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HEALTH RISK ASSESSMENT OF LEAD IN DAIRY PRODUCTS FROM VARIOUS ENVIRONMENTS IN EGYPT

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ABSTRACT. Milk and dairy products are nutritious foods that are beneficial to human health at all life stages and provide essential nutrients required by the body. However, despite their importance, these products are susceptible to contamination by toxic environmental pollutants, such as lead (Pb), originating from surrounding environmental sources. This study aimed to evaluate the potential health risks associated with Pb exposure in adults and children through the consumption of contaminated milk and dairy products from various locations in Egypt using estimated daily intake, target hazard quotient, and excess cancer risk metrics. The data indicated that the daily intake (DI) of Pb in the raw milk samples ranged from 131.6 to 557.9 µg in industrial areas, 107.7 to 456.6 µg in traffic areas, and 35.8 to 151.7 µg in rural areas. In contrast, the DI of Pb in sterilised milk ranged from 19.3 to 82.0 µg in industrial areas, 17.9 to 75.7 µg in traffic areas, and 16.0 to 67.8 µg in rural areas. For processed cheese, values ranging from 2.0 to 2.4, 2.5 to 2.9, and 2.4 to 2.8 µg were found across these areas, respectively. The mean DI values of Pb were 70.1, 59.7, and 11.5 µg for Domiati cheese samples and 112.2, 103.7, and 481.6 µg for Ras cheese from industrial, traffic, and rural areas, respectively. The measured health risk indices showed no significant risks associated with the consumption of the dairy products examined, except for raw milk, particularly when consumed in large quantities from industrial and traffic areas. Purchasing raw milk from contaminated industrial or traffic zones should be avoided to limit its consumption, particularly for children.

Keywords: dairy products; lead; risk assessment.

INTRODUCTION

Milk and dairy products are among the most important natural foods for humans at all stages of life, as they contain most of the body's essential nutrients, such as proteins, fats, carbohydrates, minerals, and vitamins (FAO, 2023). Despite its importance as an almost complete food, it may be contaminated with some toxic elements and thus cause some health problems for the consumer (Khaneghah *et al*., 2020). Heavy metals are toxic elements transferred to food from the surrounding environment. Based on their toxicity and risks to human health upon exposure, arsenic (As), lead (Pb), cadmium (Cd), and chromium (Cr) have been listed as the 1^{st}, 2^{nd}, 7^{th}, and 17^{th} priority contaminants in food (ATSDR, 2022). The presence of different levels of heavy metals in raw milk and its products is an indication of the cleanliness of milk and the levels of environmental pollution in production areas (Kwon *et al*., 2017).

Pb is a toxic metal and is considered the second element on the list of highly hazardous substances in the environment (Bortey-Sam *et al*., 2015). It is a Group 2A carcinogen, as classified by the International Agency for Research on Cancer (IARC, 2023). There are many sources of Pb transfer to the environment surrounding production, such as geological conditions and environmental emissions from industrial practices near milk production sites (Shammi *et al*., 2021). Additionally, car exhaust resulting from gasoline combustion contributes to high levels of Pb contamination in plants, roadsides, soil, air, and water (Filella and Bonet, 2017). Pb contamination in milk and dairy products can also occur through pastures and crops used as animal feed (Gakidou *et al*., 2017). Furthermore, contamination may arise from the water used in production and from the equipment and utensils involved in packaging and storage (Abdelkhalek *et al*., 2015).

Frequent consumption of Pb-contaminated dairy products can have acute and chronic health effects. Exposure to small amounts of Pb has been the cause of long-term neurological and haematological disorders, nephrotoxicity, anaemia, memory loss, and infertility (EFSA, 2012a). In addition, Pb possesses strong carcinogenic activity against vital tissues in the human body, influencing various body systems, especially the cardiovascular and skeletal systems (Geraldes *et al*., 2016). A toxic level of Pb may cause severe dementia, headaches, behavioural issues, anxiety, immobility, loss of consciousness, and death due to neurological damage (Rehman *et al*., 2018). Pb contamination in milk is particularly concerning for newborns and young children, as their nutrition largely depends on milk and its products (Aggarwal *et al*., 2022). The risk of Pb exposure is significantly higher in young children, who absorb Pb at rates 2–3 times greater than adults due to their lower body mass and higher absorption efficiency (Norouzirad *et al*., 2018). Additionally, because their bodies and neural circuits are still developing during the early years of life, they are more vulnerable to the harmful effects of Pb on brain development (Boudebbouz *et al*., 2021). Foetuses are also highly susceptible to developing birth defects; thus, pregnant women should limit their consumption of milk contaminated with heavy metals (Khaneghah *et al*., 2020). Due to the danger of Pb to adults and children, many regulatory agencies have set levels for this metal in raw milk.

According to the European Union (EUR-Lex, 2015), 20 µg/kg is the maximum permissible limit of Pb in milk.

Recently, Egypt has faced unique challenges related to food quality and safety. Therefore, there are urgent quality measurements used to control product quality. Therefore, there is a need to evaluate the safety of food in the Egyptian markets and the potential health risks. Several methods are used to assess the carcinogenic and non-carcinogenic health risks of consuming foods contaminated with heavy metals (Storelli *et al*., 2020). Assessing potential risks to human health enables the estimation of the harmful effects of exposure to toxic substances in polluted environments now and in the future (Sobhanardakani, 2018). In this study, Pb levels in raw milk and some dairy products collected from industrial, traffic, and rural areas in Egypt were evaluated in terms of their risk to consumer health. This research is an extension of a study conducted by the same research team in 2024 in which Pb levels in the aforementioned collected samples were measured and compared to the maximum permissible limits. This study aimed to evaluate Pb risk in adults and children due to the daily intake (DI) of milk or its products by calculating the estimated daily intake (EDI), target hazard quotient (THQ), and estimated cancer risk (ECR).

MATERIALS AND METHODS

Data collection

The samples were collected, prepared, and analysed for their Pb content as previously described by Abou-Arab *et al*. (2024).

Materials

High-grade concentrated nitric acid and a standard Pb element solution with a 1000 mg/L concentration were acquired from Merck (Darmstadt, Germany). The instruments used to prepare and estimate Pb in the different samples were cleaned, and the samples were diluted using redistilled water.

