steps, packaging, storing and preparation of infant formulas and children food products is very crucial to reduce exposure to toxic metals.

Keywords: Heavy metals, Infant formulas, Children food products, Risk assessment

1.0 INTRODUCTION

Breast milk has been considered as an optimum nutrition for infants by providing adequate nutritional requirements necessary for healthy growth, development and enough protection against diseases (Victoria *et al.*, 2016; Losio *et al.*, 2018). Therefore, exclusive breastfeeding has been recommended in the first six months of infancy to ensure the growth, health, and development of children to their full potential (Victoria *et al.*, 2016; WHO, 2023) Moreover, adequate and safe complementary feeding with continued breastfeeding from six months to two years of age is highly advocated (Hamid *et al.*, 2017) Milk formulas are formulated and widely given to infant as human milk substitutes especially where breastfeeding become a problem or insufficient (Losio *et al.*, 2018). The infant formula is usually prepared by drying the naturally concentrated liquid milk to form dried milk under utmost hygienic condition (Hamid *et al.*, 2017; Losio *et al.*, 2018). It is now rated the second best to breast milk in terms of nutritional requirements for growth and development as well as conferment of protection against diseases (Lyons *et al.*, 2020).

Despite the benefits of infant formulas, the issue of safety is now becoming a public concern after global scandal of melamine-contaminated baby milk saga and a recall of a batch of infant formulas produced by Mead Johnson and Company due to metals contamination (Onuorah *et al.*, 2019). Moreover, during food processing involving cooking and heat treatments, several substances are formed as by-products and may be toxic to infant and children health. The presence of some atmospheric contaminants such as heavy metals and pesticide residues in infant formulas, use of contaminated raw materials, poor production processes and adulteration of infant foods are equally a great health risk to children (Bengellini *et al.*, 2018; Lebelo *et al.*, 2021). Several reports have indicated that children are highly at risk to contaminants exposure due to many reasons like high intestinal absorption, low threshold for adverse effects, small mass and developing systems (Assi *et al.*, 2016; Omeragic *et al.*, 2021). Studies have shown that even at low concentration of exposure, heavy metals tend to bioaccumulate in vital organs and cause many developmental disorders (Omeragic *et al.*, 2021; Munir *et al.*, 2021).

Children exposure to heavy metals like lead, cadmium, chromium, arsenic, zinc, aluminum and nickel via consumption of infant formula have been reported in many studies (Pandelova *et al.*, 2012; Hamid *et al.*, 2017; Eticha *et al.*, 2018; Amarh *et al.*, 2023; Peirovi-Minaee *et al.*, 2024). Upon ingestion, about 42% of Pb is absorbed in children. Impact of lead exposure in children has been associated with cognitive and neurobehavioral impairments, kidney and liver dysfunctions (Rabiu *et al.*, 2022). Cadmium is implicated in kidney malfunction, bone demineralization, lower IQ scores and higher prevalence of Attention-Deficit/Hyperactivity Disorder (ADHD) (Pan *et al.*, 2018; Jurowski *et al.*, 2019). Al has been reported to be toxic to nervous and skeletal systems (Klein *et al.*, 1998; Bondy, 2016). However, Zn is essential element that performs several metabolic functions in living system, and the metal can as well be toxic when ingested in high amount (Kwon *et al.*, 2017). Similarly, Cr is needed for normal glucose metabolism, but consumption of high amount can leads to chronic kidney diseases (Shahid *et al.*, 2017). Reports have shown that chronic exposure to As even at low concentration can cause severe brain damage, reduced memory performance, and stunted growth, difficulty in breathing and cancer later in life (Gu *et al.*, 2020). Consumption of As is also linked to higher risk of bronchiectasis, impaired liver function, cognitive deficits, and skin cancer (Bae *et al.*, 2017; Peirovi-Minaee *et al.*, 2024).

A wealth of evidence in the literature has indicated a significant contamination of heavy metals in infant formula and children food products (Ghuniem *et al.*, 2020; Lebelo *et al.*, 2021; Munir *et al.*, 2021). A wide range of Pb and Cd concentrations from undetected level to 0.142 and 0.4mg/kg respectively in infant formula has been documented in different studies (Jurowski *et al.*, 2019; Akpe *et al.*, 2021). Similarly, high levels of Pb and Cr have been reported in milk-based, cereal-based and mixed in children food products (Onuorah *et al.*, 2019; Ghuniem *et al.*, 2020).

