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Heavy Metal Content in Breast Milk and Contributing Environmental and Maternal Factors: A Systematic Review

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ABSTRACT

Background: Breast milk is an important source of nutrition for the growth and development of infants. It is highly susceptible to the accumulation of lipophilic compounds such as heavy metals. Breast milk can become a route through which infants are exposed to toxic substances like heavy metals. This study aimed to identify variations of trace elements and their associated factors contributing to the existence of trace elements in breast milk. **Methods**: This research employed a systematic literature review methodology utilizing PubMed, Scopus, and Science Direct databases. The search strategy followed specific English keywords to align with the PRISMA Extension for Systematic Reviews guidelines. Data synthesis involved a narrative approach, summarizing the main findings and interventions outlined in the chosen studies. The included articles consisted of full-text primary research published between 2013 and 2023. To mitigate potential language bias, only publications in English were considered for inclusion**. Results**: Our systematic review, comprising nine articles, revealed the presence of toxic metals including lead (Pb), cadmium (Cd), aluminum (Al), copper (Cu), chromium (Cr), mercury (Hg), and arsenic in human milk. Associated factors contributing to this presence include food intake (such as seafood, fruit, and canned fruit), water and canned drink consumption, smoking and exposure to smoke, regional location, and medical conditions. **Conclusion**: Heavy metals, including lead, cadmium, aluminum, copper, chromium, mercury, and arsenic are present in breast milk, influenced by factors like diet, water consumption, smoking, regional zones, and medical conditions. These findings underscore the urgent need for public health policies to monitor environmental exposure in lactating mothers and to develop dietary guidelines minimizing toxic exposure.

INTRODUCTION

Breastfeeding, as recommended by the World Health Organization (WHO), is the optimal source of nourishment for infants during the first six months of life. It supports both maternal and infant health by promoting child spacing, reducing the risk of certain cancers, strengthening family bonds, and providing a secure and environmentally sustainable method of infant feeding (Binns et al., 2016; Lessen & Kavanagh, 2015; WHO, 2018).

However, despite its numerous benefits, breast milk can be susceptible to contamination by environmental toxins, particularly toxic heavy metals. These metals, such as arsenic, cadmium, chromium, lead, and nickel, are widespread environmental pollutants that can enter the body through air, water, food, and other pathways (Bagherzadeh et al., 2022; Fu & Xi, 2020). Infants, whose bodies are still developing, are especially vulnerable to the harmful effects of these contaminants.

Recent studies have reported concerning levels of heavy metals in breast milk. For example, Fu and Xi (2020) found that concentrations of chromium and lead in breast milk samples exceeded WHO limits, and over 73% of samples contained elevated levels of multiple metals. In 40% of the cases, the levels surpassed the WHO's tolerable daily intake for infants. Moreover, during pregnancy and lactation, women may release stored metals from their bodies due to increased physiological demands, compounding the risk of infant exposure.

The variability in metal content is also influenced by maternal factors such as diet. For instance, fish consumption has been positively correlated with higher levels of arsenic and boron in breast milk (Björklund et al., 2012). These findings highlight the complex interplay of environmental and maternal factors contributing to heavy metal presence in breast milk.

Although individual studies have examined heavy metal contamination in human breast milk, no comprehensive review has systematically synthesized the available evidence. To address this gap, our study aims to conduct the first systematic review focusing on heavy metals in breast milk and the factors associated with their presence. Through this review, we seek to clarify the sources, prevalence, concentrations, and health implications of heavy metals in breast milk, thereby enhancing our understanding of the risks to maternal and infant health.

METHODS

Protocol And Registration

This study follows a systematic review approach, focusing primarily on cross-sectional and longitudinal studies. It aims to explore articles concerning the presence of heavy metals in breast milk and associated factors. The research followed the guidelines outlined in The Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 (PRISMA 2020) to ensure comprehensive inclusion of all recommended details. Prospero No. ID : CRD42024545030

Inclusion criteria comprised articles published in English, studies reporting quantitative data on heavy metal concentrations in human breast milk, and research involving maternal or environmental factors potentially influencing contamination. Exclusion criteria included review articles, studies on animal milk, those lacking accessible full-text, or articles not providing measurable data on heavy metal levels. All decisions regarding article inclusion were made by two independent reviewers, with discrepancies resolved through discussion or consultation with a third reviewer.

