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Assessment of Heavy Metal Content in Chicken Eggs and Evaluating Associated Health Risks

S. M. S. Shahriar[1*], M. F. Rabby[1], M. M. Akhtar[1], S. Dipti[1], U. Kulsum[1], M. S. Hossain[1], S. M. A. Salam[1]

[1]Department of Applied Chemistry and Chemical Engineering, University of Rajshahi, Rajshahi-6205, Bangladesh

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Abstract

Chicken eggs are an excellent source of vital nutrients, such as vitamins, minerals, carotenoids, proteins, and healthy fats. Though it can significantly fulfil the nutritional needs of adults and children, the contamination of heavy metals may cause subsequent toxicity to our bodies. The ultimate goal of the experiment is to analyze the amounts of heavy metals (Pb, Cr, Ni, Zn, and Cu) in eggs and their health risk assessments. After the egg samples were processed using a di-acid digestion technique, an AAS was used to evaluate the samples. Here, only the concentrations of Pb and Cr exceeded the maximum permissible range established by WHO/FAO. According to the health risk assessment, the metals in the study (except for Pb) did not individually represent a concern by the target hazard quotient and estimated daily intake. Pb and Cr had threshold carcinogenic risks because their CR values ranged from 10^{-4} to 10^{-6}. Consumers of Ni, which has a CR > 10^{-4}, are thought to pose a carcinogenic risk to adults and children. The quantities of zinc and copper in all examined samples were deemed acceptable for human ingestion. This research provides legislators with precise and trustworthy information to enhance food safety regulations and mitigate public health threats.

Keywords: Chicken eggs; Carcinogenic effects; Heavy metals; Food safety; Risk assessment; Public health.

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1. Introduction

Eggs are a widespread, well-liked, and healthy food that costs less than other forms of animal protein that are equivalent. They are a significant source of key nutrients and constitute a significant part of many diets. They contain all of the necessary amino acids, making them a particularly good source of high-quality, well-balanced proteins. Heavy metals may increase the potential health risks in both animals and humans, despite serving a crucial function as micronutrients [1]. Heavy metals can cause adverse impacts on a variety of biochemical as well as biological processes in people, mainly in children when

* *Corresponding author*: shahan@ru.ac.bd

they are continuously ingested in hazardous amounts through food [2]. The Department of Livestock Services (DLS) reports that in 2021, 121.18 eggs were consumed per person, compared to 104.23 in 2020 and 135 in 2022. Chicken egg is an excellent source of amino acids, but they could pose a consequential prospect to our environment along with human health if they are polluted with hazardous heavy metals resulting from industrial waste, geochemical structures also agricultural operations [3]. Through a variety of mechanisms, heavy metals may interrupt the body's metabolic activity. It has been established that the increase of heavy metals in the body has an undesirable effect on human health. Lead (Pb), arsenic (As), aluminium (Al), iron (Fe), mercury (Hg), cadmium (Cd) etc. are the principal heavy metals which may have negative impacts. Additionally, heavy metals may interact toxically with several compounds found in the body, such as chloride and oxygen [4,5].

The WHO states that lead (Pb) exposure occurs primarily through ingesting substances contaminated with Pb and inhaling lead particles. Metals, mainly lead (Pb), cause toxicity in living cells by following ionic mechanisms and oxidative stress. Small amounts of lead can cause oxidative stress, hypertension, and damage to the blood circulatory system, leading to instantaneous heart attacks and even death. Increased blood circulation levels are substantially linked to increase multiple chronic cardiovascular diseases as well as mortality [5-7]. Chromium (Cr) is typically found in food in trivalent form, the hexavalent form of Cris noxious and carcinogenic to the human body as a consequence of its oxidizing capability along with easy membrane permeability. High doses of Cr(VI) can cause gastrointestinal bleeding and kidney tubule necrosis, highlighting the need for careful consumption to avoid potential health issues [8,9]. An allergic reaction has the most frequent negative impact of nickel (Ni) on human bodies. The preliminary symptoms of overexposure are dizziness, headache, vomiting, nausea as well as shortness of breath; coughing, chest pain, bluish discoloration of the skin, and in a few cases convulsions, delirium, and even death could be delayed effects [10,11]. It is widely known that domestic and research animals develop slower and consume less feed if their diets are lacking or high in minerals such as zinc (Zn) [12,13]. The long-term effects of copper dust exposure include headache, nausea, dizziness, and diarrhea, in addition to irritation of the nose, mouth, and eyes [12,13].

