Estimation of smokers' exposure to mercury from combustible tobacco products, based on the approach used in food consumers' exposure estimation.

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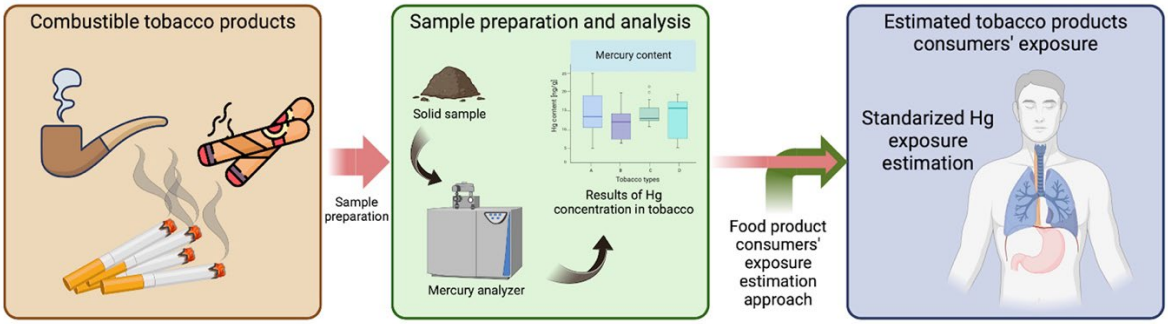
Abstract

Smoking has been known to mankind for centuries, but it is only in recent decades that much attention has been paid to the harmfulness of this habit. Mercury inhalation is particularly dangerous in this respect and smoking creates extremely favorable conditions for the emission and targeted delivery of this element into the lungs. Despite this fact, a lack of a clear method for estimating the exposure of tobacco consumers to mercury was identified. This work shows justification to transfer the approach of estimating food product consumers' exposure to estimate the exposure of combustible tobacco product consumers to this element. In addition, it was noted that researchers' attention is mainly focused on cigarettes, while the tobacco market has a wide range of combustible products. Therefore, in this work, the mercury content of cigars (8.45 ± 0.18 – 41.02 ± 0.20 μg/kg), pipe tobaccos (8.03 ± 0.52 – 25.48 ± 0.50 μg/kg), bidis (14.93 ± 0.47 – 31.79 ± 0.26 μg/kg) and cigarette tobaccos (14.22 ± 0.71 – 34.5 ± 1.4 μg/kg) was analyzed. This study demonstrates that smoking can contribute significant total mercury exposure to consumers', although it is unlikely to cause mercury poisoning regardless of other exposure sources.

Graphical Abstract



1. Introduction

Mercury poisoning is a well-known issue that has been detailed and described in the scientific literature (Ibrahim et al., 2006; Langford and Ferner, 1999; Mielcarek et al., 2022; Ronda et al., 2022; Rutkowska et al., 2014). The toxicity, biochemical properties, and cycling of mercury in the environment depend on the concentration and chemical form of this element (Ibrahim et al., 2006; Neathery and Miller, 1975; Rutkowska et al., 2014). It has been discovered that in general, organomercurials are more harmful than inorganic forms (Rutkowska et al., 2014). Mercury vapors are also highly poisonous (Beate et al., 2010). Although Hg is a liquid under normal conditions (Ibrahim et al., 2006; Langford and Ferner, 1999), it has a high vapor pressure, compared to other metals, of up to $1.71 \cdot 10^{-1}$ Pa at 20 °C (Huber et al., 2006). This vapor pressure corresponds to a mercury content of 14.09 mg/m^3 in ambient air under set temperature conditions (applying ideal gas law) (Huber et al., 2006). This value is far beyond recommended maximum volatile Hg concentrations established by the organizations cited in this work (0.2 – 1.0 μg/m^3) (Beate et al., 2010; Fresquez et al., 2015; Richardson et al., 2008). Furthermore, its vapor pressure increases exponentially rather than linearly with increasing temperature (it roughly doubles every 10 °C) (Langford and Ferner, 1999).

Environmental mercury sources can be both natural (e.g., volcanic eruptions and forest fires) and anthropogenic (Langford and Ferner, 1999; Rutkowska et al., 2014; Shen et al., 2022; Sommar et al., 2020). An example of an anthropogenic source of mercury is the use of plant protection products containing organomercury compounds (Amin-Zaki et al., 1974; Dameron and Harrison, 1998; Elhassani, 1982; Ibrahim et al., 2006; Neathery and Miller, 1975). It must be mentioned that not only the toxicity of this metal and its compounds are a great danger, but also its bioaccumulation (Ronda et al., 2022; Rutkowska et al., 2014). This effect is amplified

as the trophic level increases, in a process known as biomagnification (Langford and Ferner, 1999; Rutkowska et al., 2014).

Tobacco (*Nicotiana Tabacum L.*) and other plant products (which are the first link in the food chain) are the primary sources of exposure to mercury. It has also been observed that Hg is mostly found in plants in the form of organometallic compounds (Rutkowska et al., 2014) so it is expected that the organic form of Hg is the most prominent one in tobacco. Therefore, the risk of mercury contamination of food products should not be underestimated, especially given the number of recorded cases of severe poisoning and death (Amin-Zaki et al., 1974; Ibrahim et al., 2006; Langford and Ferner, 1999; Rutkowska et al., 2014). A prominent example is the infamous "Iraq poisoned grain disaster" of 1971, in which over 6000 people were poisoned by methylmercury after eating bread produced from contaminated wheat flour (Amin-Zaki et al., 1974; Bakir et al., 1980; Ibrahim et al., 2006).

Tobacco is one of the most extensively produced plants. According to the "Statista" website, the annual world production of tobacco ranged between 6 and 8 million tons from 1990 to 2019 (M. Shahbandeh, 2021). Such level of production stays in response to equally great market demand (Le Foll et al., 2022). Every year, millions of tons of tobacco are being smoked in a variety of places (corresponding to the dispersion of consumers) (Le Foll et al., 2022). As mentioned above, combustion processes (e.g., fossil fuels or forest fires) are significant sources of mercury emissions into the environment (Rutkowska et al., 2014; Sommar et al., 2020). Therefore millions of tons of burnt tobacco can be considered to have a moderate contribution to natural sources of Hg emissions to the environment worldwide (Le Foll et al., 2022). In addition, human exposure as a result of smoking combustible tobacco (CT) products is likely to be significant because it is direct and targeted at the lungs, where volatile mercury is well absorbed (Beate et al., 2010; Ibrahim et al., 2006; Langford and Ferner, 1999).

Native Americans smoked tobacco centuries before Europeans discovered it in the 15th century (Musk and De Klerk, 2003). It was rapidly globalized (Musk and De Klerk, 2003) and is popular in numerous countries (Le Foll et al., 2022) and vast spectrum of forms to this day. Among those, traditional pipe tobaccos, cigarettes, and bidis / biris / beedis (common in India filter-free tobacco products comparable to cigarettes wrapped in tendu (*Diospyros melanoxylon*) (Lal, 2012) leaves instead of tobacco or tissue paper (Verma et al., 2010), known under, at least, three different names (Lal, 2012; Le Foll et al., 2022; Verma et al., 2010; Watanabe et al., 1987)) were studied in this work. Even though the market offers a wide range of tobacco products, researchers' attention is frequently drawn to selective

cigarettes (Verma et al., 2010). Consumers of all CT products are exposed to a wide range of hazardous chemicals in tobacco smoke, including volatile mercury. Its toxicity results mainly due to its ability to accumulate in body tissues (Ibrahim et al., 2006; Langford and Ferner, 1999; Rutkowska et al., 2014) particularly the brain (Ibrahim et al., 2006; Langford and Ferner, 1999). Poisoning can cause diseases such as Minamata disease (caused by MeHg) (Inoue et al., 2012; Voegborlo and Akagi, 2007) or mad hatter disease/erethism (caused by free Hg vapor) (Ibrahim et al., 2006; Steckling et al., 2011).

