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Original Article

Cadmium, arsenic and lead accumulation in rice grains produced in Senegal river valley

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ABSTRACT — Exposure to Cadmium (Cd), Arsenic (As), and Lead (Pb) in short or long term can cause health problems in humans. Rice is particularly susceptible to heavy metals contamination. Rice is the major staple food of different developing countries like Senegal leading to high exposure of the population to heavy metals if the rice is contaminated. In Senegal, two types of rice are consumed: local rice mainly produced in the Senegal river valley and imported rice from Asian countries. Thus, the objective of this study was to determine heavy metals accumulation in rice grains produced in Senegal or imported. Samples of five rice varieties produced in three different areas of the Senegal river valley and samples of imported rice from Japan, Thailand and Pakistan were analyzed for As, Cd and Pb contamination. The results showed that all samples were conform in term of contamination by As, Cd and Pb. Changes in heavy metals contamination were noticed between some rice varieties and according to localities. They were not a significant difference in the risk of exposure to heavy metals between the consumption of local produced rice and imported rice. However, the high rice intake of Senegalese could affect the safety of dietary intake of these metals by rice.

Key words: Cadmium, Arsenic, Lead, Rice, Imported rice, Local rice

INTRODUCTION

Heavy metals exposure from food is a real health concern for populations (Ilmiawati *et al*., 2015; Horiguchi *et al*., 2010). The contamination comes mainly through human activities or from contaminated soil, river or groundwater. Thus, good agricultural practices like water management are needed to reduce soil contamination and then heavy metals accumulation in the plants (Sun *et al*., 2014; Li *et al*., 2017). These toxic metals accumulate in crops like rice and are significant risks for human and animal health. The toxicity of these metals is due mainly to the fact they accumulate in living organisms, a process known as bioaccumulation (Balabanova *et al*., 2015). The principal toxic effect of Cd is its effects on kidney and lung damages, and skeletal changes (Horiguchi *et al*., 2013). Exposure to Pb has negative consequences in human development and health (Khanna, 2015). Arsenic (As) is a human carcinogen and exposure to Arsenic plays an important etiological role in the carcinogenesis (Mohajer *et al*., 2013). About 30 percent of the world's energy and 20% of the protein source is provided through consumption of the rice (*Oryza sativa* L.) (WHO, 1989). Rice, the staple food in Senegal, has been considered to be an important source of heavy metals (Naseri *et al*., 2015). The demand for rice in Senegal increased by

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7% average with a growing urban population at a rate of 3.2% a year (UNSD, 2011). The average per capita rice consumption is 92 kg. Although a lot of data showed that rice is the major source of food heavy metals exposure in different countries (Tsukahara *et al*., 2003; Mondal and Polya, 2008), nevertheless, information is lacking regarding heavy metals rice contamination in Africa. Therefore, the present study was carried out to evaluate Cd, Pb and As accumulation in rice grains produced in Senegal River valley and imported to Senegal.

MATERIALS AND METHODS

Sampling

Rice samples were from the valley of river Senegal in the North of Senegal. The rice was grown by irrigation system. Six (6) varieties of rice Sahel209, Sahel177, Sahel134, Sahel108, Sahel328 and TC10 were sampled in three villages depending on the availability of the variety during visits: Thilene (Sahel 209, Sahel 177, Sahel 134, Sahel 108, TC 10), Pont Gendarme (Sahel 108, Sahel 328, Sahel 177, Sahel 134, TC 10) and Ngomene (Sahel134, Sahel108). Imported rice from Thailand, Japan, and India were collected from local shops in the region of Saint-Louis, Senegal. 3 samples of each variety of rice were collected in suitable containers and away from moisture and transferred to Jichi Medical University, Japan.

The samples were ashed by TOPwave (Analytik Jena AG, Germny) after the rice grains were fine ground with Millcer food processor. The moisture content was measured with a Moisture meter using with part of the sample. One gram of rice flour was measured with a microbalance and mixed with 7 mL of nitric acid (61%) (Kanto Chemical Industires Ltd, Tokyo, Japan) in Teflon tubes. The mixture was sonificated for 15 min. The samples were ashed according to the manufacturer's instruction. After running the Topwave for 50 min, the vessels were chilled in ice-water for 20 min. After then, the chilled vessels were opened with the vessel opening tool and the ashed materials transferred to 50 mL measuring flask. Remaining materials in the Teflon tubes were co-washed into the PP tubes with Milli-Q water. The samples were filled up to 50 mL with Milli-Q water and well mixed. All the content was transferred to PP tubes and stored at 4°C.

