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The association between toxic metals (As, Pb and Cd) exposure and rice cooking methods: A systematic review and meta-analysis

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ABSTRACT

Heavy metal exposure through rice consumption (*Oryza sativa* L.) is a human health concern. This systematic review and meta-analysis investigated the association between toxic metals exposure and rice cooking methods. Based on the inclusion and exclusion criteria, fifteen studies were selected as eligible for the meta-analysis. Our results showed a significant decrease in the content of arsenic, lead, and cadmium following the cooking rice (WMD= −0.04 mg/kg, 95% CI: −0.05, −0.03, *P* = 0.000), (WMD = −0.01 mg/kg, 95% CI: −0.01, −0.01, *P* = 0.000), and (WMD = −0.01 mg/kg, 95% CI: −0.01, −0.00, *P* = 0.000), respectively. Furthermore, based on the subgroup analysis the overall rank order of cooking methods in the rice was rinsed > parboiling > Kateh > high-pressure, microwave, and steaming. The findings of this meta-analysis indicate the beneficial effects of cooking on reducing arsenic, lead, and cadmium exposure via rice consumption.

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Introduction

Rice (Oryza sativa L.) is a nutritious cereal grain, widely consumed by a large part of the world population. This cereal crop is a major source of carbohydrates and fibers as well as contains various vitamins, minerals, and proteins, which contribute up to 50% of the world's dietary energy needs of people, especially in developing countries (Safaei et al. 2019; Mohajer et al. 2020). Besides the nutritional benefits, the presence of pollutants such as toxic metals, pesticides and mycotoxins in rice has been reported in several studies (Abtahi et al. 2017; Halder et al. 2020; Ameri et al. 2021). Toxic metals are one of the considerable contaminants that are mostly transported to grains during
Q3 agricultural or industrial sector activities (Ma et al. 2021; Liu et al. 2022). These metals are non-essential and affect different body organs chronically and acutely. In this context, metal poisoning can lead to a variety of diseases such as cardiovascular disorders, reproductive toxicity, liver and kidney disease, neurological problems, immune system disorders, DNA damage and even death in severe cases (Naseri et al. 2015; Munir et al. 2021). Previous publications have reported that rice grains contain various amounts of heavy metal contaminants. These studies represent that it is a common dietary source of As, Cd and Pb exposure in some countries, including China, Japan,

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Iran, and India (Zavala and Duxbury 2008; Sharafi et al. 2019). Arsenic (As), lead (Pb), and cadmium (Cd) are the most common toxic elements that have serious effects on human health (Siripongvutikorn et al. 2016; Gao et al. 2022). As is a carcinogen compound and its organic form is less toxic than inorganic. Exposure to inorganic As is a recognized cause of many types of cancer including skin, lungs, and bladder (Sanchez et al. 2016). Its acute and chronic toxicity is mainly associated with dysfunctions of some vital enzymes (Kumarathilaka et al. 2019). Cd is another toxic metal that identified to be one of the main public health concerns. Hence, the International Agency for Research on Cancer (IARC) categorized Cd as class 1 carcinogen. Additionally, intake of Cd is thought to be the cause of kidneys injury, bone lesions and renal disorders (IARC 2012). In humans, the major exposure to Cd occurs through contaminated food products (Zhuang et al. 2014). Pb is well known as a food pollutant that harmfully affects children's mental growth as well as it has been linked to other diseases of the cardiovascular and nervous system, kidneys and liver (Järup 2003). Pb as a toxic metal contaminates plants via air, water, or soil by absorption.

Toxic metals have been distributed worldwide and their toxicity is often dose-dependent and occurs due to accumulation in the body organs (Gupta et al. 2019). Due to the high consumption of rice by individuals and then increasing exposure levels, safety issues have created an urgent need to survey the effects of food processing techniques such as cooking on reducing, preventing, or eliminating contaminants in foodstuff. In this regard, A number of studies have suggested that rice cooking has an important role in reducing the metal content of cooked grains. These studies mostly focus on cooking methods and how much pollutants decreased by them (Pelfrêne et al. 2015). Despite raw rice, the health examination of cooked rice reflects the true exposure for humans. It is indicated that the cooking procedure has a lot to reduce the concentration of heavy metals (Adibi et al. 2014). The efficiency of this process is reported in several studies. For instance, Khan et al. (2010) have reported 15% of As removal via ordinary cooking methods (Khan et al. 2010).