1.1 Research Objectives

The rising concern about food quality and safety, especially in children has necessitated the need for continual monitoring and investigation of contaminants in food. The present study is focused to evaluate the concentration of Cd, Cr, As, Ni, Pb and Al in different brands of milk-based, cereal-based and mixed infant formula and children food products marketed and consumed in Gusau, Zamfara State, Nigeria, and compare with the permissible limits set by World Health Organization, Joint FAO/WHO Expert Committee on Food additive (JECFA, 2011).

2.0 MATERIALS AND METHODS

2.1 Materials

Nitric acid (HNO₃, 65%) and hydrogen peroxide (H₂O₂, 30%) were purchased from Sigma Aldrich (Merck) and were of analytical grades.

2.2 Study Area

The study was conducted within the Gusau municipality, Zamfara State Northwest Nigeria.

2.3 Sample Collection

A total of fifty (50) different brands of locally and internationally produced infant formulas and children food products samples, were randomly purchased from supermarkets and pharmacies in Gusau, Zamfara State, Northwest Nigeria. The samples were kept in their original packages and stored at room temperature without any processing. The infant formula samples (comprise twenty different brands) were divided into three categories: Milk-based (a single form or any combination of milk, milk powder, milk fat and milk protein, = 8), cereal-based (a single form or any combination of wheat, rice, maize and oats, n= 6) and mixed (any combination of cereals, milk, fruits and vegetables, n= 6). While thirty different brands of children food products were labelled with S1, S2, S3, to S30, respectively.

2.4 Sample Digestion and Analysis

Exactly 1.0 g of each sample of infant formula and children food product was weighed and placed in a digestion tube, and a 10 mL mixture of nitric acid (HNO₃, 65%) and hydrogen peroxide (H₂O₂, 30%) in a ratio 3:1, was gently added and shaken. The mixture was heated continuously using hotplate at constant temperature of 250°C until clear solution was observed. The clear solution was allowed to cool at room temperature and transferred into a 50 mL volumetric flask, diluted to a volume of 50 mL with deionized water, thereafter filtered using Whatman No. 1 filter paper. The preparation of each sample was conducted in triplicates. The digested samples were analyzed for Cd, Co, As, Cr, Pb and Al using Microplasma atomic emission spectrophotometer (MP-AES).

2.5 Quality Control

All sample containers and glassware were soaked overnight in nitric acid (HNO₃, 10%) and rinsed with deionized water thoroughly. All reagent used in the study were of analytical grade. 0.5 mg/L standard solutions of Cd, Co, As, Cr, Pb and Al were prepared from stock standard solution of each element. A matrix spike recovery was carry out by adding standard solution of each respective metal to known amount of sample. The samples were digested in triplicates and concentration of



metals in spiked and unspiked samples were used to calculate percentage recovery for each of the metal analyzed.

3.0 HEALTH RISK ASSESSMENTS

3.1 Daily Intake of Metals and Health Index Calculation

The estimated daily intake (EDI) of heavy metals were calculated using the following formulae:

$$\frac{C_{metal} \times D_{intake}}{B_{weight}} \dots\dots\dots 1$$

Where:

C_{metal} = concentration of metal obtained from the sample (mg/kg)

D_{intake} = daily intake of infant formula (0.345 kg/person/day) while

B_{weight} = average body weight (60 kg for adult)

The average daily consumed powder infant formula established and recommended from feeding tables and dosages by manufacturers are: 0 to 6 months (135 g/day), 6 to 12 months (160 g/day) and 12 to 36 months (200 g/day) while the average body weights of each age group was 7.5kg, 9.3kg and 12.2 kg respectively.

3.2 Non-carcinogenic Risk

The non-carcinogenic health risks in relation to meat consumption in the study area were determined using the calculated target hazard quotients (THQs) developed by the US-Environmental Protection Agency (EPA). THQ is a ratio between the measured concentration and the oral reference dose (RfD) as determined by FAO/WHO. Calculated THQ values less than one (< 1), suggests the exposed population is safe while THQ ≥ 1, indicates a concern level for the exposed population.

$$THQ = EDI/RfD \dots\dots\dots 2$$

Where: EDI = estimated daily intake of infant formula

RfD = oral reference dose (mg/kg/day)

Table 1: The Oral Reference Dose (RfD) Values of some Metals

Metal	RfD(mg/kg/day)
Lead (Pb)	0.004
Cadmium (Cd)	0.001.51
Aluminium (Al)	1.00
Chromium (Cr)	1.5
Arsenic (As)	0.0003
Cobalt (Co)	0.1

3.3 Carcinogenic Risk Assessment

The carcinogenic risk signifies the incremental probability of an individual developing cancer in lifetime due to ingestion of food contaminated with potential carcinogen (USEPA, 2010). The following equation was used to predict target cancer risks for consumption of infant formula.

$$ECR = EDI \times CSF$$

where, ECR = estimated cancer risk in a lifetime over exposure to a certain toxic metal;

CSFo = oral carcinogenic slope factor (USEPA, 2010).

