Review Article

A Literature Review on the Levels of Toxic Metals/Metalloids in Meat and Meat Products in Asian Countries: Human Health Risks

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Although it is well established that meat and meat products provide essential nutrients for human development and health, inadequate or inappropriate consumption of these foods can also lead to various health problems. Moreover, in 2015, the IARC classified the consumption of red meat and processed meat as "probably carcinogenic to humans" and as "carcinogenic to humans," respectively. However, the exposure to environmental (organic and inorganic) contaminants through the consumption of meat and meat products was not then discussed. In this paper, the recent scientific literature on human exposure to metals and metalloids through the consumption of meat and meat products has been reviewed, with a main focus on toxic metals and metalloids such as As, Cd, Hg, and Pb. According to PubMed and Scopus, Asia is the continent for which the most data have been reported since 2000, with China specifically being the country with the highest number of available papers on the topic of the present review. Therefore, this review has been focused only on Asian countries. As expected, the concentrations of metals and metalloids in meat and meat products, as well as the estimated intake derived from that consumption, have shown notable differences among regions and countries. However, as has also been previously observed for organic pollutants, the group of meat and meat products is not being, at least in Asian countries, one of the most relevant food groups contributing to human dietary exposure to toxic metals and metalloids.

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Introduction

For centuries/millennia, human consumption of meat and meat products has been - and continues to be - widespread throughout practically the entire world. Meat provides essential nutrients for human development and health. However, inadequate/inappropriate consumption can also mean potential problems, which mainly concern health, the environment, and society[1][2][3]. In relation specifically to human health, the balance between benefits and risks varies according to the regions/countries, culture, and dietary habits. Among the benefits of meat consumption, being a nutrient-rich source is probably one of the most relevant. Thus, meat contains proteins of high quality, essential fatty acids, as well as several vitamins and essential trace elements. In addition, meats are energy-dense and satiating, which makes them an important food for populations with limited food security. In developing countries/regions, meat consumption can also help to combat malnutrition by providing vital energy. In contrast to these benefits, certain habits related to inappropriate/excessive meat consumption can also pose potential adverse health effects. These include mainly cardiovascular diseases, which are basically derived from a high consumption of red and processed meats, while the risks of obesity, type 2 diabetes, and even antibiotic resistance due to the use of antibiotics in livestock production can also be increased[4][5][6]. Moreover, in 2015, the International Agency for Research on Cancer[7] stated that "*red meat was a probable carcinogen to humans (Group 2A) due to limited evidence, while consumption of processed meat was carcinogenic to humans (Group 1) given the sufficient evidence*". Since then, the consumption of red meats, as well as that of processed meats, has been classified by the IARC as "probably carcinogenic to humans" and as "carcinogenic to humans", respectively. Epidemiological evidence is strong enough to confirm that intake of red meat and processed meats such as bacon, sausages, and salami, among others, may increase the cancer risks. More specifically, colorectal cancer, but also cancer of the prostate and breast[8][9][10][11]. The N-nitroso-compounds, polycyclic aromatic hydrocarbons (PAHs), and heterocyclic aromatic amines, which are mainly generated during meat processing (curing and smoking, or when meat is heated at high temperatures), would be the organic compounds responsible for that potential carcinogenicity[8]. However, the potential role played by some organic and inorganic contaminants, with known carcinogenic potential, which are often present in raw/unprocessed meats, was not discussed by the IARC[7]. To fill this information gap, we reviewed the scientific literature to find out if certain chemical contaminants could also have some role in the potential carcinogenicity derived from the regular consumption of red meat and meat products[12][13]. The studies reporting the concentrations of some chemical contaminants, with a well-known potential carcinogenic -mainly polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs), polychlorinated biphenyls (PCBs), and PAHs- in meat and meat products, as well as the human exposure to these contaminants through the diet, were also reviewed[14]. It was concluded that meat and meat products were not the main food group contributing to the dietary intake of carcinogenic or probably carcinogenic organic contaminants, which included PCDD/Fs, DL-PCBs, benzo[*a*] pyrene and other PAHs, and hexachlorobenzene (HCB). Nevertheless, it has not been established yet if other organic pollutants frequently detected in meats, such as polychlorinated diphenyl ethers (PCDEs), polychlorinated naphthalenes (PCNs), polybrominated diphenyl ethers (PBDEs), and certain perfluorinated compounds (PFOS and PFOA), can increase the cancer risks in humans.

It must be highlighted that in the previous review by Domingo[14], only organic contaminants were included. The interest in human health risks due to dietary exposure -including consumption of meats- to chemical contaminants is evident. Therefore, a new review of the recent scientific literature on human exposure to metals/metalloids through the consumption of meat and meat products is here presented. Although some information on non-essential elements has also been included, the present review is mainly focused on four toxic metals/metalloids (As, Cd, Hg, and Pb), some of which are also potential carcinogens according to the IARC (As and Cd) and the US EPA (Pb is classified as a probable human carcinogen). Other potential carcinogenic metals are also Be, Cr(VI), and Ni[15]. Notwithstanding, Be is not usually detected in meats, while the interest in Cr (as Cr(III)) and Ni in food is rather based on their essentiality.

For searching the published information on the main topic of this review, the databases Scopus (https://www.scopus.com) and PubMed (https://www.ncbi.nlm.nih.gov/pubmed/) were used. The following keywords/terms: ‘meat’, ‘meat products’, ‘human exposure’, ‘human dietary intake’, ‘metals’, ‘metalloids’, ‘carcinogenic risks’, and ‘non-carcinogenic risks’, were used in the search. Only those articles published in English in the current century have been included. The scientific literature shows that Asia is the continent for which most data have been reported since 2000, with China specifically being the country with the highest number of available papers on the topic of the present review. To avoid excessive length in the article and complexity in comparing results among continents, the current review has been focused only on Asian countries. Details on the reviewed studies are next presented.

Analytical methods to measure metals/metalloids in meat and meat products

Various analytical methods have been used in the reviewed studies, in which the concentrations of metals/metalloids in meat and meat products have been measured. In relation to this, it should be noted that the present review does not have an analytical (chemical) component. Thus, to establish whether the analytical techniques used to measure the levels of the different metals/metalloids in the analyzed samples of meat products in the studies included here were the most suitable was not one of the objectives. Therefore, no specific attention has been paid to the details on that topic, information that is reported in the materials and methods of the studies here reviewed. Since all these studies have been published in peer-reviewed international journals, it has been assumed that the analyses of the respective elements were appropriately conducted, and the data were verified by the respective reviewers/editors. Anyhow, the techniques mainly used to determine the concentrations of metals/metalloids in samples of meat and meat products were inductively coupled plasma mass spectrometry (ICP-MS) and atomic absorption spectrometry (AAS)/graphite furnace. For the specific analyses of Hg and MeHg, cold vapor atomic absorption spectrometry (CV-AAS) was used in various surveys alternatively to ICP-MS, while for those of As, hydride generation atomic absorption spectrometry (HG-AAS) was also employed.