According to Ullah *et al*. [14] amounts of Cd, Pb, As, Mn, Hg, Cr, Fe, and Zn were found to be between 0.01 and 0.15, 0.02 and 0.67, 0.04 and 0.06, 2.5 and 38.6, 0.15 and 0.15, 0.01 and 0.15, and 1.02 and 19.4 mg/kg-fw, respectively, in the hen eggs and chicken meat samples those were thoroughly collected from nationally representative samples of poultry. Only Pb, according to the findings, was found to be above the maximum permissible range of dietary foodstuffs. The risks to human wellness attributed to dietary exposure to particular metals via hen eggs and chicken meat were assessed using the estimated daily intake (EDI), target hazard quotient (THQ) for carcinogenic and non-carcinogenic risks of individual heavy metals, total target hazard quotient (TTHQ) for combined metals, target carcinogenic risk (TCR), and cumulative carcinogenic risk (CCR) for lifetime exposure to evaluate the dangers to human health associated with dietary intake of these metals through eating chicken meat and eggs over a person's lifetime. The figured values of EDI, THQ, TTHQ, TCR, and CCR were under the corresponding range indicating safe intake of inspected food items though they are heavy metal contaminated [14-16].

The exemption to heavy metals in the environment around the world has given rise to concerns about food contamination, especially about the metal content in eggs, which are a significant component of the diet of most people, mainly children. Though environmental scientists, nutritionists, and chicken breeders are all very interested in the trace element content of eggs, there isn't much information about it that is readily accessible. Egg quality was evaluated to assess potential risks to human health based on heavy metal concentrations, given their cumulative negative effects. To our knowledge, no comprehensive health risk assessment has yet been conducted to estimate the carcinogenic and non-carcinogenic risks for infants and adults from consuming eggs in Bangladesh. Additionally, it is crucial to monitor heavy metal concentrations in chicken eggs over time, as contamination in both the environment and the food chain is increasing. Therefore, the goals of this study are: (i) to measure the concentrations of heavy metals (Pb, Cr, Ni, Zn, and Cu) in chicken eggs, including separate assessments of the albumen and yolk; and (ii) to estimate the carcinogenic and non-carcinogenic health risks associated with these heavy metals in the sampled eggs.

2. Materials and Methods

2.1. *Study area and sample collection*

Rajshahi is a significant metropolis and an important urban, commercial, and educational center in Bangladesh. Rajshahi is located 23 meters (75 ft) above sea level within the Barind Tract, at 24°22′26″N 88°36′04″E. The Padma River, which flows through the southern part of the city, has alluvial plains through which the city is situated. Pabna Upazila, a district-level subdivision, forms its borders in the district's east, north, and west. The study area is spread across five locations of Rajshahi City Corporation areas. The boiler chicken eggs were collected directly from the local market between October 2022 and November 2022. Moreover, three samples (n=3) were gathered from each location to determine the standard deviation. The sample collection locations are given in Table 1 and Fig. 1. The sample analysis was accomplished in December 2022 at the central science laboratory of the University of Rajshahi, Rajshahi, Bangladesh.

Table 1. Egg samples gathered from different points in Rajshahi City Corporation.

Sample Identification (Id) No.		Location of Collection
Albumen	Yolk	
M-1-A	M-1-Y	Meherchandi (24°22'44"N 88°38'41"E)
M-2-A	M-2-Y	Meherchandi (24°22'34"N 88°38'38"E)
K-1-A	K-1-Y	Kadirganj (24°22'33"N 88°35'45"E)
K-2-A	K-2-Y	Kadirganj (24°22'29"N 88°35'53"E)
L-1-A	L-1-Y	Laxmipur (24°22'29"N 88°34'24"E)
L-2-A	L-2-Y	Laxmipur (24°22'27"N 88°34'32"E)
Sb-1-A	Sb-1-Y	Shaheb Bazar (24°21'55"N 88°35'55"E)

Sb-2-A	Sb-2-Y	Shaheb Bazar (24°21'54"N 88°36'00"E)
S-1-A	S-1-Y	Sapura (24°23'13"N 88°35'58"E)
S-2-A	S-2-Y	Sapura (24°23'10"N 88°36'13"E)

2.2. *Sample digestion*

Through the wet digestion method, heavy metal levels in the tested eggs were assessed [17]. 1 g of each sample (albumen and yolk) was weighed to the digital balance and taken to the 100 mL glass beaker separately. After measuring the sample, 8 mL of nitric acid (69 % HNO_3) and 2 mL of peroxide (30 % H_2O_2) were added to it. After 30 min of waiting, 3 mL $HClO_4$ (70 %) was also added, and the beaker was covered by a watch glass. Then the sample was allowed to soak in the chemicals overnight at room temperature. The next day, a sample containing the beaker was put down on the hot plate and raised the temperature from 120 to 150 °C until the specimen was entirely digested, then reduce the dose to 1-3 mL. Following digestion and appropriate cooling, the resulting mixture was diluted with 10-15 mL of deionized water. Afterwards, solutions were subsequently filtered through the 42-Whatman filtering paper. Using a volumetric flask that had been washed with acid, the mixture was eventually adjusted to 100 mL adding deionized water. The concentrations of heavy metals (Pb, Cr, Ni, Zn, and Cu) were estimated with the help of atomic absorption spectrophotometer (AAS) by using the standard method.