Given the availability of the data for the removal of toxic elements in rice samples by cooking, we conducted a meta-analysis to investigate the effects of different rice preparation and cooking practices including Kateh (ordinary cooking) and Rising (boiling in excess water) on the removal of toxic metals and introducing a simple and suitable method for removing these elements from rice in order to maintain the consumer's health. Meanwhile, the random effect model was used for the meta-analysis of the data. Heterogeneity was calculated by I^2 test (Anuradha et al. 2022). To the best of our knowledge, this is the first meta-analysis assessing how cooking can significantly affect human health, especially in the population of developing nations subsistent on a rice-based diet.

Materials and methods

Literature search strategy

A comprehensive literature search was performed to evaluate the association between toxic metals exposure and rice cooking methods. For this purpose, some international databases including Scopus, PubMed, and Web of Science were screened from inception up to January 2022 using a combination of the following terms and keywords: Rice; cooking; As; Pb; Cd; heavy metals, toxic metals; and trace elements. Besides, we further examined the reference list of all obtained papers to identify other potential articles.

Inclusion/Exclusion criteria

The titles and abstracts of the articles from the literature search were screened precisely to identify the qualified studies. Moreover, in cases of unclear abstracts and titles for inclusion, the full text was also reviewed. Studies were selected according to the following criteria: (1) the paper was published in the English language, (2) reported heavy metal concentration. On the other hand, review articles, chapter books, theses, original papers published in other languages, studies that did not use rice for experiments and reports with unclear measuring units were also excluded.

Data extraction

The eligibility of studies was performed by pairs of independent reviewers in order to reduce the risk of likely bias and improve data validity. Information, such as first author, year of publication, cooking method, and mean ± SD (or SEM) value of heavy metal concentrations, were extracted from obtained studies. We exploit the WebPlotDigitizer program to extract quantitative data from different types of plots or graphs.

Statistical analysis

The concentration of toxic metals in different cooking methods was analyzed using mean and SD. Therefore, In cases where SE was reported instead of SD, we have to use $SD = SE \times \sqrt{n}$ equation, where n= sample size, to calculate SD (Borenstein et al. 2011). Heterogeneity was determined by Chi-square (I^2) index and Cochrane Q test with $P < 0.05$. When I^2 is higher than 50% or even equal to 50%, indicating evidence of heterogeneity. A sensitivity analysis was also conducted to examine the stability of the results. Egger's regression test was used to determine publication bias and displayed via funnel plot (Egger et al. 1997). Furthermore, the leave-one-out method was also used to determine the impact of each study on inferences. To explore the source (s) of heterogeneity, pre-defined subgroup analyses were also carried out. The cooking method and type of cooking water were considered as pre-defined sources of heterogeneity. Meta-analysis of data was conducted using STATA 14.0 (Statistical Software, College Station, TX, USA). P-value in statistical analyses was considered to be less than 0.05.

Results

Inclusion/Exclusion criteria

The flowchart of the systematic search in Scopus, PubMed, and Web of Science databases is presented in the PRISMA diagram (Figure 1). In the primary search, a total of 743 articles were identified after removing duplicate studies. In title and abstract screening, we excluded 660 that did not meet our inclusion criteria. The full text of eighty-three articles was assessed for detailed evaluation. Of these, 68 articles were excluded according to the eligibility criteria, providing 15 research articles for inclusion in this meta-analysis.

Study characteristics

The main details of the included studies are shown in Table 1. Three studies were conducted in Iran (Naseri et al. 2018; Sharafi et al. 2019; Ghoochani et al. 2019), three in India (Halder et al. 2014; Mandal et al. 2019; Chowdhury et al. 2020), two in the United Kingdom (UK) (Mwale et al. 0000; Raab et al. 2009), two in China (Zhuang et al. 2016; Liu et al. 2018), one in Indonesia (Silalahi et al. Q4 2018), one in Bangladesh (Rahman et al. 2006), one in Belgium (Sun et al. 2012), one in Hungary (Mihucz et al. 2007) and one in Japan (Naito et al. 2015). These studies were published between 2006 and 2020. Eleven articles reported changes in As concentration after rice cooking. Two articles evaluated the effects of cooking on both Cd and Pb levels, and two articles commonly evaluated these heavy metals. The sample size of the selected studies ranged from 3 to 100. Six different cooking methods including Kateh, Rinse, parboiling, high-pressure, microwave, and steaming were used in included studies.