Concentrations of metals/metalloids in meat and meat products consumed in Asian countries

China

Chen et al.[16] assessed the daily intake of Cd, Pb, Hg, and As by the population of Xiamen (period 2005-2009) in samples of various food groups, including meats (chicken and pork, and also offal). The mean concentrations (μg/g) of Cd, Pb, Hg, and As were the following: 0.003, 0.008, 0.005, and 0.020 in samples of chicken; 0.002, 0.011, 0.004, and 0.023 in samples of pork; and 0.055, 0.146, 0.002, and 0.005 in offal samples. The total dietary intakes of the analyzed elements were: 0.066, 0.233, 0.014, and 0.076 μg/kg bw/day, for Cd, Pb, Hg, and As, respectively. The mean estimated daily intakes (EDIs) of the analyzed elements derived from consumption of the meat products were in the following ranges: for chicken samples, 4.29 x 10^{-3} μg/kg bw/day (As) and 6.44 x 10^{-4} μg/kg bw/day (Cd); for pork

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samples, 1.65×10^{-2} μg/kg bw/day (As) and 1.43×10^{-3} μg/kg bw/day (Cd); and for samples of offal, 5.75×10^{-3} μg/kg bw/day (Pb) and 7.87×10^{-5} μg/kg bw/day (Hg). The meat of pork was the main contributor to these EDIs. In another study focused on measuring the concentrations of 16 rare earth elements (REEs) in the most consumed foods in China (meats included: fresh samples of pork, pig kidney, and pig liver), Jiang et al.[17] reported that only a few elements (Ce, Dy, Y, La, and Nd) had relatively high levels in the analyzed foodstuffs, with the levels of the rest of the REEs rather low. Specifically, in meat samples, the total mean and median REEs values were 0.080 and 0.016 μg/g, respectively. On the other hand, Chen et al.[18] estimated, for the adult population of Hong Kong, the exposure through the diet to Al, Sb, Cd, Pb, methylmercury (MeHg), Ni, Sn, and V. For this, a total diet study (TDS) was conducted. The mean concentrations (in μg/kg fw) for the potentially most toxic elements were in the following ranges: Cd, 1 (fruits, eggs, beverages)-150 (fish and seafood); Pb, 4 (dairy products, non-alcoholic beverages)-24 (fish and seafood); and MeHg, ND (legumes, fruits, vegetables, dairy products, beverages)-68 (fish and seafood). The estimated exposures to these elements were: Cd, 8.3 µg/kg bw/month; Pb, 0.21 µg/kg bw/day; and MeHg, 0.74 µg/kg bw/week. In turn, those of Ni and V were 3.1 and 0.13 µg/kg bw/day. All these values, as well as those concerning Al, Sb, and Sn, were well below the HBGVs (health-based guidance values), when these values were available. The food groups showing the greatest contribution to the dietary intake of Cd, Pb, and MeHg were the following: vegetables (36%) and fish and seafood (26%) for Cd, vegetables (30%) and non-alcoholic beverages (16%) for Pb, and fish and seafood (90%) and cereals (56%) for MeHg. Due to potential health risks to the fetus, the authors concluded that MeHg exposure during pregnancy could mean a public health concern. Anyway, meats were not among the foodstuffs with a notable contribution to the examined elements. In a survey based on the food consumption data, Tang et al. [19] evaluated the health risks for the population of Zhejiang derived from the dietary exposure to Cd, Pb, and Hg. The selected foods -collected from local markets- were the most consumed by the residents: aquatic products, vegetables, milk and dairy products, cereals, and meat (pork). The mean concentrations of Cd, Hg, and Pb found in meat of pork were 0.007, 0.014, and 0.051 μg/g, respectively, values that were considered acceptable. While in the 862 food samples analyzed in that survey, the highest mean levels of Cd and Hg were found in marine products, the highest mean Pb concentration corresponded to meat (pork). On the other hand, Jin et al.[20] published a systematic review on the concentrations of Pb in food and the dietary exposure to Pb in China. The available data on the levels of Pb in food for the period 2006-2012 were reviewed. Food samples were divided into 11 groups, with

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meat and offal as one of them. The mean Pb concentrations were 0.074 (range: 0.003-0349) μg/g and 0.181 (range 0.025-0.319) μg/g, for meat and offal samples, respectively. According to the reviewed studies, the total dietary intake of Pb by the Chinese population was 73.842 μg/day, from which 5.469 μg/day came from meat, while 0.851 μg/g came from offal. In 2012, Wu et al.[21] purchased meat products and aquatic products from local markets, grocery stores, and supermarkets in Shenzhen. The samples were analyzed to determine the levels of 14 essential and toxic elements (Cd, Hg, Pb, As, Cr, Cu, Fe, Zn, Mn, Mo, Ni, Co, Se, and Ti). Meat samples included pork, beef, duck, and chicken, as well as animal viscera (chicken liver and gizzard, pig liver and kidney). The highest concentrations were found in aquatic products (0.850 mg/kg) and in animal viscera (0.110 μg/g), for As and Cd, respectively. The target hazard quotient (THQ) values from consuming aquatic products were found to be much higher than those estimated from the consumption of meat products. Specifically, it was 3.79 times higher than consumption of pork, 14.3 times higher than that of beef, 5.62 times higher than that of poultry, and 147 times higher than that of animal viscera. The total THQ values were > 1 when the intakes of all analyzed elements from all meat products were considered.

Cheng et al.[22] measured the levels of eight elements (As, Cd, Co, Cr, Cu, Hg, Pb, and Sb) in samples of vegetables, fish, and meat purchased in 2014 from markets in Huainan. With respect to the mean concentrations of the most toxic elements in meat samples, the highest As levels were detected in chicken (0.036 μg/g), followed by beef (0.029 μg/g), while those of Cd were found in duck (2.61 μg/g) and chicken (1.09 μg/g). In turn, the highest mean levels of Hg corresponded to duck (0.790 μg/g) and chicken (0.694 μg/g), while those of Pb were detected in beef (0.165 μg/g) and pork (0.100 μg/g). The EDIs for the four toxic metals through consumption of meats from Huainan were 0.041, 0.001, 0.001, and 0.176 μg/kg bw/day, for As, Cd, Hg, and Pb, respectively. On the other hand, based on data regarding Cd concentrations from the Chinese National Food Contamination Monitoring Program, data collected between 2001 and 2009, Zhang et al.[23] assessed, for children of Jiangsu Province, the risks of Cd through long-term dietary intake. Meat was one of the food categories included in that study. The Cd concentrations were found to be the following: kidney (pig, sheep), 1711 μg/kg; liver (pig, sheep), 68.3 μg/kg; meat (from mammals other than pig), 3.7 μg/kg; pig meat, 12.6 μg/kg, and poultry, 11.8 μg/kg. For children (2-17 years old), the percentages of contribution of pig meat to the total EDI of Cd ranged between 4.4% and 4.6%. In another survey, Yin et al.[24] measured the content of total Hg (THg) and MeHg in poultry (chickens, ducks, and geese) from 2 farms in the Wanshan mercury mine (Guizhou Province, Southwestern China). Muscles (leg and breast), organs (intestine, heart, stomach, liver), and blood of the three animal species were collected in 2015. The highest Hg levels were found in the liver (THg: 23.2-3917.1 μg/kg; MeHg: 7.1-62.8 μg/kg), followed by blood (THg: 12.3-338.0 μg/kg; MeHg: 1.4-17.6 μg/kg). In chickens, the estimated Hg burdens were 15.3-238.1 μg for THg and 2.2-15.6 μg for MeHg, while in ducks they were the following: THg: 15.3-238.1 μg and MeHg: 3.5-14.7 μg, being THg: 83.8-93.4 μg and MeHg: 15.4-29.7 μg in geese.