In this study, CSF values are: Pb = 0.0085, Cr = 0.5 Cd = 0.38 and As = 1.5 mg/kg/day respectively. The acceptable risk levels for carcinogens range from 10⁻⁴ to 10⁻⁶.

3.4 Statistical Analysis

Data generated were analysed using Graph Pad In Stat version 6.03 statistical package. All results were expressed as mean value ± standard deviation (SD). Statistical differences between the groups were determined using one way ANOVA. Tukey-Kramer comparison test was used to compare means and differences were considered significant at p <0.05.

4.0 RESULTS

The mean concentrations for the studied heavy metals in infant formulas are presented in Table 2. The concentration of the metals varied among the different infant formulas analyzed. The mean concentration of the metals were in the following order: Cd > Al > Co > As > Pb > Cr. However, Co contamination was only observed in 6 - 12 months infant formulas, remarkably having a sample with highest concentration (12.75µg/g) than all the metals analyzed. The highest concentrations of Pb, Cr and Al were detected in 6 – 12 months infant formulas. While concentrations of As were significantly (p< 0.05) high in 12 – 24 months compared to other stages (0 – 6 and 6 – 12) infant formulas. Similarly, concentration of Pb were significantly (p<0.05) high in 0 – 6 months compared to 6 – 12 and 12 – 24 months infant formulas. The concentrations of the selected metals analyzed in different categories of infant formulas as milk-based, cereal-based and mixed- based are depicted in Table 3. The highest concentration of all the metals except Pb was found in mixed- based infant formulas and were in order of Co > Cd > Al > As > Cr. Significantly (p<0.05) high concentration of Pb was observed in milk-based compared to cereal and mixed based infant formulas. The concentrations of Co, As and Pb ranged from not detected to appreciable amount across the three categories of the infant formulas.

Table 2: Mean concentration of metals in infant formulas

Groups	Cd($\mu\text{g/g}$)	Co($\mu\text{g/g}$)	As($\mu\text{g/g}$)	Pb($\mu\text{g/g}$)	Cr($\mu\text{g/g}$)	Al($\mu\text{g/g}$)
0 – 6 months (n= 6)						
Mean \pm SD	2.25 \pm 0.10	ND	0.75 \pm 0.32	1.25 \pm 0.77 ^a	0.312 \pm 0.06	0.312 \pm 0.06
Range	2.00-2.50	ND	ND-1.55	ND-3.50	0.25-0.50	0.25-0.50
6 – 12 months (n= 8)						
Mean \pm SD	2.56 \pm 0.13	1.72 \pm 0.57 ^a	0.69 \pm 0.25	0.34 \pm 0.14	0.59 \pm 0.06 ^a	2.91 \pm 0.10 ^a
Range	2.25-3.50	ND-12.75	ND-1.75	ND-1.00	0.25-0.75	0.25-7.00
12-24 months (n= 6)						
Mean \pm SD	2.63 \pm 0.12	ND	1.06 \pm 0.36 ^a	0.31 \pm 0.01	0.44 \pm 0.06	0.43 \pm 0.01
Range	2.25-2.75	ND	0.50-2.00	ND-0.70	0.25-0.50	0.25-0.75

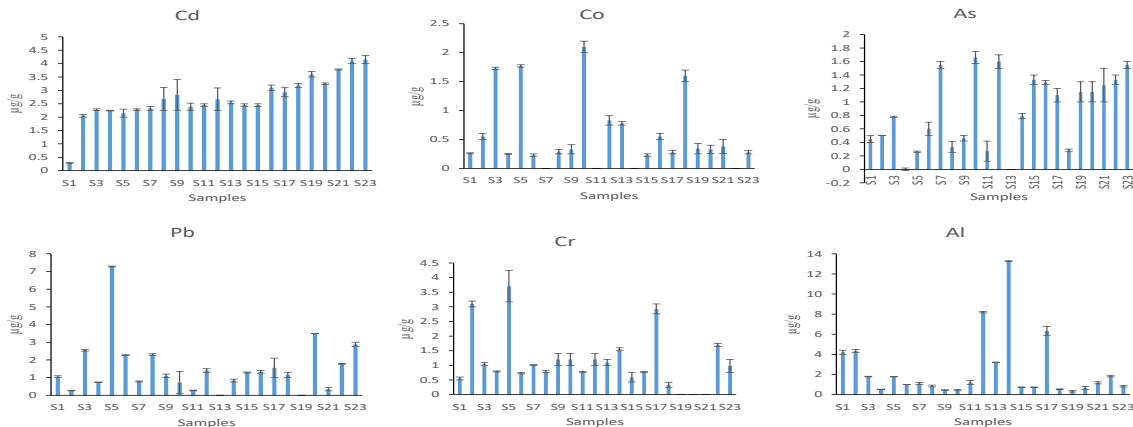
n: number of samples; ND: non-detectable; Values with superscript are considered statistically significant at $p < 0.05$