To ensure the quality of the articles, we conducted critical appraisal using JBI to assess any risk of bias that is shown in Table 1.

Tabel 1. Critical appraisal of articles

	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?
Chao et al (2014)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Motas et al (2021)	Yes	Yes	Yes	Yes	Unclear	Unclear	Yes	Yes
Castro et al (2021)	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Li et al (2014)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lin et al (2021)	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Shawahna et al (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Philip-slaboh et al 2022	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Mansour et al (2015)	No	Yes	Yes	Yes	No	No	Yes	Yes
Tratnik et al (2019)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Search Strategy

This study adhered to the PRISMA guideline for its search strategy. A thorough search was carried out across three prominent online databases, namely PubMed, Scopus, and Science Direct, to identify relevant studies. The search strings and keywords were tailored using Medical Subject Heading (MeSH) terms and Boolean operators such as "AND" and "OR" to enhance search string precision (“Heavy metals"” OR “metals”) AND (“Human Milk” OR “Breast Milk”) AND (“Associated Factor” OR “Influenced Factor”). The primary research question that directed the search process was: "What are the associated factors contributing to the presence of heavy metals in breast milk?"

Eligibility Criteria

The research team established clear inclusion and exclusion criteria for the search process. Inclusion criteria included English-language studies published from January 2013 to December 2023, full-text original research articles. Duplicate entries were removed, and remaining papers were assessed based on title and abstract relevance. Articles meeting the criteria underwent analysis using the PRISMA framework. The study criteria were defined using the PICO framework:

Participants: Heavy Metal in Human Milk or Breast Milk
Intervention: None specified
Comparison: No comparative analysis
Outcome: Primary outcome focused on heavy metal presence in breast milk and associated factors.

