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Review

Rice methylmercury exposure and mitigation: A comprehensive review

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ABSTRACT

Rice cultivation practices from field preparation to post-harvest transform rice paddies into hot spots for microbial mercury methylation, converting less-toxic inorganic mercury to more-toxic methylmercury, which is likely translocated to rice grain. This review includes 51 studies reporting rice total mercury and/or methylmercury concentrations, based on rice (*Orzya sativa*) cultivated or purchased in 15 countries. Not surprisingly, both rice total mercury and methylmercury levels were significantly higher in polluted sites compared to non-polluted sites (Wilcoxon rank sum, $p < 0.001$). However, rice percent methylmercury (of total mercury) did not differ statistically between polluted and non-polluted sites (Wilcoxon rank sum, $p = 0.35$), suggesting comparable mercury methylation rates in paddy soil across these sites and/or similar accumulation of mercury species for these rice cultivars. Studies characterizing the effects of rice cultivation under more aerobic conditions were reviewed to determine the mitigation potential of this practice. Rice management practices utilizing alternating wetting and drying (instead of continuous flooding) caused soil methylmercury levels to spike, resulting in a strong methylmercury pulse after fields were dried and reflooded; however, it is uncertain whether this led to increased translocation of methylmercury from paddy soil to rice grain. Due to the potential health risks, it is advisable to investigate this issue further, and to develop separate water management strategies for mercury polluted and non-polluted sites, in order to minimize methylmercury exposure through rice ingestion.

1. Introduction

Mercury (Hg) is a global pollutant and potent neurotoxin. Methylmercury (MeHg) is one of the most toxic forms of Hg, which can severely afflict the unborn fetus (Clarkson and Magos, 2006). Fish consumption is considered the primary human MeHg exposure pathway due to efficient biomagnification of MeHg in aquatic food chains, especially among piscivorous fish (Cabana et al., 1994; Morel et al., 1998; Mahaffey et al., 2004). This assumption is currently challenged by recent research in Guizhou province, China, where elevated rice grain MeHg levels were reported in a some villages near the former Wanshan Hg Mine (e.g., see Table 1 and references therein). In this region, median rice MeHg concentrations were up to 10 times lower than those typically measured for fish tissue (e.g., Feng et al., 2008; Horvat et al., 2003; Rothenberg et al., 2012; Zhang et al., 2010a). However, rice is a staple food, resulting in daily rice-based meals (without fish) containing MeHg exposure levels comparable to a fish meal (Zhang et al., 2010b), without the same beneficial micronutrients associated with fish ingestion (e.g., docosahexaenoic acid, DHA), potentially increasing neurodevelopmental risk to the unborn fetus (Rothenberg et al., 2011a, 2013).

In 2012, the total amount of land in rice cultivation globally was 163 million hectares (1.63 million km^2) and the global production of rice was 729 million tons, of which 90% was produced in Asia (Food and Agriculture Organization of the United Nations (FAO), 2013). Despite the importance of rice as a staple food for half the global population, MeHg exposure through rice ingestion has received relatively little comprehensive study to date, particularly in geographic regions outside of Guizhou province, China, making it difficult to assess the global extent of MeHg exposure through rice ingestion, and to provide recommendations to communities depending on rice as a staple food.

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Table 1
Global inventory of 51 studies reporting mercury concentrations for rice grain, including total mercury (THg), methylmercury (MeHg) and/or %MeHg (of THg). In addition to background information (e.g., country of origin), summary statistics include the mean and parenthetical range. NA indicates data were not available.

