

Cadmium Concentration in Brown and Polished Rice from Selected Farms in Barangay Real, Calamba City and its Potential Non-cancer Health Risk in Adult Population

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ABSTRACT

Objectives. This study was conducted to determine the cadmium (Cd) concentration in brown and polished rice collected from the 9 farms in Barangay Real, Calamba City. This study also assessed the non-cancer health risk to adults (≥ 20 years old) of long-term consumption of rice with Cd using the non-cancer hazard quotient (NHQ).

Methods. Rice grains with hull were collected in November–December 2013. Both rice types were analyzed for Cd using a graphite furnace atomic absorption spectrophotometer (GFAAS). The NHQ was calculated by dividing the estimated daily intake of Cd via rice consumption by the oral reference dose (RfD) for Cd.

Results. Mean Cd concentrations in brown and polished rice collected from the 9 farms in Barangay Real ranged from 0.0062 to 0.0725 mg/kg and 0.0047 to 0.0778 mg/kg, respectively. The NHQ values of Cd in both rice types were less than 1.0 for adults (≥ 20 years old).

Conclusion. Cd concentrations in brown and polished rice from the 9 farms did not exceed the 0.4 mg/kg maximum allowable Cd concentration in rice set by FAO/WHO. Since the NHQ did not exceed 1.0, long-term exposure to Cd through consumption of brown and polished rice from these farms is unlikely to cause non-cancer health effects in adults (≥ 20 years old). It is unlikely for adults to develop kidney diseases such as tubular proteinuria, decreased glomerular filtration rates, and itai-itai disease.

Key Words: Cadmium, brown rice, polished rice, non-cancer hazard quotient

Introduction

Cadmium (Cd) is a toxic and persistent metal in the environment. It has no function in any known biological organism.¹ It is therefore not essential for the growth and development of plants, animals, and humans. Industrial emission, mining and refining of metals, and application of Cd-rich phosphatic fertilizers, farmyard manure, sewage sludges and municipal composts deposit considerable amounts of Cd on agricultural soil.² Cd is used as protective plating on steel, stabilizers for polyvinylchloride, pigments in plastics and glass, electrode material in nickel-Cd batteries, and component of various alloys.³ Cd accumulates in the soil with an estimated half-life varying between 15 and 1,100 years.⁴ Food crops that absorb and accumulate Cd in their edible portions pose a health risk to humans.

The kidney is the critical target organ of Cd and is the first organ to display signs of toxicity.⁵ The accumulation of Cd in the proximal tubules of the kidney leads to tubular dysfunction.⁶ Tubular dysfunction is manifested as tubular proteinuria, usually detected as increased urinary excretion of low molecular weight proteins. Among these proteins, β_2 -microglobulin, *N*-acetyl- β -D-glucosaminidase (NAG), and α_1 -microglobulin (protein HC) are the common urinary markers of tubular proteinuria. Continued exposure to Cd may cause tubular dysfunction to progress to glomerular damage with decreased glomerular filtration rates (GFRs).⁷ The most severe form of chronic Cd intoxication is itai-itai disease, which is characterized by severely impaired tubular and glomerular function and generalized osteomalacia and osteoporosis.^{8,9} These are some of the non-cancer health risks of oral exposure to Cd.

Rice is a staple food in Asian countries such as Japan and China. Unfortunately, it is also a significant source of Cd. In Toyama Prefecture, Japan, the elevated level of Cd in rice was a causative factor in the occurrence of itai-itai disease in the 1960s.¹ Elevated levels of Cd were also detected in some samples of brown and polished rice from Guangdong and Taizhou, China. In Guangdong, Yang et al. revealed in their study in 2006 that 0.03–0.46 mg/kg Cd was detected in brown rice from rice plants growing near

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Lechang lead/zinc mine.¹⁰ In Taizhou, Fu et al. reported in 2008 that polished rice collected from contaminated rice paddies near e-waste recycling areas contained 0.012–0.66 mg/kg Cd. Both studies revealed that Cd concentrations in some brown and polished rice samples exceeded the 0.2 mg/kg safety limit for Cd in rice in China.¹¹ However, the maximum allowable concentration of Cd in rice set by FAO/WHO is higher at 0.4 mg/kg.¹²

There is limited information on the Cd content of rice locally grown in the Philippines. About 18.72 hectares of lowland irrigated rice fields can be found in Barangay Real, an urban barangay in Calamba City.¹³ This city has 7,662 establishments and 12 industrial parks, with plastic, electronic parts, semiconductors, and automotive parts as their major industrial products.¹⁴ These products may contain Cd because the element is used as pigment for plastics and in metal plating.³ The industries involved in the production and use of Cd can release considerable amounts of this metal into agricultural soils and receiving waters such as irrigation water, creeks, and rivers. Rice plants absorb and accumulate Cd in the grains. The presence of elevated levels of Cd in grains is an indicator of Cd pollution in the environment.

