Food Quality and Safety, 2019, 3, 1–8
doi:10.1093/fqsafe/fyy025
Review
Advance Access publication 27 February 2019

Review

Exposures and risks of arsenic, cadmium, lead, and mercury in cocoa beans and cocoa-based foods: a systematic review

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Received 16 July 2018; Revised 13 November 2018; Editorial decision 22 November 2018.

Abstract

Background: The World Health Organization has expressed concern about arsenic, cadmium, lead, and mercury as potentially harmful to human health. As such, the world body has called for appropriate preventive and interventionary measures. In response, food regulatory bodies including European Food Safety Authority are monitoring the levels of these heavy metals in cocoa and cocoa products.

Objective: Therefore, the objective of this paper is to synthesize the latest relevant available peer-reviewed publications on arsenic, cadmium, lead, and mercury with a view to highlighting the gaps to encourage further research and informing industry.

Materials and Methods: A systematic review was conducted using the European Food Safety Authority guide in PubMed database and the result was reported according to the PRISMA checklist.

Results: The results show that processing may dilute or concentrate the levels of arsenic, cadmium, lead, and mercury, depending on processing factors including the product type, processing method, and raw materials. In addition, some products exceed the European Union and Chinese Maximum Contaminant Level and may pose risk. Furthermore, the findings show that the risk of heavy metal toxicities was higher among children relative to adults at the same exposure in cocoa-based products and that correcting risk estimates for bioavailability reduces the level of estimated risk.

Conclusion: Therefore, the review concludes that further research is required to clarify the effect of processing on the level of these contaminants in specific cocoa-based foods. Moreover, conducting risk studies based on age groups and correcting for bioavailability of arsenic, cadmium, lead, and mercury enhance accuracy of risk estimates.

Recommendations: The review, therefore, recommends that a value chain approach be adopted to assessing the levels, exposures, and risks of arsenic, cadmium, lead, and mercury in cocoa-based foods and the effect of processing on these levels.

Key words: toxic heavy metals; risks; exposures; hazards; cocoa-based products.

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Introduction

The World Health Organization (WHO, 2018a) has expressed concern about arsenic, cadmium, lead, and mercury as potentially harmful to human health. As such, the world body has called for appropriate preventive and interventionary measures in addition to consumption data. To this end, food regulatory bodies including the European Food Safety Authority (EFSA, 2018), the Food Standards Agency (FSA, 2018), and the Food and Drug Administration of the United States (US FDA, 2018) are monitoring the levels in foods. A cursory search in the literature indicates that arsenic, cadmium, lead, and mercury have been well characterized in terms of their respective toxicities by transnational bodies such as the International Agency for Research on Cancer (IARC, 1993, 2012a, 2012b). Furthermore, according to the International Cocoa Organization (ICCO), per capita consumption of chocolate, a cocoa product, is on the rise in several countries including the UK, Germany, and France (ICCO, 2010). In response to these developments, the EU has enacted new guidelines for cadmium in cocoa products and cocoa derivatives, to be enforced from 2019 (EU Law and Publications Office, 2006). Does manufacturing concentrate or dilute the levels of these metals? Are exposures exceeding critical regulatory levels? What are the risks associated with current levels of exposure? What can be done about mitigation? This paper is a synthesis of the latest relevant available peer-reviewed literature on arsenic, cadmium, lead, and mercury levels, exposure and risk in cocoa and cocoa derivative foods with a view to highlight the gaps, to encourage further research and to inform industry.

Materials and Methods

The authors adopted European Food Safety Authority (2010) guide and the PRISMA protocol (Moher *et al.*, 2009) for reporting this review (Figure 1). Literature search of PubMed database was conducted. PubMed database was preferred for the key words search because it is a more comprehensive research database with toxicological data, including food toxicological data. However, Google Scholar database was also reviewed to capture additional published papers. The key words searched were lead, arsenic, mercury, and cadmium each with cocoa and chocolate (Table 1).