Methods and procedures

Milk and dairy product samples were extracted following the method described by the AOAC (2000). The Snedecor and Cochran (1980) approach was used to statistically analyse the results. SPSS software version 15.0 was utilised to separate means at $p < 0.05$ and to identify significant differences between means using the least significant difference (LSD) test. Human health risks were evaluated according to the DI of Pb. To estimate the risks associated with Pb consumption from milk and its products, the EDI, THQ, and ECR were calculated as follows.

Estimated Daily Intake (EDI)

The EDI of Pb was calculated according to the following equation (*Equation 1*), as described by Christophoridis *et al*. (2019):

$$EDI\ (mg/kg\ BW/day) = Cmetal \times Wfood\ /\ BW \quad (1)$$

where Cmetal is the mean Pb concentration in polluted milk and dairy products (mg/kg, on a fresh weight basis), Wfood represents the daily average milk and dairy product consumption (kg), and BW represents body weight (kg).

The EDI of Pb was expressed as a percentage in relation to the provisional tolerable daily intake (PTDI) set by EFSA (2012b), which is 3.6 mg/kg body weight (BW) per day, corresponding to a provisional tolerable weekly intake (TWI) of 25 µg/kg BW. The dietary risk coefficient (DRC) of Pb was assessed based on the weekly intake (WI) by age across the three levels of milk consumption. The daily reference consumption (DRC) for Pb was determined by dividing the weekly intake (WI) for each age group by its total weekly intake (TWI).

Risk levels were interpreted as follows: a DRC greater than 1 signifies that an individual's estimated exposure surpasses the established safety limits for the contaminant of interest (TWI), thereby indicating a high risk of experiencing the adverse effects associated with each contaminant; a DRC value of less than 1 indicates a low risk of exposure, suggesting that the likelihood of adverse effects in the population is minimal (Rahmani *et al.*, 2018).

Numerous studies have described the average DI of milk and dairy products for both adults and children. Gopalan and Rao (1980) and Anonymous (1998) reported that the average daily consumption of liquid milk for an adult is 250 mL/day. In contrast, Meshref *et al.* (2014) indicated that the average DI per adult (60 kg of BW) was 200 mL of milk and 22 g of cheese.

Elafify *et al.* (2023) indicated that the average daily consumption per adult (70 kg BW) was 58.97 mL milk and 18.94 g of processed cheese. Daily milk intake recommendations range from 400 to 600 mL for children aged 2–3 years, from 500 to 700 mL for those aged 4–8 years (preschoolers and schoolchildren), and from 500 to 700 mL for those aged 9–18 years (adolescents) (Bao *et al.*, 2018; Marshall *et al.*, 2018).

According to the recommended daily quantities of milk and its products for adults and children and the reference weights for ages according to Kuczmarski *et al.* (2000), the risks of Pb in milk and its products were evaluated in this study as follows:

1. Adults (60–70 kg BW)

· Raw and sterilised cow's milk: 58.97, 200, and 250 mL.

· Processed cheese: 18.94 and 22 g.

· Domiati and Ras cheese: 22 g.

2. Children

According to Kuczmarski *et al.* (2000), the average weights for boys are 13.5, 21.0, and 48.0 at the ages of 2–3, 4–8, and 9–18 years, respectively. The corresponding average weights for girls were 13.0, 20.5, and 45.0 kg.

· Aged 2–3 years: raw and sterilised cow's milk, 500 mL.

· Aged 4–8 years: raw and sterilised cow's milk, 600 mL.

· Aged 9–18 years: raw and sterilised cow's milk, 600 mL.

Target Hazard Quotient (THQ)

The THQ is the ratio of the determined dose of a pollutant to a reference oral dose (RFDo) for that substance (Zhuang, 2009). The THQ was calculated according to the following *Equation (2)*:

$$THQ = \frac{EDI\ (mg/kg/day)}{RfDo\ (mg/kg/day)} \qquad (2)$$

where RfDo is the reference dose (mg/kg BW/day), which was 0.004 mg/kg BW/day for Pb (Luo *et al.*, 2022). A THQ higher than 1 indicates that the risks of non-carcinogenic potential hazards for human health may occur, but a THQ less than 1 indicates no health risk. However, if the individual THQ is less than 1, non-carcinogenic adverse hazards may occur due to the cumulative effect of heavy elements (USEPA, 2019).

Estimated Cancer Risk (ECR)

ECR was estimated using the EDI and cancer slope factor (CSF) according to the following *Equation (3)*:

$$ECR = EDI \times CSF \quad (3)$$

where CSF values (mg/kg/day) have been established for Pb (0.0085) by regulatory bodies (Parker *et al*., 2022).

RESULTS

Estimated lead intake of adults and children from raw milk and its products collected from industrial, traffic, and rural areas

Food consumption is a reliable tool for verifying the DI and weekly intake of various nutrients and the types of pollutants they carry. Based on this information, health risks can be estimated in terms of the TWI of metals ingested through food.

According to Abou-Arab *et al.* (2024), Pb levels in the samples of raw cow milk, sterilised milk, Domiati cheese, Ras-cheese, processed cheese, and yoghurt collected from industrial, traffic, and rural areas were estimated. Pb concentrations of the collected samples were 2.23, 0.33, 3.18, 5.10, 0.11, and 0.09 mg/kg, respectively, from industrial areas, 1.83, 0.30, 2.72, 4.72, 0.13, and 0.09 mg/kg, respectively, from traffic areas and 0.61, 0.27, 1.52, 3.13, 0.13, and 0.09 mg/kg, respectively, from rural areas. As noted in the 'Methods and procedure' section, the literature provides various values for the average consumption of liquid milk and cheese. Therefore, in this study, these cited values were used as reference points for calculating the DI and WI. The obtained data are presented in *Table 1*.

The DI and WI of Pb were highest in liquid milk samples (both raw and sterilised) from industrial areas, followed by those from traffic and rural areas. This variation reflects the different milk consumption levels used in the calculations (58.97, 200, and 250 mL). Pb levels in sterilised milk were significantly lower than those in raw milk, possibly due to the reduced Pb concentrations in sterilised milk.

For processed cheese, the DI and WI of Pb were highest in samples from traffic areas, followed by rural and industrial areas, although the differences among these areas were not significant.

For Domiati and Ras cheeses, Pb intake values were highest in samples from industrial areas, followed by traffic and rural areas.