Table 3: Mean concentration of metal in three categories of infant formulas

Group	Cd($\mu\text{g/g}$)	Co($\mu\text{g/g}$)	As($\mu\text{g/g}$)	Pb($\mu\text{g/g}$)	Cr($\mu\text{g/g}$)	Al($\mu\text{g/g}$)
Milk-based (n= 8)						
Mean \pm SD	2.00 \pm 0.20	0.04 \pm 0.01	0.63 \pm 0.02	0.92 \pm 0.03 ^a	0.33 \pm 0.05 ^a	0.33 \pm 0.05 ^a
Range	0.75-2.50	ND-0.25	ND-1.50	ND-3.50	0.25-0.50	0.25-0.50
Cereal-based (n= 6)						
Mean \pm SD	2.31 \pm 0.06	0.19 \pm 0.02	0.63 \pm 0.03	0.32 \pm 0.01	0.56 \pm 0.11	2.06 \pm 0.14
Range	1.25-2.25	ND-0.50	ND-1.50	ND-0.75	0.25-0.75	0.25-6.50
Mixed-based (n= 6)						
Mean \pm SD	2.57 \pm 0.03	3.19 \pm 0.04 ^a	1.19 \pm 0.04 ^a	0.38 \pm 0.02	0.63 \pm 0.07	2.56 \pm 0.10
Range	2.25-3.50	ND-12.70	ND-2.00	ND-1.00	0.50-0.75	0.25-7.00

n: number of samples; ND: non-detectable; Values with superscript are considered statistically significant at $p < 0.05$

The concentration of the analyzed heavy metals in different children food products were presented in Figure 1. The mean concentrations of Cd, Co, As, Pb, Cr and Al are 2.61 $\mu\text{g/g}$ (ranged, 0.50-4.00 $\mu\text{g/g}$), 0.53 $\mu\text{g/g}$ (ranged, 0.00-1.75 $\mu\text{g/g}$), 0.80 $\mu\text{g/g}$ (0.00-1.5 $\mu\text{g/g}$), 1.48 $\mu\text{g/g}$ (0.00-7.25 $\mu\text{g/g}$), 1.97 $\mu\text{g/g}$ (0.00-24.25 $\mu\text{g/g}$) and 4.71 $\mu\text{g/g}$ (ranged, 0.25-40 $\mu\text{g/g}$), respectively. The concentrations were in the following order: Al > Cd > Cr > Pb > As > Co.

**Figure 1: Concentrations of the analyzed heavy metals in children food products**

The EDIs and EWIs of the studied selected heavy metals for different age groups infant formulas were calculated and presented in Table 4. The values obtained from each metal has indicated that even though significant, but are within the limits compared to potential tolerable weekly intakes (PTWI) recommended by FAO/WHO (2024). The PTWI is the highest levels of metal in the weekly and daily food that does not pose a potential risk to public health. Therefore, PTWI has been determined to be 7.0, 15.0, 25.0, 23.3, and 20.0 $\mu\text{g}/\text{kg}$ body weight/ week for Cd, As, Pb, Cr and Al respectively, by FAO/WHO, (2024). Thus, the calculated EWI values obtained from this study shows that all the analyzed metals are within the specified permissible limits.

Table 4: Mean estimates of daily intake (EDI) and weekly intake (WEI) of analyzed metals

	Month	Cd	Co	As	Pb	Cr	Al
EDI (mg/kg bw/day)	0-6 months	0.394	0.000	0.225	0.068	0.056	0.056
	6-12 months	0.441	2.671	0.116	0.059	0.102	0.451
	12-24 months	0.429	0.000	0.193	0.050	0.070	0.070
EWI (mg/kg bw/day)	0-6 months	2.758	0.000	1.575	0.476	0.392	0.392
	6-12 months	3.087	18.697	0.812	0.413	0.714	3.157
	12-24 months	3.003	0.000	1.351	0.350	0.490	0.490

In the evaluation of non-carcinogenic risk index, the THQ values were calculated for each metal analyzed are presented in Figure 2. The THQ values for each metal are in decreasing order of As 4.522 (0-10.03) > Cd 4.262 (3.600-6.020) > Al 0.643 (0.100-1.795) > Cr 0.276 (0.130-0.300) > Pb 0.246 (0-1.570) > Co 0.014 (0-0.219).

