**Manuscript type:** Original Research Article

**Title:** Toxic Metals in Hassawi Brown Rice: Fate During Cooking and Associated Health Risks

**Running Title:** Toxic metals in Hassawi rice and health risks

Saad Dahlawi1, Muhammad Atif Randhawa1,\*, Abdulaziz Abdulrahman Al Mulla1, Mohammed Tawfiq Aljassim1, Turki Kh Faraj2, 3, Hussain Ali Hussain Tawhari1, Taha Mohammed Almutawa1, Majed Fahed Khalaf Alshammari1, Asm Abdulrahman Mohammed Alismail1

1. Department of Environmental Health, College of Public Health, Imam Abdul Rahman Bin Faisal University, Dammam, Saudi Arabia.
2. Prince Sultan Institute for Environmental, Water and Desert Research, King Saud University, Riyadh, Saudi Arabia.
3. Department of Soil Science, College of Food and Agricultural sciences, King Saud University, Riyadh, Saudi Arabia.

**\*** Corresponding author: maashraf@iau.edu.sa

**Novelty Statement**

* Now a days, nutritionists are encouraging the use of brown rice in comparison to polished or white rice due to its high nutritional properties.
* Traditionally cultivated rice in Saudi Arabia since centuries is known as Hassawi rice and it is relished by local people in its brown form.
* Although brown rice is a wonderful food, but it can be a source of toxic metals accumulation during growth due to environmental pollution in the region.
* To the best of our knowledge, Hassawi rice has not been evaluated for possible contamination of heavy metals and the fate of toxic metals during different rice cooking conditions.
* Therefore, in this manuscript, we tried to determine toxic metals in Hasswai rice followed by daily intake assessments of metals through brown rice consumption and associated health risks.

**Abstract**

Rice is a dietary staple since centuries in providing vital nutrients to human body and brown rice is well known for its nutrient dense food profile. However, owing to multiple causes (anthropogenic and non-anthropogenic), it can also be a potential source of toxic heavy metals in diet. Brown Hassawi rice samples were collected from Al-Ahsa region and anlaysed for occurrence of toxic metals {arsenic (As), lead (Pb), cadmium (Cd), chromium (Cr), antimony (Sb) and nickle (Ni)} by inductively coupled plasma optical emission spectroscopy (ICP-OES). All the tested metals varied significantly in analyzed brown rice samples, while As and Pb in all three samples were exceeding their respective maximum allowable limits (MALs) defined by regulatory and health authorities (FAO/WHO) followed by Cd which was nearly approaching the MAL in 2 samples out of 3. Brown rice samples were cooked in rice:water systems viz: low rice:water ratio (1:2.5, 1:3.5) and high rice:water ratios (1:5 and 1:6) along with soaking as a pre-treatment. Soaking was unproductive in removing heavy metals from rice, whereas cooking dissipated all metals from rice except Cd which was statistically non-significant. High water cooking of rice was more effective in dissipation of metals from rice as compared to low water cooking conditions. Estimated daily intake (EDI) of heavy metals through rice consumption (162 gram/person/day) for As exceeded the provisional maximum tolerable daily intake (PMTDI) regardless of cooking conditions. Hazard risk index (HRI), also highlighted the fact that As can be a potential health hazard to brown rice consumers.

**Keywords:** Brown rice, heavy metals, environmental pollutants, daily intake, health risk

**Introduction**

Since centuries cereals like rice, wheat followed by corn, barley and sorghum are considered as dietary staple for mankind. Among these, rice (Oryza sativa L.) is the most important cereal crop and consumed by over half of the world’s population as a staple food to meet daily dietary requirements. The major rice producing countries are in the Asian region of the world such as China, Indo-Pak subcontinents, Indonesia, Korea, etc., and diverse type of rice varieties are cultivated in these countries. World rice production in year 2019 has been reported to be 782 million tonnes on 167.13 million Hectares cropping area (FAOSTAT, 2019). However, evidence shows that rice is also cultivated in some parts of the western Asian countries such as Iran, Iraq, Egypt and even in the Kingdom of Saudi Arabia with a total production of 1.226 million tonnes against 0.179 million Hactare area in year 2019 (FAOSTAT, 2019). In Saudi Arabia, Al-Ahsa region is well known for rice cultivation, and indigenous rice or landrace adapted in this part of world is known as Al-Hassawi or Hassawi rice. Hassawi rice is resistant to salinity and drought, thereby enabling it to tolerate adverse environmental conditions and has also ability to survive in harsh agro-environmental conditions. However, low resistance to lodging, photoperiod sensitivity and water scarcity in the region are hindering the widespread cultivation of Hassawi rice although it is being cultivated since centuries in this part of the world (Al-Mssallem and Al-Mssallem, 1997).

