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Tampons as a source of exposure to metal(loid)s

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A R T I C L E I N F O

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A B S T R A C T

Background: Between 52–86% of people who menstruate in the United States use tampons—cotton and/or rayon/viscose ‘plugs’—to absorb menstrual blood in the vagina. Tampons may contain metals from agricultural or manufacturing processes, which could be absorbed by the vagina’s highly absorptive tissue, resulting in systemic exposure. To our knowledge, no previous studies have measured metals in tampons.
Objectives: We evaluated the concentrations of 16 metal(loid)s in 30 tampons from 14 tampon brands and 18 product lines and compared the concentrations by tampon characteristics.
Methods: About 0.2 – 0.3 g from each tampon (n = 60 samples) were microwave-acid digested and analyzed by inductively coupled plasma mass spectrometry (ICP-MS) to determine concentrations of arsenic, barium, calcium, cadmium, cobalt, chromium, copper, iron, manganese, mercury, nickel, lead, selenium, strontium, vanadium, and zinc. We compared concentrations by several tampon characteristics (region of purchase, organic material, brand type) using median quantile mixed models.
Results: We found measurable concentrations of all 16 metals assessed. We detected concentrations of several toxic metals, including elevated mean concentrations of lead (geometric mean [GM] = 120 ng/g), cadmium (GM = 6.74 ng/g), and arsenic (GM = 2.56 ng/g). Metal concentrations differed by region of tampon purchase (US versus European Union/United Kingdom), by organic versus non-organic material, and for store- versus name-brand tampons. Most metals differed by organic status; lead concentrations were higher in non-organic tampons while arsenic was higher in organic tampons. No categoriy had consistently lower concentrations of all or most metals.
Discussion: Tampon use is a potential source of metal exposure. We detected all 16 metals in at least one sampled tampon, including some toxic metals like lead that has no “safe” exposure level. Future research is needed to replicate our findings and determine whether metals can leach out of tampons and cross the vaginal epithelium into systemic circulation.

1. Introduction

Half of the global population has or will experience menstruation. Given the average age at menarche (12 years) (Papadimitriou, 2016; Parent et al., 2003), age at natural menopause (51 years) (El Khoudary, 2020), cycle length (29 days) (Grieger and Norman, 2020; Bull et al., 2019), and bleeding duration (4 days) (Bull et al., 2019), menstruators need to manage menstrual bleeding for several days each month over the course of decades. Tampons are commonly used to manage menstrual bleeding (Dodson et al., 2021); an estimated 52–86 % of menstruators in the United States (Dodson et al., 2021; Scranton, 2013) and 43–46 % of menstruators in Spain (Medina-Perucha et al., 2022) and France (Parent et al., 2022) use tampons. Tampons are cotton and/or rayon/viscose plugs that are inserted vaginally to absorb and retain menstrual blood. Tampons comprise an absorbent core, an outer non-woven covering, a withdrawal string, and may also include an applicator (cardboard or plastic) for insertion. Menstruators may use more than 7,400 tampons (4 tampons/day × 4 days/cycle × 12 cycles/year × 39 years of cycles) over their reproductive years, with each tampon being retained in the vagina for several hours.

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Given the high prevalence and long-term use of tampons, there is a growing interest in understanding tampons as a potential source of chemical exposure. Our research group published a review (Upson et al., 2022) in which we identified 15 studies that evaluated presence of chemicals in tampons (Archer et al., 2005; Desmedt et al., 2020; DeVito and Schecter, 2002; Gao and Kannan, 2020; Griet et al., 2020; Kim et al., 2020; Kuki et al., 2019; Lin et al., 2020; Schecter et al., 1998; Shin and Ahn, 2007; Wiberg et al., 1989; French Agency for Food Environmental and Occupational Health Safety (ANSES), 2018; KEMI Swedish Chemicals Agency, 2018; Office fédéral de la sécurité alimentaire et des affaires vétérinaires (OSAV), 2016; Pors and Fuhlendorff, 2002). Across those studies, a range of chemicals were detected in tampons, including dioxins and furan congeners, polycyclic aromatic hydrocarbons (PAHs), fragrances, phthalates, parabens, bisphenols, triclocarban, glyphosate, flame retardants, and volatile organic compounds (VOCs) (Upson et al., 2022). However, no study measured metal(loids) (hereafter metals) in tampons. Metals may arise in tampons through contamination of the absorbent core materials (e.g., cotton, rayon, viscose). In particular, the uptake of metals by plants and its subsequent accumulation along the food chain is known to be a common point of exposure through biomagnification for animal and human populations (Singh and Kalamdhad, 2011). Previous studies have found that metals can leach out of contaminated soils and into plant species and affect the physiological, biochemical, and molecular processes of plants (Rashid et al., 2023; Angulo-Bejarano et al., 2021). Some metals, including lead, copper, zinc, and cadmium, can bioaccumulate in the plants that are often harvested and used in tampon blends (Angelova et al., 2004). Cotton plants readily take up metals from soil (Angelova et al., 2004; Chen et al., 2015; Kaur et al., 2018), which can be contaminated by metals through atmospheric deposition (Angelova et al., 2004; Xing et al., 2019; George et al., 2015; Huang et al., 2017), application of wastewater (Khalid et al., 2018; Khan et al., 2019), and use of metal-containing pesticides and fertilizers (e.g., arsenic in phosphate fertilizer) (Jayasumana et al., 2015). Manufacturers may also add metals during production for product whitening, antimicrobial purposes, odor reduction, lubrication, and as pigments in applicators (Lake et al., 2024; Nemeth et al., 2012; Williams, 2004; Bond and Gorton, 2023).

Metals are naturally present and non-biodegradable inorganic substances in the environment. There are several health risks associated with heavy metal toxicity. The plausible presence of metals in tampons is concerning not only given the known adverse effects of metals exposure on health (El Ati-Hellal and Hellal, 2021; Nordberg and Costa, 2021) but also the characteristics of the vaginal epithelium that allow for efficient chemical absorption into systemic circulation. The vagina has a highly permeable and vascularized mucosal membrane and contains rugae, or small folds, resulting in an increased surface area (Srikrishna and Cardozo, 2013; Hussain and Ahsan, 2005). This allows for efficient absorption; for example, vaginal administration of the medications propranolol and misoprostol results in greater bioavailability than oral or buccal administration (respectively) (Patel et al., 1983; Vorontsova et al., 2022). Vaginally absorbed chemicals do not undergo first-pass metabolism and detoxification via the liver and directly enter systemic circulation (Kim and De Jesus, 2022). Critical evidence for systemic exposure to toxins with tampon use is provided by the toxic shock syndrome outbreak of the early 1980s. In that epidemic, the Rely tampon (and other superabsorbent tampons that could be worn for extended durations) interacted with menstrual blood and vaginal microbiota over time to result in overgrowth of the bacteria *Staphylococcus aureus* and its toxin in the vagina (Vostral SL. Of Mice and (Wo) Men, 2020; Vostral, 2011). The toxin crossed the vaginal epithelium, entered systemic circulation, and produced a range of serious symptoms in individuals, including hypotensive shock and even death (Vostral, 2020).

Given the potential for vaginal chemical absorption, high prevalence of regular tampon use, and plausibility of metal presence in tampons, the objective of this pilot study was to quantify the concentrations of 16 metals (arsenic [As], barium [Ba], calcium [Ca], cadmium [Cd], cobalt [Co], chromium [Cr], copper [Cu], iron [Fe], mercury [Hg], manganese [Mn], nickel [Ni], lead [Pb], selenium [Se], strontium [Sr], vanadium [V], and zinc [Zn]) in tampons. We considered several tampon brands and product lines (tampons with different names under the same brand), and assessed variability in metal concentrations by several tampon product characteristics, including organic vs non-organic tampons, tampons purchased in the EU/UK versus US, tampons with a plastic applicator versus no applicator/cardboard applicator, and store- versus name-brand tampons.