These selected keywords were used because the authors considered them adequate to pull out all the relevant and essential data available in order to achieve the objective of the study. To ensure efficiency, the PubMed repository was searched using the Boolean script in Table 1. The search was scoped to works from 1 January 2000 to 8 May 2018 in order to describe the current body of knowledge required to achieve the objective of the review. Inclusion and exclusion criteria used were as follows: peer-reviewed papers in English were included if they had primary

- data on lead, mercury, arsenic, and cadmium concentration in cocoa, cocoa products, or chocolate;
- data on lead, mercury, arsenic, and cadmium human exposure or dietary intake in cocoa, cocoa products, or chocolate;
- data on risk characterization, including hazard quotient or hazard index, of lead, arsenic, mercury, and cadmium in cocoa, cocoa products, or chocolate; and
- relevant toxicological research output on lead, arsenic, mercury, and cadmium were included in this review.

Some papers were not included during screening because they were published in a language other than English, for example Japanese (Ogimoto *et al.*, 2009; Kataoka *et al.* 2012), German (Belz and Mohr-Kahaly, 2011) and Polish (Wojciechowska-Mazurek *et al.*, 2008); the authors could not translate and English versions were not available. Others had data that were not appropriate (for example Chavez *et al.*, (2016)) for the review. The concentration, intake, and risk data were extracted (Table 2), described, summarized, tabulated, and synthesized. To ensure uniformity for analysis, units were converted as shown in Table 3.

Results and Discussion

Included literature summaries

Rankin *et al.* (2005) reported that lead concentration in chocolate (0.070–0.230 mg/kg) was much higher than raw cocoa beans (≤0.0005 mg/kg) on average. They further explained that processing methods accounted for increased concentration with processing. Also, using isotopic analysis, they contend that the associated broad isotopic variability ($^{206}Pb/^{207}Pb$ = 1.1475–1.1977; $^{208}Pb/^{207}Pb$ = 2.4234 – 2.4673) as a signature correlated with lead contaminant levels in cocoa to production origin. Also Duran *et al.* (2009) determined the levels of cadmium (1.347 mg/kg) and lead (0.681 mg/kg) in cocoa-derived candies. Similarly, in a seminal work, Abt *et al.* (2018) investigated the levels of cadmium and lead in the

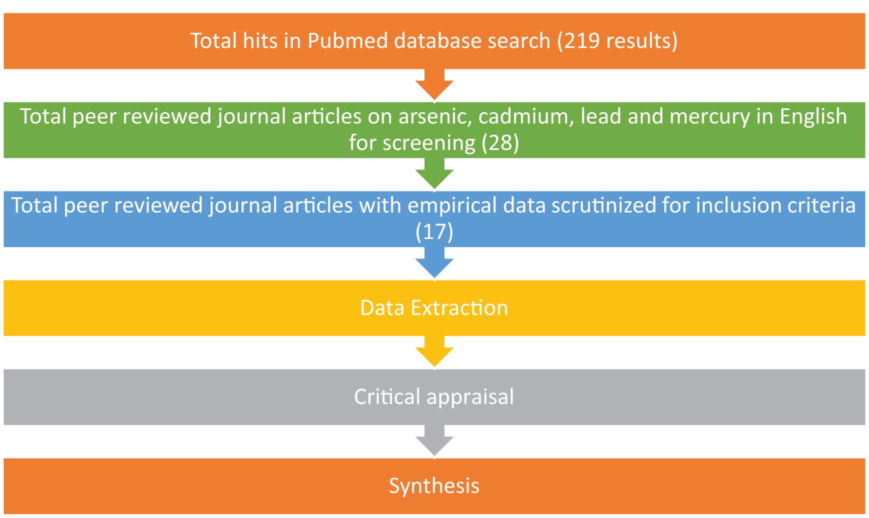

Figure 1. Systematic literature review protocol.