Noteworthy is the sensitive route of tobacco smoke delivery, i.e. through the respiratory system, which is highly vulnerable to mercury vapor absorption (Langford and Ferner, 1999). Other important aspects are the conditions in CT products during consumption. Mallock et al. discovered that tobacco embers can reach temperatures of 700-950 °C (Mallock et al., 2019), and it must be remembered that smoking requires air circulation inside the products. Similar conditions are found in Mercury Analyzer MA3000 supplied by Nippon Instruments Corporation (NIC Japan), employed in this research, where the temperature in the decomposition furnace reaches 850 °C for Hg release. This condition promotes Hg release into the smoke stream.

CT products contamination is important for medical and environmental sciences according to its adverse health effect and vast number of consumers globally (Le Foll et al., 2022). The approach described in this paper suggests broadening an already interdisciplinary issue in the field of food chemistry, as there are similarities in tobacco and food product consumption. Furthermore, the lack of new studies on the total Hg content in non-cigarette CT products was indentified. There is also a lack of a standards outlining maximum permitted mercury concentration in tobacco, analogous one used in food products (Milatou et al., 2020). This justifies a thorough investigation into the determination of mercury concentrations in these products.

The study aimed to apply the food-product Hg exposure estimating method to evaluate the mercury exposure from cigars which are becoming increasingly popular among smokers (Corey et al., 2014; DeSantis and Morgan, 2003; Kowitt et al., 2020), and other tobacco products, i.e.: pipe tobaccos, cigarettes and bidis. The analyses of rare CT products that have been carried out are extremely important and provide new information. In addition, an approach was applied for estimating consumer exposure to mercury, which has so far only been used for food products (Milatou et al., 2020).

2. Materials and methods

2.1. Sampling

The cigars used in this study were obtained from two Internet retailers available in Poland. Pipe tobaccos and cigarettes were purchased in Gdansk (a city in northern Poland) at a local tobacco store. Bidis were bought in Rajkot, located in the western province of India, Gujarat. To compare cigar tobacco and other CT products the analyses from a previous paper was extended, and all results were used to test suggested in this research approach. For that, 37 cigars, 4 shredded pipe tobaccos, 5 bidis, and 5 cigarette samples were analyzed. The previous research was extended with additional 4 shredded pipe tobaccos and 6 cigarette tobaccos. All samples were purchased in 2021-2022.

Cigars represented four origins (The Republic of Nicaragua, The United Mexican States, The Dominican Republic, and The Republic of Cuba) and reflected the whole range of varieties (small cigars, cigarillos, large machine-made cigars, and large handmade cigars) and prices. It makes them the most varied tobacco samples in this study. Since cigars are frequently made from "blends" (a mixture of tobaccos from different origins), only those whose tobacco had a homogeneous origin (according to information provided by the store) were chosen for analysis. Eleven brands of cigarette tobaccos, eight pipe tobaccos, and five bidis were also analyzed. During the process of selecting samples for analysis, a lack of information on the origin of the tobacco used in the preparation of cigarettes, bidis, and pipe tobaccos was observed. The explanation for this status quo might be that producers keep their recipes for tobacco mixtures secret. Expect cigarettes with cigarette filters and papers (and a few small filter cigars), all of the tested products were fully made from plant leaves and just this material was used for the analysis.

2.2. Sample treatment

Prior to mercury analysis with the use of the cold vapor atomic absorption spectrometry (CV-AAS) technique, some necessary steps for sample preparation were applied. It included sampling, drying, homogenizing, determination of water content, and proper storage. The entire procedure was carried out while the unique characteristics of the evaluated material were kept under consideration.

Since tobacco leaves are wrapped concentrically around the cigar axis during manufacturing (Langer et al., 1971), greater sample variability is expected to be in the cross, rather than the longitudinal, section. As a consequence, for the analysis, a "cigar slice" weighing 1-2 g was cut from the open part of each cigar (cigar foot). Each sample thus collected was dried in a laboratory dryer and homogenized in an agate mortar. Other products sampling was

performed analogously and included respectively picking for each brand: 4-5 random bidis, about 2.5 g of shredded pipe tobaccos, and three random cigarettes.

The next step was to determine the moisture content of the prepared samples. For this purpose, it was decided to choose the gravimetric method. As the determination of mercury content using the CV-AAS technique is carried out on dried samples, the determination of consumer exposure to toxic mercury on this basis is not correct. This is related to the fact that consumers smoke products containing a certain amount of water. Therefore, a conversion of the mercury content to the weight of the tobacco before drying ($C_{w.w.}$) was applied using equation (1) used in comparable studies in the literature (Majewska et al., 2018; Milatou et al., 2020).

$$C_{w.w.} = C_{d.w.} \cdot \frac{m_{d.w.}}{m_{w.w.}} \quad (1)$$

Where $C_{d.w.}$ is the mercury concentration in the dry tobacco (μg/kg), $m_{d.w.}$ and $m_{w.w.}$ are dry and wet sample weights (g).

2.3. Instrumentation

Mercury Analyzer MA3000 supplied by Nippon Instruments Corporation (NIC Japan), which uses the technique of Direct Thermal Decomposition - Gold Amalgamation – Cold Vapors - Atomic Absorption Spectrometry (CV-AAS) was used for the analysis, and purified dry oxygen was used as the carrier gas.

Calibration was performed with calibration solutions diluted in L-cysteine. 0.001 % L-cysteine solution was made with the use of 10 mg of L-cysteine (Merck), 2 cm^3 of the certified reagent grade concentrated nitric acid, and deionized water. Hg standard of MS grade purity (Merck) at a concentration of 100 mg/dm^3 was used. By diluting 1 cm^3 of standard solution to 100 cm^3 with the L-cysteine solution, 1 mg/dm^3 stock solution Hg was achieved. Next, 7 calibration solutions were prepared and analysed in 3-4 repetitions, resulting linear calibration curve between the range of 1.0 to 8.0 ng ($R^2 = 0.9972$). Calculated from the curve slope the limit of detection (LOD) and the limit of quantification (LOQ) were as follows, LOD = 1.5 μg/kg, LOQ = 4.8 μg/kg. Actually this values are method detection limit (MDL) and method quantification limit (MQL), as calibration curve was prepared in units of mass, and then calculated to units of content.

The analysis were performed with at least three repetitions. Samples were heated in a decomposition furnace to T=850 °C for 4 min to cause thermal decomposition and release Hg from the sample. Glass tube with a gold deposit, called a “gold furnace”, was used to selectively absorb mercury from generated fumes (Au-Hg amalgam generation). The release

of mercury occurred due to the decomposition of Au-Hg amalgam at temperature T=600 °C carried out for 1 min. Hg analysis was performed with the use of spectrometric analysis (wavelength 253.7 nm).

This method is characterized by high selectivity (due to amalgam formation and measurement at the characteristic mercury wavelength) and repeatability. Among the advantages of the employed method, it is worth mentioning its "greenness" (it is practically solvent-free and does not need any aggressive additives). Millipore's Milli-Q® water purification system (USA) was used for the standard solution preparation.

The powdered samples were covered with "additive B" (Wako Pure Chemical Industries Ltd.; NIC Japan) in ceramic cuvettes.