2. Materials & Methods

2.1. Tampon sample selection

For this study, we chose a variety of disposable tampon products, representing multiple manufacturers, brands, product lines, and absorbencies. We tested a total of 24 unique brand-product line-absorbency combinations (hereafter called "products"), representing 14 brands, 18 product lines, and five absorbencies (Table 1). We generally selected products that were listed as top sellers on a major online retailer, as well as "store-brand" products (products with the brand name of the store where purchased or made specifically for that store) from several large chain retailers in the US. We also generally selected products with greater absorbencies to ensure there was enough material for multiple tests. We purchased tampons between September 2022 and March 2023 from brick-and-mortar stores in the US (New York City), the European Union (EU: Athens, Greece), and the United Kingdom (UK: London, England), and from two major online retailers. Tampons purchased in the EU and UK were not the same products as purchased in the US, although there was overlap for one brand (Table 1). Within the 24 unique products, we tested 60 tampon subsamples (hereafter called "samples") representing 30 individual tampons (duplicate samples were prepared from each tampon).

2.2. Sample preparation and analysis

Detailed information about sample preparation and analysis is provided in the supplemental material (Section 1: Detailed Methods). In brief, we acid digested 0.2 – 0.3 g of tampon in a microwave digestion system (MARS 6, CEM Corporation, USA). Each sample included portions of the inner absorbent core and, if present, the non-woven outer covering (components A and C in Fig. 1) from random areas of the tampon. Duplicate samples were prepared in an identical fashion. We measured all non-mercury metals in the tampon digest using a PerkinElmer NexION 350S Inductively Coupled Plasma Mass Spectrometry with dynamic reaction cell (ICP-DRC-MS). For Hg, we used an Agilent 8900 ICP-MS equipped with an Agilent SPS 4 autosampler system. All analyses were conducted at the Trace Metal Core Facility, Columbia University, using established instrument settings (Schilling et al., 2024). We corrected metal concentrations for drift and then subtracted blank values. We calculated the method detection limit (MDL) values as 3.33 times the standard deviation of blank measurements [$n = 21$]) (Armbruster and Pry, 2008) and multiplied by the dilution factor of 100. The method quantification limit (MQL) was calculated as 10 times the standard deviation of blank measurements ($n = 21$) and multiplied by the dilution factor. We handled observations with concentrations below the MDL by using the machine-read values in the statistical analyses, however, we replaced negative Hg values with the MDL divided by the square root of 2 to allow for geometric mean calculations. The intra-assay coefficient of variation ranged from 6.7 % for Ba to 45.3 % for Hg (Supplemental Table S1). Our measures were in good agreement with the certified value for most certified metals (Ba, Ca, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Sr, V) in the IAEA-V-9 cotton reference material (range: 43 % to 116 %), and 90 % or greater of spiked metals (As, Co, and Zn) (Supplemental Table S2). More details about quality control,

Table 1
Characteristics of tampons included in the analysis.

Manufacturer	Brand	Product Line	Organic	Place of Purchase	Store Brand	Plastic Applicator	Absorbency	Number of Tampons	Number of Samples
I	A	1	No	US	No	No	Regular	1	2
I	A	2[a]	No	US	No	Yes	Super Plus	2	4[c]
I	A	3[a,b]	No	US	No	Yes	Regular	2	4[c]
I	A	3[a,b]	No	US	No	Yes	Super	2	4[c]
I	A	3[a,b]	No	US	No	Yes	Super Plus	2	4[c]
II	B	4	No	US	Yes	Yes	Super	1	3
III	C	5[a,b]	No	US	No	Yes	Regular	2	3[d]
III	C	5[a,b]	No	US	No	Yes	Super	2	4[c]
III	C	6	No	US	No	Yes	Ultra	1	2
IV	D	7[b]	Yes	US	No	Yes	Regular	1	2
IV	D	7[b]	Yes	US	No	Yes	Super	1	2
V	E	8[b]	No	US	No	Yes	Regular	1	2
V	E	8[b]	No	US	No	Yes	Super	1	2
VI	F	9	Yes	US	Yes	Yes	Super	1	2
VII	G	10	Yes	US	No	Yes	Super	1	2
VIII	H	11	No	US	Yes	No	Super Plus	1	2
III	I	12	No	US	No	No	Super Plus	1	2
III	I	13	–[e]	EU/UK	No	No	Regular	1	2
IX	J	14	No	US	Yes	Yes	Super	1	2
X	K	15	No	US	Yes	Yes	Super	1	2
XI	L	16	No	EU/UK	No	No	Regular	1	2
XII	M	17[b]	Yes	EU/UK	No	No	Regular	1	2
XII	M	17[b]	Yes	EU/UK	No	No	Super	1	2
I	N	18	Yes	US	No	Yes	Super	1	2

[a] Two packages with different lot numbers were purchased for this brand-product line combination
[b] This product line was purchased as a single package with multiple absorbencies.
[c] Two samples from a tampon in lot 1 and two samples from a tampon in lot 2.
[d] Two samples from a tampon in lot 1 and one sample from a tampon in lot 2.
[e] Packaging was lost and we were unable to determine if the product was organic or not.