The average liquid milk consumption was 500 mL/day for children aged 2–3 years and 600 mL/day for children aged 4–8 and 9–18 years. Accordingly, the DI and WI were calculated for children. The obtained data are presented in *Table 2* and *Figure 1a, 1b*. The data also showed that Pb ingested through raw and sterilised milk was high in the samples collected from industrial areas, followed by those from traffic and rural areas.

Health risk assessment of lead in raw milk and its products for adults and children

To assess the health risks associated with the ingestion of milk and its products contaminated by Pb, the EDI, THQ, and ECR were determined for adults and children. The results are presented in *Table 3, Table 4, Table 5* and *Table 6*. Most male and female adults aged 19–70 years have an average weight of 68 kg.

The DI and WI of Pb for children through raw and sterilised milk collected from the three areas under study were significantly higher than those of adults (60 and 70 kg BW) due to the increased amount of milk consumed by children of differing ages.

Table 1 – Estimated Intake (µg) of lead in Egyptian milk and its products collected from industrial, traffic and rural areas for adults (60 and 70 Kg b.w.)

Sample type	Estimated Intake (µg) of lead for adults (60 and 70 Kg b.w.)					
	Industrial areas		Traffic areas		Rural areas	
	DI	WI	DI	WI	DI	WI
1. Raw milk						
58.97 ml	131.6	921.2	107.7	753.9	35.8	250.6
200 ml	446.3	3124.1	365.2	2556.4	121.4	849.8
250 ml	557.9	3905.3	456.6	3196.2	151.7	1061.9
2. Sterilized milk						
58.97 ml	19.3	135.1	17.9	125.3	16.0	112.0
200 ml	65.6	459.2	60.5	423.5	54.2	379.4
250 ml	82.0	574.0	75.7	529.9	67.8	474.6
3. Processed cheese						
18.94 g	2.0	14.0	2.5	17.5	2.4	16.8
22 g	2.4	16.8	2.9	20.3	2.8	19.6
4. Domiati cheese						
22 g	70.1	490.7	59.7	417.9	11.5	80.5
5. Ras cheese						
22 g	112.2	785.4	103.7	725.9	68.8	481.6

DI: Daily Intake, WI: Weekly Intake

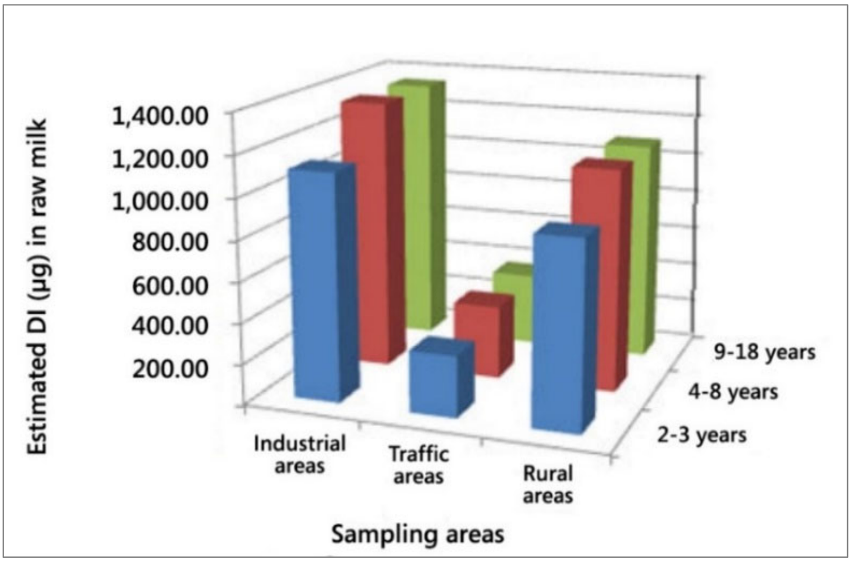

Figure 1a – Estimated daily lead intake (µg) of male and female children from raw milk collected from industrial, traffic and rural areas

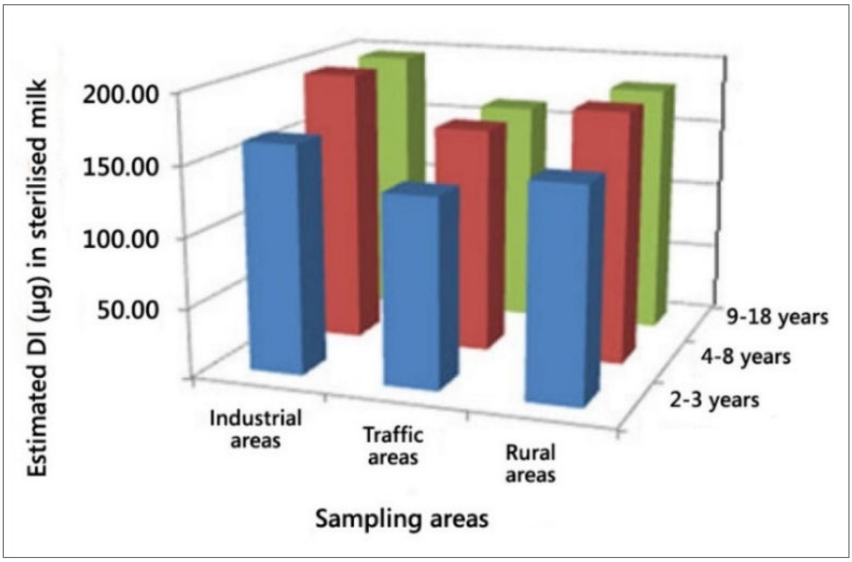

Figure 1b – Estimated daily lead intake (µg) of male and female children from sterilized milk collected from industrial, traffic and rural areas

In the present study, the health risks of Pb were evaluated for people weighing 60 and 70 kg due to the intake of raw milk and dairy products (*Table 3* and *Table 4*).

Based on the recommended milk intake and reference BWs for children, health risks were evaluated considering 500 mL of milk for children aged 2–3 years and 600 mL for children aged 4–8 and 9–18 years. The average BWs used for boys were 13.5 kg for ages 2–3 years, 21.0 kg for ages 4–8 years, and 48.0 kg for ages 9–18 years. For girls, the corresponding weights were 13.0, 20.5, and 45.0, respectively. The obtained data are summarised in *Table 5* and *Table 6*.