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Table 1. Search strategy record

Database	PubMed		
Date	8 May 2018		
Search	Hits	Included	New
((“chocolate”[MeSH Terms] OR “chocolate”[All Fields] OR “cocoa”[All Fields] OR “cacao”[MeSH Terms] OR “cacao”[All Fields]) AND (“arsenic”[MeSH Terms] OR “arsenic”[All Fields])) AND (“2000/1/1”[PDAT]: “2018/5/8”[PDAT])	10	4	4
((“arsenic”[MeSH Terms] OR “arsenic”[All Fields]) AND (“chocolate”[MeSH Terms] OR “chocolate”[All Fields])) AND (“2000/1/1”[PDAT]: “2018/5/8”[PDAT])	3	2	0
((“lead”[MeSH Terms] OR “lead”[All Fields]) AND (“chocolate”[MeSH Terms] OR “chocolate”[All Fields] OR “cocoa”[All Fields] OR “cacao”[MeSH Terms] OR “cacao”[All Fields])) AND (“2000/1/1”[PDAT]: “2018/5/8”[PDAT])	159	13	9
((“lead”[MeSH Terms] OR “lead”[All Fields]) AND (“chocolate”[MeSH Terms] OR “chocolate”[All Fields])) AND (“2000/1/1”[PDAT]: “2018/5/8”[PDAT])	96	8	0
((“mercury”[MeSH Terms] OR “mercury”[All Fields]) AND (“chocolate”[MeSH Terms] OR “chocolate”[All Fields] OR “cocoa”[All Fields] OR “cacao”[MeSH Terms] OR “cacao”[All Fields])) AND (“2000/1/1”[PDAT]: “2018/5/8”[PDAT])	9	1	0
((“mercury”[MeSH Terms] OR “mercury”[All Fields]) AND (“chocolate”[MeSH Terms] OR “chocolate”[All Fields])) AND (“2000/1/1”[PDAT]: “2018/5/8”[PDAT])	4	0	0
((“cadmium”[MeSH Terms] OR “cadmium”[All Fields]) AND (“chocolate”[MeSH Terms] OR “chocolate”[All Fields])) AND (“2000/1/1”[PDAT]: “2018/5/8”[PDAT])	15	7	2
((“cadmium”[MeSH Terms] OR “cadmium”[All Fields]) AND (“chocolate”[MeSH Terms] OR “chocolate”[All Fields] OR “cocoa”[All Fields] OR “cacao”[MeSH Terms] OR “cacao”[All Fields])) AND (“2000/1/1”[PDAT]: “2018/5/8”[PDAT])	28	14	1
		Total	16

Table 2. Included peer-reviewed papers

Data	Source
Lead concentration in cocoa, cocoa products and chocolate, and their sources	(Rankin *et al.*, 2005)
Concentration of cadmium and lead in cocoa-derived candies	(Duran *et al.*, 2009)
Concentration of cadmium and lead in chocolate varieties	(Villa *et al.*, 2014)
Cadmium and lead levels in cocoa products and intake of same	(Abt *et al.*, 2018)
Lead in chocolate-based cereal and infant food	(Guérin *et al.*, 2017)
Lead levels across geographical location	(Manton, 2010)
Concentration and bioavailability of cadmium and lead	(Mounicou *et al.*, 2003)
Levels of lead, arsenic, and cadmium in cocoa products	(Yanus *et al.*, 2014)
Arsenic, cadmium, and lead levels in cocoa products	(Lo Dico *et al.*, 2018)
Arsenic, cadmium, lead, and mercury levels in ice cream	(Conficoni *et al.*, 2017)
Bioavailability and exposure of cadmium in the medium of chocolate	(Barraza *et al.*, 2017)
Cadmium levels in cocoa beans and shells	(Arévalo-Gardini *et al.*, 2017)
Cadmium levels in cocoa beans	(Gramlich *et al.*, 2018)
Cadmium levels in cocoa beans	(Gramlich *et al.*, 2017)
Cadmium concentration in cocoa beans	(Chavez *et al.*, 2016)
Bioavailability of lead and cadmium of cocoa	(Mounicou *et al.*, 2002)