2.3. *Analysis of heavy metals*

The contents of Cr, Ni, Pb, Zn, as well as Cu in the filtrate of digested egg samples were estimated by using AAS (Model No. AA-6650, Shimadzu). A special lamp comprised of a specific metal was attached to the instrument. The equipment was calibrated using drift blanks and manually prepared standard solutions of the respective heavy metals. For all the metals, benchmark stock solutions with a concentration of 1000 ppm were supplied by Kanto Chemical Co. Inc., Tokyo, Japan. To calibrate the instrument, the concentration of these solutions was diluted to the required level. The working conditions and Limit of Detection (LOD) of AAS are displayed in Table 2.

Table 2. Shimadzu AA-6650 AAS working conditions and LOD.

Element	Wavelength (nm)	Slit width (nm)	Lamp current (mA)	Atomizer	LOD (mg/L)
Pb	283.3	0.7	10	Flame	0.052
Cr	357.9	0.5	10	Flame	0.078
Ni	232.0	0.2	12	Flame	0.140
Zn	213.9	0.7	8	Flame	0.018
Cu	324.48	0.7	6	Flame	0.077

3. Health Risk Assessment (HRA)

A method of determining the kind and likelihood of adverse health hazards in people who might have been in contact with chemicals or additional contaminants in their surroundings is known as human health risk assessment. A health questionnaire known as "health risk assessment" (HRA) is primarily developed to deliver people an assessment of their health risks and quality of life [18].

3.1. *Estimated daily intake (EDI)*

The concentration of toxic heavy metals found in eggs and the daily consumption rate of eggs were related to the EDI of heavy metal contaminants via the gastrointestinal route. In addition, a person's body weight may play a vital part in their susceptibility to contaminants. All three of these parameters are taken into consideration by the EDI. The adult EDI value was computed using equation (Eq. 1) [6,19].

$$EDI = \frac{C \times IR_d}{B_w} \quad (1)$$

Where, C stands for the concentrations of heavy metals in egg samples (mg/kg), IR_d is the daily consumption rate (g/day), and body weight (kg) is represented by B_w. The daily ingesting of eggs (17 g for kids and 32 g for adults as well) increases the body's absorption of minor metals [20]. The mean value of B_w was considered to 60 kg for adults as well as 25 kg for children.

3.2. *Non carcinogenic risk*

3.2.1. *Target hazard quotient (THQ)*

The proportion between the amount that was subjected to the hazardous element and the recommended quantity is known as Target Hazard Quotient (THQ), indicating the maximum value that does not imply negative health repercussions are anticipated. THQ is a possible way to convey a heavy metal's potential non-cancerous consequences. The THQ values were calculated by dividing the metal's EDI value (mg/kg of weight of the individual per day) by the reference value (R_fD, mg/kg per day) of the metal (Eq. 2) [21].

$$THQ = \frac{EDI}{R_f D} \quad (2)$$

Pb, Cr, Ni, Zn, and Cu each have $R_f D$ values established at 4×10^{-3}, 3×10^{-3}, 0.02, 0.3, and 0.04 mg/kg/day respectively [22-23]. When THQ is less than 1, people who are exposed are not expected to experience negative effects right away. If THQ is greater or equal to 1, this may lead to a serious health concern and proper preventative measures ought to be implemented [21].

3.2.2 *Total target hazard quotient (TTHQ)*

The THQs for each of the heavy metals are summed up to evaluate the TTHQ. The TTHQ was determined by using Eq. 3 [24].

$$TTHQ = THQ_{Pb} + THQ_{Cr} + THQ_{Ni} + THQ_{Zn} + THQ_{Cu} \quad (3)$$

While TTHQ is a value below 1, it's doubtful that there will be negative consequences, however, if TTHQ is above or equal to 1, negative effects might occur, and when TTHQ is greater than 10, the chance of chronic or even acute negative health impacts is significant [25].

3.3. ***Carcinogenic risk***

3.3.1. *Target carcinogenic risk (TCR)*

Taking into account Eq. 4 from the dependent on risk level table for Region III of the USEPA [26-28], the TCR produced by toxic metal ingestion was identified.

$$TCR = \frac{EFr \times ED \times FIR \times C \times CSFo}{Bw \times AT} \times 10^{-3} \quad (4)$$

Where, AT represents the annual average exposure to carcinogens (365 days), TCR correspond to the target threat of cancer or overall cancer risk, while CSF_o stands for the oral carcinogenic slope factor. The CSF_o for Pb, Cr, Ni, Zn, and Cu value of this factor is 0.0085, 0.5, 0.91, 0 and 0 mg/kg/day respectively [26,29,30]. The CSF_o of Zn and Cu is 0 mg/kg/day, so, in the present study, the heavy metals Pb, Cr, and Ni along with CSF_o, were considered into account to determine carcinogenic risk.

3.3.2. *Cumulative carcinogenic risk (CCR)*

The CCR for Pb, Cr, and Ni was then calculated using Eq. 5 based on the consumption of metal(oids), which may promote carcinogenic risk according to intake quantity [26,27,31].

$$CCR = \sum_{n=1}^{i} TCR_n \quad (5)$$

Here, $i = 1, 2, 3, \dots \dots\ n$ and n denotes the number of heavy metals taken into account when calculating cancer risk, while TCR stands for the target threat of cancer. The TR resulting from the intake of Pb, Cr and Ni was calculated since these metals may have either carcinogenic or non-carcinogenic impacts according to their intake amount. When TCR and/or CCR surpass 10^{-4}, an individual with exposure is at significant risk for developing cancer, in contrast to when TCR and/or CCR have values lower than 10^{-6}. Additionally, the subjected people are at threshold cancer risk if TCR and/or CCR values are in between 10^{-4} and 10^{-6} [27].