Hassawi rice is eaten in its whole form with intact outer bran layers. Now a day’s food scientists/nutritionists are encouraging the consumption of brown rice over the processed white type rice due to its nutritional significance. Brown rice contains more proteins and sufficient quantity of micronutrients making it a perfect food for human beings. Hassawi rice is traditionally well known by masses for its properties to provide strength for those who are unwell (Al-Turki and Basahi, 2015). Besides, high nutritional properties, the brown rice can be a potential source of toxic metals. Toxic metals in rice is becoming a global problem day by day due to increased urbanization, intensive agricultural operations, sewage sludge applications to soil, mining activities, etc.

Rice is more likely to accumulate heavy metals as compared to other cereal grains, particularly cadmium and arsenic (Meharg et al., 2013). Under rice growing conditions, arsenic is readily converted into arsenite, thereby enhancing upto 10 times more accumulation of arsenic in rice grain as compared to other staple crops (Williams et al., 2007). Lead is the second most element with respect to natural occurrence after arsenic and both are highly toxic to human beings particularly when exceeding their maximum allowable limits (MALs) in foods. These can also cause stress in rice plants during growing, leading to augmentation in their tissues and ultimately conferring negative consequences in consumers (Chibuike and Obiora, 2014; Nnaji and Igwe, 2014; Ashraf et al., 2015). Brown rice can accumulate more level of toxic metals like arsenic, cadmium, lead and long-term exposure to heavy metals through brown rice consumption poses both non-carcinogenic and carcinogenic health risks to the consumers (Zeng et al., 2015; Fan et al., 2017). Humans are usually exposed to heavy metals through dietary intake particularly when metals concentration in foods increases their MALs, and also through ingestion or breathing. The intake of heavy metals leads to the on-set of multiple diseases as heavy metals are known mutagenic, teratogenic and carcinogenic. The risks by taking heavy metals in relation to human exposure are cirrhosis, dementia, irreversible brain damage (encephalopathy), hemorrhage, renal dysfunction, bone diseases, sperm motility, cardiovascular diseases, gastrointestinal cancers, etc., (Jin et al., 2002; Kachenko and Singh, 2006).

Very limited studies are available in literature on the fate to toxic heavy metals during food cooking operations. Perello et al. (2008) studied the effect of food processing unit operations on concentrations of arsenic, mercury, cadmium and lead in food products and found that cooking operations exerted a limited impact on the removal of heavy metals from foods under investigation and concluded that the hypothetical reduction in heavy metals depends upon cooking conditions (time, temperature, and medium of cooking). Some studies on the impact of rice cooking conditions on arsenic levels have been carried out by few researchers (Sengupta et al., 2006; Signes et al., 2008), however the impact of cooking operations on other toxic metals is still lacking in the literature particularly for brown rice. Furthermore, to the best of our knowledge no studies are available regarding occurrence of heavy metals in brown Hassawi rice grown in Al-Ahsa region of Saudi Arabia. Therefore, the objectives of this study were to determine toxic metals in brown Hassawi rice, the fate of metals during different rice cooking conditions and to assess/document for the first time the health risks from brown Hassawi rice consumption.

**Materials and Methods**

**Hassawi Rice Procurement**

Traditionally grown rice in Al-Ahsa region of Kingdom of Saudi Arabia (Hassawi rice) was procured during 2019 from 2 rice farms and one sample was procured from fruit and vegetable market of Al-Hofuf. 4 kg of each sample were procured and brought to Environmental Safety Laboratory, College of Public Health at Imam Abdul Rahman Bin Faisal University, Dammam.

**Toxic Metals Determination**

Exactly 0.2 kg rice from each sample was used for heavy metals determination and remaining samples was stored under shade in laboratory for later studies. The oven dried brown rice sample was grinded with the help of laboratory grinder equipped with stainless steel blade. Then 2 g of grounded rice powder was digested using 12 mL of a mixture (2:l v/v) of concentrated HCl and HNO3 acids (Sigma-Aldrich, St. Louis, MO, USA). The mixture was heated for 45 minutes in a microwave accelerated reaction system (MARS 6) at a temperature and pressure not more than 180 °C and 200 psi, respectively (Noel et al., 2003). After completion of digestion, the solution was passed through Whatman No. 42 ash less filter paper and 25 mL volume was made with deionised water. The samples were stored in pre-cleaned, acid washed polyethylene bottles at refrigerated temperature till analysis. Toxic metals (As, Cd, Pb, Cr, Sb and Ni) were analysed on iCAP 6300 Duo Inductively Coupled Plasma – Optical Emission Spectrophotometer (ICP-OES, Thermo Fischer Scientific). The instrument standardization and process parameters used are detailed in our previous study (Salama et al., 2019). The method was found optimum in terms of LOD as well as recovery. All the experiments were performed in 3 replicates and results for heavy metals in rice are expressed as mean and standard deviation followed by statistical data analysis by Statistics software for determination of significance.