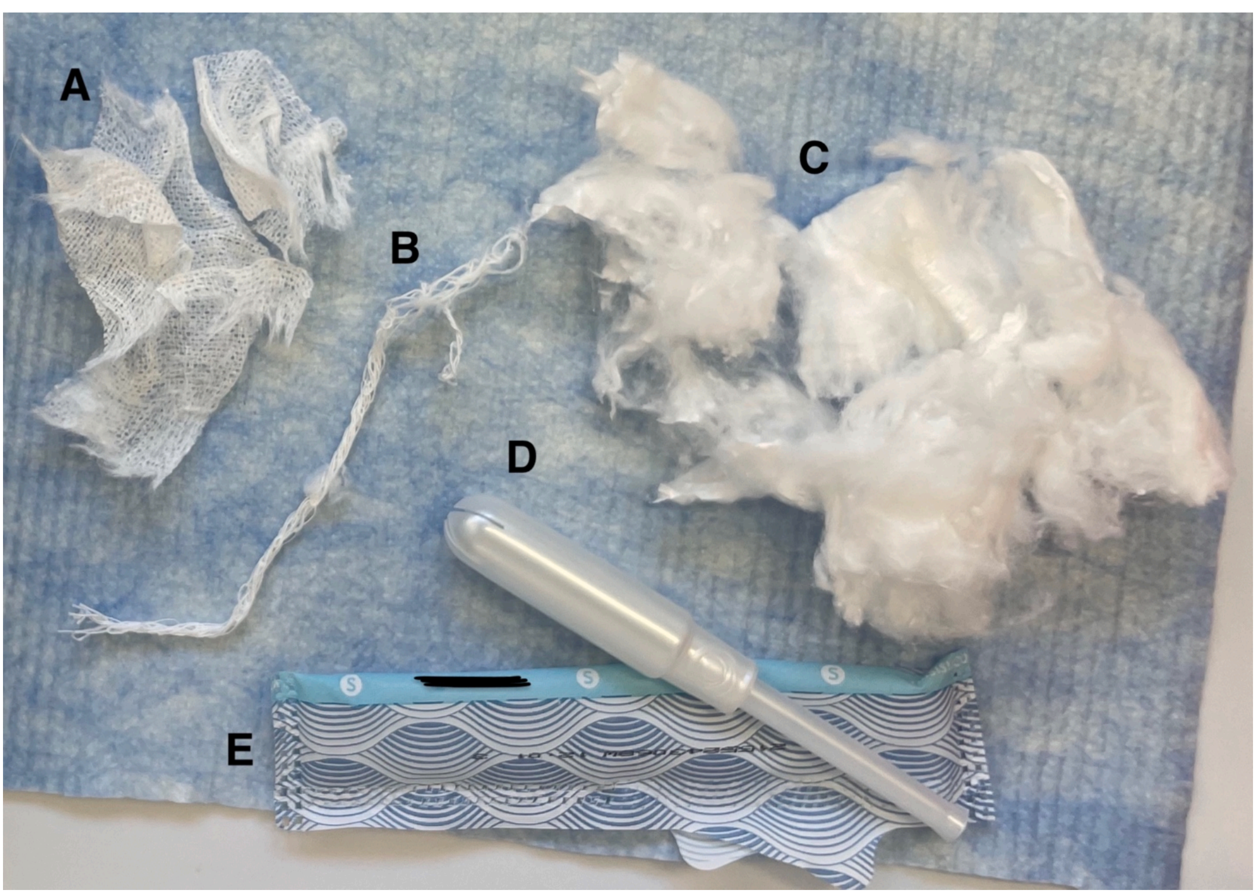

Fig. 1. A tampon separated into its components, including the (A) non-woven outer covering, (B) withdrawal string, (C) inner absorbent core, (D) applicator, and (E) wrapper.

including a discussion about metals with lower vs. higher levels of agreement, can be found in the supplemental material (Section 2: Quality Control of Cotton Certified Reference Material (IAEA-V-9) and Tampon Samples).

2.3. Statistical analysis

First, we qualitatively described the components of tampons. Next, we characterized the distribution of metal concentrations in tampons. To assess within-tampon heterogeneity, we calculated the within-tampon coefficient of variation using the root-mean-square approach (Bland, 2006) for each metal. To compare within- versus between-tampon variability, we calculated intra-class correlation coefficients (ICC) for each metal. We then calculated percentiles, geometric means (GM), and geometric standard deviations (GSD) for each metal. We measured correlations between pairs of metals using Spearman's rank correlation coefficient to account for non-normal distributions.

Lastly, we compared the median concentrations of metals by tampon product characteristics. To assess variability between (1) organic and non-organic tampons, (2) tampons purchased in the EU/UK versus US, (3) tampons with a plastic applicator versus no applicator/cardboard applicator (only 1 tampon had a cardboard applicator), and (4) store-versus name-brand tampons, we used metal-specific median quantile mixed models with a random intercept to account for potential within-tampon clustering. We assessed significance based on 95 % confidence intervals (CI). To assess variability between manufacturers and between brands, we plotted median concentrations with interquartile ranges (IQRs) and calculated the ICC for brand and manufacturer variance over total variance (separately). We did not conduct formal statistical tests due to small group sizes, as some manufacturers and brands were represented by only two samples. Similarly, to assess within-brand/product line variability, we plotted median concentrations with IQRs by tampon absorbency and by lot number, within a given brand/product line. However, as we did not have more than one absorbency for all brand/product line combinations and only had multiple lot numbers for three brand/product line combinations, we did not have sufficient observations to perform formal statistical tests.

We used Microsoft Excel for Mac Version 16.69.1 (Excel, 2022) and R version 4.1.1(R: A language and environment for statistical computing [computer program], 2021) for all statistical analyses. We used the tidyverse package version 1.3.1 (Wickham et al., 2019) for data management and the ggplot2 version 3.3.5 (Wickham et al., 2019) package for creating plots.

3. Results

3.1. Overview of tampon components

In the 24 analyzed tampon products (each representing a unique brand-product line-absorbency combination), we found that tampons generally consisted of five observable components: (A) a non-woven outer covering often wrapped around the outside of the absorbent core of the tampon; (B) a withdrawal string that was either looped through the inner core or sewn into the inner core with thread; (C) an inner absorbent core material that was tightly compressed by folding or rolling; (D) a plastic or cardboard applicator comprising a telescoping barrel and plunger; and (E) a plastic or paper wrapper (Fig. 1). Some products did not have a non-woven outer covering or an applicator.

3.2. Metal concentrations in tampons

We analyzed a total of 60 samples, representing 30 unique tampons (24 unique brand-product line-absorbency combinations) (Table 1), to determine concentrations of 16 metals. For all metals except Hg, the within-tampon coefficient of variation ranged from 12.9 % to 36.5 %, indicating lower heterogeneity and reasonable reproducibility between samples from the same tampon (Supplemental Table S1). Correspondingly, ICC values were moderate to high, ranging from 0.59 to 0.99 (Supplemental Table S1), indicating high between-tampon variability and low within-tampon variability. In contast, Hg had a higher within-tampon CV (63.3 %) and low ICC (0.03), but 91.7 % of samples were below the MDL.

All of the metals we assessed were present in quantifiable concentrations in tampons (Table 2). For 12 out of the 16 metals, we found concentrations greater than the MDL in 100 % of tampon samples. For Hg, Cr, As, and Se, we found concentrations above the MDL in 8.3 %, 10 %, 95 %, and 98.3 % of tampon samples, respectively (Table 2). Concentrations varied substantially across metals. We found the highest concentrations for Zn (GM = 52,000 ng/g, GSD = 1.93 ng/g) and Ca (GM = 39,000 ng/g, GSD = 2.17 ng/g), and the lowest concentrations for As (GM = 2.56 ng/g, GSD = 2.02 ng/g) (Table 2 and Fig. 2). Several toxic metals were detectable in all tampon samples, including As, Cd, Cr, Pb, and V. Among these, Pb had the highest concentration with a GM of 120 ng/g (GSD = 2.24 ng/g) (Fig. 2). We also observed substantial variation across metal concentrations in tampons from different brand-product-line-absorbency combinations (Supplemental Table S4). For example, tampons from Brand D had higher As concentrations but lower Pb concentrations, compared to the GM for all brands. Many metals were moderately correlated with each other, while Fe was strongly correlated (>0.8) with Ca and V, and Zn was strongly correlated with Cd (Fig. 3).

3.3. Variability by tampon characteristics

We observed large variability between brands for nearly all metals (Supplemental Figure S1). The lowest ICC for brand-level variance was 0.008 for Hg and 0.34 for Cd; ICCs for all other metals were greater than 0.5, with seven greater than 0.8 (very high between brand variability). We also observed large variability between manufacturers for nearly all metals (Supplemental Figure S2). The lowest ICC for manufacturer-level variance was also for Hg (0.02) and Cd (0.27), but Sr, Pb, and Zn also had ICC values less than 0.5. Eleven metals had ICC values greater than 0.5, with five greater than 0.8 (very high between manufacturer variability).

We found significant differences between median metal concentrations for organic versus non-organic tampon samples for all metals except Cu, Hg, Ni, and Se. Median concentrations of Ba, Cd, Co, Pb, and Zn were lower in organic tampons compared to non-organic tampons (effect estimates ranging from −48,605.46 ng/g [95 % CI: −63,500.14, –33,710.77] for Zn to −9.93 ng/g [95 % CI: −13.62, −6.23] for Cd), while median concentrations of As, Ca, Cr, Fe, Mn, Sr, and V were higher in organic tampons compared to non-organic tampons (effect estimates ranging from 4.53 ng/g [95 % CI: 2.32, 6.75] for As to 78,980.41 ng/g [95 % CI: 55,016.32, 102,944.50] for Ca) (Fig. 4 and Supplemental Table S5). We also observed significant differences between products purchased in the EU/UK and the US for three metals. Cd (effect estimate: −8.17 ng/g [95 % CI: −12.78, −3.56]), Co (−17.22 ng/g [95 % CI: −25.76, −8.68], and Pb (−133.14 ng/g [95 % CI: −177.35, −88.94]) were lower in tampons purchased in the EU/UK compared to those purchased in the US (Supplemental Figure S3 and Supplemental Table S5). We did not observe any significant differences in median metal concentrations between tampons with plastic applicators compared to those with no applicator/cardboard applicator (Supplemental Figure S4 and Supplemental Table S5). We observed differences between name-brand and store-brand tampons. Median concentrations of Cu (81.26 ng/g [95 % CI: 15.68, 146.85]), Ni (50.10 ng/g [95 % CI: 21.97, 78.23]), and Se (454.39 ng/g [95 % CI: 23.54, 885.23]) were higher in store-brand tampons compared to name-brand tampons, while the median concentration of Zn was lower in store-brand tampons compared to name-brand tampons (−21.721.58 ng/g [95 % CI: −42,772.55, −670.61]) (Supplemental Figure S5 and Supplemental Table S5).