Various drying methods for plant samples are proposed in the scientific literature (Hać et al., 2022; Ma et al., 2022; Polat et al., 2022). In this study, it was decided to use a laboratory dryer Redline by Binder. The Radwag WPS 30s moisture analyzer, the Protherm Furances PAF 120/12 muffle furnace, the freeze dryer (provided by Labconco), the desiccator, and a laboratory dryer were used. Karl Fisher titration was performed with 831 KF Coulometer by Metrohm.

Bidis homogenization was performed with an impact homogenizer instead of agate mortar because of the fibrousness of the wrapping tendu leaf that persisted even after the drying process. The powder samples obtained were kept at room temperature in Falcon® polypropylene containers. All weight measurements were taken with a professional analytical balance with a repeatability of 0.01 g (Radwag). A mercury standard—MSHG—at a concentration of 100.10 ± 0.43 µg mL−1 in 10% HCl was purchased from Inorganic Ventures, INC (USA). N-acetyl-L-cysteine was obtained from Sigma-Aldrich (Germany), nitric acid from J.T.Baker®, and Karl Fisher reagent for coulometric water determination from Aquastar®.

2.4. Calculation of health risks from consumption

Due to the lack of regulation of total Hg concentration in CT products, it was decided to use various maximum mercury level (MHgL) standards. In the present study, three cases were considered, as they may correspond to toxic mercury exposure due to the consumption of CT products, and these are as follows: dietary intake, occupational and non-occupational exposure.

The provisional tolerated weekly intake (PTWI) of inorganic mercury is one of the dedicated indicators for this element. It was established by the Joint FAO/WHO Committee on Food Additives, which had reduced its limit from 5 μg/kg body weight (bw) to 4 μg/kg bw at its 72nd meeting in 2011 (Joint FAO/WHO Expert Committee on Food Additives. Meeting (74th : 2011 : Rome, 2012). It means that a PTWI = 280 μg/70 kg bw per week can be established for an adult. The maximum limits of average dietary exposure to total mercury from foods other than fish and shellfish were even four times lower (1 μg/kg bw per week) than PTWI (Joint FAO/WHO Expert Committee on Food Additives. Meeting (74th : 2011 : Rome, 2012; Milatou et al., 2020). This index is applied mainly to food products, i.e. dietary intake.

There are some similarities between food and CT consumption. Not only do the respiratory and digestive tracks share a first stage, but also the substances from consumed products in both cases eventually enter the bloodstream. The combustion step is analogous to the digesting step in the process of obtaining absorbable compounds. Nevertheless, CT products do not meet all the criteria for food products, which could limit the use of the PTWI index in their case.

According to the WHO's "*Air Quality Guidelines – Second Edition*" the lowest observed adverse effect limit (LOAEL) for volatile mercury occurs within a concentration of 15-30 $\mu g/m^3$, and the established time-weighted average (TWA) for mercury is 1 $\mu g/m^3$ within annual averaging time (World Health Organization, 2020). In the document "*Recommendation from the Scientific Committee on Occupational Exposure Limits for elemental mercury and inorganic divalent mercury compounds*" (European Commission 2007) an exposure level of 0.02 mg/m^3 for an 8-hour TWA meets the criteria for a health-based occupational exposure limit (OEL) (Scientific Committee on Occupational Exposure Limits, 2007).

Assuming MHgL = $OEL_{(t=8h)}$ = 0.02 mg/m^3, an estimate equivalent to the PTWI index for inhaled mercury vapor – an acceptable daily dose of mercury vapor ($ADD_{Hg\ v.}$) – can be established. It is required to assume a daily inhalation ratio (DIR) [m^3] for this purpose. Although the DIR value varies depending on age, gender, and other factors, the scientific literature indicates DIR = 20 m^3 for an adult (European Chemicals Agency, 2012). It is also important to note that approximately 80% (or more) of Hg vapor is absorbed by the lungs (Beate et al., 2010; Langford and Ferner, 1999). It must be remembered, that MHgL is calculated using standards for a specific time, therefore *t* in the following equation is the time

established for the used standard. Consequently, the estimated $ADD_{Hg\ v.}$ value was calculated using the following equations (2 and 3).

$$ADD_{Hg\ v.} = \text{MHgL} \cdot \frac{DIR \cdot t}{24h} \cdot 0.8 \quad (2)$$

$$ADD_{Hg\ v.} = 0.02\ {}^{mg}/_{m^3} \cdot \frac{20\ m^3 \cdot 8\ h}{24\ h} \cdot 0.8 = 0.106(6)\ mg \quad (3)$$

According to equation 2, the calculated $ADD_{Hg\ v.}$ is, in this example case, approximately 0.107 mg. The use of this approach, however, has several limitations. To begin with, as previously mentioned, DIR is influenced by a variety of factors. Furthermore, the toxicity of mercury vapor is significantly greater for the developing brain of a fetus and a small child than for an adult, hence MHgL would be lower in these cases (Beate et al., 2010). Calculation in this study does not take into account the influence of occurring passive smoking or any susceptible subpopulations. For developing organisms like children or adolescents, a separate calculation should be performed, considering the specific toxicity impact on their organisms and different respiratory parameters (such as different DIR). Mercury vapor comes across one of its most toxic forms (Beate et al., 2010; Langford and Ferner, 1999), therefore, Table 3 includes calculated $ADD_{Hg\ v}$ for other possible air permissible limits than the OEL.

A second indicator, the maximum permissible consumption of tobacco per day (MPCT), defined by equation (4), is required for further investigation and analysis of the data. In the scientific literature on mercury exposure in fish consumers, an analogous approach is used (Milatou et al., 2020).

$$MPCT = \frac{ADD_{Hg\ v.}}{C_{w.w.}} \quad (4)$$

$ADD_{Hg\ v.}$ depends on the chosen MHgL (e.g. $OEL_{(t=8h)}$).

The maximum daily allowed consumption of tobacco is expressed in units of weight of tobacco that can be safely consumed daily to not cause Hg poisoning. It might be tough to utilize in its raw form; however, evaluating exposure in terms of burned tobacco weight seems to be the most practical and adaptable alternative.

3. Results and Discussion

Due to the current lack of information in the literature on the preparation of cigar tobacco samples for elemental analysis, this area was given special attention in this study. The analyzed material does not meet the criteria of a (fresh) plant as it contains substantially less water. Neither is it a dried or a pre-dried product. The specific CT product qualities, as well as

the smoke quality, are determined by the tobacco processing methods employed, such as curing or fermenting (Jensen and Parmele, 1950).

The water concentration in CT products varies, as shown in Table 1. Elemental analysis should be performed by comparing the results to a common reference point for all samples, i.e., dry weight. As a result, the drying process is an important step in sample preparation, in this case, to determine mercury concentration. Several different methods of drying samples were tested in this study.

Table 1. Water content in cigars, determined within the gravimetric method using a variety of drying methods. All presented values are expressed in percentages.

Sample	Desiccator	Freeze-dryer	Muffle furnace [105°]	Moisture analyzer [120°]	Laboratory dryer [105°]
La Prueba No. 2	7.61	12.4	12.4	13.9	14.2
La Prueba No. 3	7.00	12.2	12.7	14.6	15.1
Guantanamera Puritos	5.42	9.28	9.86	14.3	12.3

Moisture analyzers, which are commonly used in laboratories, appear to have limited utility as they usually can only dry one sample at a time. The aim of testing several drying methods was to determine which of the possible drying procedures gives the most similar results to those obtained using the moisture analyzer. The laboratory drier most closely met the expectations in this respect, and it also enabled the drying of several dozen samples simultaneously. As a result, it was decided to use this method, which was run for 24 h at 105 °C (until a constant weight was obtained ~ 0.01g). A muffle furnace set to the same temperature as the laboratory dryer dried the tobacco samples with less efficiency. The inertia of a furnace at 105 °C might be large since it is typically employed at higher temperature ranges. As a result, the actual temperature at which the samples were dried was probably different. Furthermore, the laboratory drier has the advantage of supporting high temperatures in the drying process with air circulation.