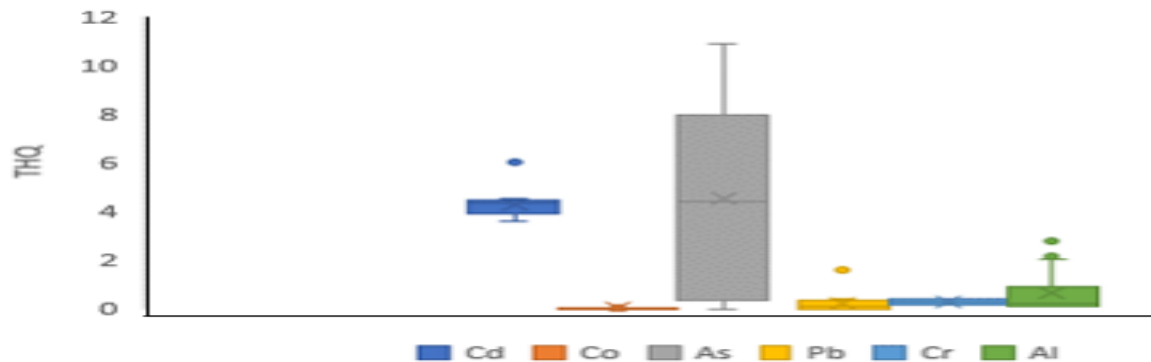


Figure 2: Box plots of THQ associated with heavy metals in infant formulas

The carcinogenic risk evaluation for Cd, As, Cr and Pb via consumption of infant formulas is presented in Figure 3. The CR value for each metal decreased in the order of As 0.213 (0-0.491) > Cd 0.164 (0.023-0.223) > Cr 0.046 (0.021-0.064) > Pb 0.001 (0-0.053).

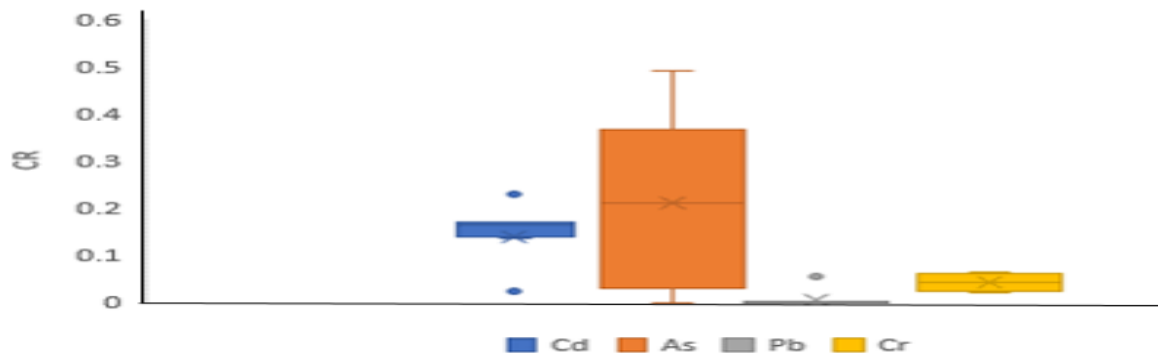


Figure 3: Box plots of CR of heavy metals in infant formulas

5. DISCUSSION

5.1. Concentration of Metals in the Infant Formulas

Infant formulas and children food products are manufactured foods meant to provide required nutritional requirement for infants and children. It is important that the nutritional contents and safety of these foods are maintained to ensure good health for infants and children. Infants and children are highly susceptible to exposure to contaminants due to their low body weight, developing system and high intestinal absorption capacity (Sager *et al.*, 2018; Castro-Gonzalez *et al.*, 2019; Ozturk *et al.*, 2023). Food contamination usually occur due to possible use of unsafe raw materials, poor production and storage methodologies, packaging process and mothers' poor personal hygiene (Abua *et al.*, 2002; Akpe *et al.*, 2021; Astolfi *et al.*, 2021; Elafify *et al.*, 2023). Heavy metals such as Pb, Cd, As, and Al have been implicated to cause several health consequences like cognitive and neurobehavioral impairments, kidney, liver and reproductive dysfunctions, severe brain damage, reduced memory performance, and stunted growth, difficulty in breathing and cancer later in life (Rabiu *et al.*, 2019; Ozturk *et al.*, 2023; Amarh *et al.*, 2023; Peirovi-Minaee *et al.*, 2024). Moreover, due to pervasive non-exclusive breast feeding and persistent use of infant formulas and children food products, it become very crucial to ascertain the concentrations of these toxic metals because of their detrimental effects.