US market. Their findings indicate that percentage cocoa powder in chocolate products was directly proportional to their corresponding lead and cadmium levels. They showed in their findings that lead in cereals with cocoa derivatives was higher than identical products without cocoa derivatives. Besides, lead shows variation across

Table 3. Description of data extracted

Variable	Units
Concentration or level hazard	mg/kg of matrix
Intake of matrix	g/week
Exposure to hazard	mg/kg-day
Risk	Qualitative

geographical location. Studies conducted by Mounicou *et al.* (2003) on cocoa powder from eight countries clearly shows variation for cadmium and lead. A similar study by Manton (2010) of cocoa samples from twelve countries also found geographical variation of lead. Mounicou *et al.* (2002) assessed mercury and lead for their bioavailability in two cocoa products. In both cocoa liquor and powder, cadmium was found to be up to 80% bioavailable, whereas lead was found to be up to about 12%. In a subsequent study, Mounicou *et al.* (2003) obtained similar results: up to 14% lead and 50% cadmium bioavailability, cadmium being more bioavailable than lead. This is comparable to values obtained by Barraza *et al.* (2017). They, however, used gastric juice to assess cadmium in the beans and liquor of cocoa in Ecuador. They found out that cadmium, in total, was 90% to 100% bioaccessible in the fundus of the human digestive system. Furthermore, they established no significant varietal bioaccessibility difference in the samples of cocoa. In addition, Villa *et al.* (2014) found a strong positive correlation between lead ($R^2 = 0.955$) and cadmium ($R^2 = 0.907$) levels and cocoa content in chocolate. Also Gramlich *et al.* (2018) assessed cocoa beans in Honduras for cadmium and found the mean (1.1 mg/kg). They established that cocoa beans showed variation according to soil factors. In a similar study, Gramlich *et al.* (2017) found a lower cocoa bean mean concentration (0.21 mg/kg) in Bolivia. They also found out that cocoa beans cadmium concentration is significantly affected by the type of cropping system for some varieties, although the difference is not clear overall. The authors further reported that there was distinct cadmium concentration difference in cocoa under monoculture and agroforestry for some varieties, with the latter being less than the former. In contrast, cadmium concentration in cocoa beans did

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not show any significant difference between cocoa cultivated under organic and conventional production. Meanwhile, Chavez et al. (2016) reported that 73% of 15 sites investigated contain more than 0.6 mg/kg of cadmium.

In all, it can be stated that studies conducted to assess the levels of arsenic, cadmium, mercury, and lead in cocoa and its derivative food products show varying results. They indicate that several factors affect these contaminants in cocoa products. These factors include soil, cultural, and processing factors. Also, available data show that arsenic, cadmium, and lead show different bioavailability. This may have significant effect on the risk of toxicity.

Trends in concentrations

The results (Table 4) show a trend of increasing concentration of arsenic in beans (0.016 mg/kg) to powder (0.041 mg/kg) of cocoa with cocoa shells (0.160 mg/kg) having the highest (Yanus *et al.*, 2014). However, the concentration from cocoa powder (0.026 mg/kg) to chocolate (0.012 mg/kg) decreases (Lo Dico *et al.*, 2018). Processing cocoa beans (0.016 mg/kg) into cocoa butter (0.0122 mg/kg) reduces the arsenic concentration slightly.