It is important to note that at higher temperatures, tobacco products emit several volatile chemicals (WHO Study Group on Tobacco Production Regulation, 2012). Water contents reported by moisture analyzer, muffle furnace, or laboratory dyer might be overvalued. The conditions could theoretically also affect the evaporation of mercury from the sample, but it should be remembered that Hg is not expected to be present in the elemental form and the temperature range associated with drying does not correlate to that used in mercury analyzers. The drying process is therefore not expected to have a significant impact on the loss of Hg

from the sample, but this has been verified in the example of one cigar. As evidenced in Figure 1, the determined mercury contents of the samples dried within different methods, vary, but are in the range of their uncertainties.

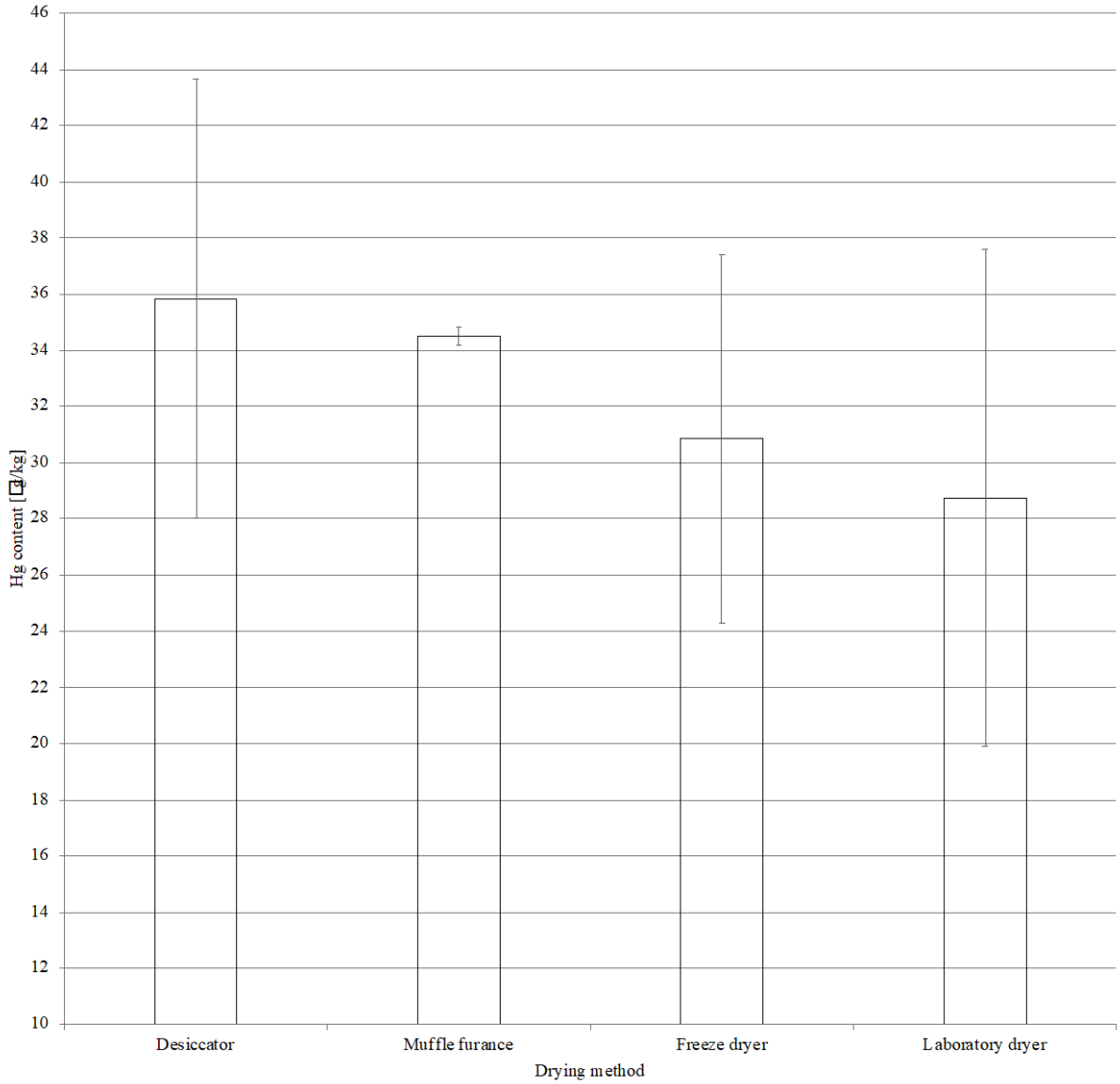


Figure 1. Comparison of mercury contents in La Prueba No.3 cigar, dried with four drying methods (the error bars result from measurement repetition expanded uncertainty).

Methods that do not use high temperatures are more reliable for estimating the water content of these kinds of materials. Lyophilization, which employs low pressure, is one of these. Although such conditions protect compounds from oxidation and degradation, this technique also does not remove water from the sample selectively. This limitation is remedied by using a desiccator that uses a selective water sorbent. This process takes place at room temperature but is very time-consuming. Chromatographic methods are also used for determining moisture content (Zhou et al., 1998), although they are better applicable to liquid samples.

It should be noted that the results of the selecting optimum drying conditions process do not reflect the real water content of the tobacco. Other substances may also evaporate during drying, which is a trivial point. The goal, however, was to select the best, repeatable procedure of sample preparation for elemental analysis. Although the Karl Fisher Titration (KFT) method is recommended in the case of tobacco products (International Organization for Standardization, 2021) it was decided not to use it in all samples, due to two reasons. Firstly sample preparation included grinding, which had to be performed on dry samples, and drying is also used in gravimetric moisture analysis, the use of gravimetric method allowed to use same samples for elemental analysis and moisture analysis (dried within the same method). Secondly, the exposure calculating method in this study does not require the determination of real and precise water content in the sample. It was decided to perform a few diagnostic KFT using two cigars, two pipe tobaccos, and two cigarette tobaccos. All six samples were freshly purchased in April 2023 in Gdańsk, Poland. Results obtained with KFT are presented in Table 2 and as can be seen, they are similar to those obtained with the gravimetric method. It was decided to present results in Table 2 as ranges, as it was observed that individual parts of cigars or individual tobacco ribbons from packages had different content of water.

Table 2. Water content in diagnostic tobacco samples was determined using Karl Fisher Titration.

Sample	Product	Water content [%]
VF	Cigar	6.46 – 11.2
Casa de Garcia	Cigar	6.00 – 12.3
Amphora Full	Pipe tobacco	14.6 – 18.7
Peterson Wild Atlantic	Pipe tobacco	14.5 – 18.3
LD	Cigarette tobacco	7.42 – 9.28
Camel	Cigarette tobacco	11.1 – 12.1

While it is usual practice in food chemistry to convert the mercury (or other heavy metals) content in a sample's dry weight to the concentration in the wet weight (using eq. 1) (Milatou et al., 2020), it was also successfully applied to tobacco (Majewska et al., 2018). This demonstrates the scientific literature’s attempts to un- or consciously recognize CT as food products (to estimate consumers' exposure to toxins). In the context of its contamination, selective designation of these products as food would allow for a more accurate assessment of consumer exposure. The main advantage of the suggested approach is that determining the precise moisture content becomes secondary. However, owing to the lack of data in this field, it is nonetheless useful information.

