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RESEARCH ARTICLE

The concentration of potentially toxic elements (PTEs) in sausages: a systematic review and meta-analysis study

Amene Nematollahi[1] · Lieil Abdi[2] · Zohreh Abdi-Moghadam[3] · Yadolah Fakhri[4] · Mohammad Borzoei[4] · Behrouz Tajdar-oranj[5,6] · Van Nam Thai[7] · Nguyen Thi Thuy Linh[8] · Amin Mousavi Khaneghah[9]

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Abstract

The contamination of fresh meat and meat products like sausages with potentially toxic elements (PTEs) is a worldwide health concern. Consequently, the related investigations concerning the levels of PTEs in sausages among databases such as Scopus, Cochrane, and PubMed were investigated 1 January 2000 to 20 August 2020. Furthermore, the concentration of PTEs in sausages was meta-analyzed based on the random effect model (REM). The findings indicated that the rank order of PTEs in sausage was Fe (432.154 μg/kg) > Cu (152.589 μg/kg) > Zn (93.813 μg/kg) > Cr (6.040 μg/kg) > Pb (1.524 μg/kg) > Ni (0.525 μg/kg) > Cd (0.115 μg/kg) > As (0.066 μg/kg). Our results showed that the PTE concentration in sausages was lower than the permitted limit except for Pb in samples reported from Nigeria, China, and Turkey. Therefore, continuous monitoring of PTEs in such products was recommended.

Keywords Potentially toxic metals · Meat · Sausage · Food contamination · Food safety

Introduction

Environmental contamination by potentially toxic elements (PTEs) is a critical issue in most industrialized countries (Sabir et al. 2003; Sobhanardakani 2018). These heavy metals (molecular weight above 3.01E+24 du/cm^3) are released into the environment (air, water, and soil) and consequently can be entered into plants as well as animal and human tissues (predominately liver, bone, and kidneys) (Bazargani-Gilani and Pajohi-Alamoti 2017; Darwish et al. 2015; Raikwar et al. 2008). PTE pollution could result from either natural activities like earth erosion and a volcano or anthropogenic activities, including mining, smelting, wastewater disposal, and pesticides and fertilizers (Ahmad et al. 2020; Fakhri et al. 2019; Raikwar et al. 2008).

PTEs are mainly classified into two main groups: essential and non-essential (toxic) elements (Atamaleki et al. 2020a; Atamaleki et al. 2019; Fakhri et al. 2019; Fakhri et al. 2020;

Responsible Editor: Philippe Garrigues

✉ Van Nam Thai
tv.nam@hutech.edu.vn

[1] Department of Food Safety and Hygiene, School of Health, Fasa University of Medical Sciences, Fasa, Iran

[2] Food Safety and Hygiene Division, Department of Environmental Health Engineering, School of Publish Health, Tehran University of Medical Sciences, Tehran, Iran

[3] Department of Food Science and Nutrition, Faculty of Medicine, Determinants of Health Research Center, Gonabad University of Medical Science, Gonabad, Iran

[4] Food Health Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran

[5] Student Research Committee, Department of Food Science and Technology, Food Science and Technology/National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[6] Halal Research Center of IRI, Food and Drug Administration, Ministry of Health and Medical Education, Tehran, Iran

[7] Ho Chi Minh City University of Technology (HUTECH), 475A, Dien Bien Phu, Ward 25, Binh Thanh District, Ho Chi Minh City, Vietnam

[8] Thuyloi University, 175 Tay Son, Dong Da, Hanoi, Vietnam

[9] Department of Food Science and Nutrition, University of Campinas (UNICAMP), Rua Monteiro Lobato, 80 Caixa Postal: 6121 CEP, São Paulo 13083-862 Campinas, Brazil