During the period 2013-2014, Hu et al.[25] collected -in food markets of the Guangdong province- samples of fresh chicken products to measure the levels of various metals/metalloids (As, Cd, Co, Cr, Cu, Mn, Ni, Pb, Se, and Zn), as well as to evaluate the human health risks associated with exposure to these elements through consumption of chicken products. Breast, drumstick, gizzard, heart, kidney, and liver were the chicken tissues/organs specifically analyzed. For the toxic elements (As, Cd, and Pb), the highest and lowest concentrations were the following: As, 0.049 μg/g (liver) and 0.012 μg/g (drumstick); Cd, 0.019 μg/g (liver) and 0.001 μg/g (drumstick), and Pb, 0.116 μg/g (breast) and 0.042 μg/g (kidney). It was concluded that exposure to inorganic As (at elevated levels) from chicken consumption could mean significant health risks for the consumers. In another survey[26], the concentrations of 11 elements (Mn, Zn, Cu, Sr, Cr, Ni, As, Cd, Pb, Co, and Sb) were determined in 29 food types. Samples were collected in 2014 in Chengdu. Among meats, samples of pork, beef, and poultry were included. The human dietary exposure to these elements was subsequently estimated. The concentrations μg/kg dry weight (dw) of As, Cd, and Pb were these: in pork samples, As, 41.8, Cd, 2.06, and Pb, 30.4; in beef samples, As, 44.9, Cd, 2.17, and Pb, 32.6, and in poultry samples, As, 30.2, Cd, 2.79, and Pb, 31.0. These results indicated that in some food meats, As, Cd, and Cr were at levels higher than the respective limit values. In another study with a similar focus conducted in Beijing, Liang et al.[27] measured the concentrations of Cr, Cd, Pb, As, and Hg in samples of foodstuffs belonging to various food groups. Regarding the group of meats, samples of mutton, beef, chicken, and pork were analyzed. The mean concentrations of Cr, Cd, Pb, As, and Hg were the following: mutton, 0.654, 0.010, 0.128, 0.046, and 0.029 μg/g; beef, 0.504, 0.015, 0.201, 0.077, and 0.010 μg/g; chicken, 0.650, 0.031, 0.291, 0.045, and 0.017 μg/g, and pork, 0.483, 0.003, 0.029, 0.043, and 0.015 μg/g. The average concentrations of Cr, Cd, Pb, As, and Hg in the meat samples were 0.573, 0.015, 0.167, 0.053, and 0.018 μg/g, respectively. The intake of these 5 elements via meat consumption was: 1.5, 60.1, 17.5, 5.5, and 1.9 μg/day, for Cd, Cr, Pb, As, and Hg, respectively, *vs.* total EDIs of 29.5, 205.5, 95.2, 34.0, and 15.6 μg/day, for Cd, Cr, Pb, As, and Hg, respectively. The highest metal contribution from meat consumption to the respective EDIs corresponded to Cr, with a percentage of 29.2% of the total intake of this metal.

The dietary Pb intake in China has been specifically assessed in various studies performed in that country. Liu et al.[28] examined the regional characteristics of dietary exposure to Pb by the Chinese population, while the potential health risks for various regions due to Pb intake through the consumption of various foodstuffs were also assessed. Data were obtained from total diet studies (TDS) conducted in the country, with the data of the last one (5^{th} TDS) collected in the period 2009-2013. With respect to meat and meat products, the highest intakes in the 5^{th} TDS corresponded to these food items: barbecued pork, duck, pig liver, and pork skin aspic. Obviously, not only in these meat products, but also in the different food groups and food items assessed, were there important differences in Pb concentrations, as well as in the dietary intake of this toxic element. Related also to the risks of dietary Pb intake, Zhang et al.[29] estimated Pb exposure via food for the residents in the vicinity of the mining areas of Nandan County. Food samples were collected in 2013 and 2014, in 24, 27, and 25 households near 3 mining areas. The most consumed meats by the population of the zone were included in the study: pork, chicken, and duck. The results showed that in the examined areas, the Pb content in meat and meat products was certainly relevant. The mean Pb concentration in meat was 3.22 (range: 2.75-4.04) μg/g, while the contribution to the total (1400 μg/day) intake of Pb was 381.8 μg/day, being only exceeded by the contribution of the group of vegetables 716.7 μg/day. The authors recommended to the residents in the region to include in their diets a more important fish and grains consumption instead of that of meats. Taking benefit of the data obtained in the 5^{th} China TDS, Wei and Cen[30] assessed the dietary exposure to Cd for residents in the Heilongjiang, Jilin, and Liaoning provinces (Northeast of the country). Meats and meat products included pork, chicken breast, pig liver, sausage, roasted chicken, beef, pork skin aspic, lamb, dorking, braised spare, ribs in brown sauce, chicken liver, roasted duck, and coagulated pig blood. There were notable differences in meat consumption for the 3 provinces: 48.61, 114.57, and 93.18 g/day, respectively. Therefore, notable differences in the daily intake of Cd through consumption of meat could be expected, with the margins of safety (MOS): 4.55, 1.82, and 2.85, respectively, for the 3 provinces. In another vein, in 2017-2019, Zhang et al.[31] assessed the benefits/risks of dietary selenium (Se) and its associated metals in 10 regions of China. It was found that Se-rich agro-food could be used as an effective supplement of Se when compared with common agro-food. The main dietary contributor of Se was the group of meats. In that group, the levels of Se were in the range 0.1728-0.2465 μg/g ww, while those (μg/g ww) of associated metals in meat samples were in the ranges: 0.0302-0.0352 for Pb, 0.1121-0.1195 for As, 0.0010-0.0010 for Cd, 0.0064-0.1140 for Hg, and 0.1018-1.0380 for Cr. As a negative result, it was found that Cr in Se-rich agro-food might mean health risks for people under 18 years old. That study did not report which specific meats were analyzed.