Cadmium concentration in cocoa shells (0.629 mg/kg) tends to be higher than in cocoa beans (0.072 mg/kg) (Kruszewski *et al.*, 2018). When cocoa beans with shell (0.629 mg/kg) are processed into powder (0.153 mg/kg), the concentration of cadmium decreases (Kruszewski *et al.*, 2018). However, when deshelled cocoa beans (0.072 mg/kg) are powdered (0.125 mg/kg), the cadmium concentration increases. As with arsenic, cadmium concentration in cocoa powder (0.125–0.533 mg/kg) is lower than in chocolate (0.058–0.116 mg/kg). Lead concentration (Table 4) generally increases from beans (0.04–0.137 mg/kg) to powder (0.103–0.575 mg/kg) (Yanus *et al.*, 2014; Kruszewski *et al.*, 2018). However, Mounicou *et al.* (2003) reported a corresponding decrease (0.042–0.051 mg/kg to 0.011 mg/kg). The concentration of lead in cocoa powder compared with chocolate is variable. Roasted cocoa beans (Table 4) has a higher cadmium concentration (0.46 mg/kg) than fermented cocoa beans (0.372 mg/kg). Similarly, fermented cocoa beans tend to have a lower lead concentration (0.042 mg/kg) than roasted cocoa beans (0.051 mg/kg).

The concentration of arsenic in chocolate (Table 4) was below the maximum contaminant level (0.5 mg/kg) of the National Food Safety Standard, China (USDA Foreign Agricultural Service, 2018) and (0.10 mg/kg) the United States of Food and Drug Administration (USFDA, 2005) for cocoa and its derivative foods.

As such, consumers are not at risk to skin cancer, hyperpigmentation, and keratosis occasioned by arsenic intake (Table 5). Similar results were obtained for cadmium and lead with some exceptions. Lo Dico *et al.* (2018) reported cadmium level (0.116 mg/kg) in chocolate greater than the European Union maximum contaminant level (MCL) (0.10 mg/kg) to be enforced 1 January 2019. In addition, cadmium level in cocoa-derived candies (0.687 mg/kg) is so high that it exceeds both EU and Chinese MCLs (Table 5). Therefore, cadmium poses a risk to consumers of cocoa-derived candies. It may cause cancers of the kidney and prostate and other kidney-related diseases (Table 6).

Table 4. Concentration of arsenic, cadmium, mercury, and lead in cocoa and cocoa derivatives in mg/kg

Shell	Beans	Butter	Powder	Liquor	Chocolate	Candy	
Arsenic							
			(35) 0.0260 ± 003		(35) 0.012 ± 0.002		(Lo Dico *et al.*, 2018)
0.160 ± 0.002	0.016 ± 0.004	0.0122 ± 0.002	0.041 ± 0.006				(Yanus *et al.*, 2014)
Cadmium							
			(35) 0.159 ± 0.020		(35) 0.116 ± 0.015*		(Lo Dico *et al.*, 2018)
	0.629 ± 0.067**		0.153 ± 0.015		0.058 ± 0.006		(Kruszewski *et al.* 2018)
0.085 ± 0.0013	0.072 ± 0.0011	<0.0031	0.125 ± 0.011				(Yanus *et al.*, 2014)
					(30) 0.0292		(Villa *et al.*, 2014)
	(2) 0.372 ± 0.052*** 0.46 ± 0.014****	(2) 0.01 ± 0.000	(2) 0.533 ± 0.016	(2) 0.282 ± 0.004			(Mounicou *et al.*, 2003)
	(94) 1.1 ± 0.2						(Gramlich *et al.*, 2018)
						0.687*,*****	(Duran *et al.*, 2009)
Lead							
			0.417 ± 0.032		0.133 ± 0.013		(Lo Dico *et al.*, 2018)
	0.137 ± 0.030**		0.575 ± 0.014		0.585 ± 0.016*****		(Kruszewski *et al.*, 2018)
1.289 ± 0.193	0.04 ± 0.008	0.067 ± 0.0015	0.103 ± 0.009				(Yanus *et al.*, 2014)
					(30) 0.048		(Villa *et al.*, 2014)
0.16	0.000512						(Rankin *et al.*, 2005)
						1.347*****	(Duran *et al.*, 2009)
	(2) 0.042 ± 0.013*** 0.051 ± 0.000****	(2) 0.022 ± 0.001	(2) 0.011 ± 0.003	(2) 0.01 ± 0.000			(Mounicou *et al.*, 2003)

*Above EU MCL of 0.10 mg/kg (EU Law and Publications Office, 2006).
**cocoa beans with shell; ***Fermented; ****roasted.
*****Above China MCL of 0.50 mg/kg (USDA Foreign Agricultural Service, 2018).