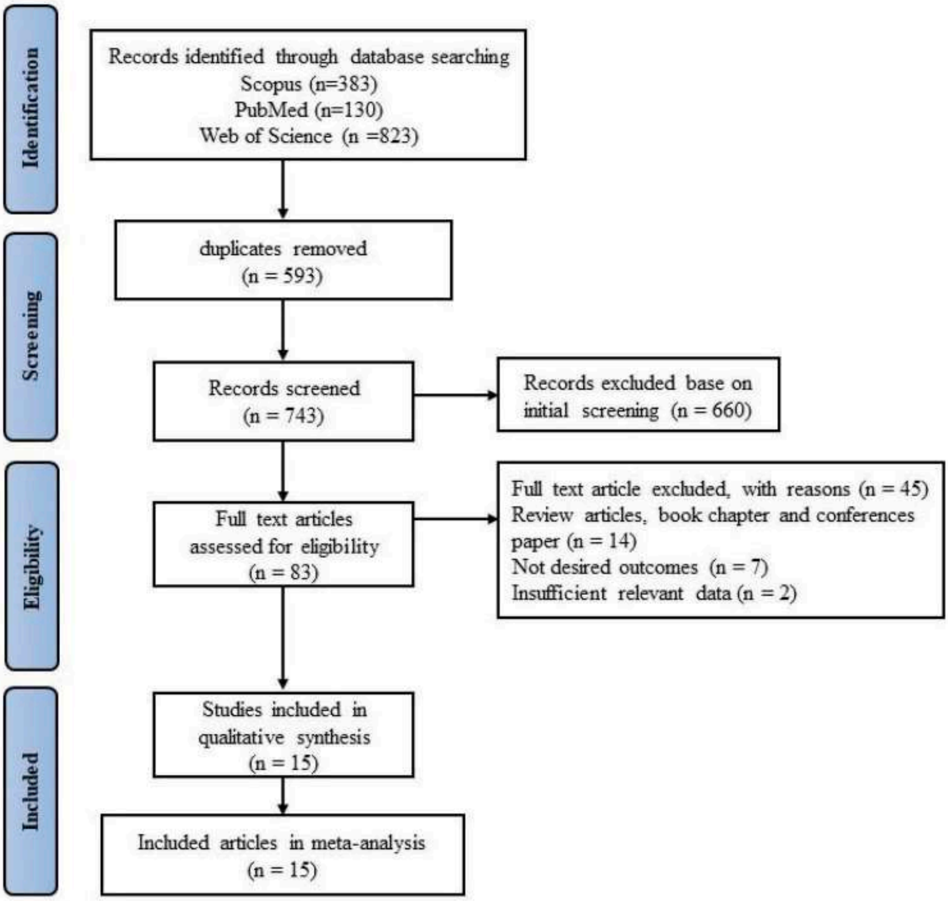

Figure 1. Flow chart of exclusion and inclusion studies based on PRISMA.

Meta-analysis results

Arsenic level change

Thirteen studies reported changes in As concentration as an outcome measure. Combined result by random effect model showed a reduction effect from cooking rice on As level as compared to raw rice (WMD= −0.04 mg/kg, 95% CI: −0.05, −0.03, $P = 0.000$) (Figure 2). However, statistically significant heterogeneity was observed between studies $I^2 = 97.8\%$, $P_{heterogeneity} < 0.000$.

Lead level change

Four studies with 294 samples reported Pb concentration as an outcome. A reduction in Pb level (WMD = −0.01 mg/kg, 95% CI: −0.01, −0.01, $P = 0.000$) was observed in studies that explored the effect of cooking on the heavy metal content of rice (Figure 3). However, considerable heterogeneity was observed among the included studies ($I^2 = 75.8\%$, $P_{heterogeneity} < 0.000$).

Cadmium level change

In order to determine the effects of cooking on Cd concentration in rice, 3 studies with 4 different preparation methods were included in the analysis. Pooled results using a random-effects model

Table 1. Characteristics of included studies.