Cd, Pb and As contents in the specimen were measured at Hiyoshi Corporation (Ohmihachiman, Shiga, Japan) using ICP-MS (7700x, Agilent, Tokyo, Japan). Typical operating parameters for the analysis were as follows: incident rf power, 1600W; carrier Ar gas flow rate, 0.56 L/min; make-up Ar gas flow rate, 0.33 L/min, nebulizer pump flow rate, 0.1 rpm. The ICP-MS was usually operated with He as the collision cell gas (4.3 mL/min) to reduce some polyatomic molecular interferences.

The Japan Calibration Service System (JCSS) single element standard solutions (1000 mg/L) were used for the source of calibration standard solutions (Kanto Chemical Industries Ltd. (KCIL), Tokyo, Japan). Internal standard mixture (Ga, In, Tl) were purchased from Kanto Chemical Industires Ltd, Tokyo, Japan. NMIJ CRM 7503-a white rice flour was used as a reference sample.

Statistical analyses

Data were expressed as geometric means. Fisher's protected least significant difference (PLSD) for multiples comparisons, after one-way ANOVA was used to analyze data (SPSS version 14.0J, SPSS, Chicago, IL, USA). Differences were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

Only 28-33% of samples contained trace amounts of Pb (Pb concentration > 0). All rice samples contained trace amounts of Cd and As.

The concentrations of Cd in rice varieties from different localities in the valley of Senegal River are represented in Table 1. Sahel 209 and Sahel 328 were harvested only from Thilene and Pont Gendarme, respectively. Sahel 177 and TC10 were sampled in Thilene and Pont Gendarme. Sahel 134 and Sahel 108 were collected from the three villages.

Table 1. Concentration of Cd (mg/kg) in rice varieties from different localities in the valley of Senegal River.

	Sahel 134	Sahel 108	TC10	Sahel 177	Sahel 328	Sahel 209
Thilene	0.015[a] (0.007-0.021)	0.009[a] (0.008-0.009)	0.020[a] (0.020-0.028)	0.009[a] (0.007-0.009)	NA	0.005 (0.003-0.006)
Pont gendarme	0.012[a] (0.010-0.013)	0.011[b] (0.010-0.011)	0.026[a] (0.024-0.027)	0.053[b] (0.052-0.053)	0.056 (0.051-0.060)	NA
Ngomene	0.032[b] (0.030-0.033)	0.004[c] (0.003-0.004)	NA	NA	NA	NA

Values are geometric means, values in the same column not sharing a letter differ significantly, $P < 0.05$. NA: rice variety no available in the sites during sampling visit.

Table 2. Concentration of As (mg/kg) in rice varieties from different localities in the valley of Senegal River.

	Sahel 134	Sahel 108	TC10	Sahel 177	Sahel 328	Sahel 209
Thilene	0.116[a] (0.115-0.117)	0.105[a] (0.102-0.108)	0.109[a] (0.104-0.112)	0.088[a] (0.083-0.090)	NA	0.105 (0.103-0.104)
Pont gendarme	0.163[b] (0.159-0.160)	0.116[b] (0.113-0.117)	0.152[b] (0.140-0.162)	0.061[b] (0.059-0.062)	0.102 (0.098-0.0101)	NA
Ngomene	0.108[c] (0.106-0.109)	0.130[c] (0.122-0.133)	NA	NA	NA	NA

Values are geometric means values in the same column not sharing a letter differ significantly, $P < 0.05$. NA: rice variety no available in the sites during sampling visit.

Cd concentration in the rice variety Sahel 108 was significantly different between localities. These concentrations were lower in Ngomene compared to the two other localities. No difference was noticed between Cd concentration in Sahel 134 samples collected in Thilene and Pont Gendarme. For this variety, Cd concentration was significantly higher in Ngomene. For the varieties Sahel 177 and TC10, Cd concentration was significantly higher in Pont gendarme than in Thilene. There was no difference in rice Cd concentration between samples from Senegal, Thailand, India, China and Japan (Table 3).

As levels in rice varieties are reported in Table 2. As concentrations in Sahel 108 were significantly different between localities with the highest values in samples from Ngomene. Sahel 134 samples from Pont Gendarme had the highest As concentration for this variety. As concentration was significantly lower in Pont Gendarme for the Sahel 177 compared to samples from Thilene. For the variety TC 10, As concentration was higher in samples from Pont Gendarme than the ones collected in Thilenee.

There was no difference in rice As contamination between rice samples from the different countries (Table 4).

Traces of Pb were present in about 28-30% of all rice samples analyzed. Likewise, if Pb was present, its concentration was below the recommended maximum content. The recommended maximum Pb content in rice is 0.3 mg/ kg according to WHO / FAO (FAO, 2004). Average amounts of Cd and Pb obtained in this study were lower compared to the allowed amount by Food and Drug Administration for department of health which announces that Cd is 0.1 ppm and Pb 0.1 ppm.