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Table 5. Various thresholds of arsenic, cadmium, lead, and mercury

Metal	RfD* mg/kg-day	PF** Per mg/ kg-day	PTWI*** μg/kg	EU MCL**** mg/kg	China MCL***** mg/kg	USFDA MCL****** mg/kg
As (Inorganic)	0.0003	1.5	15		0.5	0.1
Cd	0.001		25*******	—Milk chocolate with <30% total dry cocoa solids, 0.10 —Chocolate with <50% total dry cocoa solids; milk chocolate with ≥30% total dry cocoa solids, 0.30 —Chocolate with ≥50% total dry cocoa solids, 0.80 —Cocoa powder sold to the final consumer or drinking chocolate, 0.60 —Roots and tuber, 0.10		
Pb			25	Roots and tuber, 0.10	0.5	
Hg	0.0003($HgCl_2$) 0.0001(MeHg)		2********		0.5	

*Reference dose (US EPA IRIS 1989; 1995; 2001; IARC 2012a).
**Potency factor (US EPA IRIS, 1991).
***Provisional tolerable weekly intake (WHO 2006; 2010; 2010a; 2010b).
****Maximum contaminant level by the European Union (EU Law and Publications Office, 2006).
*****Maximum contaminant level by China (USDA Foreign Agricultural Service, 2018).
******Maximum contaminant level by USFDA (USFDA, 2005).
*******PTMI = 62 μg/day for a 70-kg person.
********PTDI.

Table 6. Toxicity data of arsenic, cadmium, lead, and mercury

Metal	Toxicity mechanism	Target organs	Adverse health outcome	
As (Inorganic)	Arsenate > arsenite > methylarsonate > dimethylarsenite	Skin	Group 1 carcinogen Hyperpigmentation Keratosis	(IARC, 2012a)
Cd	Tumor-suppressor proteins and DNA repair disruption	Kidney Prostate	Group1 Carcinogen Proteinuria Osteoporosis Kidney stones	(IARC, 2012b)
Pb	DNA repair disruption and reactive oxygen species mediation	Nerve	Group 2A carcinogen	(IARC, 2006)
Hg (MeHg)	Not identified	Liver gut CNS/ PNS	Group 2B carcinogen Neurological and behavioral disorders	(IARC, 1993)

Also, Kruszewski *et al.* (2018) reported lead concentration levels (0.585 mg/kg) in chocolate greater than the National Food Safety Standard, China, MCL (0.5 mg/kg) (USDA Foreign Agricultural Service, 2018) and the Food Standards Australia New Zealand (2016) MCL (also 0.05 mg/kg). The level of lead in cocoa-derived candies (1.347 mg/kg) was the highest the study found. This value was higher than the (0.5 mg/kg) the National Food Safety Standard, China MCL (USDA Foreign Agricultural Service 2018). Therefore, consumers maybe at risk of cancer and paresthesia (Table 6). Cocoa butter equivalents do not contribute to cadmium and lead (Kruszewski *et al.*, 2018). The review did not find any available data on mercury concentration in cocoa and cocoa-based foods.

Furthermore, the export of cocoa-derived candies and chocolate to the Australian, New Zeeland, Chinese, and EU markets stands a risk of being barred or rejected on account of exceeding their respective MCL thresholds. Products from cocoa butter may not have such entry risks.