To provide a reference to establish the quality and safety of pork in China and/or similar countries, with a high consumption of that meat, Pei et al.[32] carried out a study aimed at determining the levels of Cr, As, Cd, Hg, and Pb in samples of pork. Samples included muscle (shoulder, ham, loin, tenderloin, and belly) and edible offal (liver, kidney, and intestine) of pork, which were purchased from the city of Nanjing. The results showed that the daily intakes of the analyzed elements (3.00, 2.14, 1.00, 0.57, and 3.57 μg/kg bw/day, for Cr, As, Cd, Hg, and Pb, respectively) were clearly below the recommended values. Moreover, the target hazard quotients (HQ) and total target hazard quotients (THQ) were < 1.0. It was an indicator that human exposure to the analyzed elements, through a usual consumption of muscles and edible offal of pork, would be safe for the consumers. With similar purposes to those of previous studies carried out in China, Wang et al.[33] measured the levels of Pb, Cd, Hg, and As in samples of foodstuffs belonging to 13 food groups, which were purchased from Shenzhen markets. One of the food groups was meat (the specific analyzed meats were not reported). The mean levels of Pb, Cd, Hg, and As in meat samples were the following: 0.044, 0.0237, 0.0056, and 0.021 μg/g, respectively. Meat was one of the four major contributing foods to the cumulative probability of the hazard quotient (HQ) and hazard index (HI) values of Pb, Cd, Hg and As. With a similar objective, Han et al.[34] measured the concentrations of As, Cd, Cr, Cu, Hg, Ni, and Pb in samples of fresh meat (pork, beef, mutton, chicken, and duck) purchased from markets of the Zhejiang province. The mean concentrations of these elements were 0.018, 0.002, 0.061, 0.801, 0.0038, 0.055, and 0.029 μg/g for As, Cd, Cr, Cu, Hg, Ni, and Pb, respectively. There were a few samples in which the maximum allowable concentrations (MACs) were exceeded. More specifically, one for As, two for Hg, and ten for Pb. In relation to this, the MACs (in China) of As, Cd, Cr, Hg, and Pb in meat were 0.5, 0.1, 1, 0.05, and 0.2 μg/g, respectively. The exposure assessment suggested relatively low health risks for the individuals consuming the meat products analyzed in that survey, with low percentages (0.09% for As, 0.19% for Hg, and 0.94% for Pb) exceeding the corresponding MACs set by the Chinese legislation. Another more recent study on the same topic was conducted by Wang et al.[35]. These authors measured the concentrations of various elements (Al, As, Cr, Cd, Cu, Ni, Pb, and Zn) in samples of several foodstuffs (and drinking water) widely consumed by the residents in industrial regions of northern Ningxia. Meat samples corresponded to pork, beef, and mutton. On average, the concentrations (μg/g) of the most potentially toxic elements were the following: As, 0.218; Cd, 0.000; Cr, 0.472; Ni, 0.000, and Pb, 0.078. The non-carcinogenic risks (measured by the HI) for the meat consumers were: 0.0259, 0.4080, 0.1012, 0.000, 0.0187, 0.000, 0.0136, and 0.0995, for Al, As, Cr, Cd, Cu, Ni, Pb and Zn, respectively, with the global HI (<1): 0.7269. The carcinogenic risk of meat consumption was 2.11×10^{-4}, a value higher than those corresponding to the rest of food groups (fruits, vegetables, tubers, beans) included in that survey, being only exceeded by drinking water (2.34×10^{-4}).

The results of the studies on human exposure to metals/metalloids through meat consumption conducted in China and published throughout 2024 are next summarized. Han et al.[36] reported the Ni concentrations in samples of food items from several food groups collected in the Zhejiang Province. The group of meat and meat products included sausages, Chinese bacon, and other (not detailed) meat products. The median concentrations of Ni were 0.262, 0.252, and 0.116 μg/g for these three meat groups, respectively, with 0.258 μg/g as the median level of Ni for the set of analyzed samples. In general, dietary exposure to Ni was at acceptable levels. The exception was the age group between 0 and 6 years, for whom the EDI was found to be the highest. For that age group, the consumption of Ni-contaminated foods exceeded the recommended tolerable daily intake (TDI) set at 13 μg/kg bw/day. However, the exposure to Ni derived from meat consumption was rather low in comparison to that from other food groups. Recently, Qin et al.[37] determined the concentrations of Cu, Cr, V, Ni, As, Se, Sn, Cd, Pb, Sb, Mn, Ba, and Hg in samples of meat and meat products collected from various cities in the Shandong Province. Samples included livestock meat and offal, as well as poultry meat and offal. For the 13 analyzed elements, the total mean concentrations were 1.56 nd and 39.8 μg/g in samples of meat and offal, respectively. With respect to the potentially most toxic elements, Cr, Ni, and Pb, these were detected in 100% of the analyzed samples, while Hg was found in 95%, Cd in 51.3%, and As in 21.3%. The total HI and HQ values suggested potential health risks for those individuals consuming significant quantities of meat and meat products. On the other hand, Zeng et al.[38] investigated the relationship between the levels of various metals (Cr, Cd, Cu, Zn, Ni, and Pb) in the hair of residents in Chengdu and the exposure to these same metals through the diet of that population. Among the foodstuffs in which the levels of these elements were measured, the following meats and meat products were included: pork, beef, and chicken, as well as the gizzard, heart, intestine, liver, kidney, tripe, and brain of pig, together with duck intestines and the aorta, rumen, and omasum of bovine. The highest concentrations of Cr, Cd, Cu, Ni, and Pb were found in the group of cereals, while Zn was the only trace metal showing the highest concentration in meat and meat products. Cereals—followed by meats—were the main contributors to the dietary intake of the analyzed metals and, consequently, to the concentrations detected in the hair of the population of the area.

A summary of details corresponding to the above studies conducted is shown in Table 1.