In the scientific literature, consumer exposure to mercury from food products is stated as the maximum safe weekly intake, which is comparable to the proposed MPCT index derived and follows from the adopted standard. Previously, the OEL index was cited as an example of MHgL. Because the result appeared to be significant, it was decided to pursue the more stringent non-occupational regulatory exposure level (REL) (Richardson et al., 2008). The standards referenced in numerous publications (Beate et al., 2010; Fresquez et al., 2015; Richardson et al., 2008) were chosen and collected in Table 3, along with the calculated $ADD_{Hg\ v.}$ values (for t = 24h and DIR = 20 m^3 (European Chemicals Agency, 2012)).

Table 3. Summary of the various RELs their official names and calculated $ADD_{Hg\ v}$ factors

Organization	Author	Standard name	REL [μg/m^3]	$ADD_{Hg\ v.}$ [μg]
United States Environmental Protection Agency (US EPA) 2007	Beate et al. (Beate et al., 2010)	Reference Air Concentration (RfC)	0.3	4.8
Agency for Toxic Substances and Disease Registry (ATSDR) 1999	Fresquez et al. (Fresquez et al., 2015)	Minimal Risk Level	0.2	3.2
California Environmental Protection Agency (CalEPA) 2005	Richardson et al. (Richardson et al., 2008)	REL	0.9	14.4
World Health Organization (WHO) 2000	Richardson et al. (Richardson et al., 2008; World Health Organization, 2020)	Air Quality Guidelines as to the Annual Average Concentration	1.0	16.0

Figure 2 illustrates the results of the MPCT values as a boxplot for the ATSDR REL values. It must be remembered, that calculation was performed only for the adult smokers population, for who DIR = 20 m^3, and REL level was assumed as presented in Table 3. The samples were divided according to tobacco kind and (for cigars) country of origin. Four cigar ash samples were also analyzed, but the obtained results were scattered and on the borderline of LOQ and even LOD. LOQ = 0.35 μg/kg; LOD = 0.11 μg/kg were calculated from the different, lower calibration curve. Based on these results, the ash was found to have negligible mercury content.

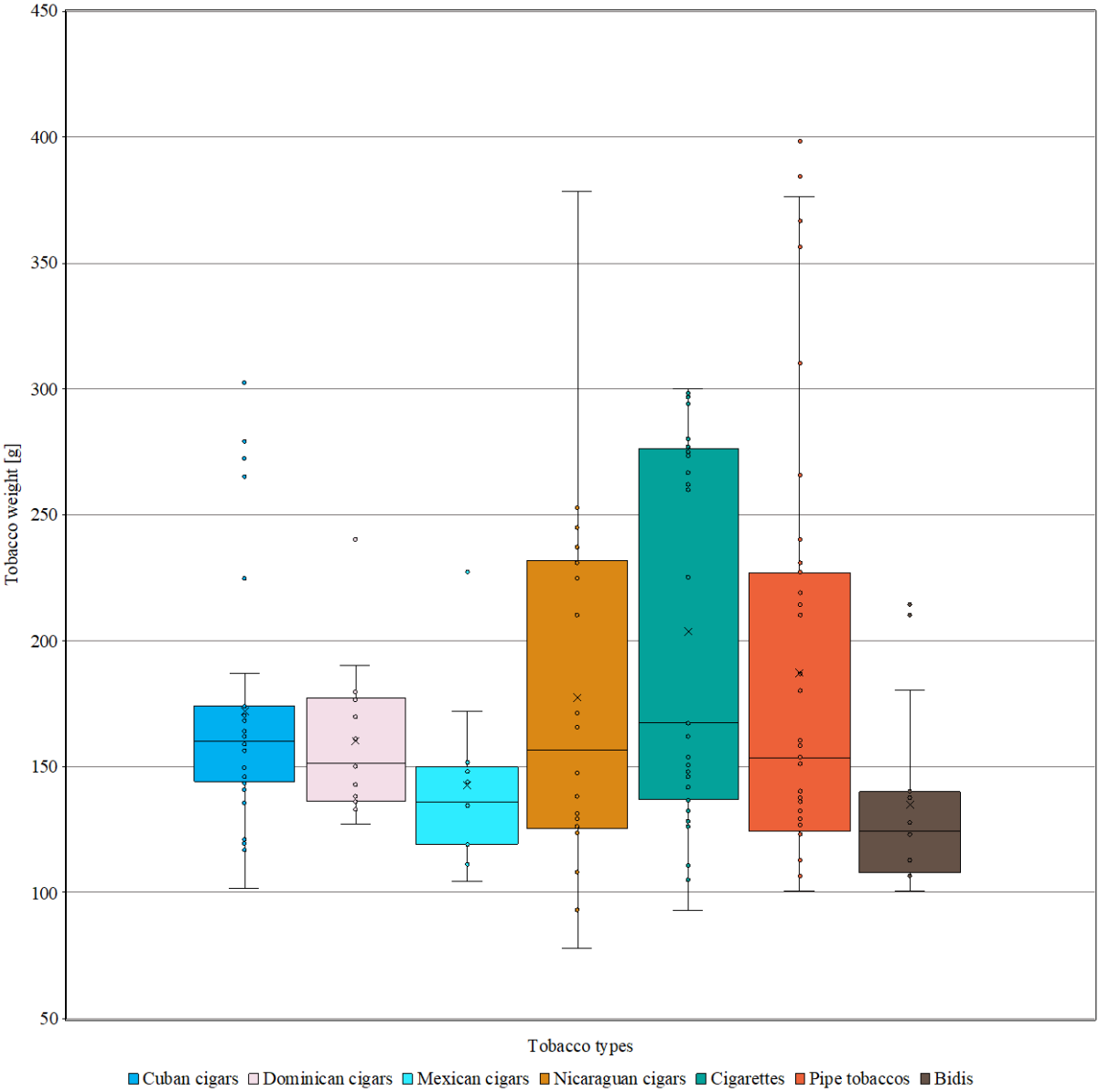


Figure 2. The maximum daily allowable weights of tobacco consumption according to its mercury content, were calculated using ATSDR REL values.

Based on the results of the study, it can be concluded that to exceed the permissible level of Hg inhalation, a significant mass of tobacco would have to be consumed. To date, there have been no reports in the literature about smokers commonly showing mercury poisoning symptoms. The concentrations determination procedure is used to confirm that the element content in CT, is in practice insufficient to directly and independently significantly expose smokers. To overcome the most stringent $ADD_{Hg\ v.}$, it would be necessary to consume at least approximately 75 grams of tobacco per day (equivalent to about 130 cigarettes). It is unlike that anyone, from a considered subpopulation, would smoke such an amount of tobacco.

Therefore it is unlike that tobacco smoking, separately from other potential sources, would cause mercury poisoning.

As can be seen in Figure 2, the three types of tobacco are characterized by elevated mercury content. These are bidi, cigarette tobacco, and Mexican cigars. The mercury results for these samples are concentrated at higher values. It is worth mentioning that these tobaccos are representing the cheapest groups among collected products. The greatest differentiation in Hg amount is observed for Nicaraguan cigars and pipe tobacco samples. Moreover, some pipe tobacco samples contain the lowest amounts of mercury among all samples in this study, however, simultaneously the sample with the highest mercury content was the Nicaragua cigar. Nevertheless, the last results might be considered an aberration.