Metal contaminant in chocolate varieties

The content of cadmium and lead in chocolate tends to vary according to the chocolate variety (Figure 2). Chocolate type can be predicted by the concentration of lead (R^2 = 0.51–1) and cadmium (R^2 = 0.95–1) by about 51%–100% and 95%–100%, respectively. Milk chocolate showed a consistent low amount of cadmium and lead relative to dark chocolate (Villa *et al.*, 2014; Abt *et al.*, 2018). However, the mean amount of lead and cadmium in a given chocolate variety, say milk chocolate, tends to vary from study (Villa *et al.*, 2014) to study (Mounicou *et al.*, 2003). Similarly, percentage cocoa solids also predict arsenic (R^2 = 0.33)

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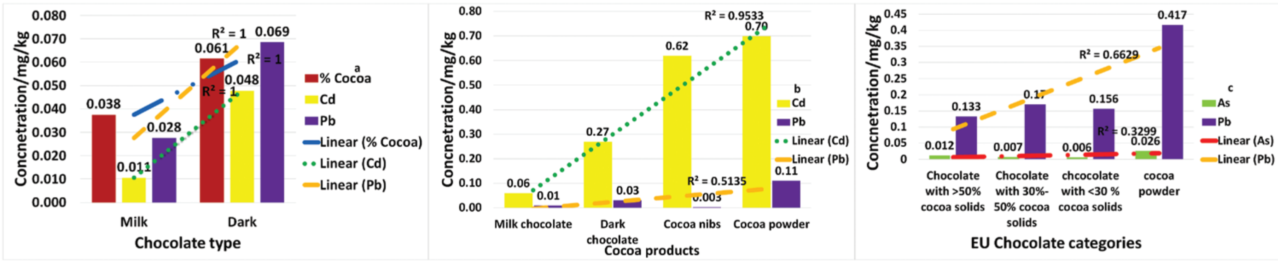

Figure 2. Variation of mean cadmium and lead levels across different chocolate varieties based on empirical data from (a) Abt *et al.* (2018), (b) Villa *et al.* (2014), and (c) Lo Dico *et al.* (2018).

Table 7. Exposure and risk indicator estimates

Cocoa derivative	Intake g/week	Cd level µg/g	Cd exposure µg/kg-BW	Cd exposure µg/kg- BW (bioavailability corrected)	Contribution to tolerable intake		
					Adults	Children	
Dark chocolate	70	0.07			1.80% PTMI	8.6% PTMI	(Villa *et al.*, 2014)
Dark chocolate	70	0.07			4.30% TWI	20.1% TWI	(Villa *et al.*, 2014)
Dark chocolate	77.3		1.94	1.88			(Barraza *et al.*, 2017)
Milk chocolate	44.2		1.11	1.07			(Barraza *et al.*, 2017)
Cocoa derived candy	140	1.347			38.20% PTMI	90% PTWI	(Duran *et al.*, 2009)

and lead (R^2 = 0.66) level by about 33% and 66%, respectively (Mounicou *et al.*, 2003).

Exposure and risk

Chocolate intake (Table 7) used by Duran *et al.* (2009), Villa *et al.* (2014), and Barraza *et al.* (2017) was either assumed or was obtained from secondary source. In dark chocolate, the difference between the cadmium exposure (1.98 ug/kg-bw) and cadmium exposure corrected for bioavailability (1.88 ug/kg-bw) (Barraza *et al.*, 2017) contributed about 17% to cadmium Provisional Tolerable Weekly Intake (PTWI) for the average 70 kg adult (World Health Organization, 2010a).