In the present study, an appreciable concentrations of Cd, As, Pb, Cr and Al were detected in different stages (0-6, 6-12 and 12-24 months) of infant formulas, except for Co which was only detected in 6-12 months infant formulas. The values of the metals obtained in this study were low and within the permissible limits of WHO. Pb contamination in 0-6 months and milk-based formulas was high than other kinds of formulas. Similarly, concentrations of As and Cd were significantly high in 12-24 months formulas compared to others. Though Pb concentration was high in some samples, but lower than 0.08-0.23 mg/kg reported by Aguzue *et al.* (2014) in infant formulas marketed in Abuja Nigeria; 0.080±0.012 mg/kg reported by Akpe *et al.* (2021) in infant formulas marketed in Calabar, Cross River Nigeria; 0.061-0.368 mg/kg reported by Amarh *et al.* (2023) in infant formulas sold in Wa, Ghana and 0.0194-0.121 reported by Ghorbani-Kalhor *et al.* (2015). Infants and children are vulnerable to lead toxicity upon exposure than adults, in fact Pb has no safe limit in children, because several health implications have been reported even at very low concentrations.

The main source of human exposure to Cd is via ingestion of food. In this study, Cd was detected in all the samples

analyzed. However, the values obtained were within the specified maximum permissible limits of 0.040 mg/kg (FAO/WHO, 2024) and lower than those reported by Amarh *et al.* (2023) who recorded a mean Cd concentration of 0.051 mg/kg; Saleh *et al.* (2019) reported a mean Cd concentration of 0.12 mg/kg for infant formulas sold in Damanhour, Egypt. In the same way, Peirovi-Minaee *et al.* (2024) reported mean Cd concentration of 0.04 mg/kg in commercially available infant formulas in Iran. Persistent ingestion of Cd through food products can cause its bio-accumulation in kidney and liver due to its long biological half-life, leading to kidney and liver dysfunction, neurological damage and altered calcium metabolism (Ghuniem *et al.*, 2020).

The mean As concentrations recorded in this study, was slightly above the maximum allowed limit of 0.1 mg/kg for infants set by the European Food Safety Authority (EFSA) and the US Food and Drug Administration (USFDA) (2009). The highest As concentrations were recorded in 12-24 months and mixed-based formulas. Akpe *et al.* (2021) reported a mean concentration of 0.001 mg/kg for infants formulas sold in Calabar, Cross River State, Nigeria. A mean of concentration of 0.428 mg/kg was reported by Gu *et al.* (2020) for Australian rice-based infant foods. Demir and Agaoglu (2023) in their study, evaluated some metal concentrations in a total of 72 infant formulas manufactured by 16 different companies in Turkey and found a mean concentration of As to be 0.529 (range 0.218-1.325 mg/kg). In fact, these values were above the permissible limits recommended by international agencies.

Several animal studies have reported that Cr is toxic, carcinogenic, induced oxidative stress, altered gene expression and induce DNA damage. In this study, high concentrations of Cr were recorded in 12-24 months and mixed-based formulas. The values were greater than that reported by Akpe *et al.* (2021) (0.004±0.001mg/kg) and Sipahi *et al.* (2014) (40.76±59.10 ng/g). Akhtar *et al.* (2017) determined the concentration of some heavy metals in different infant formula brands marketed in Paskitan and reported a mean concentration of Cr to be 0.0002. However, the mean concentrations were lower compared to 0.211 mg/kg (range 0.113-0.339 mg/kg) (Amarh *et al.*, 2023); 0.398 (range 0.009-1.742 mg/kg) (Peirovi-Minaee *et al.*, 2024). Similarly, mean concentrations of 0.21 mg/kg and 3.88 mg/kg for infant formulas sold in Mansoura City, Egypt and Chinese market respectively (Abdelkhalek *et al.*, 2015; Su *et al.*, 2020).