Author/year	Country	Rice type	Sample size	Cooking water	Cooking method	Measured outcome(s)
Mwale et al. (0000)	UK		24	DI water	Kateh, Rinse, parboiling	As
Q5 Silalahi et al., 2018	Indonesia	white rice, red rice, brown rice, black rice	3	tap water	Kateh	As
Liu et al. (2018)	China	Brown rice X2, Brown rice T15	6	DI water	Kateh, high-pressure, microwave,	As, Pb, Cd
Q6 Raab et al., 2008	UK	basmati	20	DI water	Kateh, Rinse, steaming	As
Rahman et al. (2006)	Bangladesh	BRRI dhan28, BRRI hybrid dhan1	3	groundwater	Rinse, Kateh	As
Sun et al. (2012)	Belgium	white rice, polished rice	4	DI water	Kateh	As
Chowdhury et al. (2020)	India	Parboiled, sunned	6	tap water	Rinse	As
Mihucz et al. (2007)	Hungary	Zhenshan 97, Risabell, Ko}oro¨sta´j-333	3	DI water	Rinse	As
Naito et al. (2015)	Japan	Brown, White 95DP%, White 90DP%	3	DI water	Kateh	As
Zhuang et al. (2016)	China	Rice A, B, C	12, 10, 10	DI water	Kateh	As
Q7 Sharafi et al., 2019	Iran	Iranian, Pakistani, Indian	30	DI water	Kateh, Rinse	As, Pb, Cd
Ghoochani et al. (2019)	Iran		60	tap water	Rinse	As, Pb
Halder et al. (2014)	India		29	DI water	Rinse	As
Mandal et al. (2019)	India		100	DI water	Rinse	As
Q8 Naseri et al., 2014	Iran	Maryam, Tajmahal, Abdossaeid	3	DI water	Kateh, Rinse	Pb, Cd

identified that the decrease in Cd level was significant after cooking (WMD = –0.01 mg/kg, 95% CI: –0.01, –0.00, $P = 0.000$) with significant heterogeneity across interventions ($I^2 = 96.7\%$, $P_{heterogeneity} < 0.000$) (Figure 4).

Subgroup analyses

Two subgroups were defined to explore possible sources of heterogeneity. Subgroup analyses for As, Pb, and Cd concentration changes based on the cooking method showed that generally toxic metal levels (WMD: –0.08 mg/kg, 95% CI: –0.09, –0.06) reduced significantly when the rinsed cooking method was used compared with other methods such as high-pressure (WMD: –0.01 mg/kg, 95% CI: –0.01, –0.00). Moreover, another subgroup based on the type of cooking water used in the studies did not indicate any difference in the results of heavy metal concentration (WMD: –0.03 mg/kg, 95% CI: –0.03, –0.03).

The subgroup variables with their values are displayed in Table 2. The results illustrated cooking type is a reason to describe significant heterogeneity of trace elements in rice.

Publication bias and sensitivity analysis

The publication bias was checked through a funnel plot and Egger's regression test. The shape of funnel plot reveals an asymmetric distribution of studies around the pooled effect size of As, Pb, and Cd. The results of Egger's tests of measured outcomes in the included studies were as follows: (As: $p = 0.031$, Cd: $p = 0.004$, Pb: $p = 0.003$) (Figures S1–S3). Leave-one-out sensitivity analysis was also performed to evaluate the influence of every single study on the pooled effect size. The sensitivity