Cognate to the subject matter, disease etiology is generally multifactorial. The purpose of research, therefore, is to profile or track down significant causal factors with a view to mitigating them. In nonsmokers, for example, the most significant source of arsenic, cadmium, lead, and mercury in the general population is by oral exposure (European Food Safety Authority, 2012; Omari *et al.*, 2013; Rajaee *et al.*, 2015). Besides, there is an emerging trend of exposure and risks due to arsenic, cadmium, mercury, and lead in food systems (Djahed *et al.*, 2018; Fakhri *et al.*, 2018; Fathabad *et al.*, 2018; Jeevanaraj *et al.*, 2018; Li *et al.*, 2018). Focusing on cocoa-based food systems, Salama (2018) conducted a health risk assessment of ten metals (including arsenic, cadmium, mercury, and lead). He indicated that based on the hazard index (HQ > 1), there was a risk of several toxicities including neurodevelopemtal disorders, osteoporosis, proteinuria, kidney stones, keratosis, and hyperpigmentation. Specifically, Salama (2018) reported that 2 out of 100 000 people are at risk of skin cancer based on a carcinogenic risk assessment in cocoa products. The study further showed that cancer risk increases to 3 out of 100 000 among consumers of bar chocolate and candy chocolate. This is corroborated by other findings that given the same exposures of cadmium in chocolate, children have a higher exposure (8.6 %) than adults (1.8%) (Duran *et al.*, 2009; Villa *et al.*, 2014). After analysing some products including cocoa, Barraza *et al.* (2018) found that adult consumers of cocoa were at risk (HQ > 1) of proteinuria, kidney stones, keratosis, and hyperpigmentation among other toxicities. According to their study, these toxicities were caused by a number of toxic metals such as arsenic, lead, and cadmium in cocoa. Furthermore, their study indicated that the risk of these toxicities among children was higher.

Prevention and remedial measures

The review recommends that good agricultural practices (GAP), hazard analysis critical control points (HACCP), and other industry-specific standards should be applied to avoid contamination during food production and processing. Enforcement of these standards by regulatory bodies must also be given priority in order to save lives. The use of chemical interventions and biological controls of arsenic, cadmium, mercury, and lead in food systems is in an exploratory stage (An *et al*, 2001; Lin, 2018; Massimi *et al.*, 2018; Nawani *et al.*, 2018; Wochner *et al.*, 2018). According to the WHO (2018), a toxicovigilance centre serves as a nexus that links educators, regulators, and health officers with real people in local communities. Bertrand *et al.* (2016) asserts that toxicovigilance systems ensure active and persistent assessment of communities for toxins and toxicants around the clock. Faisandier *et al.* (2015) also contend that this environmental scanning enables toxicovigilance systems to index a database of victim profiles, toxicants or toxins, exposures, and sociodemographic and medical history. They further show that this bank of information is essential for the prevention of (re-)emerging risks of toxicity using current technology. Thus, the use of food toxicovigilance to maintain continuous surveillance, investigation, management, and toxicity, and prevention of health risk by regulators holds promise.

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Conclusion

In conclusion, the concentration of arsenic, cadmium, and lead varies in the same product category. Along the value chain, their levels vary by either diminishing or concentrating, depending on several factors including production, processing, and edaphic factors. Some cocoa-based food products, including chocolate and candies, exceed the EU and Chinese MCL thresholds. Bioavailability varies for lead and cadmium, and is significant in assessing their respective risks. Exposure and risk tend to be high among children relative to adults even at the same level of intake. The quantitative human health risk assessment of cocoa in relation to arsenic, cadmium, mercury, and lead intake in cocoa-based food products has not been conducted.

To address these gaps in the literature, the study must make key recommendations. Firstly, the impact of processing on the concentration of arsenic, calcium, mercury, and lead in cocoa food derivatives be conducted using the value chain approach should be examined in order to give a holistic picture.

Secondly, exposure and risk assessment on arsenic, mercury, and lead should be conducted using methods for the metal contaminants for a broad range of finished cocoa products. Thirdly, population-based risk assessment of arsenic, calcium, lead, and mercury should be carried out to estimate the likelihood of adverse effect to vulnerable age groups, such as the elderly and children, in endemic areas such as mining areas. Such investigations should incorporate both quantitative and qualitative methods of risk assessment such as probabilistic risk assessment (PRA), margin of exposure (MOE), and hazard index (HI).

Conflict of interest statement

None declared.

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