Based upon findings of heavy metals analysis of rice samples, one rice sample was selected for determining the fate of metals during cooking and assessment of health risks to consumers due to rice consumption as detailed under.

**Fate of Toxic Metals During Rice Cooking**

The selected rice sample was used for estimation of the fate of heavy metals in brown Hassawi rice during cooking under different rice:water systems in triplicate as detailed below. Brown Hassawi rice was cooked in laboratory conditions under different rice water ratios during cooking and compared with raw as control (To), T1 soaking of rice in ample water for 20 minutes followed by cooking treatments viz:, T2 (1:2.5), T3 (1:3.5), T4 (1:5) and T5 (1:6) rice:water ratios, respectively. 100 g of rice was used in each cooking experiment and rice was soaked for 20 minutes in ample quantity of double distilled water before cooking as per routine practise followed in home cooking of brown rice. After that rice was cooked in stainless less steel pan (14 cm diameter) for 40 minutes. In low water system (T3 and T4), all water was absorbed by rice during cooking, whereas extra water in high water cooking system (T5 and T6) was collected and also analysed for possible presence of heavy metals. Both the cooked rice and drained water were collected and preserved in high density polyethylene bags and kept under refrigerated conditions till further processing. The rice samples were dried in oven till constant weight and then analysed for metals as stated above, whereas water was analysed as such. All the experiments were performed in 3 replicates and results are expressed as mean and standard deviation followed by statistical data analysis by Statistics software for determination of significance.

**Dietary Intake Assessment**

Rice is a dietary staple in KSA and daily intake (mg/person/day) of metals through consumption of rice was calculated by multiplying concentration of specific metal with the per capita daily consumption of rice and divided by average body weight of human adult (Khan et al., 2008). Later on, daily intake of toxic heavy metals through consumption of rice were calculated and compared with recommended values of WHO/FAO. According to FAOSTAT (2015), per capita rice consumption in KSA was 162 g/person/day, and average body weight of a Saudi Citizen is 71 Kg (Mohamed et al., 2017). Therefore, daily intake values were thus calculated for the cooked rice in low-water and high-water cooking system. The data was compared with provisional tolerable daily intake (PTDI) or provisional maximum tolerable daily intake (PMTDI).

**Health Risk Index**

Health risk index by consumption of rice was calculated by following the guidelines of Khan et al. (2008). Daily intake assessment values of heavy metals were used for determining health risk index of heavy metals in rice. Health risk index was calculated by dividing daily intake of metals in rice by the oral reference dose, as shown below:

HRI = DIM / RfD

The HRI > 1 for any metal means that the consumer/population is at health risk.

**Results**

**Screening of toxic elements from rice**

In the first phase of study, raw Hassawi rice was analysed for possible contamination with toxic metals. The statistical results presented in Table 1 clearly describes that occurrence of heavy metals varied in rice samples with respect to variation in field. All the samples were exceeding in arsenic and lead contents with reference to their respective maximum allowable limits (MALs) prescribed by FAO/WHO. Cd and Cr contents are within their MALs prescribed by FAO/WHO in rice/food stuff intended for human consumption. While FAO/WHO have not defined/established MAL for Sb and Ni in rice/food stuffs. The highest arsenic (0.476 mg/kg), Cd (0.374 mg/kg), Cr (0.386 mg/kg) and Ni (1.386 mg/kg) contents were found in rice sample procured from farm 2. Interestingly, highest cadmium was recorded in farm 1 rice sample and regarding nickel contents the sample procured from Al-Hofuf fruit and vegetable market was at the top.

**Effect of Cooking on Heavy Metals in Rice**

Keeping in view the metals occurrence in analysed rice samples, farm 2 rice sample was selected for further studies and estimation of health risk assessments as detailed in methodology section of the manuscript. Mean squares of the effect of cooking conditions on heavy metals of rice has been shown in Table 2. It is clear from statistical results that cooking conditions (rice:water ratios system) significantly affected all the tested metals (As, Pb, Cr, Sb and Ni) in brown Hassawi rice except Cd which was non-significant. The soaking of rice for 20 minutes in ample deionised water did not affected the toxic metal contents and its impact was almost zero on reduction of heavy metals from rice. While cooking under low rice:water system (T2 and T3) and cooking under high rice:water system (T4 and T5) behaved differently. In general, rice cooking treatments T4 and T5 resulted in more removal of heavy metals from rice as compared to T2 and T3 (Figure 1). Arsenic contents in cooked rice (T4 & T5) was much more affected among all the metals in this investigation. In T5 maximum reduction has been observed in As contents (55%) in cooked rice as compared to raw rice, followed by Pb and Sb contents which decreased by 32.49% & 29.57%, respectively. Cr contents was least affected among all the metals and maximum reduction upto 8.81% has been observed in T5 treatment i.e. cooked with rice:water ratio as 1:6 (Fig. 2).

