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Research Article

# Implications and Significance of Mercury in Rice

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ABSTRACT

Previous research on rice asserts certain heavy metals, like mercury, in the agricultural soils are incorporated into the rice plant. Mercury is considered to be the most toxic heavy metal. This study aims to investigate mercury levels in rice grown in the United States versus rice imported from Asia. In this study, 29 samples of rice were compared for mercury content (12 from Thailand, 6 from India, 6 from China, compared to 5 control samples from the USA). Samples ranged from 0.18 to 6.01 ng of element / g. Further research is needed to establish standards for mercury toxicity.



## Introduction

Rice, a known food staple in many countries provides phytosterols, polyphenols, and carbohydrates. This crop has been demonstrated to have agricultural challenges such as contamination with mercury. One of several known heavy metals with significant systemic toxic effects, mercury is a source of contamination of rice through environmental and occupational pollutants. This article discusses the implications of mercury in rice and illustrates why more research on rice is needed.

## I Rice

A staple food for more than half of the world's population, rice is China's number one crop and China is the most common consumer of this crop in the world [1, 2]. It is an important nutritional source of carbohydrates, vitamins, minerals, polyphenols, and phytosterols [3]. In fact, it has a higher balance of essential amino acids (an amino acid score) than wheat or maize. Based on the nutritional profile alone, rice is arguably one of the most vital foods in the world.

Rice baby cereal and rice-containing teething biscuits are the two main sources of rice for infants in the United States [4, 5]. Often introduced as one of the first foods at the start of the complementary feeding period for infants, rice is frequently found in gluten-free products as well [4-6]. About 30% of the U.S. population is decreasing gluten content or attempting to avoid it altogether [6]. Thus, almost one in four people who are consciously searching for gluten free alternatives ingest rice. With such increasingly extensive consumption, nutritional studies of rice are critical to understand the effect on the American diet.

Research on rice contends certain heavy metals in the agricultural soils and are incorporated into the rice plant [7]. Once integrated in the rice plants, mercury, cadmium, chromium, lead, and arsenic are potent toxins humans ingest [7]. With no established biological function, these toxins are classified as systemic toxins since they can induce multiple organ

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damage [7, 8]. Risk of exposure to heavy metals such as those found in the soil of rice plants is greatest via ingestion compared to that of topical contact or inhalation [7].

Data from a study analyzing the bioaccumulation factor (also known as the soil-to-rice transfer factor or enrichment factor) which examines the potential for a metal to transfer from soil to a plant indicated both mercury and cadmium had higher mobility than lead, nickel, chromium, and arsenic [7]. Mercury is considered to be the most toxic heavy metal [9]. Since it has been discovered to cross the placenta during pregnancy, enter breast milk, contaminate infant cereals, this article will discuss all of which are important sources of nutrition for a developing human combined with the higher risk for toxicity at a younger age: this metal will be the focus of this article [4, 9].

## II Mercury

A heavy metal neurotoxin, mercury exists in three forms: elemental mercury ($Hg^0$), inorganic mercury ($Hg^{2+}$), and organic mercury usually found as methylmercury (MeHg) [10, 1]. Routes of exposure, health effects, absorption, excretion, and biomarkers are dependent upon the type of mercury; but all forms are toxic [11, 12]. The most biomagnified and toxic type of mercury is methylmercury [1]. Sources of methylmercury include fish, shellfish, organ meats of terrestrial animals, and rice [11].

Methylmercury exposure was initially considered to be mainly through fish consumption; however, recent literature reveals rice can be a significant source [13, 14]. Even though rice is a staple food, little research on methylmercury exposure through consumption requires further examination [13]. Starting in the 1960s, there was an initial concern for mercury levels in rice from fungicide use [13].

Ninety-five percent of methylmercury ingested is absorbed in the gastrointestinal tract [15]. Once absorbed, most binds to the hemoglobin in erythrocytes, but it can bind glutathione, metallothionein, become suspended in plasma, or form covalent bonds to cysteine residues on various proteins [9, 12, 15]. When bound to cysteine residues it depletes cellular antioxidants and creates a methylmercury-cysteinyl compound which can cross the blood brain barrier [9, 12, 15]. Once it enters the central nervous system, it becomes demethylated forming inorganic mercury which can accumulate [9]. Within the brain, the mercury acts as a neurotoxin by disrupting the production of neurotransmitters [9]. Methylated mercury also inhibits thioredoxin reductase, glutathione peroxidase, and thioredoxin disturbing the oxidant/antioxidant balance [9]. Increase in oxidative stress in addition to calcium and glutamate dysregulation are the main activities involved with the neurotoxicity caused by mercury [15].