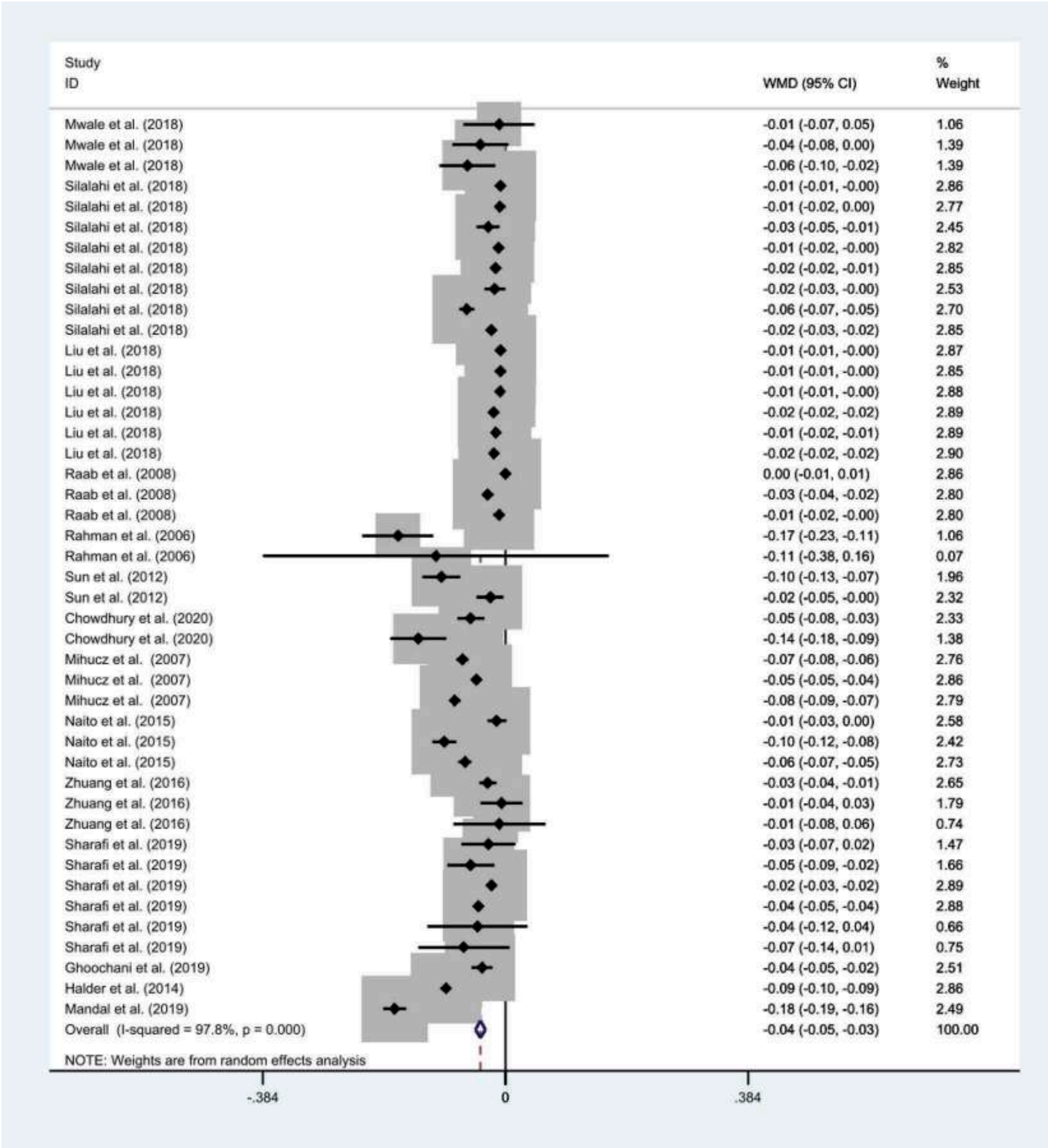

Figure 2. Forest plot presenting mean difference (WMD) and 95% CI for the effect of cooking rice on as levels.

analysis showed that the omission of every single study didn't have a considerable effect on the results (Figures S4–S6).

Discussion

Heavy metal poisoning is related to the toxic accumulation of certain metals, which causes a variety of disorders. Therefore, due to their toxicity and carcinogenic nature, most researchers all over the world have reported the concentration of these metals in food as the main source of human exposure. On the other hand, there have been several types of research on reducing heavy metal intake, especially in the most commonly consumed crops such as rice. Among the different approaches, cooking methods are one of the easiest and most effective ways to reach this goal.