As can be seen, the proposed approach is convenient to use because it allows a quick estimate of customer exposure based on their smoking habits. Therefore, the consideration of CT product consumers' Hg exposure, analogous to food product consumers, is justified. The lack of a standard or index of tolerable highest concentration for volatile mercury in inhaled products is, however, currently a significant disadvantage and limitation. In this study, calculations were based on limits for allowed air contamination that were appropriately adapted. Therefore, the establishment of official indices of acceptable Hg concentration in CT products is necessary for the correct determination of consumer exposure using the suggested approach.

Although the concentration of mercury in tobacco may not be life-threatening to consumers, it should be considered in the context of the high environmental pollution burden worldwide (Landrigan et al., 2018) and the diverse variety of substances contained in tobacco smoke (WHO Study Group on Tobacco Production Regulation, 2012), to which smokers are exposed to. There are three types of combined harmful effects documented in the literature: synergistic, antagonistic, and additive (Meynard et al., 2021). This indicates that toxins can have different impacts on humans when they react together than when they occur alone. This is exemplified by the established stronger than just additive adverse health effects of tobacco smoke and arsenic in humans (Ferreccio et al., 2013).

The necessity for the establishment of an index for the maximum permissible mercury content in CT products, as previously advocated, is made even more urgent by the fact that smoke is an additional source of mercury exposure for consumers. Although the concentration of Hg in the environment varies, tobacco contributes to total exposure for smokers and those around them (passive smoking). As a result, it is reasonable to expect that the value of such an index should be lower than the RELs used in this study. Moreover, the suggested approach gives the

possibility to standardize mercury exposure and use it to estimate total exposure. Such standardization gives also the possibility to estimate a budget for exposure and verify contribution of each component.

It should be noted that the results presented in this paper represent actual data, but are used as a model to demonstrate the implementation of the proposed tobacco consumers' exposure estimation approach. It is assumed in this work that full thermal decomposition of mercury compounds occurs during smoking and that the Hg is fully emitted as a vapor into the smoke. However, it has been proven that in tobacco products, the temperature of the tobacco changes gradiently as it is smoked, resulting in an occurrence of a distillation zone (Mallock et al., 2019). Some mercury compounds likely evaporate before they decompose with the release of Hg, and the evaporated mercury compounds show different adverse health effects than mercury vapor alone (Langford and Ferner, 1999). Nevertheless, the approach proposed in this study can be applied to various elements as well as their compounds to calculate proper ADD. However, as afomentioned, it is important to always remember that the adverse health effect of various toxins is not necessarily additive.

Human urine, blood, and hair have been reported to be used as biomonitors for air contamination with Hg vapor (Beate et al., 2010). This fact was applied to calculate the conversion factors for Hg air contamination to its level in the urine/blood/hair of exposed humans. Also, an in vitro exposure to mercury vapor increased levels of this element in cut human head hair (Beate et al., 2010; Hać and Krechniak, 1993). It should be noted that smoking was considered an influencing factor in the population analyzed in the study by Beate et al. on reference concentrations of mercury vapor (Beate et al., 2010).

Approach pesented and applied in this study uses estimated ADD $_{\text{Hg v.}}$ values for only one group of consumers, that can be considered as standard smokers. Meanwhile, there is a vast number of subpopulations, that differ within, environmental exposure (eg. employees of some industry branches), physical workers whose DIR factor may differ, adolescents and children, who might be more toxicologically sensitive, and possibly others. Therefore it is advisable to take into account subpopulations and their characterization while estimating exposure (European Chemicals Agency, 2012). For that purpose suggested approach can be used.

Despite numerous efforts to promote smoking cessation (Le Foll et al., 2022; WHO Study Group on Tobacco Production Regulation, 2012), significant tobacco production (M. Shahbandeh, 2021) and a high number of smoking-related deaths persist worldwide (Le Foll et al., 2022). In addition to attempts to reduce the number of tobacco users, the use of each cigarette as an air filter could be considered. Using mercury as an example, by placing a

health-neutral agent in the filter (Pauly et al., 1997), effectively immobilizing Hg vapor (Langford and Ferner, 1999), smoking would decontaminate (from this element) not only the smoke but also the ambient air. This would both relieve smokers' organisms and have a positive impact on the environment. The problem of collecting used contaminated filters could be obtained with any motivation system, such as deposit system. Price of cigarette package could be discounted for consumers giving back in settlement used filters. A single cigarette would have little impact on decontaminating the atmosphere, but a large number of them could help to eliminate Hg from the atmosphere and reduce its emissions from CT products. This approach can be considered inspired by a similar path occurring in nature: filtrating water mussels (Elliott et al., 2008). On the scale of a lake or sea, a single organism does not have a significant meaning, but thousands and millions of them do (Vaughn, 2018).

4. Conclusions

The study demonstrates that implementing the same method to combustible tobacco products to estimate mercury exposure from food is feasible and convenient to use. Simultaneously, this is the first time such an approach has been used with CT. Its employment requires the use of an appropriate standard or index for the maximum permissible inhalation dose of volatile mercury for a specific subpopulation, providing a basis for its application. Because there are none, the most restrictive REL for airborne Hg pollution was adopted as an alternative strategy. Therefore, the urgent need to define a suitable index for combustible tobacco products, for a variety of subpopulations of smokers was identified.

Based on research, CT products alone are believed to be unlikely to cause mercury poisoning in smokers themselves (for standard, adult smokers population which was considered in this study), according to the MRL index provided by ATSDR. It should be noted, however, that more Hg sources in the human environment also affect their organisms, so exposures should be added up. Furthermore, a phenomenon known as the combined toxicity effect was described in the scientific literature, suggesting that the adverse health effect of volatile Hg could be exacerbated when it is mixed with other components of smoke. There is a lack of baseline studies of noncigarette CT products in the scientific literature, which must be performed and developed. As a result, further research is suggested in this area.

It is also advisable to extend the verification regarding the possible influence of the drying method on the loss of elements from the sample. For that purpose different drying methods can be used or different homogenization methods, i.e. eg. cryogenic grinding. Such an approach would eliminate possible Hg loss during drying and would eliminate the step of

recalculation mercury content from dry weight to wet weight. In further research, it is advisable to perform optimization of the drying method and if the increased temperature would be employed, a standard addition method might be useful. An important step towards estimating consumer exposure to toxic elements contained in CT is also to estimate their real distribution pathway to the human body. For this purpose, it is worth conducting a smoke analysis, which however is associated with some technical laboratory difficulties.

The method suggested in this study enables estimation of consumers' exposure to mercury from combustible tobacco products using the method used for food products consumers. Such computational method is however limited, so it advisable is to expand research including population studies with verification of bioavailability by the organism, speciation studies, and using it with a wider spectrum of elements.

Transferring the exposure estimation method used for food consumers to tobacco consumers has another key advantage. Applying the same estimation method to food and smoking allows further convenient estimation of total exposure. Such standardization provides new opportunities for further research.

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Conflict of interest statement

The authors have no conflicts of interest to declare. All coauthors have seen and agree with the contents of the manuscript and they have no financial interest to report. Authors certify that the submission is original work and is not under review at any other publication.