This study aimed to determine the Cd concentration in brown and polished rice from the 9 farms in Barangay Real, Calamba City. The risk of non-cancer health effects to adults (≥ 20 years old) from long-term consumption of rice with Cd using the non-cancer hazard quotient (NHQ) was also assessed.

Materials and Methods

Study Setting

There are 12 farms in Barangay Real, Calamba City with a total land area of 18.72 ha. Only 9 farms, with a total land area of 11.92 ha, were covered in this study. The remaining 3 farms were not sampled because the rice plants were not ready for harvest until the last week of March 2014 and stored rice grains were not available during the sampling period (November–December 2013).

Sampling

Rice plants grown in farms 1, 4, 5, 6, 7, 8, and 9 were harvested from the last week of November to the first week of December 2013. Rice plants were randomly collected starting from the four corners and then towards the center of each farm. Rice grains were then detached from the panicles and mixed together as one composite sample. At least 1 kg of composite rice grains with hull was collected from each farm. For farms 2 and 3, grains that were stored after harvest in the third week of October 2013 were collected from storage bins in the last week of November 2013. The farmers stated the varieties of rice they planted in their farms.

Dehulling or Milling of Rice Grains

Nine labelled bags of air-dried rice grains with hull were brought to the Analytical Services Laboratory of the International Rice Research Institute (IRRI) for dehulling and milling. The rice grains with hull turned into brown rice after passing through a Satake husker. The brown rice was further milled using a Grainman mill, which produces polished rice after the bran layers are removed.

Digestion of Sample and Analysis of Cd

Weighed (0.5 ± 0.05 g) test portions of ground rice grain were placed in 10 mL of concentrated nitric acid (HNO_3) contained in an open tube (2.5×20 cm digestion tubes) and pre-digested overnight at ambient temperature ($22\text{--}26^\circ\text{C}$). After pre-digestion, the samples were transferred to a temperature-controlled block digester for 6 hours at 125°C and diluted to the 25 mL calibration mark with 1% nitric acid. Analysis of the Cd content of the digest was done in duplicate using GFAAS (Perkin Elmer HGA 900 Graphite Furnace, with AS 800 Autosampler and AAnalyst 400 atomic absorption spectrometer equipped with Cd electrodeless discharge lamp). For graphite furnace operation, gaseous argon was used. Absorption of the solution was measured at 228.8 nm. Limit of detection of Cd was at 0.0017 mg/kg.

About 24 paired samples of brown and polished rice were analyzed for Cd. These samples were divided among the 9 farms depending on the size of the farm (Table 1).

Table 1. Number of paired brown and polished rice samples allotted for each farm for Cd analysis.

Farm	Size (ha)	No. of Paired Rice Samples
1	3.42	4
2	1.25	3
3	0.75	2
4	0.6	2
5	1.9	3
6	1.0	3
7	0.5	2
8	2.0	3
9	0.5	2
TOTAL	11.92	24

Quality Control

The instrument settings were optimized and checked if the required sensitivity was achieved through the results of sensitivity check standard. Instrument calibration using the working standards was performed. The overall performance in each step of the analysis was also monitored by the use of suitable reference materials (RMs). Internal and external RMs traceable to National Institute of Standards and Technology (NIST) or National Institute for Environmental Studies (NIES) standards were incorporated for every batch of samples analyzed.

Non-cancer Risk Characterization of Cd through Rice Consumption

Estimated Daily Intake (EDI)

The estimated daily intake (EDI) of Cd depends on the concentration of Cd in brown and polished rice and the associated amount of rice consumption.¹⁵ The EDI was determined using the following equation:

$$EDI = \frac{C \times Con \times EF \times ED}{Bw \times AT}$$

- C = mean Cd concentration in rice (mg/kg)
 Con = average daily consumption of rice by Filipinos
 = brown rice: 230.14 g/person¹⁶
 = polished rice: 326.25 g/person¹⁷
 EF = exposure frequency (365 days/year)
 ED = exposure duration (30 years)
 Bw = average adult body weight (\geq 20 years old for both gender)
 = 54.77 kg/person¹⁸
 AT = averaging time = ED \times 365 day/year = 10,950 days