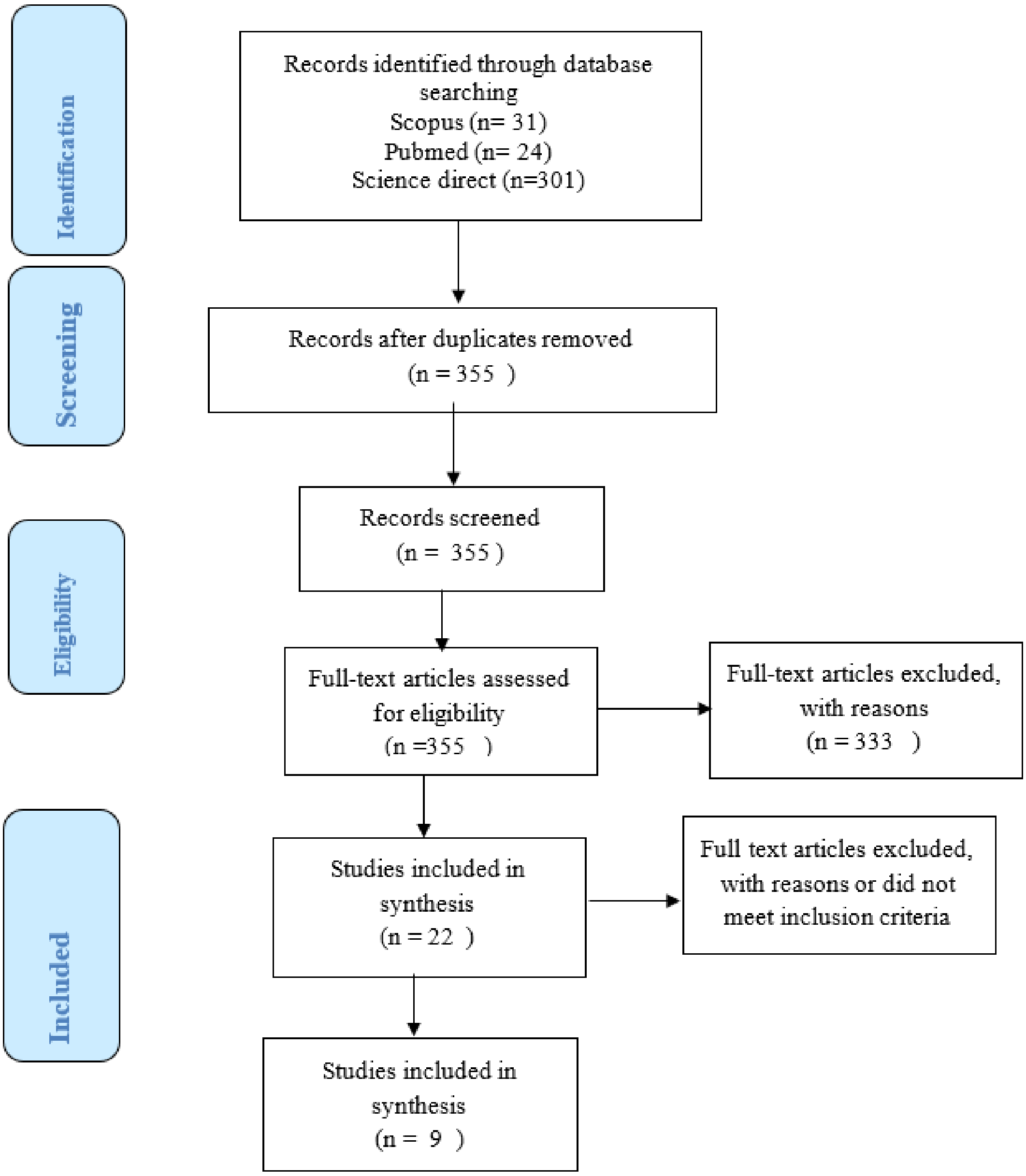

Figure 1. Flow Chart PRISMA

RESULTS

Heavy Metals Founds in Breast Milk

Lead concentrations in breast milk were assessed across various developmental stages and geographic regions. Chao et al. found lead levels ranging from 22.36 ng/mL to 0.45 ng/mL, with colostrum exhibiting significantly higher levels compared to mature and transitional milk ($p < 0.01$) (Chao et al., 2014). Lin's research in Taiwan reported an average lead level of 6.49 ± 5.23 ng/mL in breast milk from 228 samples, while Shawahna's investigation in Palestine found that 13.8% breast milk samples exceeded the WHO recommended lead levels, particularly among urban-dwelling breastfeeding women (aOR 4.96; 95% CI 1.10, 22.38) (Lin et al., 2023). Additionally, Philip-Slaboh's study highlighted a higher prevalence of elevated lead levels in diabetic women compared to non-diabetic individuals (95.8% vs. 95.8%) (Philip-Slaboh et al., 2023).

In the study by Castro et al., various elements in breast milk samples were examined. Magnesium was detected in 75% of the samples, with a median concentration of 33.35 mg/L (interquartile range: 31.23–37.88 ng/mL) (Castro et al., 2021). Copper and chromium were present in all samples but did not exceed concentrations of 0.5 ng/mL. Zinc was found in 55% of samples, with concentrations approximately four times higher at 2.09 mg/L (range: 0.95–4.18 ng/mL). Barium, cadmium, strontium, and selenium had the lowest concentrations (< 0.10 mg/L), with selenium and strontium detected in over 82% of samples, while barium and cadmium were found in only 18% and 14% of samples, respectively. Mercury and cadmium concentrations were slightly higher in breast milk of women with diabetes than non-diabetic individuals (Philip-Slaboh et al., 2023).

Moreover, research involving 34 breastfeeding mothers in Taiwan indicated that colostrum displayed the highest levels of cadmium (of 1.37 ± 0.94 ng/mL,), aluminum (56.45 ± 22.77 ng/mL), and arsenic (1.50 ± 1.50 ng/mL) (Chao et al., 2014). The mean concentrations of arsenic in breast milk were consistent at 0.6 ng/mL for both diabetic and non-diabetic women. Additionally, Li's study in China reported a geometric mean (GM) of 14 ng/mL for mercury (Hg) levels in breast milk from 195 out of 197 samples, while previous study found mean of mercury 0.76 ± 0.98 ng/mL in 228 breast milk samples (Li et al., 2014). These collective findings contribute valuable insights into the elemental composition of breast milk and its potential implications for maternal and infant health.