Estimated Daily Intake (EDI)

The percentage of EDI of Pb from milk and dairy product samples (mg/kg BW/day) compared to the PTDI ranged from <1 to 61.1% for individuals with an average BW of 60 kg (*Table 3*) and from <1 to 52.8% for those weighing 70 kg (*Table 4*).

These findings suggest no significant health risks from Pb exposure in the analysed dairy products, except for raw milk consumed at high intake levels (200 and 250 mL/day). In these cases, PTDI values for raw milk ranged from 205.6 to 258.3% in samples from industrial areas and from 169.4 to 211.1% in samples from traffic areas for individuals weighing 60 and 70 kg. The DRC for Pb in raw milk and its products was calculated, depending on the intake and BW (*Table 3* and *Table 4*). DRC was <1 in the dairy products of sterilised milk and the processed, Domiati, and Ras cheeses collected from the three areas. A DRC > 1 was observed with high raw milk intake (200 and 250 mL/day) for adult weighing 60 and 70 kg.

The Pb EDI for raw and sterilised milk was assessed in male and female children aged 2–3, 4–8, and 9–18 years. The results are shown in *Table 5* and *Table 6*.

Table 2 – Estimated Intake (µg) of lead in raw and sterilized milk collected from industrial, traffic and rural areas for male and female children

Sample type	Estimated Intake (µg) of lead for male and female children											
	Raw milk						Sterilized milk					
	2–3 years		4–8 years		9–18 years		2–3 years		4–8 years		9–18 years	
	DI	WI	DI	WI	DI	WI	DI	WI	DI	WI	DI	WI
Industrial areas	1115.9	7811.3	1339.0	9373.0	1339.0	9373.0	164.0	1148.0	196.7	1376.9	196.7	1376.9
Traffic areas	913.1	6391.7	1095.7	7669.9	1095.7	7669.9	151.4	1059.8	181.6	1271.2	181.6	1271.2
Rural areas	303.4	2123.8	364.1	2548.7	364.1	2548.7	135.6	949.2	162.7	1138.9	162.7	1138.9

DI: Daily Intake; WI: Weekly Intake

Table 3 – Risk assessment of lead in adult persons of body weight 60 kg consumed different amounts of milk and its products collected from industrial, traffic and rural areas

Sample type	Industrial areas					Traffic areas					Rural areas				
	EDI*	PTID %	DRC	THQ	ECR	EDI*	PTID %	DRC	THQ	ECR	EDI*	PTID %	DRC	THQ	ECR
1.Raw milk															
58.97 ml	2.2 E-03	61.1	0.616	0.548	1.9 E-05	1.8 E-03	50.0	0.504	0.450	1.5 E-05	6.0 E-04	16.7	0.168	0.150	5.1 E-06
200 ml	7.4 E-03	205.6	2.072	1.850	6.3 E-05	6.1 E-03	169.4	1.708	1.525	5.2 E-05	2.0 E-03	55.6	0.560	0.500	1.7 E-05
250 ml	9.3 E-03	258.3	2.604	2.325	7.9 E-05	7.6 E-03	211.1	2.128	1.900	6.5 E-05	2.5 E-03	69.4	0.700	0.625	2.1 E-05
2.Sterilized milk															
58.97 ml	3.2 E-04	8.9	0.090	0.080	2.7 E-06	3.0 E-04	8.3	0.084	0.075	2.6 E-06	2.7 E-04	7.5	0.076	0.068	2.3 E-06
200 ml	1.1 E-03	30.6	0.308	0.275	9.4 E-06	1.0 E-03	27.8	0.280	0.250	8.5 E-06	9.0 E-04	25.0	0.252	0.225	7.7 E-06
250 ml	1.4 E-03	38.9	0.392	0.350	1.2 E-05	1.3 E-03	36.1	0.364	0.325	1.1 E-05	1.1 E-03	30.6	0.308	0.275	9.4 E-06
3.Processed cheese															
18.94 g	3.4 E-05	0.9	0.010	0.009	2.9 E-07	4.1 E-05	1.1	0.012	0.010	3.5 E-07	4.1 E-05	1.1	0.012	0.010	3.5 E-07
22 g	3.9 E-05	1.1	0.011	0.010	3.3 E-07	4.8 E-05	1,3	0.013	0.012	4.1 E-07	4.7 E-05	1.3	0.013	0.012	4.0 E-07
4. Domiati cheese															
22 g	1.2 E-03	33.3	0.336	0.300	1.0 E-05	9.9 E-04	27.5	0.277	0.248	8.4 E-06	5.6 E-4	15.6	0.157	0.140	4.8 E-06
5. Ras cheese															
22 g	1.9 E-03	52.8	0.532	0.475	1.6 E-05	1.7 E-03	47.2	0.476	0.350	1.5 E-05	3.2 E-05	0.9	0.009	0.008	2.7 E-07

*EDI mg/kg b.w/day

Table 4 – Risk assessment of lead in adult person of body weight 70 kg consumed different amountof milk and its products collected from industrial, traffic and rural areas

Sample type	Industrial areas					Traffic areas					Rural areas				
	EDI*	PTID %	DRC	THQ	ECR	EDI*	PTID %	DRC	THQ	ECR	EDI*	PTID %	DRC	THQ	ECR
1. Raw milk															
58.97 ml	1.9 E-03	52.8	0.532	0.475	1.6 E-05	1.5 E-03	41.7	0.420	0.375	1.3 E-05	5.1 E-04	14.2	0.143	0.128	4.3 E-06
200 ml	6.4 E-03	177.8	1.792	1.600	5.4 E-05	5.2 E-03	144.4	1.456	1.300	4.4 E-05	1.7 E-03	47.2	0.476	0.425	1.5 E-05
250 ml	8.0 E-03	222.2	2.240	2.000	6.8 E-05	6.5 E-03	180.6	1.820	1.625	5.5 E-05	2.2 E-03	61.1	0.616	0.550	1.9 E-05
2. Sterilized milk															
58.97 ml	2.8 E-04	7.8	0.078	0.070	2.4 E-06	2.6 E-04	7.2	0.073	0.065	2.2 E-06	2.3 E-04	6.4	0.064	0.058	2.0 E-06
200 ml	9.4 E-04	26.1	0.263	0.235	8.0 E-06	8.6 E-04	23.9	0.241	0.215	7.3 E-06	7.7 E-04	21.4	0.216	0.193	6.6 E-06
250 ml	1.2 E-03	33.3	0.336	0.300	1.0 E-05	1.1 E-03	30.6	0.308	0.275	9.4 E-06	9.7 E-04	26.9	0.272	0.243	8.2 E-06
3. Processed cheese															
18.94 g	2.9 E-05	0.8	0.008	0.007	2.5 E-07	3.5 E-05	1.0	0.010	0.009	3.0 E-07	3.5 E-05	1.0	0.010	0.009	3.0 E-07
22 g	3.4 E-05	0.9	0.010	0.009	2.9 E-07	4.1 E-05	1.1	0.012	0.010	3.5 E-07	4.0 E-05	1.1	0.011	0.010	3.4 E-07
4. Domiati cheese															
22 g	1.0 E-03	27.8	0.280	0.300	8.5 E-06	8.5 E-04	23.6	0.238	0.213	7.2 E-06	4.8 E-04	13.3	0.134	0.120	4.1 E-06
5. Ras cheese															
22 g	1.6 E-03	44.4	0.448	0.400	1.4 E-05	1.5 E-03	41.7	0.420	0.375	1.3 E-05	9.8 E-04	27.2	0.274	0.245	8.3 E-06