Contamination of Al in infant formulas is a matter of serious public health concern and should be given due consideration. Animal and epidemiological studies have

demonstrated a strong association between exposure to and neurological, hematological, skeletal, immunological and kidney dysfunction (Bondy, 2016; Ogunfowokan *et al.*, 2016; Alejandro *et al.*, 2017; Ibrahim *et al.*, 2022). In this study, the highest mean concentration of Al was observed in 6-12 months and mixed-based formulas and far below the values of 10.37 (6.28-12.88 mg/kg) reported by Ozturk *et al.* (2023) in infant formulas available in Turkish markets. Bosaran (2022) reported 718-698 $\mu\text{g}/\text{kg}$, 189-653 $\mu\text{g}/\text{kg}$ (Chekri *et al.*, 2019) and 1.3-17.7 $\mu\text{g}/\text{kg}$ (de Souza *et al.*, 2019). Our study was consistent with a mean concentration of Al reported by Garuba *et al.* (2024) in processed foods for infants and toddlers collected from local stores in Houston, Texas. Evidence has shown considerable accumulation of Al in the central nervous system of premature infant upon exposure greater than 5 $\mu\text{g}/\text{kg}/\text{day}$ (Klein *et al.*, 1998).

5.2 Concentration of Metals in the Children Food Products

Based on the findings of this study, high concentrations of aluminum, cadmium and chromium were observed in children food products (Figure 1). The highest concentrations of aluminum have been recorded in food samples S1, S2 and S14 (40.0, 25.5 and 13.3 $\mu\text{g}/\text{g}$) respectively. Elevated concentrations of cadmium were observed in children food product samples S21, S22 and S23 (3.8, 4.0 and 4.0 $\mu\text{g}/\text{g}$) respectively. While S5, S14 and S22 have the highest concentrations of chromium 24.3, 1.5 and 1.8 $\mu\text{g}/\text{g}$ respectively. The values recorded in this study were greater than values of Al (4.089 $\mu\text{g}/\text{g}$), Cd (0.017 $\mu\text{g}/\text{g}$) and Cr (0.267 $\mu\text{g}/\text{g}$) recorded by Garuba *et al.* (2024). Remarkably, all the samples having elevated concentrations of the analyzed metals appeared to be plant-based products. Therefore, the contamination may be a result of the food chain contamination during the planting process. Al is considered ubiquitous because it is the third most abundant element in the earth's crust, being unavoidably present in tap water, evaporated salt and in most ingredients, such as flour, and baking powder used in making several foods for our children. Ogunfowokan *et al.* (2016) indicated that Al contamination in Nigerian foods can occur from multiple sources, including packaging, processing equipment, and additives used during food production. Ayanda *et al.* (2019) reported the Cd contamination in various food products in Nigeria, emphasizing the risk posed by foods grown in contaminated soils. This is particularly relevant for grains and cereals, which can absorb Cd from the contaminated environment. Adie and Osibanjo (2009) reported Cr contamination in processed foods in Nigeria, linking it to industrial pollution and the use of contaminated water in food processing.

Pb and As were detected in almost all the samples and the highest concentrations were observed in S5 and S10 (7.3 and 1.8 $\mu\text{g}/\text{g}$ respectively). However, the values were lower than that reported by Alharbi *et al.* (2023) Pb (15.5-11.1 $\mu\text{g}/\text{kg}$) and As (35.2-53.8 $\mu\text{g}/\text{kg}$) in baby foods in the kingdom of Saudi Arabia. Similarly, Ugochukwu *et al.* (2019) reported Pb contamination in most Nigerian foods with elevated Pb levels in various processed foods, including chocolates, which are often consumed by children. Akinyele and Shokunbi (2015) demonstrated similar findings, reporting significant As levels in rice and rice products, which are staples in many Nigerian households. This indicates a widespread issue with As contamination in foods commonly consumed by children. Therefore, presence of these toxic metals in baby foods raise the concerns about their safety for consumption by children and calls for serious regulatory mechanisms to address this menace (Shabita *et al.*, 2020; Igweze *et al.*, 2020; Almutairi *et al.*, 2021).

5.3. Health Risk Assessment

5.3.1. Exposure assessment

The estimated daily and weekly intake values of metals recorded in this study, were assumed to be due to consumption of dry (as sold) undiluted milk-based, cereal-based and mixed-based formulas because deionized water was used in the process. A significant EDI and EWI values observed in this study, though within the proposed Potential Tolerable Daily and Weekly Intakes values for metals set by the Joint Food and Agriculture Organization and the World Health Organization Expert Committee on Food Additives (JECFA, 2011). Ibrahim *et al.* (2020) evaluated the presence of Pb and Hg in infant formulas in Egypt and found the concentrations of these metals to be above the permissible limits and PTWI. Contrarily, a study conducted in Ethiopia, the EDI and HI of Cd, Pb and Zn were lower than the permissible limits and threshold of one (Eticha *et al.*, 2018). The PTWI for Co was determined in 6-12 months formulas as it was not detected in other age stage formulas. Infant and children appeared to eat larger portions of food per body weight ratio compared to adults. Therefore, this tend to expose them to higher dietary risks of exposure to many toxic compounds (Gu *et al.*, 2020; Su *et al.*, 2020; Mielech *et al.*, 2021). Moreover, metals cannot be completely avoided from foods and drinking water due to their natural and anthropogenic sources.