Rice samples from Pont Gendarme showed higher Cd concentration for the varieties Sahel 108, Sahel Sahel 177. The Cd concentration in imported rice and rice produced in Senegal was not different. The variety Sahel 328 cultivated in Pont Gendarme showed higher Cd concentration than other types of rice. These results showed that imported rice and local produced rice have same risk in term of Cd exposure.

Table 3. Concentration of Cd in rice samples from different countries.

Countries	Cadmium (mg/kg)
India	0.019[a] (0.018-0.020)
Thailand	0.010[a] (0.009-0.011)
Japan	0.004[a] (0.004-0.005)
China	0.038[a] (0.006-0.185)
Senegal	0.013[a] (0.003-0.058)

Values are geometric means, values in the same column not sharing a letter differ significantly, $P < 0.05$.

Table 4. Concentration of As in rice samples from different countries.

Countries	Arsenic (mg/kg)
India	0.092[a] (0.090-0.094)
Thailand	0.131[a] (0.130-0.134)
Japan	0.102[a] (0.100-0.104)
China	0.028[a] (0.002-0.107)
Senegal	0.111[a] (0.060-0.161)

Values are geometric means, values in the same column not sharing a letter differ significantly, $P < 0.05$.

The contamination of rice by As can be a health concern in countries where rice is the staple food. As content in rice and local produced rice was approximately the same in this study. As in rice, particularly the inorganic forms, is a matter of concern for human and animal health (EFSA, 2009; Sun *et al*., 2008) because it is considered as carcinogen and any exposure constitutes a risk. Long-term exposure to inorganic As is associated with an increased risk for various carcinomas (ATSDR, 2007). Therefore, there are no determined limits for either total or inorganic As in any food, including rice (Francesconi, 2007). However, China regulates the level of inorganic As in rice and the maximum contaminant level permitted is 0.15 mg/kg (Zhu *et al*., 2008). These inorganic As forms are higher in rice than the organic As (Mania *et al*., 2017).

The differences between heavy metals contaminations could come from environmental conditions and agricultural practices. Some data showed that the As concentration in crops varies according to the soil where the rice was cultivated and the type of rice (Torres-Escribano *et al*., 2008). Also, the anaerobic growing conditions of flooded rice paddies allow it to take up As, sequester it and accumulating it (Rai *et al*., 2011). As bioavailability under the flooded conditions is the main reason for an enhanced As accumulation by flooded rice. Thus, growing rice in aerobically conditions can decrease the As transfer from soil to grain (Xu *et al*., 2008). Two rice varieties were collected from each of the three villages. For these rice varieties, the results showed that if Cd concentration was high in a locality, the As concentration for the same variety was lower in this locality compared to other localities. The water management in each locality seemed to affect Cd and As concentration in rice grains. Although anaerobic conditions in paddy soil effectively reduces Cd concentration in rice, flooding of the paddy field increases As uptake by rice (Koyama, 1975). Thus, irrigation system and water management is recognized to determine the uptake of Cd and As by rice (Arao *et al*., 2009). In our study areas, flooded is produced by an irrigation system using water from the river Senegal. These conditions may explain the fact that they were more As (0.11 mg/kg) than Cd (0.02 mg/kg) in the rice harvested from the valley of river Senegal. Therefore, to control the rice contamination by heavy metals in these areas, water management has to be done because it can affect Cd and As bioavailability in the soil and consequently on their accumulation in plants and crops. Also, especial care is required for irrigation system to minimize exposure to heavy metals from rice consumption (Hu *et al*., 2015). Growing rice with less irrigation or under rained conditions lead to less As concentration (Rahaman and Sinha, 2013) and more Cd concentration in aerobic rice (Kawasaki *et al*., 2012). The Cd concentration in the imported and locally produced rice were below the recommended Cd content in rice of 0.2 mg/kg according to FAO (FAO, 2004). The Cd Concentrations in his study also were not higher than data reported by other authors (Zazooli *et al*., 2010; Watanabe *et al*., 1996; Zeng *et al*., 2008) especially in Asian countries.

In conclusion, this study showed that rice consumed in Senegal, local production and imported rice, contained trace amounts of Pb, As and Cd. However, the metals contents were below the recommended maximum content. Imported and locally produced rice are acceptable in terms of heavy metals contamination. However, production sites, rice varieties, irrigation water management are required to reduce heavy metals exposure for Senegalese populations who use rice as the main staple food. Periodic biomonitoring and potential health risk assessment should be done for high-risk populations, notably among children.

Conflict of interest---- The authors declare that there is no conflict of interest.

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