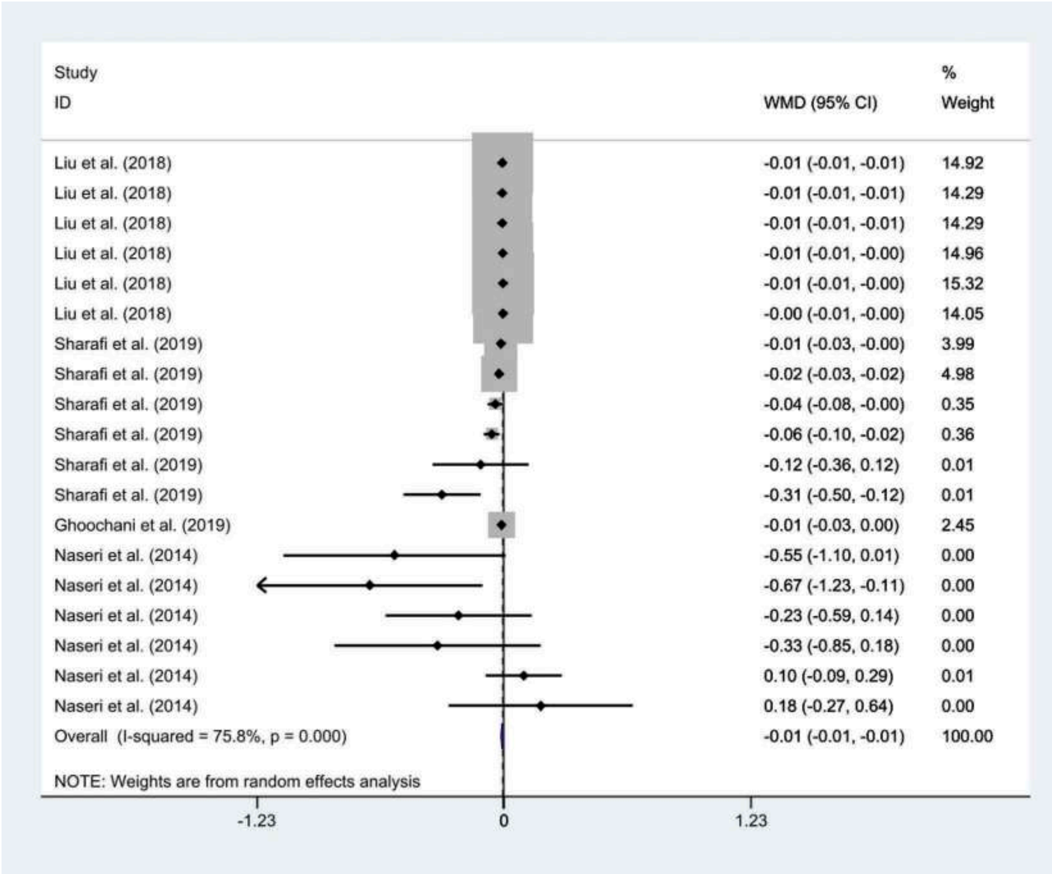

Figure 3. Forest plot presenting mean difference (WMD) and 95% CI for the effect of cooking rice on Pb levels.

However, whilst rice cooking methods have been well-reviewed, to the author's knowledge, this is the first quantitative analysis elucidating the overall effect of rice cooking preparation on As, Pb, and Cd levels; thus, we sought to conduct a systematic review and meta-analysis of association between toxic metals exposure and rice cooking methods. Our findings mainly suggest that cooking rice reduces As, Pb, and Cd exposure in the intervention group compared to controls and the association was statistically significant. A subgroup analysis showed that cooking reduces heavy metal intake, particularly when the rinse cooking method is used for preparation.

It has been reported that the rice cooking method can minimize the risk of toxic metals prior to consumption because of the preparation process. Heavy metal content in cooked rice depends on the method of cooking. In general, there are various household rice cooking practices such as rinsed, Kateh, high-pressure, microwave, and cooking by steamer. Among them, the most common ones are rinsed and Kateh. The rinsed cooking method is boiling rice with excess water that after boiling residual water is discarded. While the Kateh method is a cooking type that rice is boiled with less water and water is absorbed and/or evaporated before it is cooked. In this meta-analysis, cooking seems to have a significant effect on the reduction of As, Pb, and Cd. Some authors studied the effect of cooking cereal on the concentration of toxic metals. A study by Guozhi Zhang et al. (2021) investigated the effect of cooking heavy metal bioaccessibilities in green wheat (Zhang et al. 2021). In consistent with our findings they reported that the concentration of As, Cd, and Pb in raw green wheat is much higher than in cooked wheat. Another study suggested significant reductions in As and Cd may be achieved as a result of cooking rice in excess water (Gray et al. 2016). One of