4. Statistical Analysis

The SPSS statistical program, version 18, was used to conduct the statistical analysis. Standard deviation (SD) was used to express all values. The level of p value at * ≤ 0.05, ** ≤ 0.01, and *** ≤ 0.001 were used to indicate significant differences among the samples (n=3).

5. Result and Discussion

5.1. ***Heavy metals***

The amount of Pb, Cr, Ni, Zn, and Cu in egg samples (albumen and yolk) and their maximum level of concentration (Max), minimum concentration (Min), mean concentrations of individual heavy metals, mean concentrations of individual heavy metals in whole egg, percentage relative standard deviations (%RSD) as well as Standard Deviations (SD) are displayed in Tables 3 and 4. The measurements were made in mg/kg of the albumen and yolk samples of the eggs.

Table 3. Heavy metal concentrations (mg/kg) in egg albumen.

Sample Id	Metal concentrations (mg/kg) in egg albumen				
	Pb	Cr	Ni	Zn	Cu
M-1-A	9.362±0.83***	BDL	1.319±0.04***	2.522±0.15***	1.726±0.08***
M-2-A	6.072±0.54***	0.593±0.06***	1.038±0.01***	2.843±0.19***	0.474±0.03***
K-1-A	4.363±0.36***	BDL	BDL	0.540±0.04***	0.317±0.02***
K-2-A	3.497±0.24***	BDL	BDL	2.722±0.15***	0.546±0.04***
L-1-A	6.083±0.54***	0.427±0.03***	0.377±0.02***	5.893±0.69***	1.966±0.09***
L-2-A	4.475±0.32***	0.682±0.04***	0.564±0.05***	3.043±0.27***	1.721±0.06***
Sb-1-A	6.964±0.58***	0.595±0.03***	0.823±0.04***	2.902±0.28***	2.279±0.15***
Sb-2-A	1.742±0.05***	BDL	0.663±0.03***	2.145±0.21***	2.436±0.23***
S-1-A	2.614±0.17***	0.853±0.07***	1.696±0.01***	3.303±0.23***	2.440±0.14***
S-2-A	5.175±0.42***	0.596±0.04***	1.133±0.11***	4.402±0.38***	2.525±0.27***
Min	1.742	0.427	0.377	0.540	0.317
Max	9.362	0.853	1.696	5.893	2.525
Mean	5.031	0.535	0.846	3.029	1.643
SD	2.223	0.268	0.514	1.395	0.875
%RSD	44.19	50.10	60.78	46.08	53.26
AL	0.5	0.002	1.65	20	10

BDL = below detection limit, Min = minimum, Max = Maximum, SD = Standard deviation, %RSD = percentage relative standard deviations, AL = Acceptable limit for chicken eggs [32- 34]. Results are shown as mean ± SD, where the sample size is 3 (n=3). The p value at * ≤ 0.05, ** ≤ 0.01 and *** ≤ 0.001 were used to indicate significant differences.

Table 4. Heavy metal concentrations (mg/kg) in egg yolk.

Sample Id	Metal concentration (mg/kg) in egg yolk				
	Pb	Cr	Ni	Zn	Cu
M-1-Y	4.365±0.37***	BDL	1.508±0.06***	12.21±1.14***	0.704±0.06***
M-2-Y	1.739±0.07***	BDL	2.441±0.13***	11.79±1.08***	1.097±0.02***
K-1-Y	3.489±0.28***	BDL	0.476±0.03**	11.62±1.07***	3.173±0.43*
K-2-Y	4.365±0.37***	BDL	0.099±0.01***	15.19±1.68**	2.381±0.35***
L-1-Y	4.369±o.38**	0.685±0.05***	BDL	13.75±1.14***	8.640±0.73***
L-2-Y	6.083±0.54***	0.514±0.04***	BDL	13.97±1.15**	1.721±0.06***
Sb-1-Y	6.967±0.55***	0.178±0.01***	0.753±0.03***	15.67±1.34***	2.597±0.15***
Sb-2-Y	6.96±0.55***	BDL	0.564±0.02***	13.64±1.33***	1.723±0.18***
S-1-Y	3.492±0.27*	0.685±0.05***	0.288±0.01***	14.40±1.39***	2.827±0.17*
S-2-Y	5.239±0.42***	0.944±0.08***	0.378±0.02***	16.00±1.54**	2.286±0.28***
Min	1.739	0.178	0.099	11.62	0.704
Max	6.967	0.944	2.441	16.00	8.640
Mean	4.706	0.601	0.813	13.824	2.715
MWE	9.737	1.136	1.659	16.853	4.358
SD	1.649	0.282	0.782	1.563	2.217
%RSD	35.04	46.92	96.22	11.31	81.69

AL	0.5	0.002	1.65	20	10

BDL = below detection limit, Min = minimum, Max = maximum, MWE = mean concentrations of individual heavy metals in whole egg, SD = standard deviation, %RSD = percentage relative standard deviations, AL = acceptable limit for chicken eggs [32-34]. Results are shown as mean ± SD, where the sample size is 3 (n=3). The p value at * ≤ 0.05, ** ≤ 0.01 and *** ≤ 0.001 were used to indicate significant differences.