Biomarkers of mercury include blood, cord blood, urinary, and hair levels [16]. Half-life of methylmercury is 70-80 days; however, it concentrates in the brain, liver, kidneys, placenta, peripheral nerves, bone marrow, and fetal brain [10]. In fact, about 10% of body methylmercury is located in the brain which has a stronger affinity for methylmercury and has a concentration of 3-6 times higher than in the blood [10]. When assessing methylmercury levels, adverse health effects are present with greater than 5 µg/L in whole blood and 1 µg /g in hair [9]. Note hair is 250-300 times more concentrated than blood mercury levels plus methylmercury is about 80-98% of the hair total mercury [11]. Moreover, median cord blood mercury levels have been demonstrated to be statistically higher than maternal concentrations, reflecting the strong transfer ability of mercury to enter cord blood [17, 18]. Urinary levels of mercury may be also assessed, but this test reflects exposure to inorganic mercury and is not a useful indicator of methylmercury exposure [11].

Excretion of methylmercury is mainly via urine and stool but can also occur through sweat, tears, saliva, and breastmilk [12]. Effects of methylmercury are dependent on the age, route of exposure, dose, distribution, and possibly in part due to the genetic susceptibility of a person [9-12]. For infants and fetuses the impact of mercury may be more profound since they are still developing [10-12]. They can present with severe cerebral palsy like symptoms such as mental retardation, cerebellar ataxia, primitive reflexes, dysarthria, and hyperkinesias [11]. For adults, they can have autoimmune disorders, neurological disorders, or other medical conditions [9, 11].

## Results

**Table 1:** Mercury levels from high to low along with the corresponding rice colour.

| Sample ID | Client ID | Hg | Colour |
|---|---|---|---|
| 143-27 | TG-21-20-11-2019 China | 6.01 | other |
| 143-8 | EC-9-20-11-2019 Thailand | 4.47 | white |
| 143-19 | GK-13-20-11-2019 Thailand | 4.10 | white |
| 143-18 | GK-15-20-11-2019 Thailand | 3.73 | white |
| 143-4 | SD-4-21-11-2019 USA | 3.71 | brown |
| 143-2 | BMB-5-18-11-2019 Thailand | 3.16 | white |
| 143-11 | GK-12-20-11-2019 Thailand | 2.99 | white |
| 143-13 | GK-17-20-11-2019 Thailand | 2.98 | white |
| 143-15 | GK-16-20-11-2019 Thailand | 2.95 | white |
| 143-25 | SD-2-21-11-2019 USA | 2.84 | white |
| 143-20 | BMB-3-18-11-2019 China | 2.82 | other |
| 143-12 | BMB-1-18-11-2019 Thailand | 2.55 | brown |
| 143-24 | TG-19-20-11-2019 China | 2.51 | other |
| 143-3 | TG-23-20-11-2019 China | 2.41 | white |
| 143-17 | GK-11-20-11-2019 Thailand | 2.35 | white |
| 143-23 | GK-14-20-11-2019 Thailand | 2.13 | white |
| 143-5 | SD-5-21-11-2019 USA | 2.07 | brown |
| 143-1 | SD-1-21-11-2019 USA | 2.00 | white |
| 143-28 | TG-20-20-11-2019 China (B&W Rice) | 1.91 | other |
| 143-26 | TG-22-20-11-2019 India | 1.80 | brown |
| 143-7 | EC-10-20-11-2019 India | 1.68 | white |
| 143-9 | BMB-4-18-11-2019 Thailand | 1.43 | white |
| 143-21 | SD-3-21-11-2019 USA | 1.26 | brown |
| 143-16 | GK-18-20-11-2019 India | 1.21 | white |
| 143-6 | EC-8-20-11-2019 India | 1.11 | white |
| 143-14 | EC-7-20-11-2019 India | 0.68 | white |
| 143-22 | BMB-2-18-11-2019 Thailand | 0.50 | other |
| 143-29 | TG-20-20-11-2019 China (Peas) | 0.18 | other |

The content of 29 rice samples was analysed for methyl mercury using inductively coupled plasma mass spectrometry (ICP-MS). Concentration was quantified per ng of element / g sample. The sample from China (Sample ID: 143-27) was the highest with 6.01 ng of element / g sample. This rice was not white or brown, it was 'other' coloured. There were many samples from Thailand, seven of the top ten, which had the highest mercury amount. There were two samples from the United States in the top ten, with 3.71 ng of element/ g sample (Sample ID:143-4) and 2.84 ng of element/ g sample (Sample ID: 143-25). These samples were part of the control. There were no samples from India in the top ten. With regards to colours, eight out of the top ten samples were white rice, one brown and one 'other'. The lowest concentration of methyl mercury was 0.18 ng of element / g sample (Sample ID: 143-29). This sample was from China and 'other' coloured.