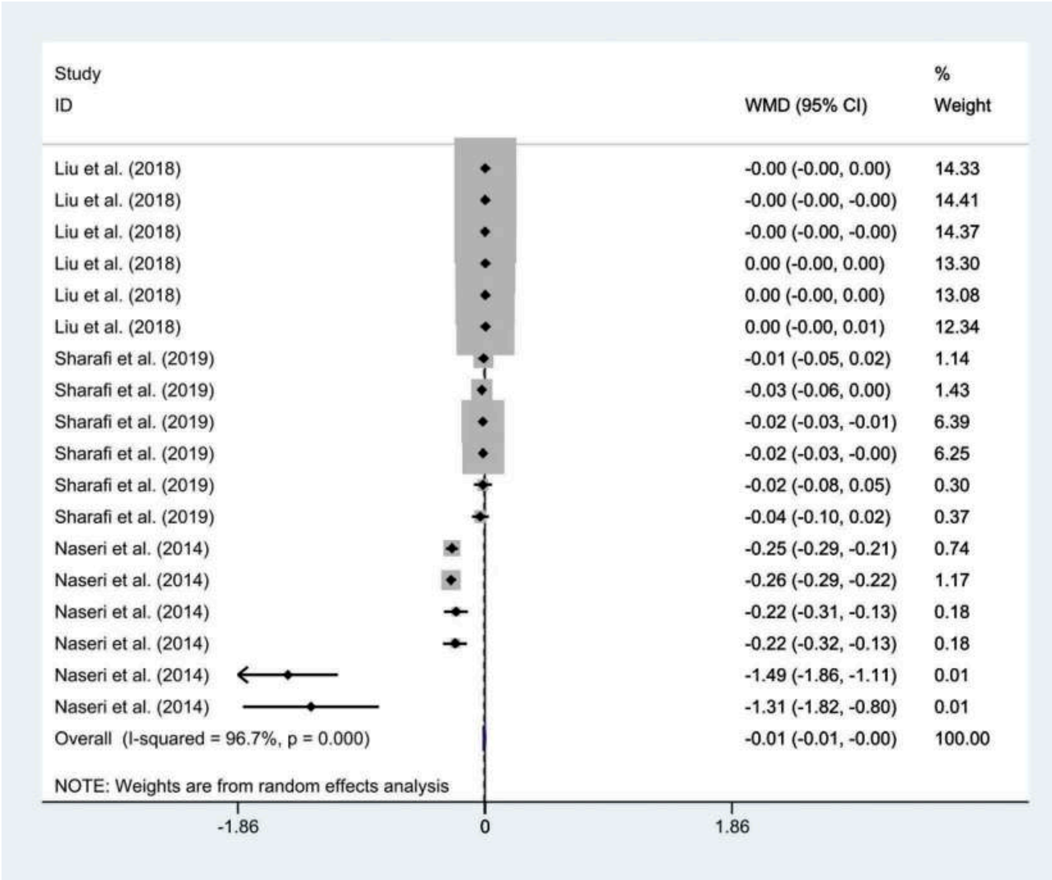

Figure 4. Forest plot presenting mean difference (WMD) and 95% CI for the effect of cooking rice on Cd levels.

Table 2. Subgroup analysis of the association between cooking rice and toxic metal exposure.

Subgroup	layers	Study number	WMD 95% CI	p value	I^2 (%)
Cooking method	Kateh	40	−0.02 (−0.03, −0.02)	0.000	96.1
	Rinse	27	−0.08 (−0.09, −0.06)	0.000	97.1
	parboiling	1	−0.06 (−0.10, −0.02)	0.000	0
	high-pressure	6	−0.01 (−0.01, −0.00)	0.000	96.9
	microwave	6	−0.01 (−0.01, 0.00)	0.000	98.6
	steaming	1	−0.01 (−0.02, −0.00)	0.000	0
	Overall	81	−0.03 (−0.03, −0.03)	0.000	98.3
Cooking water	DI water	71	−0.03 (−0.03, −0.03)	0.000	98.5
	tap water	10	−0.03 (−0.05, −0.02)	0.000	89.9
	Overall	81	−0.03 (−0.03, −0.03)	0.000	98.3

the main reasons for this finding is that by penetrating water into rice, metals are dissolved in water, Q9 and eventually, the water containing dissolved metals is discarded (Adibi et al. 2014b). Hence, it can be stated that the rinse method eliminates more toxic metals compared to Kateh. For this reason, it is recommended for household rice cooking. Although, conventional cooking is more effective in preserving the essential elements and water-soluble B vitamins than the rinse method (Azam et al. 2021; Rezaei et al. 2022). The results of this meta-analysis are consistent with Mohapatra et al. (2021), who demonstrated that cooking decrease the As and Pb contaminants in sorghum grains (Mohapatra et al. 2021). Compared to our results, some other studies have indicated that cooking is less efficient in toxic metal removal. For example, Perello et al. (2008) and Signes et al. (2008) reported that all cooking methods increased considerably the As concentration in cooked rice compared with raw rice (Perello et al. 2008; Signes et al. 2008). The difference between the results of previous studies and the current study may be due to differences in the concentration of As in cooking water.