The concentrations of Pb in albumen and yolk were ranged from 1.742 mg/kg to 9.362 mg/kg and 1.739 mg/kg to 6.967 mg/kg, respectively. The maximum amount of Pb was identified in sample M-1-A (9.362 mg/kg), while the minimum value was estimated in sample Sb-2-A (1.742 mg/kg). However, for the yolk, sample Sb-1-Y has the greatest content (6.967 mg/kg) and sample M-2-Y has the lowest value (1.739 mg/kg). The acceptable limit of Pb provided by the World Health Organization (WHO) is 0.5 mg/kg for chicken eggs [32-34]. This study found that 100 % of albumin and yolk samples exceeded the acceptable limit for Pb. This finding of the current research is higher than the findings of Kabeer *et al.* [32], Ardakani [33], Islam *et al.* [34], Chowdhury *et al.* [35], and Farahani *et al.* [36]. The higher concentration of Pb in broiler chicken eggs may be caused by the contaminated feed and closeness of poultry farms to the industrial area. According to Kan and Meijern [37], enhanced Pb levels in eggs are proportional to the concentration of Pb in feed.

The obtained samples had Cr values ranging from 0.427 mg/kg to 0.853 mg/kg for albumen and for yolk 0.178 mg/kg to 0.944 mg/kg. The maximum concentration of Cr in albumen was identified in sample S-1-A (0.853 mg/kg), while the lowest value was found in samples L-1-A (0.427 mg/kg). However, for the yolk, sample S-2-Y has the greatest content (0.944 mg/kg) and sample Sb-1-Y have the lowest value (0.178 mg/kg). The Cr concentration in 40 % albumen and 50 % yolk samples was undetectable, but the rest of the samples exceeded the maximum permissible limit, which is 0.002 mg/kg [32-34]. Sarkar [38] found the mean concentration of Cr in albumen and yolk 0.920 and 0.694 ppm respectively, which are higher than the current study. This research's results are higher than those of Kabeer *et al.* [32] and Ardakani [33]. The mean concentration of Cr in egg yolk was higher than in egg white, similar to that reported by Kabeer *et al.* [32]. Kan and Meijer [37] state that higher Cr content in eggs correlates positively with higher Cr level in the feed.

The Ni contents of the samples varied from 0.377 to 1.696 mg/kg for albumen and 0.099 to 2.441 mg/kg for the yolk. The maximum concentration of Ni in albumen was identified in sample S-1-A, while the lowest value was found in sample L-1-A. However, for the yolk, sample M-2-Y has the greatest content and sample K-2-Y has the lowest value. The acceptable limit of Ni is set at 1.65 mg/kg for the chicken egg [32]. In the study, all the albumen and yolk samples were separately under the permissible limit except S-1-A and M-2-Y. However, the mean concentration of Ni in the whole egg was the same as the permissible limit. The mean concentrations of Ni in albumen and yolk of the current research are higher than the findings of Kabeer *et al.* [32]. The findings of the current studies are lower than the findings of Chowdhury *et al.* [35], Sarkar [38], and Demirulus [39].

According to Demirulus [39], the increased intake of feed polluted with nickel is a contributing factor in the greater levels of nickel found in eggs.

Zn is a necessary metal for human intake in tiny amounts, but excessive amounts can seriously harm the liver and digestive system [32]. Zn levels in the obtained samples varied from 0.54 to 5.89 mg/kg for albumen and 11.62 to 16.00 mg/kg for yolk. The highest concentration of Zn in albumen was identified in sample L-1-A, while the lowest value was found in samples K-1-A. However, for the yolk, sample S-2-Y has the greatest content, and sample K-1-Y has the lowest value. All the eggs under evaluation fell within the acceptable limit of Zn (20 mg/kg) developed by FAO/WHO [32,34]. This study's mean level of Zn in albumen and yolk is higher than the results of Kabeer *et al.* [32], and Islam *et al.* [34]. The development of the current research is lower than that of Chowdhury *et al.* [35] and Demirulus [39]. Samad *et al.* [40] summarized that the higher Zn contamination in eggs is primarily due to a higher intake of contaminated feed.