Khaneghah et al. 2020; Mostafaii et al. 2020). They are considered toxic due to their bio-accumulative, biomagnifative, non-degradable, and persistent nature in the environment, food chains, and particular body tissues. PTE exposure could result in several adverse effects, vis., DNA damage, apoptosis, and different kinds of cancer (Khan et al. 2015; Oyekunle et al. 2019). Cadmium (Cd), arsenic (As), lead (Pb), and mercury (Hg) are the most critical toxic metals which have detrimental effects on several human's organs particularly the brain, lungs, heart, and kidneys, even in trace amount during long-term exposure (Abedi et al. 2011; Amari et al. 2017; Gaya and Ikechukwu 2016; Khalafalla et al. 2016; Nkansah and Ansah 2014). Cd and Pb can also lead to anemia, blood pressure rise, and cardiovascular diseases (Heshmati et al. 2020; Hoha et al. 2014). Also, Pb, Cd, and Hg can cause disorders in the central nervous system (Halagarda et al. 2018; Logochura et al. 2020). Zinc (Zn), iron (Fe), copper (Cu), and chromium (Cr) are the most crucial essential elements which are necessary for low amounts of human health de Souza et al. (2019). When it comes to these elements, it is worthy to note that they are micronutrients, although they become potentially toxic at considerably high intakes (Khan et al. 2014; Manea et al. 2017; Pleadin et al. 2020; Raikwar et al. 2008). In this regard, Cu and Zn serve as a cofactor in several enzymatic systems and macronutrient metabolism (Raikwar et al. 2008) while, when ingested in higher concentrations, they can cause deficiencies in aging- and heart-related diseases (Nkansah and Ansah 2014).

Thus, the high concentration of PTEs in the environment results in contamination of foods such as meat and meat products despite contributing considerably to human nutrition as an important source of protein, fat, and a variety of micronutrients (vitamins B3, B6, B12, and D; phosphorous, Zn, and Fe) (Nkansah and Ansah 2014; Wafaa Abid and Daoud El-Zubair 2018; Wang et al. 2019). Food ingestion is regarded as the main route of human exposure to PTEs, accounting for about 50% in comparison to other routes of exposure, i.e., inhalation and skin contact (Alturiqi and Albedair 2012; Bortey-Sam et al. 2015; Darwish et al. 2015; Oyekunle et al. 2019; Wafaa Abid and Daoud El-Zubair 2018).

Alterations in socioeconomic level, the trend towards development, and common convenience are among the reasons people consume fast foods like sausages and hams (Oyekunle et al. 2019; Sobhanardakani 2018). Sausages are the oldest and most consumed meat products worldwide (Logochura et al. 2020), which is composed of minced meat (chicken and cow), water, oil, flour, salt, and spices filled in intestine or artificial plastic (Halagarda et al. 2018; Peña-Saldarriaga et al. 2020).

PTEs could make their way into livestock through inhalation, skin contact, and ingestion routes. In this regard, several sources, including contaminated feed, green fodder, veterinary drugs, pesticides, fertilizers, and industrial chemicals, were reported as livestock contamination by PTEs (Zahrana and Hendy 2015). Furthermore, previous studies have reported that PTE contamination could occur in meat products in the course of processing via raw material, water, and additives like spices as well as packaging material, i.e., from farm to fork (Abedi et al. 2011; Bounar et al. 2020; Logochura et al. 2020; Manea et al. 2017). Thus, such products could be a potential source of dietary exposure to PTEs.

However, many investigations have been conducted to measure the PTE's sausages worldwide (Alves et al. 2017; de Souza et al. 2019; Djinovic-Stojanovic et al. 2017; Hoha et al. 2014; Hwang et al. 2011; Oyekunle et al. 2019; Velasco-Reynold et al. 2008); no systematic review study was performed. Hence, in this work, the concentration of PTEs (As, Cr, Cd, Pb, Cu, Zn, Fe, and Ni) in sausages was meta-analyzed on a global scale.

Material and method

Search strategy

Cochrane protocol was applied to a systematic review, and the following selection of articles was performed considering the PRISMA protocol (Fig. 1) (Alipour et al. 2020; Higgins and Green 2011; Liberati et al. 2009). Scopus and PubMed databases were used to retrieve the related articles regarding the concentration of PTEs in sausages from 1 January 2000 to 12 September 2020. Keywords consist of "trace metals," "heavy metals," OR metals OR "toxic metal" OR metal (oid) s OR element AND meat OR "meat products" OR sausages were used. The reference list of articles was screened to find more related articles.