5.3.2. Non-carcinogenic Risk

Based on the target hazard quotient calculated, Cd, As, Pb, Cr and Al were selected for evaluating their non-carcinogenic effects on infant's health upon consumption of infant formulas. Therefore, the THQ of Cd, As, Pb and Al were found to be above threshold of 1 in some

formulas, indicating high potential health risk from consumption of some analyzed infant formulas. Metals like Pb, Cd, As and Al have been reported to be very toxic and induced several metabolic derangements, affecting liver, kidney, skin, nervous, hematopoietic, cardiovascular and reproductive systems (Rabiu *et al.*, 2019). Akpe *et al.* (2021) reported THQ values between nil to 1.04 for some metals in infant formulas in Cross River State Nigeria. Similarly, Peirovi-Minaee *et al.* (2024) reported THQ value for Pb (0-3.067), Cu (0.39-2.44) As (0.15-1.75) and Cd (0.016-5.91) in commercially available infant formulas in Iran. Moreover, in health risk assessment of selected heavy metals in infant food sold in Wa, Ghana, the THQ value for As, Cd, Cr, Ni and Pb were 0.32-3.21, 0.75-1.10, 0.65-1.94, 0.08-0.12 and 0.26-1.13, respectively, indicating potential health risk upon consumption (Amarh *et al.*, 2023). In two different studies in Turkey, the calculated THQ values for all the analyzed metals in the infant formulas appeared less than 1 (Ozturk *et al.*, 2023; Demir and Agaoglu, 2023), thus, indicating that the infant formulas are safe.

5.3.3. Carcinogenic Risk

In principles, carcinogenic risk values are classified as follows: any values between 10^{-4} and 10^{-6} are considered acceptable, lower than 10^{-6} is considered negligible and those above 10^{-6} are considered unacceptable and likely to cause cancer (Ullah *et al.*, 2017). Findings from this study have indicated that As, Cd, Cr and to some extent Pb have a likelihood to cause cancer, provided the infant formula samples used in this study are consumed for long time. The cancer risk values for Cd, Cr and Ni in infant formulas in Iran were reported to be in carcinogenic class (Perovi-Minaee *et al.*, 2024). Amarh *et al.* (2023) reported that all the infant food samples analyzed have likelihood to cause cancer.

It has been observed that, in some communities infant formulas and children food products serve as the major food for infants and children. Therefore, adequate nutritional ingredients and safety of these products must be maintain at all cost. This will ensure proper growth and development of children even to later adult stage. Moreover, proper monitoring and evaluation of the infant and children food products at different manufacturing stages will definitely reduce probabilistic metals contamination and subsequent exposure to the toxic metals.

6.0 CONCLUSION

It is deem necessary to evaluate food contamination, especially in infant formulas and children food products. Selected toxic heavy metals concentration were analyzed and their potential health risk were equally determined.

The findings of this study revealed that a significant concentration of the metals analyzed was detected in all the infant formulas samples. The mean concentration of the metals were in the following order: Cd > Al > Co > Pb > As > Cr. The results further indicate that the concentration of Cd, As, Pb and Al in some samples were above the permissible limits established by WHO. The concentrations of metals in children food products were in the decreasing order of Al > Cd > Cr > Pb > As > Co. Remarkably, all the samples having elevated concentrations of the analyzed metals appeared to be plant-based products. Therefore, the contamination may be a result of the food chain contamination during the planting process. The study also indicated the EWI values calculated for all the metals where within the safe limits set by JECFA compared to the PTWI. Furthermore, the health risk indices estimated, indicated that the THQ values of Cd, As, Pb, and Al were greater than the threshold value of 1. This implies that the infant formulas marketed at the time of this study in the area have likelihood to induce non-carcinogenic health risk over long term consumption. Based on CR values established in this study, Cd, As, Cr and to some extent Pb have values above 10^{-6} . Thus, making them unfit for human consumption and demonstrating potential health risk to infants. Therefore, it is become necessary, to conduct routine assessment and stringent monitoring and full enforcement of regulations to curtail children food contamination due to their high susceptibility to contaminants.

DECLARATION OF COMPETING INTEREST

The authors declared no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

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