Cu is another essential element for humans and animals, but when levels are exceeded, it can deposit and harm the liver of humans [41]. The obtained samples had a range of Cu content, from 0.317 to 2.525 mg/kg for albumen and 0.704 to 8.640 mg/kg for yolk. The maximum concentration of Cu albumen was identified in sample S-2-A, while the lowest value was found in sample K-1-A. However, for the yolk, sample L-1-Y has the greatest content, and sample M-1-Y has the lowest value. According to statistical analysis, the mean Cu concentrations in the albumen, yolk, and whole egg are within acceptable ranges (10 mg/kg) set by the WHO [32,35]. This study found Cu concentration in egg albumen and yolk higher than the results of Kabeer *et al.* [32], Chowdhury *et al.* [35], Sarkar [38], and Demirulus [39], but lower than the findings of Islam *et al.* [34] and Ardakani [33]. This study found that the mean concentration in egg yolk was comparatively higher than egg white, which was also reported by Kabeer *et al.* [32].

5.2. ***Health risk assessment***

To determine the degree of health risk resulting from contaminants like heavy metals in chicken eggs collected from the Rajshahi City Corporation area, EDI was evaluated assuming that the neighbourhood's residents only eat locally produced chicken eggs. The EDI of those heavy metals from consuming eggs by adults and children of the Rajshahi City Corporation area are displayed in Table 5.

Table 5. The EDI of heavy metals by consuming eggs for adults and children.

Sample Id	EDI (mg/kg/day)									
	Pb		Cr		Ni		Zn		Cu	
	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child
M-1-A	0.00461	0.00636	-	-	0.00065	0.00089	0.00124	0.00171	0.00085	0.00117
M-2-A	0.00299	0.00413	0.00029	0.00040	0.00051	0.00071	0.00140	0.00193	0.00023	0.00032
K-1-A	0.00215	0.00296	-	-	-	-	0.00027	0.00037	0.00016	0.00022
K-2-A	0.00172	0.00237	-	-	-	-	0.00134	0.00185	0.00027	0.00037
L-1-A	0.00299	0.00413	0.00021	0.00029	0.00019	0.00026	0.00290	0.00401	0.00097	0.00134
L-2-A	0.00220	0.00304	0.00034	0.00046	0.00028	0.00038	0.00150	0.00207	0.00085	0.00117
Sb-1-A	0.00343	0.00473	0.00029	0.00041	0.00041	0.00056	0.00143	0.00197	0.00112	0.00155

Sb-2-A	0.00086	0.00118	-	-	0.00033	0.00045	0.00105	0.00146	0.00120	0.00166
S-1-A	0.00128	0.00177	0.00042	0.00058	0.00084	0.00115	0.00162	0.00224	0.00120	0.00166
S-2-A	0.00255	0.00352	0.00029	0.00041	0.00056	0.00077	0.00217	0.00299	0.00124	0.00172
M-1-Y	0.00215	0.00297	-	-	0.00074	0.00103	0.00601	0.00830	0.00035	0.00048
M-2-Y	0.00086	0.00118	-	-	0.00120	0.00166	0.00580	0.00802	0.00054	0.00075
K-1-Y	0.00172	0.00237	-	-	0.00023	0.00032	0.00572	0.00790	0.00156	0.00216
K-2-Y	0.00215	0.00297	-	-	0.00005	0.00007	0.00748	0.01030	0.00117	0.00162
L-1-Y	0.00215	0.00297	0.00034	0.00047	-	-	0.00677	0.00935	0.00425	0.00588
L-2-Y	0.00299	0.00414	0.00025	0.00035	-	-	0.00688	0.00950	0.00085	0.00117
Sb-1-Y	0.00343	0.00474	0.00009	0.00012	0.00037	0.00051	0.00771	0.01070	0.00128	0.00177
Sb-2-Y	0.00343	0.00473	-	-	0.00028	0.00038	0.00672	0.00928	0.00085	0.00117
S-1-Y	0.00172	0.00237	0.00034	0.00047	0.00014	0.00019	0.00709	0.00979	0.00139	0.00192
S-2-Y	0.00258	0.00356	0.00047	0.00064	0.00019	0.00026	0.00788	0.01090	0.00113	0.00155
PTDI	0.003		0.0028		0.0167		0.2		0.1667	
TDI	0.0036		1.5		0.02		-		0.04	

The EDI of Pb, Cr, Ni, Zn, and Cu from egg samples varied from 1.28×10^{-3} to 4.61×10^{-3}, 0.00 to 4.65×10^{-4}, 0.00 to 1.20×10^{-3}, 2.66×10^{-4} to 7.88×10^{-3}, and 9.68×10^{-4} to 4.25×10^{-3} mg/kg-day, respectively, for the adult people of those considered area. For children, EDI varied from 1.18×10^{-3} to 6.36×10^{-3}, 0.00 to 6.42×10^{-4}, 0.00 to 1.66×10^{-3}, 3.67×10^{-4} to 1.09×10^{-2}, and 7.46×10^{-4} to 5.88×10^{-3} mg/kg/day, respectively, for Pb, Cr, Ni, Zn, and Cu. The provisional tolerable daily intake (PTDI) limits for Pb, Cr, Ni, Zn and Cu are 0.003 [41], 0.0028 [42], 0.0167 [43], 0.2 [44] and 0.1667 mg/kg-day [45] respectively. The tolerated daily intake (TDI) values are 0.0036, 1.5, 0.02 and 0.04 mg/kg-day for Pb, Cr, Ni, and Cu respectively [45,46]. This study revealed that the EDI values for Pb, 20 % of the sample, exceeded the PTDI and TDI for adults. For children, 50 % of the sample exceeded the PTDI, and 35 % of the sample exceeded the TDI, which may indicate that the intake of Pb through tested egg consumption has potential health effects. The EDI for Cr, Ni, Zn, and Cu in the tested egg samples was considerably lower than the PTDI and TDI limits, and this could imply that getting Ni, Zn, and Cu from eggs has no negative health consequences.