## Discussion

It is well established that marine fish found at the top of the food chain, are high in methylmercury and contribute a risk factor in those who consume fish on a regular basis especially in pregnant women and mothers who breastfeed their neonates and infants [19-21]. When fish is combined with a diet largely composed of rice, risk for toxic methylmercury levels is greatly increased, a phenomenon known as bioamplification [22, 23]. Our study seeks to consider the specific communities in Virginia for whom fish and rice are staples in the diet and are, thus at a greater risk for bioamplification. According to the United States Census Bureau as of July 1, 2019, the Hispanic community makes up 9.6% of Virginia's total population [24]. Much of the Hispanic population resides in the coastal region, with only 2%-4% living in Southwest Virginia [25]. We report that most of our rice samples examined contained heavy metals (Table 1) and if eaten with other foods, especially marine fish high in methylmercury, may result in methyl-mercury toxicity over time [22, 23, 26, 27]. This is exacerbated because of the long half-life ($t_{1/2,}$ +/- 72 days) of methyl-mercury in the human body [27-29]. The exception being lactating females where methyl-mercury may move from the mother's blood directly into her breastmilk , making breast-feeding neonates and infants a high risk group and extremely vulnerable to methyl-mercury toxicity [30-32].

The data (Table 1) shows that the rice grown in the United States (control) did not significantly differ in concentration of mercury when compared to rice grown in other countries in Asia. We contacted the manufacturers and distributors of our control samples to comment on the specific origin of rice. The representatives we spoke to offered no comment. Major sources of Hg include burning of fossil fuels and long-range atmospheric transport [33]. It is possible that the United States has other attributing factors that cause similar mercury contents in rice paddies that differ from rice in the countries from which our samples were grown. One possible hypothesis we could surmise is from the finding that the water supply in the United States could be a potential source for mercury contamination concerning rice grown in United States soil [34, 35].

This hypothesis stems from the data collected. The top ten rice samples included two from the United States, which were supposed to be a control. No rice grown in India was in the top ten. Of the top ten countries, seven samples were from Thailand, two from the United States, and the highest sample from China. This could have been due to the specific region the rice was cultivated in China. This area could have had a higher fossil fuel emission due to industrial plants in the same area [33]. Of the top ten samples with the highest mercury content, eight were white, one was brown and one was an 'other' colour. Colour, relating to the outer coating of the rice could be a source of further investigation. Does rice colour correlate with higher or lower amounts of mercury across certain regions? If so, what could be the cause of the higher or lower readings?

The amount of MeHg in rice samples shown in (Table 1) demonstrates the need for further research on mechanisms of mitigation of MeHg in rice growing and preparation. There is a lack of qualitative data on tolerable daily mercury levels recommendations supplied by the FDA, thus it is difficult to inform the at risk populations on provisional tolerable weekly intake, PWTI [36]. More research is needed on Hg content in commercially available rice, such that the FDA can monitor MeHg content and advise vulnerable populations accordingly - as is done with Hg content in fish. As well as, improved consumer information regarding not only mercury, but also other heavy metal warning labeling of rice and rice products. Vulnerable populations of note are expecting mothers, neonates, and infants. These risk groups are more vulnerable to smaller amounts of exposure due to body weight and varying metabolic pathways [32, 37-39].

MeHg is also readily able to pass through the placenta and to breast milk, making fetuses and breastfeeding children particularly susceptible [30]. In addition to the concerns of fetal exposure and breast milk, commercially available baby food often contains rice. The developing status of the central nervous system (CNS) in these populations, increases the likelihood that damage to CNS caused by MeHg is more permanent and more severe [40, 41]. These concerns call for future studies on MeHg concentrations and other heavy metals, specifically in breast milk and rice-containing baby food products. In the future, packaging should advertise potential warnings for expecting mothers, lactating mothers, and children, so that consumers are aware that the rice food product contains heavy metals, that consumption and exposure should be limited, and that there are associated side effects that can be seen from increased mercury consumption.

The paper highlights the importance of improved integration of warning labels for high risk populations due to increasing evidence of high amounts of mercury in rice and rice products. It was originally thought that fish and rice from areas of high pollution would have increased mercury when compared to areas that have decreased pollution, but this study proves that rice in all areas, regardless of amount of pollution or type of pollution, have high levels of mercury. Thus, as rice becomes more of a staple in food items consumed, it is imperative that action needs to be taken to reduce exposure and harm and that more research needs to be conducted to conclude the sources of high mercury levels in specific regions.

## Conclusion

Solutions for addressing exposure to this ubiquitous metal and its subsequent diverse health implications include further research, public education, and increased regulations for mercury levels in rice. Research assessing which sources of rice have high mercury concentrations so causes can be more closely examined are needed. Public education to mothers, nullipara women, and all humans about the significance of mercury exposure in foods and or breastmilk will potentially mitigate the amount of exposure. Limiting levels of mercury in rice to ameliorate transfer and exposure to this heavy metal should be analysed.

## Conflicts of Interest

None.

## Funding

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