*EDI mg/kg b.w/day

The percentage of Pb EDI in raw milk in males compared to their PTDI ranged from 777.8 to 2305.6, 638.9 to 1888.9, and 211.1 to 638.9% in the samples from industrial, traffic, and rural areas, respectively (*Table 5*). The corresponding values in females (*Table 6*) were 833.3 to 2388.9, 666.7 to 1944.4, and 225.0 to 638.9%.

These values indicate potential health risks from Pb upon high intake. In sterilised milk, Pb EDI ranged from 113.9 to 333.3, 105.6 to 305.6, and 94.4 to 277.8% in males and from 122.2 to 361.1, 111.1 to 333.3, and 100.0 to 183.3% in females for samples from industrial, traffic, and rural areas, respectively. The DRC for Pb in raw and sterilised milk were estimated depending on the intake and BW (*Table 5* and *Table 6*). DRC was >1 in the samples from industrial and traffic areas, whereas a DRC around 1 was found in samples from rural areas.

Target Hazard Quotient (THQ)

As shown in *Table 3* and *Table 4*, the Pb THQ in adults weighing 60 and 70 kg was <1 in sterilised milk as well as processed, Domiati, and Ras cheeses. A THQ > 1 was observed with a high raw milk intake (200 and 250 mL/day), with values ranged (1.850 - 2.325) in industrial areas samples and (1.525 - 1.900) in traffic areas samples, for adults weighing 60 kg.

The corresponding values for a person weighing 70 kg were ranged (1.6 - 2.0) and (1.300 - 1.625). In children, the Pb THQ in raw and sterilised milk samples was >1 in the samples from industrial and traffic areas; however, it was around 1 in the samples from rural areas (*Table 5* and *Table 6*).

Estimated Cancer Risk (ECR)

The ECR of Pb was assessed in raw milk and its products in adults weighing 60 and 70 kg (*Table 3* and *Table 4*). The ECR values were above 10^{-6} in raw and sterilised milk samples and Domiati cheese from the 3 areas under study. The ECR values were above 10^{-6} in Ras cheese collected from industrial and traffic areas. For processed cheese, the ECR values were lower than 10^{-6}, which is considered negligible. The ECR was assessed in contaminated raw and sterilised milk consumed by male and female children (*Table 5* and *Table 6*).

The ECR values were above 10^{-6} in all samples collected from the three areas for children of different ages, which is considered unacceptable.

DISCUSSION

Estimated lead intake of adults and children from raw milk and its products collected from industrial, traffic, and rural areas

People consume food that contains nutritional elements that maintain all bodily functions and growth and supply it with energy, vitality, and activity. This food may be a source of many pollutants, such as heavy metals. Abou-Arab *et al.* (2024) reported that milk and some of its products collected from different environments in Egypt (industrial, traffic, and rural areas) had different Pb levels. These variations are due to the areas of sample collection. Variations in the Pb levels of milk and dairy products depend on their proximity to industrial areas and production systems (Anyanwu *et al.*, 2018).

Table 5 – Risk assessment of lead in male infants and children consumed raw and sterilized milk collected from industrial, traffic and rural areas

Parameter	Children aged (years)					
	Raw milk			Sterilized milk		
	2–3	4–8	9–18	2–3	4–8	9–18
Industrial areas						
EDI*	8.3E-02	6.4E-02	2.8E-02	1.2E-02	9.4E-03	4.1E-03
PTDI%	2305.6	1777.8	777.8	333.3	261.1	113.9
DRC	23.24	17.92	7.84	3.36	2.63	1.15
THQ	20.75	16.00	7.00	3.00	2.35	1.03
ECR	7.1E-04	5.4E-04	2.4E-04	1.0E-04	8.0E-05	3.5E-05
Traffic areas						
EDI*	6.8E-02	5.2E-02	2.3E-02	1.1E-02	8.7E-03	3.8E-03
PTDI%	1888.9	1444.4	638.9	305.6	241.7	105.6
DRC	19.04	14.56	6.44	3.08	2.44	1.06
THQ	17.00	13.00	5.75	2.75	2.18	0.95
ECR	5.8E-04	4.4E-04	2.0E-04	9.4E-05	7.4E-05	3.3E-05
Rural areas						
EDI*	2.3E-02	1.7E-02	7.6E-03	1.0E-02	7.8E-03	3.4E-03
PTDI%	638.9	472.2	211.1	277.8	216.7	94.4
DRC	6.44	4.76	2.13	2.80	2.18	0.952
THQ	5.75	4.25	1.90	2.50	1.95	0.85
ECR	2.0E-04	1.5E-04	6.5E-05	8.5E-05	6.6E-05	2.9E-05

*EDI mg/kg b.w/day

Table 6 – Risk assessment of lead in female infants and children consumed raw and sterilized milk collected from industrial, traffic and rural areas