5. References

Amin-Zaki, L., Elhassani, S., Majeed, M.A., Clarkson, T.W., Doherty, R.A., Greenwood, M., 1974. Perinatal methylmercury poisoning in Iraq. Am. J. Dis. Child. 130, 1070–1076. https://doi.org/10.1542/peds.54.5.587

Bakir, F., Rustam, H., Tikriti, S., Al-Damluji, S.T.F., Shihristani, H., 1980. Clinical and epidemiological aspects of methylmercury poisoning. Postgrad. Med. J. https://doi.org/10.1136/pgmj.56.651.1

514 Beate, L., Stephan, B.O.R., Gustav, D., 2010. Proposal for a Revised Reference Concentration
515 (RfC) for mercury vapour in adults. Sci. Total Environ. 408, 3530–3535.
516 https://doi.org/10.1016/j.scitotenv.2010.04.027
517 Corey, C.G., King, B.A., Coleman, B.N., Delnevo, C.D., Husten, C.G., Ambrose, B.K.,
518 Apelberg, B.J., Centers for Disease Control and Prevention, 2014. Little filtered cigar,
519 cigarillo, and premium cigar smoking among adults--United States, 2012-2013. MMWR.
520 Morb. Mortal. Wkly. Rep. 63, 650–654.
521 Dameron, C.T., Harrison, M.D., 1998. Mechanisms for protection against copper toxicity, in:
522 American Journal of Clinical Nutrition. https://doi.org/10.1093/ajcn/67.5.1091S
523 DeSantis, A.D., Morgan, S.E., 2003. Sometimes a Cigar [Magazine] is More Than Just a
524 Cigar [Magazine]: Pro-Smoking Arguments in Cigar Aficionado, 1992-2000. Health
525 Commun. 15, 457–480. https://doi.org/10.1207/S15327027HC1504_05
526 Elhassani, S.B., 1982. The many faces of methylmercury poisoning. Clin. Toxicol. 19, 875–
527 906. https://doi.org/10.3109/15563658208992523
528 Elliott, P., Aldridge, D.C., Moggridge, G.D., 2008. Zebra mussel filtration and its potential
529 uses in industrial water treatment. Water Res. 42, 1664–1674.
530 https://doi.org/10.1016/j.watres.2007.10.020
531 European Chemicals Agency, 2012. Guidance on information requirements and chemical
532 safety assessment. Chapter R.8: Characterisation of dose [concentration] - response for
533 human health, in: Guidance on Information Requirements and Chemical Safety
534 Assessment. European Chemicals Agency, Helsinki, Finland, pp. 1–186.
535 Ferreccio, C., Yuan, Y., Calle, J., Benítez, H., Parra, R.L., Acevedo, J., Smith, A.H., Liaw, J.,
536 Steinmaus, C., 2013. Arsenic, Tobacco Smoke, and Occupation: Associations of
537 Multiple Agents with Lung and Bladder Cancer Catterina. Epidemiology 24, 898–905.
538 https://doi.org/10.1097/EDE.0b013e31829e3e03.
539 Fresquez, M.R., Gonzalez-Jimenez, N., Gray, N., Watson, C.H., Pappas, R.S., 2015. High-
540 throughput determination of mercury in tobacco and mainstream smoke from little
541 cigars. J. Anal. Toxicol. 39, 545–550. https://doi.org/10.1093/jat/bkv069
542 Hać, E., Krechniak, J., 1993. Mercury concentrations in hair exposed in vitro to mercury
543 vapor. Biol. Trace Elem. Res. 39, 109–115. https://doi.org/10.1007/BF02783181
544 Hać, P., Padariya, C., Cieślik, B.M., Konieczka, P., 2022. Evaluation of mercury content in
545 combustible tobacco products by employing cold vapor atomic absorption spectroscopy
546 and considering the moisture content: a comprehensive study. Monatshefte fur Chemie
547 829–836. https://doi.org/10.1007/s00706-022-02965-1

548 Huber, M.L., Laesecke, A., Friend, D.G., 2006. Correlation for the vapor pressure of mercury.
549 Ind. Eng. Chem. Res. 45, 7351–7361. https://doi.org/10.1021/ie060560s
550 Ibrahim, D., Froberg, B., Wolf, A., Rusyniak, D.E., 2006. Heavy metal poisoning: Clinical
551 presentations and pathophysiology. Clin. Lab. Med. 26, 67–97.
552 https://doi.org/10.1016/j.cll.2006.02.003
553 Inoue, S., Yorifuji, T., Tsuda, T., Doi, H., 2012. Short-term effect of severe exposure to
554 methylmercury on atherosclerotic heart disease and hypertension mortality in Minamata.
555 Sci. Total Environ. 417–418, 291–293. https://doi.org/10.1016/j.scitotenv.2011.11.076
556 International Organization for Standardization, 2021. Tobacco and tobacco products —
557 Determination of water content — Karl Fischer method. ISO 6488:2021.
558 Jensen, C.O., Parmele, H.B., 1950. Fermentation of Cigar-Type Tobacco. Ind. Eng. Chem. 42,
559 519–522. https://doi.org/10.1021/ie50483a032
560 Joint FAO/WHO Expert Committee on Food Additives. Meeting (74th : 2011 : Rome, I.,
561 2012. Safety evaluation of certain food additives and contaminants : prepared by the
562 Seventy fourth meeting of the Joint FAO/WHO Expert Committee on Food Additives
563 (JECFA) 605–684.
564 Kowitt, S.D., Ross, J.C., Jarman, K.L., Kistler, C.E., Lazard, A.J., Ranney, L.M., Sheeran, P.,
565 Thrasher, J.F., Goldstein, A.O., 2020. Tobacco quit intentions and behaviors among
566 cigar smokers in the united states in response to covid-19. Int. J. Environ. Res. Public
567 Health 17, 1–14. https://doi.org/10.3390/ijerph17155368
568 Lal, P., 2012. Estimating the size of tendu leaf and bidi trade using a simple back-of-the-
569 envelop method. Ambio 41, 315–318. https://doi.org/10.1007/s13280-011-0181-1
570 Landrigan, P.J., Fuller, R., Acosta, N.J.R., Adeyi, O., Arnold, R., Basu, N. (Nil), Baldé, A.B.,
571 Bertollini, R., Bose-O'Reilly, S., Boufford, J.I., Breysse, P.N., Chiles, T., Mahidol, C.,
572 Coll-Seck, A.M., Cropper, M.L., Fobil, J., Fuster, V., Greenstone, M., Haines, A.,
573 Hanrahan, D., Hunter, D., Khare, M., Krupnick, A., Lanphear, B., Lohani, B., Martin,
574 K., Mathiasen, K. V., McTeer, M.A., Murray, C.J.L., Ndahimananjara, J.D., Perera, F.,
575 Potočnik, J., Preker, A.S., Ramesh, J., Rockström, J., Salinas, C., Samson, L.D.,
576 Sandilya, K., Sly, P.D., Smith, K.R., Steiner, A., Stewart, R.B., Suk, W.A., van Schayck,
577 O.C.P., Yadama, G.N., Yumkella, K., Zhong, M., 2018. The Lancet Commission on
578 pollution and health. Lancet 391, 462–512. https://doi.org/10.1016/S0140-
579 6736(17)32345-0
580 Langer, A.M., Macler, A.D., Rubin, I., Cuyler Hammond, E., Selikoff, I.J., 1971. Inorganic
581 Particles in Cigars and Cigar Smoke. Science (80-.). 174, 585–587.