Region/Province/City	Metals/metalloids analyzed	Samples of meat and meat products analyzed	Remarks	Reference
Xiamen	Cd, Pb, Hg, As	Meat of chicken and pork, and offal	Pork meat was the main contributor to the EDI	Chen et al. [16]
Hong Kong	Al, Sb, Cd, Pb, MeHg, Ni, Sn, V	Data on the levels of meat/meat products were obtained from a Total Diet Study (TDS)	Meat and meat products were not a food group showing a high contribution to the intake of Cd, Pb and MeHg	Chen et al. [18]
Zheijang	Cd, Pb, Hg	Meat of pork	Among the samples of the food groups analyzed, the highest mean Pb level corresponded to meat of pork	Tang et al. [19]
Shenzhen	Cd, Hg, Pb, As, Cr, Cu, Fe, Zn, Mn, Mo, Ni, Co, Se and Ti	Pork, beef, duck and chicken. Also, animal viscera (chicken liver and gizzard; pig liver and kidney)	The total THQ values were > 1 when the intakes of all analyzed elements in all meat products were considered.	Wu et al. [21]
Huainan	As, Cd, Co, Cr, Cu, Hg, Pb, Sb	Meat of beef, chicken, and duck	The EDIs for As, Cd, Hg and Pb, through the consumption of meats were: 0.041, 0.001, 0.001 and 0.176 μg/kg bw/day, respectively.	Cheng et al.[22]
Jiansgu Province	Cd	Data were obtained from the National Food Contamination	The highest Cd levels were found in kidney (followed by liver) of pig and sheep	Zhang et al.[23]

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Region/Province/City	Metals/metalloids analyzed	Samples of meat and meat products analyzed	Remarks	Reference
		Monitoring Program (2001-2009)		
Wanshan, Guizhou Province	Hg, MeHg	Meat poultry (chickens, ducks and geese)	The highest concentrations of Hg and MeHg corresponded to the samples of liver, followed by blood	Yin et al. [24]
Guandong Province	As, Cd, Co, Cr, Cu, Mn, Ni, Pb, Se, Zn	Chickens (breast, drumstick, gizzard, heart, kidney and liver)	As, found at elevated levels in some samples, could mean health risks for the consumers	Hu et al. [25]
Chengdu	Mn, Zn, Cu, Sr, Cr, Ni, As, Cd, Pb, Co, Sb	Meat of pork, beef and poultry	In some meat samples, As, Cd and Cr levels were higher than the respective limit values	Wang et al.[26]
Beijing	Cr, Cd, Pb, As, Hg	Meats of mutton, beef, chicken and pork	The average concentrations of Cr, Cd, Pb, As, and Hg in meat samples were: 0.573, 0.015, 0.167, 0.053 and 0.018 μg/g, respectively.	Liang et al.[27]
Nandan County	Pb	Meats of pork, chicken and duck	The mean Pb concentration in meat samples was 3.22 (2.74-4.04) µg/g. The contribution to EDI of 381.8 µg Pb/day *vs* a total of 1400 µg Pb/day	Zhang et al.[29]
Heilongjiang, Jilin and Liaoning	Cd	Data were obtained from the 5th TDS. Meat and	Notable differences were found for the EDIs	Wei and Cen[30]

Region/Province/City	Metals/metalloids analyzed	Samples of meat and meat products analyzed	Remarks	Reference
Provinces		meat products included: pork, chicken breast, pig liver, sausage, roasted chicken, beef, pork skin aspic, lamb, dorking, braised spare, ribs in brown sauce, chicken liver, roasted duck and coagulated pig blood	corresponding to the 3 Provinces. It, considering not only the levels of Cd in the analyzed samples, but also the different dietary habits	
Ten Chinese regions	Se and various associated metals	Se-rich food samples	The main dietary contributor of Se was meat. In that food group, the levels of Se were in the range 0.1728-0.2465 μg/g	Zhang et al.[31]
Nanjing	Cr, As, Cd, Hg, Pb	Pork muscle (shoulder, ham, loin, tenderloin and belly), and also offal (liver, kidney and intestine)	The EDIs (from pork consumption) were the following 3.00, 2.14, 1.00, 0.57 and 3.57 μg/kg bw/day for Cr, As, Cd, Hg, and Pb, respectively. All were below the recommended values.	Pei et al. [32]
Shenzen	Pb, Cd, Hg, As	Meats (not detailed in the paper)	The mean levels of Pb, Cd, Hg and As in meat samples were: 0.044, 0.0237, 0.0056, and 0.021 μg/g, respectively.	Wang et al.[33]
Zhejiang Province	As, Cd, Cr, Cu, Hg, Ni, Pb	Fresh meat of pork, beef, mutton, chicken and duck	The exposure assessment suggested relatively low health	Han et al. [34]

Region/Province/City	Metals/metalloids analyzed	Samples of meat and meat products analyzed	Remarks	Reference
			risks for subjects consuming meats. Only low percentages (0.09% for As, 0.19% for Hg, and 0.94% for Pb) exceeded the MACs set by the Chinese legislation	
Northern Ningxia	Al, As, Cr, Cd, Cu, Ni, Pb, Zn	Meats of pork, beef and mutton	The average concentrations (μg/g) of the most potentially toxic elements were: As, 0.218; Cd, 0.000; Cr, 0.472; Ni, 0.000, and Pb, 0.078	Wang et al.[35]
Zheijang Province	Ni	Sausages, Chinese bacon, and other meat products	The median level of Ni was 0.258 μg/g, for the set of analyzed samples, being the EDI at acceptable values	Han et al. [36]
Shandong Province	Cu, Cr, V, Ni, As, Se, Sn, Cd, Pb, Sb, Mn, Ba, Hg	Livestock meat and offal; poultry meat and offal	For the 13 analyzed elements, the total mean concentrations were 1.56 nd 39.8 μg/g, in samples of meat and offal, respectively.	Qin et al. [37]
Chengdu	Cr, Cd, Cu, Zn, Ni, Pb	Pork, beef and chicken, as well as gizzard, heart, intestine, liver, kidney, tripe and brain of pig. Also duck intestines and aorta,	The only trace metal showing the highest concentration in meat and meat products was Zn. The rest of analyzed	Zeng et al. [38]

Region/Province/City	Metals/metalloids analyzed	Samples of meat and meat products analyzed	Remarks	Reference
		rumen and omasum of bovine.	elements showed their respective highest levels in other food groups.	

Table 1. A summary of scientific studies published in China in the current century on the levels of metals/metalloids in meat and meat products and their intake