To assess within-brand/product line variability, we plotted median concentrations of metals for tampons of different absorbencies

Table 2
Distribution of metal concentrations (ng/g) in tampon samples.

Metal	n > MDL (%)	MDL Range	Percentiles 25th	Median	75th	Maximum	Geometric Mean	Geometric Standard Deviation
As	57 (95 %)	0.05 – 3.11	1.69	2.30	3.70	14.1	2.56	2.02
Ba	60 (100 %)	0.88 – 2.33	394	1,500	2,200	8,200	1,100	4.60
Ca	60 (100 %)	406 – 8,600	23,000	29,000	79,000	170,000	39,000	2.17
Cd	60 (100 %)	0.05 – 2.39	2.48	9.63	15.1	56.1	6.74	2.67
Co	60 (100 %)	0.12 – 1.04	12.5	23.8	31.6	231	19.8	2.17
Cr	6 (10 %)	21.1 – 141	< MDL	< MDL	< MDL	103	< MDL	–
Cu	60 (100 %)	2.92 – 11.4	45.6	71.3	116	846	78.9	2.00
Fe	60 (100 %)	33.3 – 327	1,500	2,100	5,500	25,000	3,099	2.68
Hg	5 (8.3 %)	2.00	< MDL	< MDL	< MDL	18.8	< MDL	–
Mn	60 (100 %)	1.84 – 6.20	285	369	431	1,030	296	2.38
Ni	60 (100 %)	0.76 – 2.66	63.9	75.6	106	166	80.1	1.44
Pb	60 (100 %)	0.39 – 1.72	50.8	173	215	468	120	2.24
Se	59 (98.3 %)	3.80 – 4.52	8.69	11.5	56.5	1,500	28.5	6.04
Sr	60 (100 %)	1.90 – 6.68	88.0	182	254	1,600	190	2.74
V	60 (100 %)	0.10 – 1.05	2.95	4.55	13.4	65.8	6.37	2.71
Zn	60 (100 %)	253 – 1,200	34,000	65,000	84,000	160,000	52,000	1.93

Note: Machine read values were used for tampon sample metal concentrations below the MDL. MDL = method detection limit.

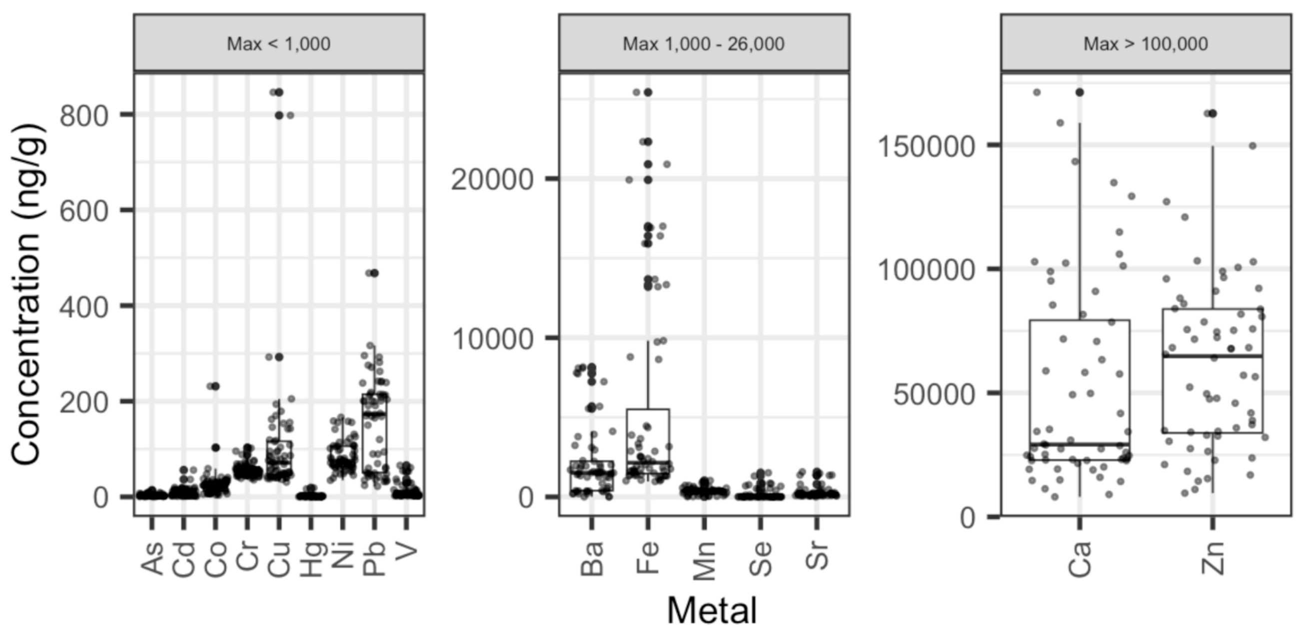

Fig. 2. Boxplots of metal distributions in tampon samples (n = 60). Machine read values were used for metal concentrations below the MDL; please note that 54/60 (90 %) of Cr and 55/60 (91.7 %) of Hg in tampon samples were below the MDL. The figure is split into three panels for visualization purposes only.

(Supplemental Figure S6) and from different lot numbers (Supplemental Figure S7), within their respective product lines. Generally, concentrations of metals were similar across absorbency and lot number.

4. Discussion

In a selection of widely available tampons, we found measurable concentrations of all 16 metals assessed. We confirmed the presence of several toxic metals, including Pb, Cd, and As, but did not find substantial presence of Cr or Hg. We also found high concentrations of Ca and Zn in tampons, compared to the concentrations of other metals. We found low variability of metal concentrations within individual tampons, but high variability between different tampons. For example, when comparing metal concentrations by tampon characteristics, we found differences in the metal concentrations in organic versus non-organic tampons for most metals, for products purchased in the EU/UK versus US for four metals, and for store-brand versus name-brand tampons for four metals, but no category had consistently lower concentrations of all or most metals.