Based on the observed results, it has been concluded that there was a significant change in the removal of toxic metals in cooking processes and the removal value from the highest to lowest was As > Pb > Cd. Similarly, Some previous studies have shown less Cd removal compared to As and Pb after cooking rice. Khan et al. (2010) declared no significant change in the concentration of Cd after the cooking procedure (Khan et al. 2010). In a meta-analysis of 40 selected studies, rice was more likely to be contaminated with toxic elements compared to other cereal-based foods (Khaneghah et al. 2020). Therefore, as mentioned earlier in order to avoid or eliminate a variety of carcinogenic risks and non-carcinogenic metals, cooking can play an important role. On the other hand, to find the source of significant heterogeneity and the most effective method for heavy metal removal we performed a subgroup analysis. A subgroup analysis revealed that cooking method could be one of the modulating factors between rice consumption and toxic metal exposure. Consequently, it seems that the rinse cooking method is the best one to reduce As, Pb, and Cd compared with Kateh, parboiling, high-pressure, microwave, and steaming. Rezaei Malidareh et al. (2016) indicated that the rinse cooking method is more effective in decreasing Pb and Cd in consumed rice (Rezaei Malidareh et al. 2016). In another research Albergamo et al. (2018) studied the transfer of trace elements in different food products after cooking. They found that the amount of trace elements in pasta and bread was significantly lower than wheat (Albergamo et al. 2018). The main reason for the high effectiveness of the rinse method is that during the boiling of rice, some elements could enter the water and after cooking they are removed by discarding excess water (Hajeb et al. 2014). On the other hand, high-pressure, microwave, and steaming methods had lower effects than others. Another important factor identified in the subgroup analyses was the type of water for cooking. A review article conducted by Kumarathilaka et al. (2019) showed that cooking rice with highly contaminated water does not decrease the As level in cooked rice (Kumarathilaka et al. 2019). In other words, by using cooking water within the standard range of toxic metals reduction in these elements can be expected.

The main strength of the present study was that this is the first meta-analysis to assess the effects of cooking methods on toxic metal exposure caused by rice consumption. Prior to this meta-analysis, the evidence base was not uniform and needed a quantitative evaluation which we have provided. Moreover, we were able to stratify analyses based on the type of processing procedure and the quality of cooking water. However, there are some limitations that need to be addressed in this meta-analysis. Since the sample sizes of some included studies in our analysis were small, results can lead to spurious resultant effect sizes. Additionally, some other data including the type of rice and control group values were not available in a number of studies. The relation between rice cooking and other toxins needs to be investigated in future studies.

Conclusions

This systematic review and meta-analysis evaluated the association between toxic metals exposure and rice cooking methods. The results of this study showed that the rice cooking processes can reduce the risk of As, Pb, and Cd exposure. In addition, our findings showed that the concentration of these metals in rinsed rice was lower than in other methods, which might be due to their elimination during preparing steps. The overall rank order in the reduction of toxic metals by cooking processes was As > Pb > Cd. Considering the dangerous effects of these metals on health, more restricted control measures for monitoring the chemical quality of rice are highly recommended. On the other side, further studies should be conducted to assess the impacts of cooking methods on essential and non-essential trace elements in various food products.

CRediT authorship contribution statement

Kiandokht Ghanati: Conceptualization, Methodology, Investigation, Supervision. Afsaneh Mohajer: Investigation, Methodology, Writing – original draft. Payam Safaei: Data collection, Investigation, Writing – original draft. Hemn Sleman Ali: Formal analysis, Investigation. Hiran Sarwar Karim: Methodology, Software. Parisa Sadighara: Conceptualization, Methodology, Data collection. Ebrahim Molaee-Aghaee: investigation, Resources.

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Disclosure statement

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