Parameter	Children aged (years)					
	Raw milk			Sterilized milk		
	2–3	4–8	9–18	2–3	4–8	9–18
Industrial areas						
EDI*	8.6E-02	6.5E-02	3.0E-02	1.3E-02	9.6E-03	4.4E-03
PTDI%	2388.9	1805.6	833.3	361.1	266.7	122.2
DRC	24.08	18.20	8.40	3.64	2.69	1.23
THQ	21.50	16.25	7.50	3.25	2.40	1.10
ECR	7.3E-04	5.5E-04	2.6E-04	1.1E-04	8.2E-05	3.7E-05
Traffic areas						
EDI*	7.0E-02	5.4E-02	2.4E-02	1.2E-02	8.9E-03	4.0E-03
PTDI%	1944.4	1500.0	666.7	333.3	247.2	111.1
DRC	19.5	15.12	6.72	3.36	2.49	1.12
THQ	17.50	13.50	6.00	3.00	2.23	1.00
ECR	6.0E-04	4.6E-04	2.0E-04	1.0E-04	7.6E-05	3.4E-05
Rural areas						
EDI*	2.3E-02	1.8E-02	8.1E-03	6.6E-03	7.9E-03	3.6E-03
PTDI%	638.9	500.0	225.0	183.3	219.4	100.0
DRC	6.44	5.04	2.27	1.85	2.21	1.01
THQ	5.75	4.50	2.03	1.65	1.98	0.90
ECR	2.0E-04	1.5E-04	6.9E-05	5.6E-05	6.7E-05	3.1E-05

*EDI mg/kg b.w/day

The levels of Pb contamination in milk and its products explain the health risks resulting from its presence, and these risks can be estimated through the DI or weekly intake of Pb consumed with food. The DI of Pb has been established based on GEMS by the United Nations Environment Programme. The acceptable DI indicates the maximal daily dose/BW/day of a substance (additive contaminants, residues) that can be accepted considering lifelong exposure.

In the present study, the estimated Pb intake was calculated to assess any possible risks to consumers of milk and its products according to the DI. For adults, the DI of Pb through raw milk, sterilised milk, Domiati cheese, and Ras cheese were highest in the samples collected from industrial areas, followed by traffic and then rural areas. The DI and WI of Pb in milk samples from the three areas under investigation were lower than those recommended by the Codex Alimentarius Commission (2014), which recorded that a DI of Pb by adults of 0.5 mg/person/day, equivalent to 3.5 mg/person/ week. With respect to children, the DI of Pb through both raw and sterilised milk was higher than that recorded in adult persons due to the higher milk consumption. The DI of Pb in young children is greater than that in older children. The data revealed that Pb had the highest calculated DI for children consuming 500 and 600 mL raw and sterilised milk per day, especially milk from industrial and traffic areas due to their high Pb concentrations. Milk can pose a risk to children's health due to the Pb levels detected in the tested samples, as these concentrations exceed the permissible levels and a high quantity of milk is consumed daily. Cheeses may not pose a risk to human health due to the low quantity of cheese consumed daily. The weekly intake of Pb in children and adolescents aged 2–18 years surpasses the TWI at various levels of milk consumption. Given the cumulative nature of Pb and the reliance of children on milk for nutrition (MINDES, 2019), long-term toxicity may pose a concern for this age group, even at low exposure levels (400 mL/day).

Many local and international studies have estimated the DI and WI of Pb through milk and its products, and the values obtained varied because they depended on the amount of milk and its products consumed daily or weekly and the person's age or BW. Abdelfatah *et al.* (2019) reported that the DI of Pb of an average Egyptian adult (60 kg BW, 0.2 kg of cow milk/day) was 0.536 mg Pb/day from mean milk consumption and 0.102 mg/day/person from 0.045 kg kariesh cheese per day.

Castro-Bedrinana *et al.* (2021) reported that Pb exposure of an average Peruvian adult (25 years old, 65.6 kg BW, 0.150 kg of milk/day) was 87 μg Pb/day from mean milk consumption, and the WI of Pb was 610 μg.

They stated that children aged 2–5 and 6–15 years, with average milk consumption, had a WI of Pb WI of 2019 and 2423 μg, respectively, exceeding the risk value.

In those older than 20 years, the WI of Pb was below the risk values. In children and adolescents up to 19 years old, milk consumption at the three evaluated volumes (400, 500, and 600 mL) results in a WI of Pb that surpasses the TWI references, except for 2-year-old children with a high daily milk intake of 0.6 kg.

Health risk assessment of lead in raw milk and its products for adults and children

The assessment of risks to human health not only depends on the Pb concentrations in milk and its products but also on consumption rates. In the present study, health risk assessment indices were calculated based on the volume or weight of milk or dairy products consumed daily for all ages (males and females) under investigation. The results of these estimated risks differ with consumption volume and weight. As the intake of milk and its products increases, the risk increases due to the increased Pb intake, increasing the risk to the consumer, especially children. To estimate the non-carcinogenic risks associated with the consumption of Pb-contaminated milk and its products, the EDI and THQ were calculated. To estimate the long-term cancer risk, the ECR was also determined.

Estimated Daily Intake (EDI)

The EDI was calculated to assess the health risks in adults and children associated with the ingestion of Pb-contaminated milk and its products from industrial, traffic, and rural areas collected by Abou-Arab *et al*. (2024). For adults (60 and 70 kg BW), the EDI was high in the various samples, and these values were highest in the samples from industrial areas, followed by traffic and rural areas. EDI values were high in the case of people who consumed raw milk in large quantities (200 and 250 mL/day) compared to those who consumed them in low quantities (58.97 mL/day). The BW also has a clear effect on the EDI, as an increasing BW decreases the EDI. Based on the present results, raw milk poses a threat to human health due to the high Pb levels in the tested samples, as these concentrations exceed the permissible values and there is a high daily milk intake. Cheeses may not pose a risk to human health due to the small amount of cheese consumed daily. Previous studies in different Governorates of Egypt, such as Mansoura (Elafify *et al*., 2023), Sharkia (Abdelfatah *et al*., 2019), Aswan (Khalil, 2018), Beni-Suef (Meshref *et al*., 2014), Dakahlia (Salah *et al*., 2013), and El-Qaliubiya (Malhat *et al*., 2012), have reported that EDI values in raw milk were 8.56E−05, 9.0E−03, 2.5E−03, 7.1E−04, 6.4E−02, and 0.0036 mg/kg BW/day, respectively. Elafify *et al*. (2023), Khalil (2018), and Meshref *et al*. (2014) reported that EDI values in Kareish cheese were 7.92E−05, 6.23E−05, and 1.6E−04 mg/kg BW/day, respectively. In addition, Elafify *et al*. (2023) showed that the EDI of processed cheese was 3.40E−05.