**Estimated Daily Intakes of Metals from Hassawi Brown Rice**

Table 3 represent the estimated daily intakes (EDIs) of some toxic heavy metals from rice consumption. According to FAOSTAT data in 2015, per capita rice consumption in KSA was 162g/person/day. The estimated daily intakes of heavy metals have been determined for each detected metal in rice. Permitted maximum tolerable daily intake (PMTDI) values for different toxic metals studied in current investigation are also shown in Table 3. The results showed that all heavy metals except arsenic are within safe limit of consumption with respect to their respective, PMTDI. The EDI of arsenic is estimated as 74.35 and 73.06 (µg/day) in T2 and T3, respectively. However, excess water cooking of rice in high water system and drainage of excess water from rice resulted in significant reduction of arsenic intake through rice. The arsenic contents decreased to 49.73 and 34.18 (µg/day) in T4 and T5, respectively. Although, As contents decreased up to 55% in T5, however Arsenic EDI was still higher than PMTDI (25.2 µg/day). T5 proved to be more effective in reducing metal contents among all the treatments and in case of Cd and Pb, 52.81 and 147.74 (µg/day) EDI has been recorded through daily rice consumption in T5, respectively, which is near about 75 and 60% of their respective PMTDI values. While the calculated EDI values for Cr and Sb are far below their PMTDI.

**Health Risk Index of Metals from Rice Intake**

For determining the real health risks, health risk index (HRI) was calculated based upon the EDIs and oral reference dose of each toxic metal. The results illustrated that no health risk is involved in consumption of brown Hassawi rice with respect to cadmium, lead, chromium, antimony and nickel as their calculated values for HRI are less than 1.00 (cut off value). However, arsenic in brown rice may pose potential health hazards to the brown rice consumers (Table 4). Although, arsenic contents were significantly reduced during rice cooking in different treatments, but its health risk value was still more than 1. In case of arsenic, T5 cooking treatment was most effective and it decreased health risk value from 3.62 (raw) to 1.61, meaning that it reduces the health risk. It is interesting to note that although Pb contents were exceeding its MAL in all tested rice samples, but calculated HRI values revealed that brown rice is safe for human consumption. In cooked brown rice, HRI value for Pb decreased from 0.856 (T0) to 0.578 (T5) and it is well below the cut off value (1.00).

**Discussion**

The results clearly elucidated that both arsenic and lead contamination in brown rice can be a threat for human beings. Although cadmium contamination in rice is within safe limits, however it is at marginal level and nearly approaching the upper safer limit. Arsenic contamination in rice is a natural process, particularly if arsenic contaminated water is being used for irrigation or soil itself is having high load of arsenic due to the nature of rock formation, etc. It has already proven that under rice growing conditions arsenic is readily converted into arsenite, thereby enhancing upto 10 times more accumulation of arsenic in rice grain as compared to other staple crops (Williams et al., 2007). Furthermore, anthropogenic activities also lead to deposition of arsenic in soil such as smelting and mining processes and use of arsenic as active ingredient in insect pest control programs in agriculture for crop protection, etc (IARC, 84). Fu et al. (2008)**,** reported heavy metal contamination in brown rice from three districts of Hunan province in China and found that arsenic level ranged from 0.106 to 1.15 mg/kg with mean value of 0.336 mg/kg. In China, MAL of arsenic in brown rice is 10 mg/kg (GB 2762-2012 China Food Safety National Standard for Maximum Levels of Contaminants in Foods). When comparing with Chinese MAL value set for arsenic contents in rice, the Hassawi rice looks to be safe for human consumption, although it exceeded the FAO/WHO, maximum allowable limit. The results of present findings are comparable with Fan et al. (2017), they reported the levels of arsenic, lead and cadmium ranging from 0.21-0.98, 0.04-1.07, 0.006-0.24 mg/kg, respectively in brown rice near mining area in central China. In a recent investigation of some imported rice varieties sold in the local markets of Almadinah Almunawarah, KSA, the results revealed that country of origin affected the concentration of toxic metals (arsenic, cadmium, lead and chromium) in rice grains and researchers urged the regulatory authorities to monitor the heavy metals contents of rice imported in the Kingdom of Saudi Arabia (Shraim, 2017).