Bangladesh

Ullah et al.[39] determined the levels of several elements (Pb, Cd, Cr, As, Hg, Mn, Fe, and Zn) in three varieties of chicken meat (broiler, local, and sonali) purchased from markets in Dhaka. The dietary intakes of these elements were subsequently estimated, and the carcinogenic and non-carcinogenic risks for the consumers were also evaluated. The concentrations (μg/g) of the analyzed elements were in the following ranges: 0.03-2.73 (Pb), 0.01-0.015 (Cd), 0.025-0.67 (Cr), 0.04-0.06 (As), 0.01-0.015 (Hg), 0.15-0.63 (Mn), 2.50-38.6 (Fe), and 1.02-19.4 (Zn). The MACs were exceeded only by Pb, while the target hazard quotient (THQ) and total target hazard quotient (TTHQ) for combined elements, as well as the carcinogenic risks for lifetime exposure, were below their respective allowable benchmarks. In another study, also conducted in Dhaka, Hossain et al.[40] determined the concentrations of Pb, Cd, Fe, Cr, Cu, and Zn in various tissues/organs of chicken (muscle, liver, gizzard, heart, kidney, and brain), which are regularly consumed by the Bangladeshi population. The non-carcinogenic and carcinogenic risks of the intakes were also assessed. The levels (μg/g) found in the different parts of the chickens ranged as follows: 0.33±0.2-4.6±0.4 (Pb), 0.004±0.0-0.125±0.2 (Cd), 0.006±0.0-0.94±0.4 (Cr), 4.05±4.2-92.31±48.8 (Fe), 0.67±0.006-4.15±2.7 (Cu), and 4.45±0.62-23.75±4.3 (Zn). The THQ and TTHQ values were found to be < 1 (no carcinogenic risks for the consumers), while the carcinogenic risks for the elements with potential carcinogenicity were within acceptable limits. On the other hand, in addition to measuring the levels of antimicrobial drug residues in chickens consumed in Bangladesh, Bokthiar et al.[41] also determined the levels of As, Cd, and Pb in broiler chicken (bones, meat, as well as combinations of liver, kidney, and gizzard). Samples were obtained from farms and supermarkets in the districts of Dhaka, Chattogram, Gazipur, Rajshahi,

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and Barisal. The analyzed broiler edible tissues showed concentrations of As and Cr below the respective maximum residual limits (MRL), but not those of Pb. In a similar line to that of previous studies carried out also in Bangladesh, recently, Chowdury and Alam[42] reported the results of a survey aimed at measuring the concentrations of six metals (Cd, Cr, Pb, Ni, Fe, and Cu) in samples of meat, brain, and liver of seven animal species (poultry, somali chicken, cow, quail, duck, pigeon, and goat), collected from the Noakhali district. As in previous surveys, the non-carcinogenic and carcinogenic risks due to the intake of these metals were also assessed. There were considerable differences in the levels of the analyzed metals depending on the specific element, the animal species, and the specific tissue. For the two potentially most toxic analyzed elements (Cd and Pb), the maximum and minimum values (μg/g) were the following: for Cd in brain, 0.46 (cow) and 0.04 (quail), in muscle, 0.45 (cow) and ND (quail), and in liver, 2.40 (cow) and 0.69 (pigeon). For Pb in brain, 7.54 (poultry) and 3.07 (quail), in muscle, 5.01 (pigeon) and 1.64 (quail), and in liver, 81.87 (goat) and 2.79 (pigeon). Regarding the potential health risks for consumers, it was concluded that overexposure to Cd through meat consumption could increase the cancer risks, being children more susceptible than adults.

India

In 2017, in 5 major metropolitan cities of Tamil Nadu, Mathaiyan et al.[43] collected samples of various parts (breast, liver, neck, and kidney) of common broiler chickens, in which the levels of the toxic elements As, Cd, Hg, and Pb were measured. The maximum and minimum mean concentrations (μg/g) of these elements were the following: As, 0.78 (liver) and ND (neck and kidneys); Cd, 0.019 (breast and liver) and 0.014 (neck); Hg, 0.27 (breast) and ND (neck and kidneys), and Pb, 1.29 (breast) and 0.077 (neck). The EDIs were found to be in the ranges: 0.0002-0.0036, 0.0002-0.0002, 0.0008-0.0051, and 0.0072-0.0182 mg/day/person, for As, Cd, Hg, and Pb, respectively. The authors concluded that, in general, samples of meat and edible organs of chicken exceeded the values regarding the maximum residue levels (MRL). However, the exposure to As, Cd, Hg, and Pb from consumption of chicken in Tamil Nadu was within the allowable levels. With similar purposes, and with samples also collected in Tamil Nadu, Pappuswamy et al.[44] measured the levels of Cd, Pb, and Zn in samples of blood, intestine, breast, liver, and gizzard of chickens purchased from markets in 3 districts in that Indian region. The maximum and mean ranges of concentrations (μg/g) of the toxic metals Cd and Pb were found in the intestine (0.26-0.42) and gizzard (ND-0.54) for Cd, and in the heart (2.9-6.24) and blood

(ND-2.56) for Pb. It was concluded that the levels of these metals were generally within the permissible limits, but they were surpassed in the liver of chickens from Coimbatore (one of the 3 districts included in the study). Blood from chickens from the 3 districts could also mean risks for consumers.

Thailand

Nookabkaew et al.[45] measured the concentrations of various trace elements in samples of rice, eggs, vegetables, and fruits, and animal meats. Infant formulas and drinking water were also included in that study, in which samples were randomly collected from several commercial centers in Bangkok in the period 2005-2008. With respect to toxic elements, it was found that pig kidney and liver contained high concentrations of As and Cd. Regarding food safety of meats, exposure to As and Cd from poultry and pig liver or rice consumption meant a potentially high weekly/monthly intake for children. In a subsequent study, Aendo et al.[46] measured the concentrations of Pb, Cd, Co, and Cr in duck meat (also in duck eggs). The potential non-carcinogenic and carcinogenic risks for consumers of duck products were also assessed. Ninety samples of duck meat were obtained from 11 farms from various regions of the country. The mean concentrations in duck meat were 1.94, 0.22, 0.10, and 0.37 μg/g, for Pb, Cd, Co, and Cr, respectively. It meant that 72.22% of the Cd and 66.66% of the Pb levels were above the standard set by the FAO/WHO. Anyhow, using the database of contamination in duck (eggs and meat), the Total Target Hazard Quotient (TTHQ) of Pb, Cd, Co, and Cr was < 1 in all age/gender groups of individuals. The authors suggested the possibility of higher health risks due to duck eggs consumption rather than that of duck meat.

Iran

Abedi et al.[47] determined the levels of Cd and Pb in 5 brands of various types (German, cocktail, hot dog, Lyoner, dry and jambon) of cooked beef sausages, which were purchased in 2009 in supermarkets in Teheran. The results were very variable depending on the specific kind and brand of the sausages. For Pb, the maximum and minimum values were 158.7 μg/g ww (German) and 24.0 (cocktail) μg/g ww, while for Cd those values were 13.5 μg/g ww (hot dog) and 2.2 μg/g ww (German). The mean levels of Pb and Cd in all the analyzed samples were 53.5 and 5.7 μg/g, respectively. Using these values, the EDIs of Pb and Cd were 1.47 and 0.16 μg /day, respectively, which were considered acceptable for consumers. On the other hand, Raeeszadeh et al.[48] determined the levels of As and Se, as well as several metals