Concerningly, we found Pb in all the tested tampons. There is no safe exposure level to Pb; any proportion of Pb that may leach out of a tampon and reach systemic circulation might contribute to negative health outcomes. Pb is stored in bones, where it replaces Ca, and can be retained in the body for decades (United States Department of Health and Human Services Agency for Toxic Substances and Disease Registry, 2020). Pb is associated with numerous adverse neurological, renal, cardiovascular, hematological, immunological, reproductive, and developmental effects (United States Department of Health and Human Services Agency for Toxic Substances and Disease Registry, 2020). Of particular note, even low-level exposure to Pb (≤ 10 μg/dL in blood) can result in neurobehavioral impacts in adults and children, including decreased cognitive function such as impaired attention, memory, and learning ability (United States Department of Health and Human Services Agency for Toxic Substances and Disease Registry, 2020). As and Cd are also associated with numerous adverse health outcomes (United States Department of Health and Human Services Agency for Toxic Substances and Disease Registry, 2012; United States Department of Health and Human Services Agency for Toxic Substances and Disease

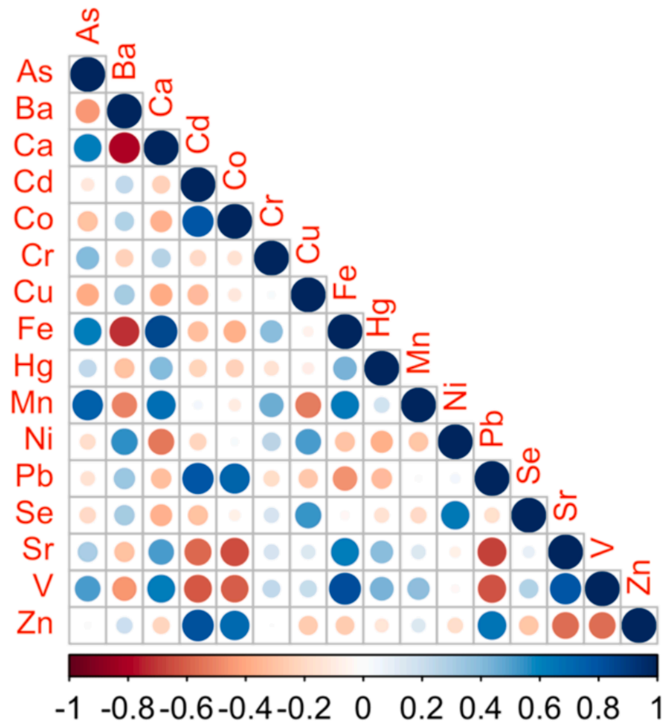

Fig. 3. Correlation matrix of metals analyzed in 60 tampon samples. Machine read values were used for sample concentrations below the MDL; please note that 54/60 (90%) of Cr and 55/60 (91.7%) of Hg were below MDL in tampons. Darker red corresponds to a negative correlation, while darker blue corresponds to a positive correlation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Registry, 2007). Inorganic As is a known carcinogen and is associated with cardiovascular disease, dermatitis and other dermal effects, and respiratory and neurological disease (United States Department of Health and Human Services Agency for Toxic Substances and Disease Registry, 2007). One study evaluating the effect of vaginal arsenic exposure through douching in rats found that vaginal As exposure had effects on oxidative mechanisms in the uterus and ovaries (Irnawati et al., 2022). Cd targets the renal system and can cause kidney damage; it is also associated with cardiovascular disease (United States Department of Health and Human Services Agency for Toxic Substances and Disease Registry, 2012). However, very little scientific work on the potential health effects of dermal exposure (or vaginal exposure) to As or Cd has been conducted (United States Department of Health and Human Services Agency for Toxic Substances and Disease Registry, 2012; United States Department of Health and Human Services Agency for Toxic Substances and Disease Registry, 2007).

There are several routes through which metals can be introduced to tampons, including manufacturing uses of metals in tampons. First, the raw materials of cotton, rayon, or viscose may be contaminated during production (e.g., through atmospheric deposition, wastewater application) (Angelova et al., 2004; Xing et al., 2019; George et al., 2015; Khalid et al., 2018; Bednar et al., 2002). Tampons in our study were made in several different countries, with the largest number made in the US (other locations include the Czech Republic, Israel, Mexico, Slovenia, Taiwan, and the EU). Unfortunately, packaging frequently did not state from where the raw ingredients were sourced, and for several US-made tampons, the packaging stated "made in USA with global ingredients," making it impossible to know where the raw materials were sourced. Second, tampons may be contaminated with metals from water during the manufacturing process; for example, water in the EU and US is sometimes contaminated with lead (Brown and Margolis, 2012; Hayes and Skubala, 2009). Third, metals may also be intentionally added to tampons during manufacturing for various purposes. For example, several metals we detected, including Ca, Co, Cr, Cu, Ni, and Zn, may be

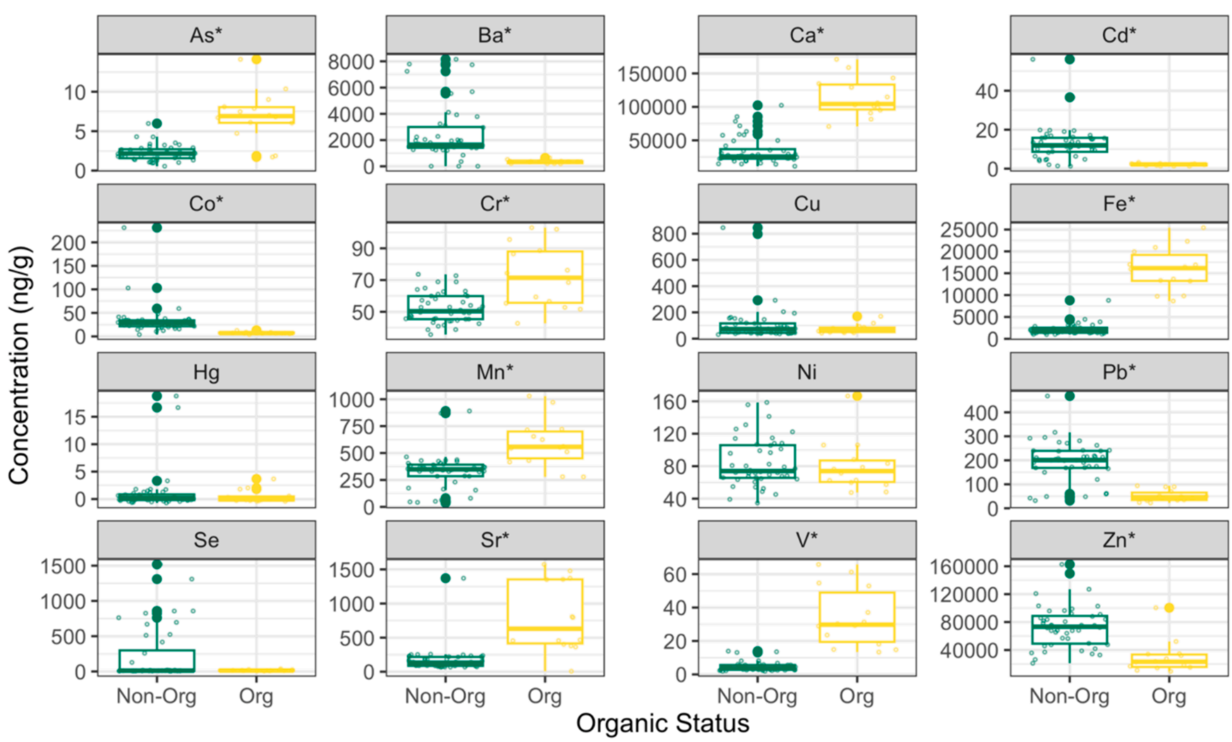

Fig. 4. Comparison of metal concentrations in organic (yellow) versus non-organic (green) tampons, n = 58. We did not have information on organic status for two tampon samples (one product) due to packaging loss. *Significant difference after running median quantile regression. Machine read values were used for sample concentrations below the MDL. Please note that 52/58 (90 %) of Cr and 55/60 (91.7 %) of Hg samples were below the MDL. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

added to tampons as antimicrobial agents designed to release from the tampon when it absorbs liquid (menses) (Nemeth et al., 2012; Ratko, 2023).All of these metals, as well as Fe and Mn, may also be added to tampons for odor control (Williams, 2004; Fell et al., 2010). Additionally, patents suggest that manufacturers may add some of the metals we tested to tampons as lubricants to aid in smooth insertion (Ca, Sr, and Zn) (Bond and Gorton, 2023). The two metals we detected in the highest concentrations, Ca and Zn, are used for odor control, lubrication, and as antimicrobial agents, perhaps explaining why we observed them in such high concentrations. Relatedly, Zn-infused underwear can be found on the market advertised as helping control odor (e.g., Huha). These uses of metals may also partially explain the variation in metal concentrations we observed by manufacturer and brand. Metals are also used as pigments to color applicators or parts of the tampon (Ba, Cd, Co, Fe, Mn, Zn) (Bond and Gorton, 2023; Lake et al., 2024). We found no differences in metal concentrations for tampons with plastic applicators compared to those with no or cardboard applicators, potentially suggesting metals used as pigments in applicators may not be driving our observed metal concentrations. However, this finding should be confirmed with more samples to increase statistical power.