The deposition of lead can be due to the auto mobile exhaust and its aerial contamination. The sources of heavy metals in rice can be attributed to the municipal waste disposal, application of cadmium rich fertilizers and irrigation with unsafe water. In this respect, Pescod (1992) pointed out that the threshold values of heavy metals in irrigation water leading to crop damage are 2000 µg L-1 for Zn, 200 µg L-1 for Cu, 5000 µg L-1 for Fe, 200 µg L-1 for Mn, 200 µg L-1 for Ni, 5000 µg L-1 for Pb and 10 µg L-1 for Cd. The long-term use of treated sewage/industrial effluent has resulted in deposition of more toxic metals like arsenic (67%), lead (55%), nickel (84%), chromium (75%), cobalt (78%) and zinc (130%) in sewage irrigated soil samples in comparison to adjacent soil samples irrigated by well water and this practice is going on in Al-Ahsa Governate (Al-Omron et al., 2012). The excessive buildup of heavy metals in soils and ultimately in rice can lead to initiation of various clinical problems in animals and human leading to poor health, renal dysfunction, bone diseases, cirrhosis, encephalopathy, cardiovascular diseases, dementia, hemorrhage, systemic cancers and sperm motility. Although, the cadmium contents are within acceptable limit in rice, but the limits are very near to MAL. Higher exposure to cadmium can result in diseases of multiple disorders including skeleton problems as it is related with cancerous risk as compared to lead which is non- cancer risk factor.

The reduction in arsenic contents during rice cooking in different rice:water conditions can be attributed to the dissolution of arsenic in excess water used during cooking conditions which ultimately resulted in arsenic removal from rice. Whereas in T2, no excess water was available and in T3 the excess water was evaporated to dryness condition of rice cooking. This fact has been explained by some researchers that excess water cooking and then drainage of excess water from rice results in arsenic reduction (Signes et al., 2008). Similar type of trend has been observed in this study and arsenic contents affected much more in this investigation as compared to other heavy metals studied. Very few studies have been conducted on the fate of heavy metals during rice cooking conditions. Gray et al. (2016) noticed that metals are more easily removed from parboiled rice than brown rice. Liu et al. (2018) reported that cadmium decreased only upto 3% whereas lead content was decreased by 20% during rice cooking. Similar results have been observed in present investigation and As contents dissipated more from rice followed by Pb and Sb (Fig. 2). Although Cd contents decreased more in high rice:water system (T4 & T5), however it was non-significantly decreased as compared to As and Pb (Fig. 1). Cadmium is absorbed by roots and deposited in the endosperm which ultimately makes its removal difficult during rice cooking.

EDI of Cd and Pb due to rice consumption were found to be within safe limit of PMTDI. Against a PMTDI of 70 for cadmium, T5 was considered safer as it decreased EDI from 60.59 to 49.41 (µg/person/day). Similarly, for lead once again T5 was found to be more effective and it resulted in decrease of EDI value from 218.86 to 147.74 (µg/person/day) against the PMTDI value of 214 (µg/person/day). This means that rice cooking in high water system is desirable to remove the toxic elements from rice. This is also a common practise in household rice cooking, that rice is boiled in excess water and extra water is removed and rice cooking is completed to desired degree. In a recent study published in 2019, Saudi citizens in Narjan city consumed more quantity of rice and average rice intake per adult during FFQ (food frequency questionnaire) survey has been reported to 243g/day (Mohammed et al., 2017). By keeping in view 243g/day rice intake, the EDI values of not only arsenic but also cadmium and lead surpassed their respective, PMTDI values. However, out of 243g/day rice intake, how much volume/share is occupied by brown rice is still unclear. Brown rice is gaining popularity now a days with increased awareness of health promoting properties among household consumers. Hassawi rice is only cultivated in Al-Ahsaa region in Kingdom of Saudi Arabia since centuries and local residents are used to eat brown Hasswai rice in their traditional way and usually take about 2 servings during a week. Furthermore, Hassawi rice is also relished by indigenous people during traditional occasions and gatherings in a variety of way. However, now trend is decreasing, and people are shifting towards more economical and viable options of rice varieties available in the region. Keeping in view all these considerations, it can be summarised that daily intake of brown rice is low and there is no health risks involved in eating of brown Hassawi rice, rather it can provide beneficial nutrients for health and can play important role in maintaining the balanced diet.

The high-water cooking of rice and drainage of excess water from rice during cooking gave better results in reducing the health risks as visible in HRI data. However, the health risk increases when metals intake come from multiple sources in the form of combined exposure to metals. In our previous finding on dates, we calculated the health risks to Saudi citizens from daily consumption of dates (Salama et al., 2019). When daily date consumption is coupled with daily brown rice intake, then combined health risk will be more than the specified HRI value for Cd and Pb. It means that Saudi citizens may be at risk due to toxic metals in their diet. However, no detailed studies are available in literature to find out the risks from dietary intake of heavy metals to Saudi citizens.