Selection criteria and data extraction

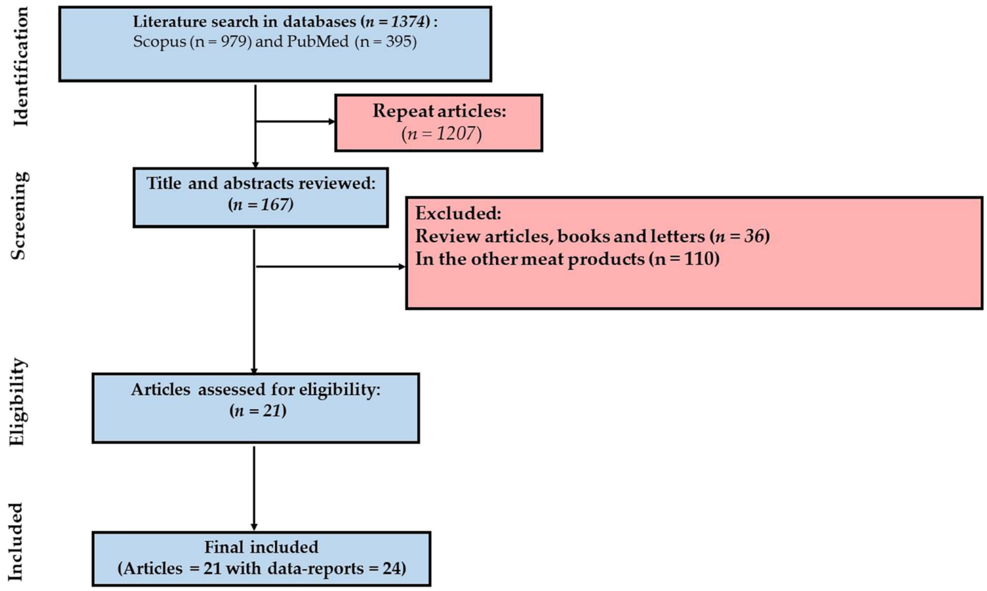
Our inclusion criteria included access to English language full text, descriptive study, reporting the mean or range concentration of PTEs, and available sample size of the sausage. Letters to editors, books, review articles, and conferences were excluded. The country, year of study, sample size, average concentration, standard deviation, and detection method were extracted from retrieved articles.

Meta-analysis of data

A meta-analysis of data was conducted based on the standard error of the concentration of PTEs. Standard error was calculated using Eq. 1:

$$SE = \frac{SD}{\sqrt{n}} \quad (1)$$

Fig. 1 Selection process of articles based on PRISMA



A standard error is defined as SE, standard deviation, SD, and sample size (Peck et al. 2015).

The Chi-square and I^2 indexes were applied to detect heterogeneity. When I^2 is higher than 50%, heterogeneity is high (Higgins et al. 2008; Higgins Thompson 2002; Quan and Zhang 2003); therefore, a random effect model (REM) was used.

Results and discussion

Concentration of PTEs in sausages

Twenty-one articles with 497 sample sizes of sausages were included in the current meta-analysis (Fig. 1, Table 1). The rank order of PTEs in sausages was Fe (432.154 μg/kg) > Cu (152.589 μg/kg) > Zn (93.813 μg/kg) > Cr (6.040 μg/kg) > Pb (1.524 μg/kg) > Ni (0.525 μg/kg) > Cd (0.115 μg/kg) > As (0.066 μg/kg) (Figs. 2, 3, 4, 5, 6, 7, 8, 9). The concentration of essential metals like Fe, Cu, and Zn is much higher than toxic heavy metals like Cd and As. Fe is the most abundant element in the Earth's crust(Atamaleki et al. 2020b). The main reason for the high concentration of Fe in meats and their products is probably the intake of high concentrations of Fe by calves during grazing from soil (Blanco-Penedo et al. 2009). Moreover, Khan et al. (2007) reported that lack of Fe and Zn is unusual in pasturing livestock due to an ordinarily ample level in soils and fodders (Khan et al. 2007). Fe generally exists in the muscle as myoglobin (heme iron). Therefore, meat and meat products are considered a significant Fe source for humans (González Weller et al. 2014; Singh et al. 2016). Living organisms (plants, cattle, and humans) require essential elements, including Fe, Zn, and Cu, for several physiological mechanisms and absorb them selectively from the environment and food. In contrast, toxic heavy metals, including Pb, Cd, and As, play no beneficial role in living organisms and treat an organism's health. Consequently, the rate of toxic metals absorption in the plants and animal bodies from the environment and feed is low, effectively (Ogwok et al. 2014; Zeinali et al. 2019), which confirms lower amounts of sausages compared to essential metals.