Table 6. The THQ and TTHQ of heavy metals by consuming eggs for adults and children.

Sample Id No.	THQ										TTHQ	
	Pb		Cr		Ni		Zn		Cu			
	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child
M-1-A	1.152	1.591	-	-	0.032	0.045	0.004	0.057	0.021	0.029	1.209	1.722
M-2-A	0.747	1.032	0.097	0.134	0.026	0.035	0.005	0.064	0.006	0.008	0.881	1.273
K-1-A	0.537	0.741	-	-	-	-	0.009	0.012	0.004	0.005	0.550	0.758
K-2-A	0.43	0.593	-	-	-	-	0.004	0.062	0.007	0.009	0.441	0.664
L-1-A	0.748	1.034	0.07	0.097	0.009	0.013	0.01	0.134	0.024	0.033	0.861	1.311
L-2-A	0.55	0.76	0.112	0.155	0.014	0.019	0.005	0.069	0.021	0.029	0.702	1.032

Sb-1-A	0.857	1.183	0.098	0.135	0.02	0.028	0.005	0.066	0.028	0.039	1.008	1.451
Sb-2-A	0.214	0.296	-	-	0.016	0.023	0.004	0.049	0.03	0.041	0.264	0.409
S-1-A	0.321	0.444	0.14	0.193	0.042	0.058	0.005	0.075	0.03	0.041	0.538	0.811
S-2-A	0.636	0.879	0.098	0.135	0.028	0.039	0.007	0.1	0.031	0.043	0.800	1.196
M-1-Y	0.537	0.742	-	-	0.037	0.051	0.02	0.277	0.009	0.012	0.603	1.082
M-2-Y	0.214	0.296	-	-	0.06	0.083	0.019	0.267	0.014	0.019	0.307	0.665
K-1-Y	0.429	0.593	-	-	0.012	0.016	0.019	0.263	0.039	0.054	0.499	0.926
K-2-Y	0.537	0.742	-	-	0.002	0.003	0.025	0.344	0.029	0.04	0.593	1.129
L-1-Y	0.538	0.743	0.112	0.155	-	-	0.023	0.312	0.106	0.147	0.779	1.357
L-2-Y	0.749	1.034	0.084	0.117	-	-	0.023	0.317	0.021	0.029	0.877	1.497
Sb-1-Y	0.857	1.184	0.029	0.04	0.019	0.026	0.026	0.355	0.032	0.044	0.963	1.649
Sb-2-Y	0.857	1.183	-	-	0.014	0.019	0.022	0.309	0.021	0.029	0.914	1.540
S-1-Y	0.43	0.594	0.112	0.155	0.007	0.01	0.024	0.326	0.035	0.048	0.608	1.133
S-2-Y	0.645	0.891	0.155	0.214	0.009	0.013	0.026	0.363	0.028	0.039	0.863	1.520

Table 6 shows the THQ of observed heavy metals in eggs of different types in each area. The THQ value for Pb was more than unity in 5 % samples for adults and 35 % samples for children, which is considered unsafe for consumption. Therefore, the consumers are at risk of Pb, which can cause non-carcinogenic risks to the consumers. At the same time, the THQ value for Cr, Ni, Zn, and Cu is less than 1, which is considered safe for human consumption. The value of TTHQ is greater than 1 in 10 % of egg samples for adult consumers and greater than 1 in 70 % of samples for children. This signifies the possibility of adverse consequences for children.

Table 7. The TCR and CCR of heavy metals by consuming eggs for children and adults.