**Conclusion**

Current study revealed that toxic metals are present in brown Hassawi rice. Arsenic and lead contents in all samples exceeded the maximum allowable limits (MALs) defined by FAO/WHO. Although cadmium contents did not surpass the MAL, however in few samples cadmium contents were very near to the MAL specified for cadmium. Soaking was ineffective in removing the heavy metals from rice. Cooking of rice in excess water and drainage of the extra water from rice during cooking exerted significant effect on all metals, except Cd. Cooking of rice in low rice:water ratio system was found less effective in comparison to the cooking in high rice:water ratio system. Estimated daily intake (EDI) data showed that Hassawi rice is safe for consumption in relation to provisional maximum tolerable daily intake values (PMTDI) with the exception of the arsenic. Health risk index (HRI) in case of arsenic was also exceeding the cut off value (1.00), whereas for all the remaining elements HRI was less than one.

**Author Contributions**

The authors confirm contribution to the paper as follows: study conception and design: Dahlawi S., Randhawa M.A., Faraj T.K., following lab experiments: Almulla A.A., Randhawa M.A., Tawhari H.A.H., Almutawa T.M., Alshammari M.F.K., Alismail A.A.M. Data analysis and interpretation: Almulla A.A., Dahlawi S., Aljassim M.T., Faraj T.K., draft manuscript preparation: Tawhari H.A.H., Almutawa T.M., Alshammari M.F.K., Alismail A.A.M., critical revision of the article and final approval of the version to be published: Dahlawi S., Randhawa M.A., Aljassim M.T., Faraj T.K.

**References**

Al-Mssallem IS, MQ Al-Mssallem (1997). Study of glutelin (storage protein of rice) in Al-Hassawi rice grains. *Arab Gulf J Sci Res* 15:633–646

Al-Omron AM, SE El-Maghraby, MEA Nadeem, AM El-Eter, H Al-Mohani (2012). Long term effect of irrigation with the treated sewage effluent on some soil properties Al-Hassa Governorate, Saudi Arabia. *J Saudi Soc Agric Sci* 11:15-18

Al-Turki TA, MA Basahi (2015). Assessment of ISSR based molecular genetic diversity of Hassawi rice in Saudi *Arab Sau J Biol Sci* 22:591–599

Ashraf U, AS Kanu, Z Mo, S Hussain, SA Anjum, I Khan et al (2015). Lead toxicity in rice: effects, mechanisms, and mitigation strategies – a mini review. *Environ Sci Pollut Res* 22:18318–18332

Chibuike GU, SC Obiora (2014). Heavy metal polluted soils: effect on plants and bioremediation methods. *Appl Environ Soil Sci* 2014: 12 pages DOI: 10.1155/2014/752708

China Food Safety National Standard for Maximum Levels of Contaminants in Foods (GB 2762-2012). https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Maximum Levels of Contaminants in Foods \_Beijing\_China - Peoples Republic of\_12-11-2014.pdf. Accessed on 30-08-20.

Fan Y, T Zhu, M Li, J He, R Huang (2017). Heavy metal contamination in soil and brown rice and human health risk assessment near three mining areas in central China. *J Healthcare Eng* Article ID 4124302, 9 pages DOI: 10.1155/2017/4124302

FAOSTAT data available at: <http://www.fao.org/faostat/en/#data/QC>, accessed on 10-09-20.

Fu J, Q Zhou, J Liu, W Liu, T Wang, Q Zhang, G Jiang (2008). High levels of heavy metals in rice (Oryza sativa L.) from a typical E-waste recycling area in southeast China and its potential risk to human health. *Chemosphere* 71: 1269-1275

Gray PJ, SD Conklin, TI Todorov, SK Kasko (2016). Cooking rice in excess water reduces both arsenic and enriched vitamins in the cooked grain. *Food Add Cont* 33:78–85

Hald T, W Aspinall, B Devleesschauwer, R Cooke; T Corrigan, AH Havelaar, HJ Gibb, PR Torgerson, MD Kirk, FJ Angulo et al (2016). World Health Organization estimates of the relative contributions of food to the burden of disease due to selected foodborne hazards: a structured expert elicitation. *PLoS ONE* 11:e0145839

IARC 84 (2004). Some drinking-water disinfectants and contaminants including arsenic, Geneva

Jin T, M Norberg, W Frech, X Dumont, A Bernard, T Ye (2002). Cadmium bio-monitoring and renal dysfunction among a population environmentally exposed to cadmium from smelting in China (ChinaCad). *Biometals* 15: 397–410

Kachenko AG, A Singh (2006). Heavy metals contamination in vegetables grown in urban and metal smelter contaminated sites in Australia. *Wat Air Soil Poll* 169:101–123

Khan S, Q Cao, YM Zheng, YZ Huang, YG Zhu (2008). Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environ Pollut* 152:686–692

Liu K, J Zheng, F Chen (2018). Effects of washing, soaking and domestic cooking on cadmium, arsenic and lead bioaccessibilities in rice. *J Sci Food Agric* 98:3829–3835