We detected differences in most metals in organic versus non-organic tampons. All of the organic tampons in our study advertise they are made of 100 % cotton, whereas the non-organic tampons were made of rayon or a cotton/rayon/viscose mix. This difference may explain part of the variation in metal concentrations between organic and non-organic products. For example, As may be more abundant in 100 % organic cotton products because of the application of natural fertilizers in organic cotton fields (e.g., animal waste or plant-based compost), which can lead to geochemical changes in soil by altering pH (O'Hallorans and Colberg, 1993). This may increase the bioavailability of As in soil, although more studies are needed to confirm this hypothesis. However, prior research has not shown a clear difference in metal concentrations between dyed cotton textiles and viscose textiles (Sungur and Gülmez, 2015) (viscose is a type of rayon). For example, Sungur and Gülmez (2015) measured concentrations of heavy metals in several textiles, including dyed cotton materials, and compiled metal concentration data from prior studies. The concentrations of Co, Cr, Cu, Fe, Mn, Ni and Pb found in cotton textiles of various colors were similar to those we found in tampons, although tampon metal concentrations were on the low end of that observed range (Sungur and Gülmez, 2015). Rujido-Santos et al. (2022) evaluated metal concentrations in a selection of dyed textiles made of various fibers, including several that had proportions of cotton and viscose. Broadly, the concentrations of As, Ba, Cd, Cr, Cu, Fe, Ni and V were higher in dyed textiles than what we found in tampons, while concentrations of Mn and Pb were similar (Rujido-Santos et al., 2022). In contrast, Zn concentrations in tampons are higher than that reported for textiles in other studies (Sungur and Gülmez, 2015; Rujido-Santos et al., 2022) (e.g, our GM = 52,000 ng/g versus a maximum of 5,000 ng/g in Saracoglu et al. (2008)). This further supports the hypothesis that Zn is added intentionally to tampons during manufacturing. However, none of the packaging of the tampons we assessed listed Zn as an ingredient, including the tampons purchased in New York, which requires tampon manufacturers to list ingredients in tampons sold in the state of New York (Menstrual product labeling, 2020).

In all three government bodies (US, EU, UK) where we purchased tampons for this study, regulations around tampons are not extensive and do not require regular product testing. In the US, the Food and Drug Administration (FDA) classifies tampons as medical devices and regulates their safety (Kwak et al., 2019). However, there is no requirement to test tampons for chemical contaminants, and the FDA only recommends that tampons not contain two dioxin compounds or pesticide residues (United States Food and Drug Administration, 2005). In the EU, tampons are regulated under the General Product Safety Directive (2001/95/EC) (Kwak et al., 2019) and follow a code of "good practice" developed by the tampon manufacturing industry (Ms. Jourova on behalf of the Commission, 2016). This code similarly does not require testing for chemicals (Absorbent Hygiene Products Working Group of EDANA, 2020). In the UK, tampons are regulated under the General Product Safety Regulations 2005, which requires that "no producer shall place a product on the market unless the product is safe" and that consumers are provided with enough information to "assess the risks inherent in a product" (The General Product Safety Regulations, 2005). In contrast, the EU restricts the concentrations of Pb, Cd, Cr (VI) and As in textile fabrics to be less than 1 mg/kg (European Commission, 2018). While the concentrations of Pb, Cd, and As we found in tampons were all lower than 1 mg/kg, we highlight that tampons are in contact with vaginal mucosa rather than the skin with which other textiles are in contact, which may increase absorption, potentially resulting in higher exposure risk even from low concentrations. In general, regulations in the US, EU, and UK protecting consumers from potential contaminants in tampons are nearly nonexistent, and none of these governments requires manufacturers to test their products for harmful chemicals, including metals.

Although our study found the presence of toxic metals in tampons, future studies are necessary to assess whether metals can leach out of tampons and become bioaccessible for vaginal absorption. Thus, we cannot speculate on potential harm to the health of menstruators. It is critical that future studies evaluate the potential for metal leaching from tampons and uptake into the body. Previous studies have conducted risk assessments for other types of chemicals found in tampons, but generally came to discrepant conclusions about their risk to tampon users (Upson et al., 2022). A major obstacle in interpreting these risk assessments is the lack of data on the absorption of chemicals through the vaginal mucosa. As a result, some studies extrapolated risks of vaginal absorption based on dermal absorption studies, despite distinct differences in vaginal and dermal tissue (Upson et al., 2022). To our knowledge, no risk assessments have investigated vaginal exposure to metals.

4.1. Limitations

We acknowledge that our study has some limitations. First, we did not have sufficient power to assess statistical differences by absorbency, lot number, brand, or manufacturer. We focused on including as many brands as possible, rather than including more samples of a smaller number of brands, so that we could gain a more representative understanding of metal concentrations in tampons. Second, although we compared tampons purchased in the US with those purchased in the EU/UK, we cannot consider the three non-US tampons included in this analysis to be representative of most tampons available in the EU/UK, although they are very common. Additionally, given the limited overlap in brands of tampons purchased across different locations, it is not possible to fully attribute any detected differences specifically to differences in location and not brands. Third, we conducted multiple statistical tests, which increases the possibility of Type I error (false positives). However, we feel this is a reasonable tradeoff considering that our analysis is exploratory. We drew conclusions about differences in metal concentrations by tampon characteristics based on robustness of the results and the strength of the association rather than relying upon statistical significance alone. Furthermore, even if some differences were found significant due to chance, our main finding of non-zero metal concentrations in all samples is unequivocal. Finally, this study does not provide information about potential bio-accessibility of tampon metals and thus we cannot estimate health risks (if any) from tampon use. However, we do note that studies evaluating heavy metals in cosmetics (e.g., soap, lotion, eye liners / shadows, lipsticks) have found that several metals, including Pb, can be dermally absorbed from such products (Bocca et al., 2014).

4.2. Conclusions

To our knowledge, our study is the first to assess concentrations of metals in tampons, despite the potential for substantial vaginal absorption of metals and the widespread and frequent use of tampons among menstruators. We found measurable concentrations of all 16 metals assessed, including the toxic metals Pb (GM = 120 ng/g), Cd (GM = 6.74 ng/g), and As (GM = 2.56 ng/g). We also found elevated concentrations of Ca (GM = 39,000 ng/g) and Zn (GM = 52,000 ng/g) in tampons. Future research is necessary to replicate our findings and determine whether metals can leach out of tampons and cross the vaginal epithelium into systemic circulation. Our findings point towards the need for regulations requiring the testing of metals in tampons by manufacturers. This is especially important considering that we found measurable quantities of several toxic metals, including Pb, which has no known "safe" exposure level.

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CRediT authorship contribution statement

Jenni A. Shearston: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Kristen Upson:** Writing – review & editing, Conceptualization. **Milo Gordon:** Writing – review & editing, Validation. **Vivian Do:** Writing – review & editing. **Olgica Balac:** Investigation. **Khue Nguyen:** Writing – review & editing. **Beizhan Yan:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Marianthi-Anna Kioumourtzoglou:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Kathrin Schilling:** Writing – review & editing, Supervision, Resources, Investigation, Conceptualization.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2024.108849.