Rice country of origin	Sampling/ purchasing site	Polluted site?	Market-basket survey?	Polished rice grain?	Sample size	THg (ng/g)	MeHg (ng/g)	%MeHg (of THg)	Method[a]	Reference	Reference no.
India	Riyadh, Saudi Arabia	No	Yes	Yes	17	1.6 (<3.0–3.309)	NA	NA	AAS	Al-Saleh and Shinwari (2001)[b]	1
Thailand		No	Yes	Yes	4	1.8 (<3.0–3.5)	NA	NA			
Egypt		No	Yes	Yes	2	1.631 (0.513–2.75)	NA	NA			
USA		No	Yes	Yes	2	23.7 (3.8–43.5)	NA	NA			
Australia		No	Yes	Yes	2	<3.0	NA	NA			
Philippines	Mindanao, Philippines	Yes, gold mining	No	No	NA	20 (1–43)	NA	NA	Flame-AAS	Appleton et al. (2006)[b]	2
Philippines	Mindanao, Philippines	Yes, gold mining	No	Yes	NA	18 (8–50)	NA	NA			
Brazil	Brazil	No	Yes	Yes	23	2.3 (0.3–10.4)	NA	NA	ICP-MS	Batista et al. (2012)	3
China	Jiangsu province, China	Yes, industrial runoff	No	No	23	5.7 (1.0–13)	NA	NA	ICP-MS	Cao et al. (2010)	4
China	Zhoushan Island, China	No	No	No	6	9	4	44.4	CV-AAS	Cheng J. et al. (2009)	5
China	Guizhou province, China	Yes, chemical plant	No	No	13	30.7	18.7	NA	CV-AAS (THg), Electron capture (MeHg)	Cheng J. et al. (2013)	6
China	Shanghai, China	No	No	No	NA	8.1	6.0	NA			
Cambodia	Kampong, Cambodia	No	Yes	Yes	6	8.14 (6.16–11.7)	1.44 (1.17–1.96)	NA	AAS (THg), CVAFS (MeHg)	Cheng Z. et al. (2013)	7
	Kratie, Cambodia	Yes, gold mining	Yes	Yes	6	12.7 (9.90–16.7)	1.54 (1.06–2.31)	NA			
	Kandal, Cambodia	No	Yes	Yes	6	10.2 (5.91–15.1)	2.34 (0.48–5.23)	NA			
Brazil	Recife and Sao Paulo, Brazil	No	Yes	Yes	9	3.1 (2.1–4.4)	NA	NA	CV-AFS	da Silva et al. (2010)	8
Spain	Valencia, Spain	No	Yes	Yes	6	2.1 (1.6–3.3)	NA	NA			
Japan	Valencia, Spain	No	Yes	Yes	5	3.1 (1.2–7.8)	NA	NA			
Thailand	Valencia, Spain	No	Yes	Yes	4	2.6 (1.3–3.7)	NA	NA			
Spain	Palma de Mallorca, Spain	No	Yes	Yes	12	4.48 (2.15–7.25)	NA	NA	CV-AFS	da Silva et al. (2013)	9
China	22 provinces, China	No	No	Yes	92	2 (trace-19)	NA	NA	AFS	Fang et al. (2014)[c]	10
China	Guizhou province, China	Yes, Hg mining	No	Yes	25	58.5 (21.1–191.9)	14.6 (7.5–27.6)	27.2 (7.9–65.9)	CV-AFS	Feng et al. (2008)[d]	11
China	Guizhou province, China	Yes, Hg mining	No	Yes	18	21.3 (10–66.9)	5.7 (3.3–10.2)	30.8 (6.1–72.3)			
China	Guizhou province, China	Yes, Hg mining	No	Yes	27	33.1 (4.9–214.7)	4.0 (1.9–14.7)	17.7 (2.4–75.1)			
China	Guizhou province, China	No	No	Yes	24	7 (3.2–15.1)	2.5 (.8–4.3)	40.8 (9.6–88.3)			
China	Zhejiang et al., China	Yes, e-waste	No	Yes	13	22 (15.6–68.4)	NA	NA	Hydride generation-AFS	Fu et al. (2008)	12
China	Jiangsu province, China	Yes, industrial pollution	No	Yes	155	14.5	NA	NA	Hydride generation- AFS	Hang et al. (2009)	13
China	Guizhou province, China	Yes, Hg mining	No	No	10	149 (11.1–569)	38.9 (8.03–144)	42.7 (5.46–72.3)	CV-AFS	Horvat et al. (2003)	14
China	Guizhou province, China	Yes, power plant, and chemical plant	No	No	4	14.5(2.53–33.4)	11.3(071–28)	59.0(28.1–83.8)			
Italy	Italy	No	Yes	Yes	1	5.21	0.86	16.5			
China	Zhejiang province, China	No	Yes	Yes	224	5.0 (<5.0–88)	NA	NA	HG-AFS	Huang et al. (2013)	15
China	Zhejiang province, China	No	No	Yes	216	22.4 (2.46–65.85)	NA	NA	AFS	Jiang et al. (2012)	16
Indonesia	Indonesia	Yes, gold mining	No	No	6	NA	57.7 (10.6–115)	NA	CV-AFS	Krisnayanti et al. (2012)	17
Indonesia	Indonesia	Yes, gold mining	No	Yes	1	NA	1.02	NA			