MD Kirk, SM Pires, RE Black, M Caipo, JA Crump, B Devleesschauwer, D Döpfer, A Fazil, CL Fischer-Walker, T Hald et al (2010). World Health Organization estimates of the global and regional disease burden of four foodborne chemical toxins, 2010: a data synthesis. *PLoS Med* 12:e1001940

Meharg AA, G Norton, C Deacon, P Williams, EE Adomak, A Price, Y Zhu, G Li, F Zhao, S McGrath, A Villada, A Sommella, PMCS De-Silva, H Brammer, T Dasgupta, MR Islam (2013). Variation in rice cadmium related to human exposure. *Environ Sci Technol* 47:5613–5618

Mohamed H, PI Haris, EI Brima (2017). Estimated dietary intakes of toxic elements from four staple foods in Najran city, Saudi Arabia. *Int J Environ Res Pub Health* 14:1575 DOI: 10.3390/ ijerph14121575

Nnaji JC, OU Igwe (2014). Fractionation of heavy metals in soil samples from rice fields in New Bussa, Nigeria. *Int J Chem Tech Res* 6:5544-5553

Noël L, JC Leblanc, T Guérin (2003). Determination of several elements in duplicate meals from catering establishments using closed vessel microwave digestion with inductively coupled plasma mass spectrometry detection: estimation of daily dietary intake. *Food Add Cont* 20:44-56

Perello G, R Marti-Cid, JM Llobet, JL Domingo (2008). Effects of various cooking processes on the concentrations of arsenic, cadmium, mercury, and lead in foods. *J Agric Food Chem* 56:11262–11269

Pescod M (1992). Waste water treatment and use in agriculture. Bull. FAO # 47 (125) (Rome).

Raab A, C Baskaran, J Feldmann, A Meharg (2009). Cooking rice in a high water to rice ratio reduces inorganic arsenic content. *J Environ Monitor* 11:41–44

Salama KF, MA Randhawa, AA Al-Mulla, OA Labib (2019). Heavy metals in some date palm fruit cultivars in Saudi Arabia and their health risk assessment. *Int J Food Prop* 22:1684-1692

Sengupta MK, MA Hossain, A Mukherjee, S Ahamed, B Das, B Nayak, A Pal, D Chakraborti (2006). Arsenic burden of cooked rice: traditional and modern methods. *Food Chem Toxicol* 44:1823–1829

Shraim AM (2017). Rice is a potential dietary source of not only arsenic but also other toxic elements like lead and Chromium. *Arab J Chem* 10:S3434–S3443

Signes A, K Mitrab, F Burlo, AA Carbonell-Barrachina (2008). Effect of cooking method and rice type on arsenic concentration in cooked rice and the estimation of arsenic dietary intake in a rural village in West Bengal, India. *Food Add Cont* 25:1345–1352

US EPA-IRIS. United States, Environmental Protection Agency, Integrated Risk Information System. 2006. <http://www.epa.gov/iris/subst>. Accessed on 30-08-20.

WHO Expert Committee on Biological Standardization; Meeting and World Health Organization. WHO Expert Committee on Biological Standardization: Sixtieth Report; World Health Organization: Geneva, Switzerland, 2013; Volume 977.

WHO Expert Committee on Biological Standardization; Meeting and World Health Organization. WHO Expert Committee on Biological Standardization: Sixty-Third Report; World Health Organization: Geneva, Switzerland, 2013; Volume 980.

WHO/FAO. Joint FAO/WHO Food Standards Programme Codex Committee on Contaminants in Foods. The Neth. 2011, 21–25 March, 2011.

Williams PN, A Villada, C Deacon, A Raab, J Figuerola, AJ Green, AA Meharg (2007). Greatly enhanced arsenic shoot assimilation in rice leads to elevated grain levels compared to wheat and barley. *Environ Sci Technol* 41: 6854–6859

Zeng F, W Wei, M Li, R Huang, F Yang, Y Duan (2015). Heavy metal contamination in rice-producing soils of Hunan province, China and potential health risks. *Int J Environ Res Pub Health* 12:15584–15593

**Table 1. Occurrence of some heavy metals (mg/kg) in Brown Hassawi raw rice**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Heavy Metals** | **Farm 1**  | **Farm 2** | **Al-Hofuf Market**  | **\*MAL** |
| **As** | 0.425 ± 0.019ab | 0.476 ± 0.025a | 0.395 ± 0.019b | 0.2 \*\* |
| **Cd** | 0.298 ± 0.027b | 0.374 ± 0.015a | 0.371 ± 0.031a | 0.4 \*\* |
| **Pb** | 1.358 ± 0.024a | 1.351 ± 0.017a | 0.975 ± 0.013b | 0.3 \*\* |
| **Cr** | 0.298 ± 0.011b | 0.386 ± 0.013a | 0.381 ± 0.015a | 1.0 \*\*\* |
| **Sb** | 0.094 ± 0.011c | 0.257 ± 0.023a | 0.204 ± 0.024b | - |
| **Ni** | 0.985 ± 0.019c | 1.386 ± 0.029a | 1.197 ± 0.049b | - |

\*MAL means maximum allowable limits

Similar letters in a row are non-significant among each other (P>0.05)

\*\* FAO/WHO Food Standards Programme Codex Committee on Contaminants in Foods. The Neth. 2011, 21–25(march), 2011

\*\*\*China Food Safety National Standard for Maximum Levels of Contaminants in Foods (GB 2762-2012).