References

Absorbent Hygiene Products Working Group of EDANA, 2020. Edana Code of Practice for tampons placed on the European market. Version 3.
Angelova, V., Ivanova, R., Delibaltova, V., Ivanov, K., 2004. Bio-accumulation and distribution of heavy metals in fibre crops (flax, cotton and hemp). Ind. Crop. Prod. 19 (3), 197–205.
Angulo-Bejarano, P.I., Puente-Rivera, J., Cruz-Ortega, R., 2021. Metal and metalloid toxicity in plants: An overview on molecular aspects. Plants. 10 (4), 635.
Archer, J.C., Mabry-Smith, R., Shojaee, S., Threet, J., Eckert, J.J., Litman, V.E., 2005. Dioxin and furan levels found in tampons. J Womens Health (larchmt). 14 (4), 311–315.
Armbruster, D.A., Pry, T., 2008. Limit of blank, limit of detection and limit of quantitation. The Clinical Biochemist Reviews. 29 (Suppl 1), S49.
Bednar, A.J., Garbarino, J.R., Ranville, J.F., Wildeman, T.R., 2002. Presence of organoarsenicals used in cotton production in agricultural water and soil of the southern United States. J Agric Food Chem. 50 (25), 7340–7344.
Bland M. How should I calculate a within-subject coefficient of variation? 2006; https://www-users.york.ac.uk/~mb55/meas/cv.htm#:~:text=In%20the%20study%20of%20measurement,within%2Dsubject%20coefficient%20of%20variation. Accessed March 10, 2023.
Bocca, B., Pino, A., Alimonti, A., Forte, G., 2014. Toxic metals contained in cosmetics: A status report. Regul. Toxicol. Pharm. 68 (3), 447–467.
Bond, T., Gorton, P., 2023. Composition for thin walled molded parts (U.S. Patent No. 11,826,240 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/11826240.
Brown, M.J., Margolis, S., 2012. Lead in drinking water and human blood lead levels in the United States. MMWR 61 (04), 1–9.
Bull, J.R., Rowland, S.P., Scherwitzl, E.B., Scherwitzl, R., Danielsson, K.G., Harper, J., 2019. Real-world menstrual cycle characteristics of more than 600,000 menstrual cycles. Npj Digital Med. 2 (1), 83.
Centers for Disease Control aand Prevention. Toxic shock syndrome–United States. 1980. *MMWR Morb Mortal Wkly Rep.* 1997;46(22):492-493; discussion 494-495.
Chen, Z., Zhao, Y., Fan, L., Xing, L., Yang, Y., 2015. Cadmium (Cd) localization in tissues of cotton (Gossypium hirsutum L.), and its phytoremediation potential for Cd-contaminated soils. Bull. Environ. Contam. Toxicol. 95 (6), 784–789.
European Commission. Commission Regulation (EU) No 2018/1513 of 10 October 2018 amending Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as regards certain substances classified as carcinogenic, mutagenic or toxic for reproduction (CMR), category 1A or 1B. *Official Journal of the European Union.* 2018;L 256:1-7.
Desmedt, B., Marcelis, Q., Zhilivoda, D., Deconinck, E., 2020. Sensitizing fragrances in absorbent hygiene products. Contact Dermatitis 82 (5), 279–282.
DeVito, M.J., Schecter, A., 2002. Exposure assessment to dioxins from the use of tampons and diapers. Environ Health Perspect. 110 (1), 23–28.
Dodson, R.E., Cardona, B., Zota, A.R., Robinson Flint, J., Navarro, S., Shamasunder, B., 2021. Personal care product use among diverse women in California: Taking Stock Study. J. Eposure Sci. Environ. Epidemiol. 31 (3), 487–502.
El Ati-Hellal, M., Hellal, F., 2021. Heavy metals in the environment and health impact. Environ. Health 51.
El Khoudary, S.R., 2020. Age at menopause onset and risk of cardiovascular disease around the world. Maturitas 141, 33–38.
Fell, D.A., Lan, M., Georger, W.A., Arehart, K.D., Do, B.T., Martin, S.M., 2010. Absorbent articles with improved odor control (U.S. Patent No. 7,745,685, B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/7745685.
French Agency for Food Environmental and Occupational Health & Safety (ANSES). Opinion of the French Agency for Food, Environmental and Occupational Health & Safety on the safety of feminine hygiene products, Request No. 2016-SA-0108. In: 2018.
Gao, C.J., Kannan, K., 2020. Phthalates, bisphenols, parabens, and triclocarban in feminine hygiene products from the United States and their implications for human exposure. Environ Int. 136, 105465.
George, J., Masto, R.E., Ram, L.C., Das, T.B., Rout, T.K., Mohan, M., 2015. Human exposure risks for metals in soil near a coal-fired power-generating plant. Arch. Environ. Contam. Toxicol. 68 (3), 451–461.
Grieger, J.A., Norman, R.J., 2020. Menstrual cycle length and patterns in a global cohort of women using a mobile phone app: retrospective cohort study. J Med Internet Res. 22 (6), e17109.
Griet, J, Van Deun, M, Bertels, D, Poelmans, E, Vanermen, G, 2020. Monitoring of the Belgian market with regard to organic residues in tampons sanitary napkins - Part 2: Target analyses. In: Federal Public Service. Health Food Chain Safety and Environment 2020.
Hayes, C.R., Skubala, N.D., 2009. Is there still a problem with lead in drinking water in the European Union? J Water Health. 7 (4), 569–580.
Huang, X., Hu, J., Qin, F., et al., 2017. Heavy metal pollution and ecological assessment around the Jinsha coal-fired power plant (China). Int. J. Environ. Res. Public Health 14 (12), 1589.
Hussain, A., Ahsan, F., 2005. The vagina as a route for systemic drug delivery. J Control Release. 103 (2), 301–313.
Irnawati, I., Idroes, R., Akmal, M., Suhartono, E., Rusyana, A., Seriana, I., 2022. The effect and activity of free radical enzymes due to arsenic exposure through the vulva and vagina. Open Access Macedonian Journal of Medical Sciences. 10 (B), 2279–2285.
Jayasumana, C., Fonseka, S., Fernando, A., et al., 2015. Phosphate fertilizer is a main source of arsenic in areas affected with chronic kidney disease of unknown etiology in Sri Lanka. Springerplus 4, 90.
Kaur, R., Bhatti, S.S., Singh, S., Singh, J., Singh, S., 2018. Phytoremediation of heavy metals using cotton plant: a field analysis. Bull. Environ. Contam. Toxicol. 101 (5), 637–643.
KEMI Swedish Chemicals Agency. Survey of hazardous chemical substances in feminine hygiene products: A study within the government assignment on mapping hazardous chemical substances 2017-2020. In. Stockholm, Sweden: Swedish Chemicals Agency; 2018.
Khalid, S., Shahid, M., Bibi, I., Sarwar, T., Shah, A.H., Niazi, N.K., 2018. A review of environmental contamination and health risk assessment of wastewater use for crop irrigation with a focus on low and high-income countries. Int J Environ Res Public Health. 15 (5).