(Pb, Cd, Zn, Ni, Cu, Cr, and Co) in samples of various meats (beef, turkeys, sheep, and ostriches) collected in Sanandaj City, Kurdistan province. The maximum and minimum mean concentrations (μg/g) for those elements, considered the most potentially toxic analyzed in that survey, were the following: 11.79 (sheep) and 0.13 (turkey) for Pb; 4.31 (beef) and 0.16 (ostrich) for Cd; and 0.88 (turkey) and 0.20 (beef) for As. Regarding health risks for consumers, the target hazard ratios (THQ) ranged between 0.0069 (ostrich) and 0.769 (beef) for Pb, 0.121 (ostrich) and 3.283 (beef) for Cd, and 0.057 (turkey) and 0.393 for As. A THQ value > 1 for Cd indicated that concentrations of that metal in beef (also in sheep) were at the warning level. In contrast, for all the analyzed elements (including As, Cd, and Pb), and taking into account the target risks (TR) of cancer for metals in the different species, these were considered acceptable. Recently, Sarlak et al.[49] reviewed the studies published during the 2010s decade on the occurrence of Pb in various animal-based food groups in Iran. Among these groups, the studies on red meat, white meat, and meat products were included. Only a few surveys on the concentrations of metals in meat and meat products were detected. The meat consumption -according to the authors- has been reduced in recent years in Iran. Consequently, they highlighted the difficulties in estimating exposure to metals through meat consumption. A rather expected conclusion was the occurrence of higher Pb concentrations in offal than in muscle tissues.

Korea

Lee et al.[50] measured the dietary exposure to As, Cd, Pb, and Hg by the Korean population. For this, a total of 116 foods/dishes (in table-ready state), which represented 66.5% of the total food intake, were included in that survey. The EDIs were: 38.5, 14.3, 24.4, and 1.61 μg/person of 55 kg bw/day, for As, Cd, Pb, and Hg, respectively, values that were all within the safe limits (under 30% of the respective PTWIs). The group of meat and meat products was not an important contributor to the intakes of the analyzed elements. In contrast, a high contribution of foodstuffs such as rice, vegetables, and fish and seafood was noted. With respect to Cd, the results by Lee et al.[50] were in agreement with those of Moon[51], who, in a review on the relationship between the concentrations of Cd in blood and the dietary intake by the Korean population, found that fish and shellfish (3.00 μg/day), grains and cereals (3.36 μg/day), and vegetables (2.11 μg/day) were the food groups showing the most important contributions to the dietary exposure to Cd, after seaweed (3.66 μg/day). In that review, the mean total dietary intake of Cd was estimated to be 15.25 (range: 2.48-90.5) μg/day for the Korean population.

Saudi Arabia

In 2010, Othman[52] measured the concentrations of Pb in various foods available in local markets in Riyadh city. Human Pb exposure through daily intake was estimated using a questionnaire (Food Consumption Survey) responded to by the local population. Among the 10 food groups (vegetables, fruits, meat and meat products, milk and dairy products, etc.) included in that study, the highest Pb levels did not correspond to the group of meat and meat products. The highest concentrations of this heavy metal were found in sweets (range: 0.011-0.199 μg/g), vegetables (range: 0.002-0.195 μg/g), and legumes (range: 0.014-0.094 μg/g). However, considering the daily consumption of the food items in the respective food groups, the highest dietary contributors to Pb intake were vegetables (25.4%), cereals (24.2%), and milk and milk products (12.9%), while sweets reached 8.2% of a total EDI of 24.57 μg Pb/person/day, a value lower than the reference JEFCA value for Pb. In another survey also conducted in Riyadh, Nasser[53] measured the levels of several heavy metals (Cd, Cu, Fe, Ni, Pb, and Zn) -together with the fungal and microbial contents- in 13 samples of canned meats, mainly chicken and beef. In relation to the non-essential elements (Cd and Pb), the levels of Cd ranged between 0.16 and 0.62 μg/g, with 4 samples showing concentrations above the maximum permissible level. In turn, the Pb levels ranged between 0.27 and 1.1 μg/g, with all samples showing concentrations above the maximum permissible level, while Ni could be detected in only 3 samples (all above the maximum permissible level for this element). The author remarked on the interest of these results to prevent health risks to consumers, considering that canned meats are easily accessible and frequently consumed in the country. More recently, Korish and Attia[54] determined the levels of As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, and Zn in samples of meat (fresh and frozen broilers), meat products (burger and frankfurter), and liver of chickens collected from markets in Jeddah. For the potentially most toxic elements, As was not detected in any sample, while Cd and Pb were not detected in samples of broiler meat. However, both Cd and Pb were found in samples of meat products (burger: 0.433 and 16.69 μg/g, for Cd and Pb, respectively, and liver (1.12 and 16.51 μg/g, for Cd and Pb, respectively). In another survey, the levels of Cd and Pb were also measured by Aljazzar et al.[55] in samples of bovine meat and edible offal (round, tongue, colon, lung, rumen, liver, and kidney), which belonged to cattle reared in Al-Ahsa. As could be expected, the lowest mean concentrations of Cd and Pb were found in samples of muscle: 0.21 and 0.06 μg/g, for Cd and Pb, respectively. In contrast, the highest mean levels of both metals were detected in the kidney (Cd: 0.21 μg/g) and liver (Pb: 0.55 μg/g). The EDIs in adults ranged between 0.04 mg/kg bw/day (colon) and 0.11 mg/kg bw/day (muscle) for Pb, and between 0.04 mg/kg bw/day (tongue) and 0.40 mg/kg bw/day (muscle) for Cd. The risk assessment for adults showed HR and HI values <1 (including, for HI, the combined risk of Pb and Cd).

Other Asian countries

In Taiwan, Chen et al.[56] measured the concentrations of As, Cd, Co, Mn, Mo, Pb, Se, and Sb in samples of livestock meat (beef, mutton, and pork) and poultry (chicken, duck, and goose). The ranges (μg/g) of the analyzed metals/metalloids were the following: 0.005-0.035 (As), <0.002-0.003 (Cd), 0.002-0.033 (Co), 0.106-0.365 (Mn), 0.029-0.140 (Mo), 0.009-0.046 (Pb), 0.108-0.349 (Se), and <0.002-0.003 (Sb). With respect to the most toxic elements, the concentrations of Pb were higher in duck samples, while the highest As levels were found in samples of chicken and pork. The results of that survey did not suggest health risks for consumers. In Iraq, Ali et al.[57] determined the concentrations of Se and 9 heavy metals (Cd, Co, Cr, Cu, Mn, Ni, Pb, Hg, and Zn) in samples of chicken liver collected in markets in Erbil city, Kurdistan. For the 3 potentially most toxic elements, the mean concentrations (μg/g) were 0.07±0.037, 0.278±0.10, and 0.11±0.083, for Cd, Pb, and Hg, respectively. Lead and Hg -together with Cu- were the only analyzed elements that exceeded the permissible limits in poultry set by the FAO/WHO. In Armenia, Pipoyan et al.[58] carried out the evaluation of the dietary exposure to Ni for an adult population of Yerevan city. The potential associated health risks were also assessed using the data from a (2018-2019) TDS. Composite meat (beef/veal, pork, sausages, and chicken, as well as the local foods pelmeni and khinkali) samples contained processed (grilled, boiled, and pan-fried) subsamples. In meat samples, the mean levels of Ni (μg/g) were the following: beef/veal, 0.200; pork, 01.84; chicken, 0.192; sausages, 0.155; and pelmeni/khinkali, 0.196. The EDI of Ni for the Armenian population was 0.147 μg/kg bw/day (specifically, 0.157 and 0.142 μg/kg bw/day, for females and males, respectively). The contribution of meat and meat products was rather low in comparison to that of the main contributors: fruits and vegetables, and bread and flour-based products. In Pakistan, recently, Mushtaq et al.[59] measured the levels of As, Cr, Co, Pb, Mn, and Hg in samples of meat (including kidney and liver) of cattle, goats, and broilers, which were collected in 20 different places in Quetta (Balochistan). The highest concentrations of Cr, Pb, and Hg were found in liver samples. Most metal levels were within the normal ranges in the analyzed samples of goats and cattle. In terms of EDIs, goat and cattle products were the main contributors to the intakes of As, Co, Pb, and Hg, with that of Hg (also that of Cr) in adults exceeding the RfD (oral reference dose). Regarding the THQ, only As had a value >1.