- Limit is not available or not defined

**Table 2. Mean squares of cooking treatments on heavy metals in rice**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **As** | **Cd** | **Pb** | **Cr** | **Sb** | **Ni** |
| **Treatment** | 5 | 0.03707\*\* | 0.00103NS | 0.10737\*\* | 0.00058\* | 0.00340\*\*  | 0.00906\*\* |
| **Error** | 12 | 0.00016 | 0.00036 | 0.00024 | 0.00012 | 0.00011 | 0.00007 |

\*\*Highly Significant (P value < 0.01), \*Significant (P value < 0.05), NS Non-significant (P value > 0.05)

**Table 3. Estimated daily intake of heavy metals through rice consumption in relation to PMTDI**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **As** | **Cd** | **Pb** | **Cr** | **Sb** | **Ni** |
| **T0** | 77.112 | 60.588 | 218.862 | 62.532 | 41.634 | 224.532 |
| **T1** | 76.950 | 60.264 | 218.052 | 62.370 | 41.310 | 224.370 |
| **T2** | 74.358 | 60.588 | 211.248 | 59.616 | 39.042 | 213.192 |
| **T3** | 73.062 | 59.616 | 209.304 | 59.940 | 38.394 | 212.058 |
| **T4** | 49.734 | 58.158 | 165.078 | 57.834 | 30.294 | 209.304 |
| **T5** | 34.182 | 52.812 | 147.744 | 57.024 | 29.322 | 201.755 |
| **\*PMTDI** | 30 [a] | 70 [b] | 250 [c] | 7000 [d] | 360 [e] | - |

Estimated daily intake (µg/person/day/162g rice)

\*Provisional maximum tolerable daily intake (µg/person/day)

[a] MD Kirk, SM Pires, RE Black, M Caipo, JA Crump, B Devleesschauwer, D Döpfer, A Fazil, CL Fischer-Walker, T Hald et al (2010). World Health Organization estimates of the global and regional disease burden of four foodborne chemical toxins, 2010: a data synthesis. *PLoS Med* 12:e1001940

[b] Hald T, W Aspinall, B Devleesschauwer, R Cooke; T Corrigan, AH Havelaar, HJ Gibb, PR Torgerson, MD Kirk, FJ Angulo et al (2016). World Health Organization estimates of the relative contributions of food to the burden of disease due to selected foodborne hazards: a structured expert elicitation. *PLoS ONE* 11:e0145839

[c] WHO Expert Committee on Biological Standardization; Meeting and World Health Organization. WHO Expert Committee on Biological Standardization: Sixtieth Report; World Health Organization: Geneva, Switzerland, 2013; Volume 977.

[d] WHO Expert Committee on Biological Standardization; Meeting and World Health Organization. WHO Expert Committee on Biological Standardization: Sixty-Third Report; World Health Organization: Geneva, Switzerland, 2013; Volume 980.

[e] US EPA-IRIS. United States, Environmental Protection Agency, Integrated Risk Information System. 2006.

- Not available

**Table 4. \*Health Risk Index (HRI) of rice consumption due to heavy metals intake**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **As** | **Cd** | **Pb** | **Cr** | **Sb** | **Ni** |
| **T0** | 3.620 | 0.853 | 0.856 | 0.001 | 0.146 | 0.158 |
| **T1** | 3.613 | 0.849 | 0.853 | 0.001 | 0.145 | 0.158 |
| **T2** | 3.491 | 0.853 | 0.826 | 0.001 | 0.137 | 0.150 |
| **T3** | 3.43 | 0.840 | 0.819 | 0.001 | 0.135 | 0.149 |
| **T4** | 2.335 | 0.819 | 0.646 | 0.001 | 0.106 | 0.147 |
| **T5** | 1.605 | 0.744 | 0.578 | 0.001 | 0.103 | 0.142 |
| **Oral Ref. Dose\*\*** | 0.0003 | 0.001 | 0.0036 | 1.5 | 0.004 | 0.02 |

\*HRI = EDI (mg/kg/day) / Oral Ref. Dose (mg/kg/day)

\*\* US EPA-IRIS. United States, Environmental Protection Agency, Integrated Risk Information System. 2006.