Khan, Z.I., Ahmad, K., Batool, F., et al., 2019. Evaluation of toxic potential of metals in wheat crop grown in wastewater-contaminated soil in Punjab, Pakistan. *Environ. Sci. Pollut. Res.* 26 (24), 24958–24966.
Kim, J., De Jesus, O., 2022. Medication routes of administration. StatPearls [internet]. StatPearls Publishing.
Kim, M., Park, H.J., Bae, O.N., Baek, S.H., 2020. Development and uncertainty estimation of cryogenic homogenization and static headspace–gas chromatography–mass spectrometry method for the simultaneous determination of twelve toxic volatiles in disposable menstrual products. Microchem. J. 158.
Kuki, Á., Zelei, G., Nagy, L., Nagy, T., Zsuga, M., Kéki, S., 2019. Rapid mapping of various chemicals in personal care and healthcare products by direct analysis in real time mass spectrometry. Talanta 192, 241–247.
Kwak, J.I., Nam, S.-H., Kim, D., An, Y.-J., 2019. Comparative study of feminine hygiene product regulations in Korea, the European Union, and the United States. Regul. Toxicol. Pharm. 107, 104397.
Lake, D.D., Minoguchi, R., Qureshi K., Weisman, P.T., Matsuzaka, K., Nishikawa, T., 2024. Tampon product including applicator having components molded of pulp-based composite (U.S. Patent No. 12,004,929 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/12004929.
Lin, N., Ding, N., Meza-Wilson, E., et al., 2020. Volatile organic compounds in feminine hygiene products sold in the US market: A survey of products and health risks. Environ Int. 144, 105740.
Medina-Perucha, L., López-Jiménez, T., Holst, A.S., et al., 2022. Use and perceptions on reusable and non-reusable menstrual products in Spain: a mixed-methods study. PLoS One 17 (3), e0265646.
Menstrual product labeling, SECTION 399-AAAA New York State(2020).
Microsoft Excel [computer program]. 2022.
Ms. Jourova on behalf of the Commission. Parliamentary question - E-013116/2015 (ASW). In:2016.
Nemeth, K.A., Osborn, T.W., Wang, F., 2012. Feminine hygiene article having calcium sugar acid salt (European Patent No. EP 2 427 223 B1). European Patent Office. https://patentimages.storage.googleapis.com/26/e7/ac/b39329eceda7c2/EP2427223B1.pdf.
Nordberg GF, Costa M. *Handbook on the toxicology of metals: volume I: general considerations.* Academic press; 2021.
Office fédéral de la sécurité alimentaire et des affaires vétérinaires (OSAV). Substances chimiques présentes dans les protections hygiéniques: Evaluation des risques. In: DFI Dfdli, ed: Confédération suisse; 2016.
O'Hallorans, J.M., Colberg, O., 1993. Effect of chicken manure on chemical properties of a Mollisol and tomato production. Journal of Agriculture-University of Puerto Rico. 77, 181.
Papadimitriou, A., 2016. The evolution of the age at menarche from prehistorical to modern times. J. Pediatr. Adolesc. Gynecol. 29 (6), 527–530.
Parent, A.-S., Teilmann, G., Juul, A., Skakkebaek, N.E., Toppari, J., Bourguignon, J.-P., 2003. The timing of normal puberty and the age limits of sexual precocity: Variations around the world, secular trends, and changes after migration. Endocr. Rev. 24 (5), 668–693.
Parent, C., Tetu, C., Barbe, C., et al., 2022. Menstrual hygiene products: A practice evaluation. Journal of Gynecology Obstetrics and Human Reproduction. 51 (1), 102261.
Patel, L.G., Warrington, S.J., Pearson, R.M., 1983. Propranolol concentrations in plasma after insertion into the vagina. Br Med J (clin Res Ed). 287 (6401), 1247–1248.
Pors J, Fuhlendorff R. Mapping of chemical substances from tampons, Survey of chemical substances in consumer products, survey No. 12. In: Danish Environmental Protection Agency, ed2002.
R: A language and environment for statistical computing [computer program]. Vienna, Austria: R Foundation for Statistical Computing; 2021.
Rashid, A., Schutte, B.J., Ulery, A., et al., 2023. Heavy metal contamination in agricultural soil: environmental pollutants affecting crop health. Agronomy 13 (6), 1521.
Ratko, T., 2023. Absorbent intimate hygiene product for preventing and treating infection (U.S. Patent No. 2023/0218448 A1). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/20230218448.
Rujido-Santos, I., Herbello-Hermelo, P., Barciela-Alonso, M.C., Bermejo-Barrera, P., Moreda-Piñeiro, A., 2022. Metal content in textile and (nano) textile products. Int. J. Environ. Res. Public Health 19 (2), 944.
Saracoglu, S., Divrikli, U., Soylak, M., Elci, L., Dogan, M., 2008. Determination of trace elements of some textiles by atomic absorption spectrometry. J. Trace Microprobe Tech. 21 (2), 389–396. https://doi.org/10.1081/TMA-120020273.
Schecter, A.J., Papke, O., Marquardt, S., 1998. Dioxins and dibenzofurans in American sanitary products: tampons, sanitary napkins, disposable and cloth diapers, and incontinence pads. Organohalogen Compd. 36, 281–284.
Schilling, K., Glabonjat, R.A., Balac, O., et al., 2024. Method validation for (ultra)-trace element concentrations in urine for small sample volumes in large epidemiological studies: application to the population-based epidemiological multi-ethnic study of atherosclerosis (MESA). Anal Methods. 16 (2), 214–226.
Scranton, A., 2013. Chem fatale: Potential health effects of toxic chemicals in feminine care products. Women's Voices for the Earth.
Shin, J.H., Ahn, Y.G., 2007. Analysis of polychlorinated dibenzo-p-dioxins and dibenzo-furans in sanitary products of women. Text. Res. J. 77 (8), 597–603.
Singh, J., Kalamdhad, A.S., 2011. Effects of heavy metals on soil, plants, human health and aquatic life. Int J Res Chem Environ. 1 (2), 15–21.
Srikrishna, S., Cardozo, L., 2013. The vagina as a route for drug delivery: a review. Int Urogynecol J. 24 (4), 537–543.
Sungur, Ş., Gülmez, F., 2015. Determination of metal contents of various fibers used in textile industry by MP-AES. J. Spectrosc. 2015, 640271.
The General Product Safety Regulations 2005. In. Vol 2005 No. 1803. United Kingdom2005.
United States Department of Health and Human Services Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Arsenic.* August 2007.
United States Department of Health and Human Services Agency for Toxic Substances and Disease Registry. *Toxiclological Profile for Cadmium.* September 2012.
United States Department of Health and Human Services Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Lead.* US Department of Health and Human Services;2020.
United States Food and Drug Administration. Menstrual Tampons and Pads: Information for Premarket Notification Submissions (501(k)s) - Guidance for Industry and FDA Staff. In:2005.
Upson, K., Shearston, J.A., Kioumourtzoglou, M.-A., 2022. Menstrual products as a source of environmental chemical exposure: A review from the epidemiologic perspective. Current Environmental Health Reports. 9 (1), 38–52.
Vorontsova, Y., Haas, D.M., Flannery, K., et al., 2022. Pharmacokinetics of vaginal versus buccal misoprostol for labor induction at term. Clin. Transl. Sci. 15 (8), 1937–1945.
Vostral, S.L., 2011. Rely and toxic shock syndrome: a technological health crisis. Yale J. Biol. Med. 84 (4), 447.
Vostral SL. Of Mice and (Wo)Men: Tampons, Menstruation, and Testing. In: Bobel C, Winkler IT, Fahs B, Hasson KA, Kissling EA, Roberts TA, eds. *The Palgrave Handbook of Critical Menstruation Studies.* Singapore2020:673-686.
Wiberg, K., Lundström, K., Glas, B., Rappe, C., 1989. PCDDs and PCDFs in consumers' paper products. Chemosphere 19 (1–6), 735–740.
Wickham, H., Averick, M., Bryan, J., et al., 2019. Welcome to the tidyverse. Journal of Open Source Software. 4 (43), 1686.
Williams, K.E., 2004. Fibrous articles having odor adsorption ability and method of making same (U.S. Patent No. 6,702,797 B2). U.S. Patent and Trademark Office. https://ppubs.uspto.gov/dirsearch-public/print/downloadPdf/6702797.
Xing, W., Zheng, Y., Scheckel, K.G., Luo, Y., Li, L., 2019. Spatial distribution of smelter emission heavy metals on farmland soil. Environ Monit Assess. 191 (2), 115.