We also present an overview of the distribution of heavy metals in breast milk (BM) based on data from various countries, as shown in Figure 1. Spain was recorded as the country with the highest number of different heavy metals detected, indicating a highly diverse potential for exposure. On the other hand, Taiwan also showed the presence of various metals, including multiple occurrences of lead (Pb) and cadmium (Cd), suggesting repeated exposure or data collection from several study sources. Countries such as Nigeria, Slovenia, and Egypt exhibited exposure to multiple types of metals simultaneously, reflecting the risk of multi-metal contamination. Meanwhile, China and Palestine showed the presence of only a single type of heavy metal in breast milk, namely mercury (Hg) in China and lead (Pb) in Palestine. These findings highlight the geographic variations in the types and amounts of heavy metals that may enter the mother's body and be excreted through breast milk.

Table 2 Main results of reviewed studies

Authors	Design	Country	Instruments	Main results	
				Heavy Metals Founds in Breast Milk	**Associated Factors**
Chao et al. (2014)	Longitudinal study	Taiwan	Residential area, maternal age, parity, weight fluctuations, quantity of dental amalgam fillings, level of education, occupation, newborn, and water sources. A questionnaire regarding the frequency of food intake.	The concentrations of Pb (13.22 ± 3.58 ng/mL), Cd (1.37 ± 0.94 ng/mL), Al (56.45 ± 22.77 ng/mL), and As (1.50 ± 1.50 ng/mL)	Demographic factors; Maternal age, educational attainment, parity, the age of breastfeeding mothers showed a statistically significant correlation with the lead content in colostrum. Food and life style factor; Smoking behavior of the mothers
Motas et al. (2021)	Cross-sectional study	Spain	Not using any instruments	Females residing in the industrial area exhibited the highest concentrations of Al, Zn, As, Pb, Hg, and Ni in their breast milk. Conversely, women's breast milk in the agricultural zone contained the highest levels of Mg, Cr, and Fe.	1. Daily water intake 2. Fruit consumption 3. Vegetarian mother 4. Current or pass smoking habit
Castro et al. (2021)	Cross-sectional study	Spain	Food Frequency Questionnaire	Barium, calcium, cadmium, chromium, copper, selenium, strontium, and zinc uniformity across milk samples from the three dietary clusters, with the exception of magnesium (Mg).	canned drinks consumption
Li et al. (2014)	cross-sectional study	China	Demographic and food intake	Hg levels in breast milk was 14 ng/mL	Frequency of fish consumptions
Lin et al. (2021)	Longitudinal study	Taiwan	Demographic, life habits, and diet.	The mean lead concentration in breast milk was 6.49±5.23 ng/mL (mean±SD), while the mercury level was 0.76±0.98 ng/mL.	Residential areas Household cleaning items Beauty products Potable water Internal organs Eggs

Authors	Design	Country	Instruments	Main results	
				Heavy Metals Founds in Breast Milk	Associated Factors
					Seafood Canned food
Shawahna (2021)	cross-sectional study	Palestine	Demographic and Potential lead exposure sources	1. Lead concentrations in 11 out of 80 (13.8%) breast milk samples exceeded the levels recommended by the World Health Organization 2. The probability of breast milk lead concentrations reaching or exceeding 5 ng/mL was elevated among women in major region (adjusted odds ratio 4.96;) compared to people in rural locations..	1. Eye Kohl 2. Hair Dye
Philip-Slaboh et al. (2022)	cross-sectional study	Nigeria	Demographic, the findings of laboratory examinations conducted on breast milk, concentrating on the makeup and levels of harmful heavy metals.	Higher levels of Arsenic (63.9% compared to 62.5%), Lead (95.8% compared to 95.8%), Mercury (68.1% compared to 72.2%), and Cadmium (84.7% compared to 86.1%) were found in the milk samples from both diabetic and non-diabetic groups, respectively.	Diabetes Mellitus
Mansour et al. (2015)	Cross-sectional study	Egypt	Not using any instruments	The average concentrations of cadmium and lead were 0.025 ± 0.024 ng/mL and 1.185 ± 1.739 ng/mL in Zagazig, and 0.348 ± 0.154 ng/mL in Belbees, and 0.012 ± 0.122 ± 0.102 ng/mL in Abokabeer, respectively.	Women who are exposed to smoking, whether actively or passively.
Tratnik et al. (2019)	Cross-sectional study	Slovenia	Demographic information, household characteristics, health status and lifestyle factors,	The average concentrations of lead, mercury, and arsenic were 0.23, 0.14, and 0.18, respectively.	1. Fish consumption 2. Canned food