Discussion and conclusions

The present article was aimed at reviewing the scientific data regarding the concentrations in meat and meat products -consumed in Asian countries- of various toxic metal/metalloids: As, Cd, Hg, and Pb, but also other elements with potential (mainly carcinogenic) health risks (Cr(VI) and Ni). The intake of these elements derived from the consumption of meat and meat products has also been reviewed. Asia is the continent for which more information on this topic has been published in the current century, with China being the country with the most available studies found in the scientific literature (databases PubMed and Scopus). The studies reviewed here correspond to several Asian regions and countries. As could be expected, important differences in the levels of metal/metalloids in meat and meat products have been observed. These differences depend on various factors, not only the specific country/region and the specific areas of sampling in each region/country but also the dietary habits of the different groups of the population. Logically, the highest values were found in those areas that are environmentally polluted by some specific element.

With respect to the characteristics of the current review, it must be highlighted that it is a literature review. It is neither a systematic review nor a meta-analysis. Moreover, as above commented, the analytical methods used in the revised papers have not been discussed/questioned. This is out of the aim of this review, considering that all the studies included have been already published in international peer-reviewed journals. Consequently, it is assumed that the experimental methods were adequate.

It is well known that humans are mainly exposed to chemical (organic and inorganic) contaminants through the diet. Therefore, for non-occupationally exposed populations, exposure to essential and non-essential trace elements depends basically on the dietary intakes. In order to establish whether the reported EDIs of the toxic metal/metalloids might mean significant/relevant health risks for the regular consumers of meat and meat products in Asian countries, information (from international organizations) on the current tolerable daily/weekly/monthly intake of the most toxic elements is next summarized. With respect to As, in 2004, the International Agency for Research on Cancer included this element in Group 1 (carcinogenic to humans). In 2009, the European Food Safety Agency (EFSA) considered that the PTWI of 15 μg/kg bw/week, which had been used until then, was not suitable, establishing a new $BMDL_{01}$ (benchmark dose lower confidence limit) of 0.3-8 μg/kg bw/day for inorganic As (InAs). In 2010, based on new epidemiological data, the Joint Food and Agriculture

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Organization of the United Nations (FAO)/WHO Expert Committee on Food Additives (JEFCA) set a safety limit of 3.0 µg/kg bw/day (2-7 µg/kg bw/day, based on the range of estimated total dietary exposure). For inorganic As (InAs), the previously established PTWI of 15 µg/kg bw/week (which would be equivalent to 2.1 µg/kg bw/day) was not considered appropriate. Regarding Cd, the IARC also classified this metal as a carcinogen to humans (Group 1). In 2005, the JECFA established a PTWI of 7 μg Cd/kg bw/week, but in 2009, the EFSA re-evaluated the current information about Cd, setting a new tolerable weekly intake (TWI) of 2.5 μg Cd/kg bw/week. In 2021, the TWI of Cd was not reviewed -and consequently not modified- by the JECFA. With respect to Hg and MeHg, in 2012 the EFSA suggested a TWI of 4 μg/kg bw/week for inorganic Hg (InHg), and 1.3 μg/kg bw/week for MeHg. These same values were also recommended by the JEFCA in 2011. Regarding Pb, the IARC classified this element as a possible carcinogen to humans (Group 2B), and the JECFA established a PTWI of 25 μg/kg bw/week. However, in 2010, considering that sufficient evidence on the critical health effects of Pb was not available, the EFSA concluded that the PTWI of 25 μg/kg bw/week was not adequate. Since then, considering that there is no sufficient evidence of thresholds for several critical health effects of Pb, there is not any recommended tolerable daily/weekly intake for that metal. Thus, instead of using values of tolerable Pb intake, the EFSA proposed to assess the Pb risk by means of BMDLs. On the other hand, the EFSA published a scientific opinion on the risk to human health from Cr in food (mainly vegetables and bottled drinking water). A TDI of 0.3 mg/ kg bw/day was established for Cr(III), which is an essential nutrient and the main form of Cr in foodstuffs. However, considering that animal studies have shown that Cr(VI) might cause cancer, the EFSA has not established a TDI for Cr(VI). In relation to Ni, in 2020, the EFSA updated the recommendations to avoid risks to human health from Ni in food and in drinking water. Due to the application of the updated benchmark dose guidance, the TDI was increased from 2.8 to 13 µg Ni/kg bw/day.

The results reported in the studies reviewed here show that, in general, human exposure to As, Cd, Hg, and Pb -and other metals such as Cr(VI) and Ni- due to regular/frequent consumption in Asian countries of meats, mainly poultry, pork, and beef, and meat products (including offal), should not mean significant/relevant health risks for consumers. The contribution of Pb (an element analyzed and detected in most studies) through the consumption of meat and meat products to the total dietary intake of this element means a rather low percentage compared with those of other food groups. It is well known that at least the environmental levels of Pb and Hg have notably decreased in recent decades. Therefore, it is expected that -in a parallel way- the concentrations of these and other toxic

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elements will also decrease in the next years. Notwithstanding, there is an important number of Asian countries for which scientific information (at least in English) is not available. To prevent potential health risks derived from exposure to toxic metal/metalloids -as well as organic contaminants- through the consumption of meat and meat products, as well as other food groups, knowing their levels in foodstuffs and the human exposure is a key issue. Anyway, as also previously observed for organic pollutants in meat and meat products[14][2], at least in Asian countries, the group of meat and meat products is not one of the most relevant food groups contributing to the human dietary exposure to toxic metal/metalloids.

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