To assess the health risks of Pb-contaminated dairy products, the EDI was compared to the TDI. The Joint FAO/WHO Expert Committee on Food Additives set the PTWI of Pb at 25 µg/kg BW, which is equivalent to 3.6 µg/kg BW/day for all groups (EFSA, 2012b). In the present study, the % EDI of Pb in milk and its products (mg/kg BW/day) compared to their PTDIs ranged from <1 to 61.1% in the samples, which is below the risk value, except in raw milk when 200 and 250 mL/day (%EDI, more than 100%) is consumed. In general, in adults (60–70 kg BW), there is no potential health risk from Pb upon consumption of the analysed dairy products. However, with a mean intake of 200 or 250 mL of milk/day, the effects may be more adverse over time if remedial or regulatory actions are not taken. Similar results were obtained in Egypt by Elafify *et al.* (2023) and El Sayed *et al.* (2011), who reported that the percentage of EDI of milk was 13.59 and 13.90, respectively.

Globally, EDI values for raw milk in the present study are relatively similar to those investigated (µg/kg BW/day and %EDI) by Giri and Singh (2020) in India (0.26, 7.2%), Capcarova *et al.* (2019) in Slovakia (6.4, 177.8%), Zhou *et al.* (2019) in China (0.0016, 0.04%), Ismail *et al.* (2017) in Pakistan (0.14, 3.9%), and Muhib *et al.* (2016) in Bangladesh (0.005, 0.1%). Boudebbouz *et al.* (2021) demonstrated that the worldwide EDI of Pb ranges from 0 to 123 µg/kg bw/day, accounting for 0–3417% of the PTDI. High values were recorded in highly polluted areas of India and Pakistan, accounting for 3417 and 2719% of PTDI, respectively. There are regions in which the EDI represents 100% of PTDI (Capcarova *et al.*, 2019). In this study, for this group of people, who consumed 200–250 mL of raw milk daily, the EDI for Pb accounted for 205.6–258.3% and 169.4–211.1% of the PTDI in samples collected from industrial and traffic areas, respectively. In the present study, with lower Pb pollution levels, the EDI and PTDI decreased with the samples collected from rural or industrial areas. These results agree with those reported by Akele *et al.* (2017) and Muhib *et al.* (2016).

With respect to the EDI of Pb for male and female children, data show that 2–3-year-old children had the highest DI, while those aged 9–18 years had the lowest DI. The PTDI of raw and sterilised milk was higher than 100% for children of all studied ages (2–3, 4–8, and 9–18 years), exceeding the risk values. These percentages were much lower in sterilised milk than in raw milk due to the lower Pb contamination and much lower in older ages than younger ages because of the higher milk consumption compared to the child's weight. The Pb EDI values in females were higher than in males, which may be due to their lower weight compared to their age and the amount of milk consumed. In Egypt, Hafez and Kishk (2008) recorded EDI values for Pb of 0.4–0.82 µg/kg BW/day for infants (<1 year) who consumed milk. In Perú, Orellana *et al.* (2019) reported that the EDI of Pb was 5.9×10^{-3} mg/kg/day. In Pakistan, Ismail *et al.* (2015) reported an EDI ranging from 0.051 to 0.631 µg/kg/day in children and adolescents that were 1–16 years old. These values are lower than those found in this study.

The DRC of Pb was also calculated and evaluated by dividing the weekly intake by the TWI. The Pb DRC of raw milk and dairy products depends on the intake and BW.

In the present investigation, the consumption of raw and sterilised milk was 58.97, 200 and 250 mL/day, while cheese consumption was 18.94 and 22 g/day for adults with a BW of 60 and 70 kg. Therefore, DRC was <1 in the dairy products under investigation due to the low consumption level. In contrast, a DRC>1 was observed with the high raw milk intake (200 and 250 mL/day). The DRC values decreased in people whose average BW was 70 kg compared to their counterparts with an average BW of 60 kg when the quantity of dairy products consumed remained constant. Globally, the results of Pb DRC values in our study are relatively similar to those found by Giri and Singh (2020) in India (0.08), Capcarova *et al*. (2019) in Slovakia (1.8), Ismail *et al*. (2017) in Pakistan (0.04), Akele *et al*. (2017) in Ethiopia (0.07), and Muhib *et al*. (2016) in Bangladesh (0.001).

The Pb DRC through milk consumption depends on the intake level and age in male and female children. In raw milk samples collected from industrial areas, the DRC values were >20, >17, and >7 for children aged 2–3, 4–8, and 9–18 years, respectively. The corresponding values were >19, >14, and >6 in traffic areas and >6, >4 and >2 in rural areas. The DRC of Pb in children under 8 years old was higher than that recorded for children over 8 years old due to higher milk consumption in relation to BW and lower (about 1 or slightly higher) in young and old adults due to lower milk consumption. The Pb DRC by milk consumption for females was higher than that for males, which may be due to their lower weight compared to their age and the amount of milk consumed.

With respect to Pb DRC in sterilised milk consumption for children, the values were <4 for both male and females in the samples collected from industrial and traffic areas and about 1 in the samples from rural areas due to the lower Pb levels in sterilised milk. This research indicates that the DRC for children aged 2 to 18 years is elevated, suggesting that Pb exposure may predispose them to diseases associated with metal accumulation. Children are particularly susceptible to adverse effects due to their dietary habits and physiology, which facilitates the absorption of greater doses, considering their BW compared to adults (Venancio *et al*., 2020).

This scenario heightens short-term health risks, and long-term Pb accumulation can significantly impair health in later life, even when the current DRC is below 1. The DRC reported in Puebla, Mexico, was lower than that calculated in this study (Castro Gonzalez *et al*., 2017). The authors indicated that the Pb level in milk was 46 µg/kg, with a DRC for children of 0.03. In milk typically consumed by adults and children in Bangladesh, which contains 270 µg/kg of Pb, levels of 0.04 and 0.11 have been reported (Shaheen *et al*., 2016). This may be attributed to the low daily milk intake of adults and children, at 33.7 and 31.5 g/day, respectively. Based on previous results, DRC values decrease with age, and after 18 years, the DRC value is lower.