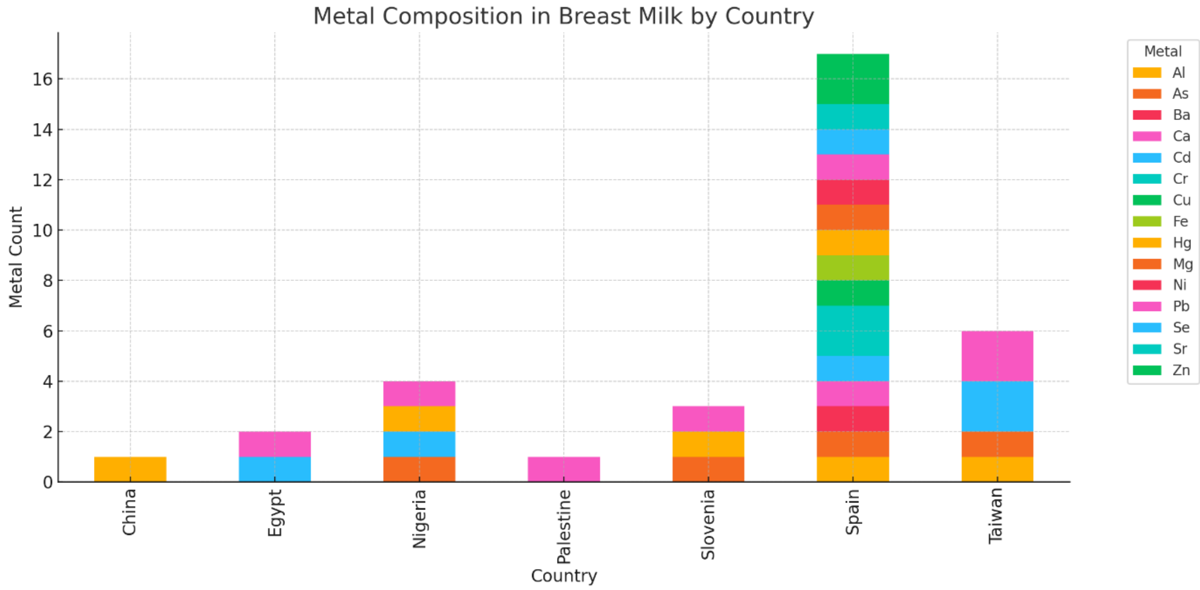

Figure 1. Metal composition in Breast Milk by Country

DISCUSSION

The detection of heavy metals and trace elements such as lead, cadmium, aluminum, copper, chromium, mercury, and arsenic in breast milk underscores the pervasive nature of environmental contamination and its potential transfer through lactation. Concerns are amplified by reports indicating that elements like chromium, manganese, and arsenic may exceed internationally recommended safety thresholds. Moreover, the presence of additional metals such as cobalt, molybdenum, antimony, and vanadium in breast milk, as highlighted by Björklund et al. (2012), reflects the complexity of maternal exposure pathways, which are often influenced by industrial pollution, regional dietary habits, and lifestyle factors. These findings call for enhanced public health measures and more targeted research to better understand the implications of such exposures on infant development.