https://doi.org/10.1126/science.174.4009.585
Langford, N.J., Ferner, R.E., 1999. Toxicity of mercury. J. Hum. Hypertens. 13, 651–656. https://doi.org/https://doi.org/10.1038/sj.jhh.1000896
Le Foll, B., Piper, M.E., Fowler, C.D., Tonstad, S., Bierut, L., Lu, L., Jha, P., D. Hall, W., 2022. Tobacco and nicotine use. Nat. Rev. Dis. Prim. 8, 1–18. https://doi.org/10.1038/s41572-022-00353-x
M. Shahbandeh, 2021. Global tobacco production 1990-2019 [WWW Document]. URL https://www.statista.com/statistics/261189/global-tobacco-production-since-1980/
Ma, L.-J., Ma, N., Cao, J.-L., Wan, J.-B., 2022. Characterizing the influence of different drying methods on chemical components of Panax notoginseng leaves by heart-cutting two-dimensional liquid chromatography coupled to orbitrap high-resolution mass spectrometry. Food Chem. 369, 130965. https://doi.org/https://doi.org/10.1016/j.foodchem.2021.130965
Majewska, U., Piotrowska, M., Sychowska, I., Banaś, D., Kubala-Kukuś, A., Wudarczyk-Moćko, J., Stabrawa, I., Góźdź, S., 2018. Multielemental analysis of tobacco plant and tobacco products by TXRF. J. Anal. Toxicol. https://doi.org/10.1093/jat/bky016
Mallock, N., Pieper, E., Hutzler, C., Henkler-Stephani, F., Luch, A., 2019. Heated Tobacco Products: A Review of Current Knowledge and Initial Assessments. Front. Public Heal. 7, 1–8. https://doi.org/10.3389/fpubh.2019.00287
Meynard, A., Espinoza-González, C., Núñez, A., Castañeda, F., Contreras-Porcia, L., 2021. Synergistic, antagonistic, and additive effects of heavy metals (copper and cadmium) and polycyclic aromatic hydrocarbons (PAHs) under binary and tertiary combinations in key habitat-forming kelp species of Chile. Environ. Sci. Pollut. Res. 28, 18300–18307. https://doi.org/10.1007/s11356-021-13261-6
Mielcarek, K., Nowakowski, P., Puścion-Jakubik, A., Gromkowska-Kępka, K.J., Soroczyńska, J., Markiewicz-Żukowska, R., Naliwajko, S.K., Grabia, M., Bielecka, J., Żmudzińska, A., Moskwa, J., Karpińska, E., Socha, K., 2022. Arsenic, cadmium, lead and mercury content and health risk assessment of consuming freshwater fish with elements of chemometric analysis. Food Chem. 379. https://doi.org/10.1016/j.foodchem.2022.132167
Milatou, N., Dassenakis, M., Megalofonou, P., 2020. Mercury concentrations in reared Atlantic bluefin tuna and risk assessment for the consumers: To eat or not to eat? Food Chem. 331, 127–267. https://doi.org/https://doi.org/10.1016/j.foodchem.2020.127267
Musk, A.W., De Klerk, N.H., 2003. History of tobacco and health. Respirology 8, 286–290.

https://doi.org/10.1046/j.1440-1843.2003.00483.x
Neathery, M.W., Miller, W.J., 1975. Metabolism and Toxicity of Cadmium, Mercury, and Lead in Animals: A Review. J. Dairy Sci. 58, 1767–1781. https://doi.org/10.3168/jds.S0022-0302(75)84785-0
Pauly, J.L., Stegmeier, S.J., Mayer, A.G., Lesses, J.D., Streck, R.J., 1997. Release of carbon granules from cigarettes with charcoal filters. Tob. Control 6, 33–40. https://doi.org/10.1136/tc.6.1.33
Polat, S., Guclu, G., Kelebek, H., Keskin, M., Selli, S., 2022. Comparative elucidation of colour, volatile and phenolic profiles of black carrot (Daucus carota L.) pomace and powders prepared by five different drying methods. Food Chem. 369, 130941. https://doi.org/https://doi.org/10.1016/j.foodchem.2021.130941
Richardson, G., Brecher, R., Scobie, H., Hamblen, J., Samuelian, J., Smith, C., 2008. Mercury vapour (Hg0): Continuing toxicological uncertainties, and establishing a Canadian reference exposure level. Regul. Toxicol. Pharmacol. 53, 32–38. https://doi.org/10.1016/j.yrtph.2008.10.004
Ronda, O., Grządka, E., Ostolska, I., Orzeł, J., Cieślik, B.M., 2022. Accumulation of radioisotopes and heavy metals in selected species of mushrooms. Food Chem. 367. https://doi.org/10.1016/j.foodchem.2021.130670
Rutkowska, M., Dubalska, K., Bajger-Nowak, G., Konieczka, P., Namieśnik, J., 2014. Organomercury compounds in environmental samples: Emission sources, toxicity, environmental fate, and determination. Crit. Rev. Environ. Sci. Technol. 44, 638–704. https://doi.org/10.1080/10643389.2012.728825
Scientific Committee on Occupational Exposure Limits, 2007. Recommendation from the Scientific Committee on Occupational Exposure Limits for manganese and inorganic manganese compounds. European Comission. https://ec.europa.eu/social/BlobServlet?docId=3852&langId=en
Shen, J., Yin, R., Algeo, T.J., Svensen, H.H., Schoepfer, S.D., 2022. Mercury evidence for combustion of organic-rich sediments during the end-Triassic crisis. Nat. Commun. 13, 1–8. https://doi.org/10.1038/s41467-022-28891-8
Sommar, J., Osterwalder, S., Zhu, W., 2020. Recent advances in understanding and measurement of Hg in the environment: Surface-atmosphere exchange of gaseous elemental mercury (Hg0). Sci. Total Environ. 721, 137648. https://doi.org/10.1016/j.scitotenv.2020.137648
Steckling, N., Boese-O'Reilly, S., Gradel, C., Gutschmidt, K., Shinee, E., Altangerel, E.,

Badrakh, B., Bonduush, I., Surenjav, U., Ferstl, P., Roider, G., Sakamoto, M., Sepai, O., Drasch, G., Lettmeier, B., Morton, J., Jones, K., Siebert, U., Hornberg, C., 2011. Mercury exposure in female artisanal small-scale gold miners (ASGM) in Mongolia: An analysis of human biomonitoring (HBM) data from 2008. Sci. Total Environ. 409, 994–1000. https://doi.org/10.1016/j.scitotenv.2010.11.029

Vaughn, C.C., 2018. Ecosystem services provided by freshwater mussels. Hydrobiologia 810, 15–27. https://doi.org/10.1007/s10750-017-3139-x

Verma, S., Yadav, S., Singh, I., 2010. Trace metal concentration in different Indian tobacco products and related health implications. Food Chem. Toxicol. 48, 2291–2297. https://doi.org/10.1016/j.fct.2010.05.062

Voegborlo, R.B., Akagi, H., 2007. Determination of mercury in fish by cold vapour atomic absorption spectrometry using an automatic mercury analyzer. Food Chem. 100, 853–858. https://doi.org/10.1016/j.foodchem.2005.09.025

Watanabe, T., Kasahara, M., Nakatsuka, H., Masayuki, I., 1987. Cadmium and lead contents of cigarettes produced in various areas of the world. Sci. Total Environ. 66, 29–37. https://doi.org/10.1016/0048-9697(87)90074-X

WHO Study Group on Tobacco Production Regulation, 2012. WHO Study Group on Tobacco Product Regulation. Report on the Scientific Basis of Tobacco Product regulation: Fourth Report of a WHO Study Group., World Health Organization technical report series.

World Health Organization, 2020. Air quality guidelines for Europe Second Edition. World Health Organization. Regional Office for Europe, Copenhagen PP - Copenhagen. https://apps.who.int/iris/handle/10665/107335

Zhou, X., Hines, P.A., White, K.C., Borer, M.W., 1998. Gas Chromatography as a Reference Method for Moisture Determination by Near-Infrared Spectroscopy. Anal. Chem. 70, 390–394. https://doi.org/10.1021/ac970776r