The exposure frequency is set at 365 days/year since Filipinos consume rice daily. For non-cancer health effects, 30 years is used as the default exposure duration that is the 90th percentile for time spent at one residence.¹⁵

The average body weight (54.77 kg) was computed as an average of adult mean body weights for both males and females, aged 20-39, 40-59, 60 years and above at 56.44 kg, 57.28 kg, and 50.6 kg, respectively.¹⁸ Average daily consumption of polished rice by Filipinos is 326.25 g/person, which is calculated from the 119.08 kg average annual per capita consumption of rice.¹⁷ Mendoza, a crop scientist at the University of the Philippines Los Baños, has said that with brown rice Filipinos will only consume an average of 84 kg per capita per year or 230.14 g daily consumption per person.¹⁶

Non-cancer Hazard Quotient (NHQ)

$$NHQ = \frac{EDI}{RfD}$$

EDI = Estimated Daily Intake

RfD = Reference Dose for Cd = 0.001 mg/kg/day¹⁹

The possibility of non-cancer health effects from long-term consumption of brown and polished rice with Cd to adults (\geq 20 years old) was evaluated using the NHQ. This compares an exposure level (EDI) over a specified time period with a reference dose (RfD) derived for a similar exposure period. If NHQ is less than or equal to 1.0, it is unlikely for even sensitive populations to experience non-

cancer health effects. If it exceeds 1.0, there may be concern for potential non-cancer health effects.²⁰

NHQ assumes that there is a level of exposure (i.e., RfD) below which it is unlikely for even sensitive populations to experience adverse health effects.²⁰ Specifically, the RfD for Cd is based on the highest level of Cd in the human renal cortex (i.e., the critical level) not associated with significant proteinuria (i.e., the critical effect).¹⁹ Tubular proteinuria is the earliest manifestation of Cd-induced renal damage, particularly to the proximal tubules where Cd mainly accumulates.⁵

Results

Cd Concentration in Rice in the Nine Farms

In all the 9 farms in Barangay Real, the mean Cd concentration in brown rice was 0.0302 mg/kg, which ranged from 0.0062 to 0.0725 mg/kg. In polished rice, the mean Cd concentration in all the 9 farms was 0.0295 mg/kg, ranging from 0.0047 to 0.0778 mg/kg (Table 2).

The mean Cd concentrations in both brown (0.0725 mg/kg) and polished rice (0.0778 mg/kg) collected from farm 1 were the highest among the 9 farms. This was followed by farm 7 with 0.0395 mg/kg Cd in brown rice and 0.0385 mg/kg Cd in polished rice. The lowest mean Cd concentrations in both brown (0.0062 mg/kg) and polished rice (0.0047 mg/kg) was collected in farm 2.

Table 2. Mean Cd concentration (mg/kg) in brown and polished rice collected from the 9 farms in Barangay Real, Calamba City.

Farm	No. of samples	Variety	Mean Cd Concentration (mg/kg)	
			Brown Rice	Polished Rice
1	4	NSIC Rc 238 with 2% red rice	0.0725	0.0778
2	3	NSIC Rc 238	0.0062	0.0047
3	2	NSIC Rc 148	0.0195	0.0195
4	2	NSIC Rc 238 with <1% red rice	0.0165	0.0135
5	3	NSIC Rc 148	0.0190	0.0167
6	3	NSIC Rc 238	0.0240	0.0207
7	2	NSIC Rc 238 with 10% red rice	0.0395	0.0385
8	3	NSIC Rc 128 with 5% red rice	0.0237	0.0217
9	2	NSIC Rc 238 with <1% red rice	0.0320	0.0315
TOTAL (all farms)	24	-	0.0302	0.0295

NHQ Values for Adults (\geq 20 years old) in Rice in the Nine Farms

In all the 9 farms, the calculated NHQ value for adults for brown rice was 0.1269 while that for polished rice was 0.1757. The NHQ values in both rice types in the 9 farms did not exceed 1.0 (Table 3).

Table 3. Summary of the NHQ values for adults (≥ 20 years old) in the 9 farms in Barangay Real, Calamba City.