Sample Id No.	TCR						CCR	
	Pb		Cr		Ni			
	Adult	Child	Adult	Child	Adult	Child	Adult	Child
M-1-A	3.92E-5	5.41E-5	-	-	5.91E-4	8.16E-4	6.30E-4	8.70E-4
M-2-A	2.54E-5	3.51E-5	1.46E-4	2.02E-4	4.65E-4	6.42E-4	6.36E-4	8.79E-4
K-1-A	1.82E-5	2.52E-5	-	-	-	-	1.82E-5	2.52E-5
K-2-A	1.46E-5	2.02E-5	-	-	-	-	1.46E-5	2.02E-5
L-1-A	2.54E-5	3.51E-5	1.05E-4	1.45E-4	1.69E-4	2.33E-4	2.99E-4	4.13E-4
L-2-A	1.87E-5	2.58E-5	1.68E-4	2.32E-4	2.53E-4	3.49E-4	4.40E-4	6.07E-4
Sb-1-A	2.91E-5	4.02E-5	1.46E-4	2.02E-4	3.69E-4	5.09E-4	5.44E-4	7.51E-4
Sb-2-A	7.28E-6	1.01E-5	-	-	2.97E-4	4.10E-4	3.04E-4	4.20E-4
S-1-A	1.09E-5	1.51E-5	2.10E-4	2.90E-4	7.60E-4	1.05E-3	9.81E-4	1.36E-3
S-2-A	2.16E-5	2.99E-5	1.47E-4	2.03E-4	5.08E-4	7.01E-4	6.77E-4	9.34E-4
M-1-Y	1.83E-5	2.52E-5	-	-	6.76E-4	9.33E-4	6.94E-4	9.58E-4
M-2- Y	7.28E-6	1.01E-5	-	-	1.09E-3	1.51E-3	1.10E-3	1.52E-3
K-1-Y	1.46E-5	2.02E-5	-	-	2.13E-4	2.95E-4	2.28E-4	3.15E-4
K-2-Y	1.83E-5	2.52E-5	-	-	4.44E-5	6.13E-5	6.27E-5	8.65E-5
L-1-Y	1.83E-5	2.53E-5	1.69E-4	2.33E-4	-	-	1.87E-4	2.58E-4
L-2-Y	2.55E-5	3.52E-5	1.27E-4	1.75E-4	-	-	1.53E-4	2.10E-4
Sb-1-Y	2.92E-5	4.03E-5	4.38E-5	6.05E-5	3.37E-4	4.66E-4	4.10E-4	5.67E-4
Sb-2-Y	2.91E-5	4.02E-5	-	-	2.53E-4	3.49E-4	2.82E-4	3.89E-4
S-1-Y	1.46E-5	2.02E-5	1.69E-4	2.33E-4	1.29E-4	1.78E-4	3.13E-4	4.31E-4
S-2-Y	2.19E-5	3.03E-5	2.32E-4	3.21E-4	1.69E-4	2.34E-4	4.23E-4	5.85E-4

The TCR and CCR of Pb, Cr, and Ni caused by the consumption of chicken eggs is estimated and presented in Table 7. If TCR or CR is greater than 10^{-4}, the people who are exposed can be at a serious carcinogenic risk; however, when TCR or CCR is less than 10^{-6}, the exposed people are not in a significant risk. Furthermore, when the value of TCR or CCR is from 10^{-4} to 10^{-6}, it is considered to be in permissible range [38]. The TCR values of Pb were 7.28×10^{-6} to 3.92×10^{-5} for adults and 1.01×10^{-5} to 5.41×10^{-5} for children, in case of Cr, the values ranged from 4.38×10^{-5} to 2.32×10^{-4} for adult and 6.05×10^{-5} to 3.21×10^{-4} for children and Ni were from 4.44×10^{-5} to 1.09×10^{-3} for adults and 6.13×10^{-5} to 1.51×10^{-3} for children. TCR values for Pb and Cr were between 10^{-4} to 10^{-6} values, hence, they are threshold carcinogenic hazards. In the case of Ni, calculated TCR values were higher than 10^{-4} in 95 % of samples for both children and adults. The CCR found greater than 10^{-4} in 85 % of the samples, both for adults and children. According to the TCR and CCR, tested egg samples are considered for consumers to be at considerable carcinogenic health risk.

6. Conclusion

According to the consequences of this study, the selected metal concentrations in the chicken eggs were statistically significant. Pb, Cr, Ni, Zn, and Cu concentrations were measured in several egg samples (both albumen and yolk) that were consumed in various areas of Rajshahi City, Bangladesh. The heavy metal concentrations (Ni, Zn, and Cu) were measured within the limits, while the detected concentrations of Pb and some samples of Cr in the eggs exceeded guideline values. In comparison with egg albumen, which had a higher quantity of Pb, egg yolks had greater amounts of Cr, Ni, Zn, and Cu. The EDI of heavy metals for adults in the area was lower than the WHO-recommended acceptable daily intakes for all metals except Pb. Surprisingly, children have a higher EDI for all metals in the egg than adults. The THQ values of the metals for all of the locations were below 1 (except Pb). This indicates that metals pose no risk separately except Pb. This study also mentioned that the consumption of contaminated eggs can pose potential human health risks based on the TTHQ determination. Pb and Cr were threshold carcinogenic risks because their TCR values ranged from 10^{-4} to 10^{-6}. In the case of Ni, in 95 % of samples, computed TCR values were higher than 10^{-4}, which is regarded as placing consumers, including adults and children, at significant risk for developing cancer. Additionally, the CCR values demonstrate that consumers from the studied egg samples are believed to be at substantial carcinogenic risk. To protect the public's health, it would appear that frequent national inspections of the poultry feed supply chain, in particular, should be given considerable consideration. In conclusion, the presence of heavy metals in eggs emphasizes the importance of robust, frequent national monitoring of egg contamination as well as the quality of safe animal feed as a major source of contamination. As a result, a more complete assessment is required to give the correct direction for regulatory agencies in the country for the benefit of a healthy nation, particularly one free of heavy metal poisoning.

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