Target Hazard Quotient (THQ)

THQ is recommended for assessing the potential health risks associated with the intake of various contaminants in humans. This measure does not quantitatively assess a population's likelihood of exposure to health risks but rather reflects the level of risk associated with exposure (USEPA, 2000). THQ represents the ratio of a given contaminant dose to the reference oral dose (RFDO) for that specific substance. The recommended RFDO for Pb is 0.004 mg/kg BW per day, according to Luo *et al*. (2022). A THQ higher than 1 indicates a potential risk to human health, but a THQ less than 1 indicates no risk (USEPA, 2019).

Data from the current study show that adult consumers weighing 60 and 70 kg in industrial and traffic areas are exposed to potential health risks from consuming raw milk in large quantities (200 and 250 mL/day) due to the presence of Pb residues at high levels, with THQ (Pb) values >1.

The THQ values for Pb did not exceed 1 for any of the dairy products tested (sterilised milk, processed cheese, Domiati cheese, and Ras cheese). Therefore, there is no potential risk of consuming these products in the quantities under study.

This finding agrees with those detected in some Governorates of Egypt, such as Sharkia (Abdelfatah *et al*., 2019), Aswan (Khalil, 2018), and Beni-Suef (Meshref *et al*., 2014), in which THQ values of 2.57 in raw milk, 0.400 in cow's milk, 0.0178 in Kareish cheese, and 0.0182 in Domiati cheese, 2E−01 in raw milk, and 4.6E−02 in Kareish cheese have been reported. Globally, the Pb THQ values in the present are relatively similar to those found by Ghafari and Subhanardakani (2017) in Iran (7.29E−03). In contrast, a higher globally revised THQ value of >1 has been reported for Pb in raw milk samples tested in other countries, including Pakistan (3.53), India (3.5), and Turkey (3.1) (Boudebbouz *et al*., 2021).

In the current study, the Pb THQ values for children at different ages were higher than those detected in adults. In raw milk samples collected from industrial areas, the THQ values were >20, >16, and >7 for children that were 2–3, 4–8, and 9–18 years old, respectively. The corresponding values were >17, >13, and >5 in traffic areas and >5, >4, and >1 in rural areas. The THQ values for children up to 8 years old were higher than those over that age due to their higher milk intake. The THQ values for female children were higher than those for male children due to their lower weight compared to their age and the amount of milk consumed.

Regarding Pb THQ values of sterilised milk, the values were <4 for both males and females in the samples collected from industrial and traffic areas and about 1 in the samples from rural areas due to the lower Pb concentrations of Pb in sterilised milk. The results indicate that the THQ for all samples collected from industrial and traffic areas was higher than 1. As a result of the high Pb absorption of children and its cumulative properties in the body, its DI or weekly intake, even in small concentrations, can pose a risk to children with long-term consumption.

Estimated Cancer Risk (ECR)

Exposure to certain chemicals and environmental pollutants at certain concentrations in the long term may increase the probability of cancer. ECR values lower than 10^{-6} are considered negligible, and those above 10^{-6} are considered unacceptable. Values between 10^{-4} and 10^{-6} are considered acceptable (Ullah *et al*., 2017); thus, the cancer risk values found in the present investigation for adults (60 and 70 kg BW) are within the ranges tolerated in the samples collected from the three areas. In addition, the Pb ECR was higher in the samples from industrial areas, followed by traffic and then rural areas.

The Pb ECR values in raw and sterilised milk for male and female children indicate that the risk of cancer was slightly less than 1×10^{-4} in raw milk, indicating a low potential carcinogenic risk for children. These values were lower in sterilised milk. Similar results were obtained in Perú (Orellana *et al*., 2019) and Bangladesh (Islam *et al*., 2015a, b), where the cancer risk ranged from 2.2×10^{-5} to 8.9×10^{-5}), with a mean of 6.0×10^{-5} for children.

In the current study, risk was calculated based on the daily milk intake for all ages.

The results of this risk estimate differ from the intake reported by the USDA (2015) for children, as they set average milk consumption amounts of 500 mL for children aged 2–3 years, 600 mL for children aged 4–8 years, and 600 mL for children aged 9–18 years for both males and females, suggesting that as milk intake increases, the risk increases. By consuming milk, children absorb a high Pb concentration and excrete very little of it; thus, it accumulates in the liver, kidneys, bones, and brain, causing various health disorders. In general, the raw and sterilised milk intended for adults and children used in this study is likely to cause cancer if consumed over a long period.

CONCLUSION AND RECOMMENDATIONS

The results obtained in this study indicate high levels of Pb in milk and milk products collected from industrial, road and rural areas, as the concentrations in most samples were above the permitted limits. The highest levels of Pb were in samples collected from industrial areas, followed by those from traffic areas, and the lowest concentrations were observed in samples from rural areas. Despite the present results, the health risk assessment indices comprising the EDI, THQ, and ECR indicated no potential health risk upon consumption of the analysed dairy products, except for raw milk when consumed in large quantities. The purchase of raw milk from polluted industrial or traffic areas should be avoided, and milk overconsumption should be limited, especially for children.

Residents in the examined regions are unlikely to face health risks from dairy product consumption; however, serious issues may arise due to the influence of other dietary and non-dietary factors on the overall daily Pb intake. Nevertheless, an absence of risk to human health cannot be determined. Children and adults are cautioned against the detrimental effects of this hazardous substance.

For residents of industrial areas and areas crowded with cars and vehicles within large cities are exposed to high levels of Pb from industrial pollution and car exhaust and through various foods, especially dairy products, putting them at risk for major health problems.

The risk of high Pb levels can be avoided by guiding preventive strategies, including conditions surrounding milk production, monitoring water and animal feed on farms, evaluating manufacturing and packaging methods, using appropriate containers for transporting raw milk and its products, and conducting appropriate studies to identify treatment methods.

Artisanal producers should be trained ensure that they are aware of Pb and its dangers. We must stress the importance of routinely checking food samples for Pb, particularly milk and its derivatives. To validate these results, additional research is required.

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Abbreviation list

Abbreviation	Definition
DI	Daily Intake
WI	Weekly Intake
TWI	Tolerable Weekly Intakes
ADI	Acceptable Daily Intake
RfDo	Reference Doses
EI	Estimated Intake
CSF	Cancer Slope Factor
EDI	Estimated Daily Intake
ECR	Excess Cancer Risk
PTDI	Provisional Tolerable Daily Intake
DRC	Dietary Risk Coefficient
THQ	Target Hazard Quotient

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