Farm	NHQ	
	Brown Rice	Polished Rice
1	0.3046	0.4634
2	0.0261	0.0280
3	0.0819	0.1162
4	0.0693	0.0804
5	0.0798	0.0995
6	0.1008	0.1233
7	0.1660	0.2293
8	0.0994	0.1293
9	0.1345	0.1876
TOTAL (all farms)	0.1269	0.1757

Discussion

Cd Concentration in Rice in the Nine Farms

In the 9 farms in Barangay Real, Calamba City, the mean Cd concentration reached up to 0.0725 mg/kg in brown rice while 0.0778 mg/kg in polished rice (Table 2). These levels did not exceed the maximum allowable Cd concentration in rice set by FAO/WHO, which is 0.4 mg/kg.¹²

In another study conducted in Naboc area, Mindanao, Philippines, the Cd content of rice reached as high as 1.025 mg/kg. This exceeded the 0.4 mg/kg Cd limit in rice. Naboc area is near a gold mine with paddy soil containing less than 1 mg/kg Cd. Specifically, the Cd content of rice from this area ranged from 0.057 to 1.025 mg/kg, with a mean of 0.2907 mg/kg.²¹

On the other hand, Solidum et al. studied the Cd content of the 10 types/varieties of rice (cooked), sold in a market in Manila. The source of the rice, whether the rice was imported or locally grown, was unknown. The study revealed that Cd concentrations in the 10 types/varieties of cooked rice did not exceed the maximum allowable Cd concentration in rice. About 0.0127-0.0143 mg/kg Cd was detected from cooked whole grain, sinandomeng, violet *malagkit*, passion, brown rice, jasmine, *malagkit*, dinurado, red rice, and National Food Authority (NFA) rice.²²

Non-cancer Risk Characterization of Cd in Rice

Cd accumulates mainly in the proximal tubules of the kidneys with a biological half-life of about 10–30 years. It is very poorly excreted through urine and feces, with only about 0.001% of the body burden excreted per day.²³ The non-cancer health effects of Cd through oral intake include tubular proteinuria, decreased glomerular filtration rates, and itai-itai disease (kidney failure and bone disease).⁷⁻⁹

The possibility of non-cancer health effects from long-term consumption of brown and polished rice with Cd to adults (≥ 20 years old) was evaluated using the NHQ. In all the 9 farms, the NHQ values of Cd in both brown and polished rice were less than 1.0 for adults (Table 3). This means that it is unlikely for adults (≥ 20 years old) to experience non-cancer

health effects as a result of long-term consumption of brown or polished rice with low Cd content from Barangay Real.

However, it should be noted that this study only considered the intake of Cd via rice consumption. There are also other possible food sources of Cd such as vegetables, shellfish and crustaceans as well as drinking water.²⁴ Inhalation and dermal absorption are other routes of Cd exposure.²⁵ Thus, there are other sources of Cd that can contribute to the total Cd burden of the human body.

Conclusion and Recommendations

Brown rice from all the 9 farms in Barangay Real included in the study had a mean Cd concentration of 0.0302 mg/kg, ranging from 0.0062 to 0.0725 mg/kg while polished rice had a mean Cd concentration of 0.0295 mg/kg, ranging from 0.0047 to 0.0778 mg/kg. Cd concentrations in both brown and polished rice did not exceed the 0.4 mg/kg maximum allowable Cd concentration in rice set by FAO/WHO.¹²

The NHQ values for adults (≥ 20 years old) were less than 1.0 in both brown and polished rice with low Cd contents. Thus, Cd concentrations in brown and polished rice from the 9 farms in Barangay Real, Calamba City are unlikely to cause non-cancer health effects such as tubular proteinuria, decreased glomerular filtration rates, and itai-itai disease in adults as a result of long-term consumption.

Based on the results, the following recommendations can be drawn to better assess the Cd concentration in the surrounding environment and rice, and the non-cancer health risk:

1. Irrigation water and soil samples from the farms should be analyzed for Cd. This is to better explain the source of Cd stored in the rice grains.
2. Another study should cover both dry and wet season to observe the effect of seasons on the Cd concentrations in rice, soil, and water.
3. For a site-specific risk characterization of exposure to Cd in rice, the following exposure data of the adult residents of Barangay Real, Calamba City should be collected: average daily consumption of rice; frequency of rice consumption in a year (number of days in a year); and the mean body weight of the adult residents. These data should be used in the calculation of the non-cancer hazard quotient.
4. This study is limited to only one source of Cd exposure, which is rice. Household surveys can be done to identify other possible sources or route of exposure to Cd by the residents such as other food sources (vegetables, shellfish, crustaceans, drinking water), cigarette smoke, and occupational exposure.

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