The influence of maternal diet, particularly seafood consumption, on heavy metal concentrations in breast milk has been consistently documented across various studies. Fish intake is associated with increased levels of lead and mercury, with seafood serving as a significant source of exposure to arsenic and mercury due to the process of biomagnification in aquatic ecosystems (Li et al., 2014; Lin et al., 2021; Ju et al., 2012). In addition to these elements, seafood may also contribute to cadmium exposure in mothers, with breast milk acting as a possible route of elimination for this metal (Dursun et al., 2016). A notable association has also been observed between fish consumption and boron concentrations in breast milk, which raises questions regarding current regulatory limits on boron, given the naturally high boron content in marine products. Further supporting evidence suggests that regular consumption of fish is linked to elevated mercury levels in biological samples (Choi and Jun, 2008). Comparative studies indicate that populations with higher seafood intake, such as those in Japan, tend to exhibit greater mercury accumulation in breast milk compared to populations with lower fish consumption, as observed in China (Gao et al., 2007).

Mothers with higher daily water intake had increased lead and aluminum concentrations in breast milk compared to those with lower intake, likely due to elevated lead levels in drinking water from industrial spills and aging plumbing. Similar results were found in a study in Egypt (Mandour et al., 2013). Industrial activities in the area release waste with high mercury levels, contaminating nearby waters. Despite water consumption, detection of BPA in human breast milk was associated with canned beverage ingestion (Castro et al., 2021).

Smoking contributes to the presence of metal substances in breast milk. Mansouri et al. found significantly elevated levels of cadmium (Cd), lead (Pb), and mercury (Hg) in breast milk of individuals exposed to both passive and active smoking compared to non-smokers. Additionally, there were notable differences in arsenic (As) concentrations between non-smokers and active smokers (Mansour et al., 2015). Studies in Poland confirm that exposure to tobacco smoke raises heavy metal concentrations, including cadmium and lead, in colostrum and mature milk. These elevated levels may disrupt the function of vital bioactive compounds essential for newborn and infant growth and development (Szukalska et al., 2021). The reason is that tobacco contains elevated levels of cadmium (ranging from 0.1 to 0.2 µg per cigarette), which can be readily absorbed through the respiratory system (Ramirez, 2002).

Regional areas significantly influence the infiltration of external substances and heavy metals into breast milk. Industrial pollution, particularly in coastal regions, along with electronic waste disposal and pesticide use, contributes to increased exposure to toxic heavy metals. Coal combustion releases lead into the air through ash residue and smoke, while waste incineration also emits Pb. Leaded gasoline usage contributes to urban air pollution and elevated Pb levels in pregnant women. Industrial farming practices should be discouraged to prevent chemical transmission through the food chain. The impact of mercury (Hg) concentration in breast milk on infant development during exclusive breastfeeding is uncertain (Dorea, 2004).

Medical conditions, along with environmental factors and dietary intake, contribute to the presence of substances like arsenic, lead, mercury, and cadmium in breast milk. Despite exceeding WHO limits, statistical analysis yielded insignificant results. Postpartum mothers with diabetes are expected to have similar levels of harmful heavy metals in breast milk as those without diabetes (Chao et al., 2014).

Limitations of this review include high heterogeneity across studies in terms of geographic coverage, analytical methods, and exposure assessment. The majority of included studies were cross-sectional, limiting the ability to establish causality or track changes over time. Future research should aim to standardize sampling protocols and employ longitudinal study designs to better understand temporal patterns and causal relationships. Greater emphasis on biomarkers of exposure and health outcomes in infants is also needed to assess the long-term impact of heavy metal exposure through breastfeeding.

CONCLUSION

Understanding factors affecting heavy metal concentrations in breast milk is crucial. These include dietary habits, water consumption, smoking, regional factors, substance exposure, and medical conditions. Factors like consuming seafood or canned food, living in industrial areas, and using cosmetics are linked to higher heavy metal levels. Breastfeeding education programs must also inform mothers about reducing risk through safer food choices, limiting exposure to industrial pollutants, and cautious use of cosmetics. These findings can support the development of evidence-based breastfeeding guidelines and public health policies aimed at protecting maternal and infant well-being.

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