To the best of our knowledge, supplementation of feed (for cattle and poultry) with essential elements like Fe, Zn, and Cu is a common approach that verifies the higher amount of these elements in meat products. However, meat products may contain toxic heavy metals in lower concentrations, mainly resulting from the feed, water, litter, and the environment (Korish and Attia 2020).

When it comes to Cu concentration, the fact is that its deficiency in cows is a relatively common condition. Thus, cows' feed is often fortified with elevated Cu amounts, far higher than physiological needs (Blanco-Penedo et al. 2009). Another reason for the high concentration of Cu and Zn could be that leftover Cu and Zn intake, which is not absorbed within the animal body, is excreted through the feces, resulting in Cu Zn-enriched manures. Afterward, using these manures as fertilizers in the grasslands for cattle rearing or hay/fodder manufacture can increase soil Cu and Zn levels and their intake by plants and animals (Blanco-Penedo et al. 2009; Sobhanardakani 2018).

One of the probable reasons for the presence of a higher amount of Pb than other toxic metals in sausages is probably the existence of a higher amount of this element in the feed used for animals on the farm, especially mineral salt compounds (Marçal et al. 2001). Furthermore, Nkansah and Ansah (2014) reported that using Pb-containing ingredients and equipment during sausage production could result in a high Pb concentration in the final product (Nkansah and Ansah 2014).

Table 1 Main characteristics included in our study

Country	Sample size	As±SD (μg/kg)	Cd±SD (μg/kg)	Pb± SD (μg/kg)	Cr± SD (μg/kg)	Ni± SD (μg/kg)	Fe± SD (μg/kg)	Zn± SD (μg/kg)	Cu± SD (μg/kg)	Method of detection	Ref
Brazil	14	NM	NM	47.00±32.00	106.00±47.00	NM	NM	15,100.00 ±2440.00	833.00±346.00	ICP-OES	de Souza et al. (2019)
Nigeria	18	192.00±88.00	433.00±187.00	283.00±121.00	NM	NM	NM	1938.00±750.00	1946.00±1018.00	AAS	(Oyekunle et al. 2019)
Spain	12	NM	NM	NM	NM	NM	NM	NM	2600.00±2200.00	AAS	(Velasco-Reynold et al. 2008)
Portugal	20	0.05±0.02	0.02±0.01	0.17±0.08	NM	NM	NM	NM	NM	AAS	(Alves et al. 2017)
Serbia	14	NM	NM	NM	NM	NM	NM	32.70±8.31	NM	ICP-MS	(Djinovic-Stojanovic et al. 2017)
Romania	12		0.16±0.01	0.82±0.01	NM	NM	NM	38.40±1.03	0.84±0.12	AAS	(Hoha et al. 2014)
South Korea	70	0.02±0.01	0.002±0.001	0.01±0.00	NM	NM	NM	NM	NM	ICP	(Hwang et al. 2011)
Egypt	40	NM	0.04±0.00	0.21±0.03	NM	NM	NM	NM	NM	AAS	(Khalafalla et al. 2016)
Saudi Arabia	13	NM	NM	0.93±0.42	NM	0.28±0.10	16.90±2.54	7.90±1.98	NM	AAS, ICP-A-ES	(Nasser 2015)
Serbia	3	0.04±0.02	0.03±0.02	0.04±0.02	NM	NM	NM	NM	NM	AAS	(Škrbić et al. 2013)
Egypt	20	0.20±0.09	0.11±0.08	0.18±0.13	1.13±0.18	2.22±0.16	135.00±10.48	38.59±2.96	3.45±0.38	ICP-OES	(Zahrana and Hendy 2015)
Portugal	24	0.03±0.13	0.01±0.00	0.05±0.05	NM	NM	NM	NM	NM	AAS	(Ferreira et al. 2006)
Slovakia	83	NM	0.01±0.00	0.11±0.05	NM	NM	NM	NM	NM	AAS	(Golian et al. 2008)
Indonesia	20	NM	0.01±0.02	0.36±0.07	NM	NM	NM	NM	NM	AAS	Harlia and Balia (2010)
India	17	NM	0.24±0.03	1.35±0.26	0.54±0.09	NM	NM	35.72±8.71	0.93±0.14	AAS	(Santhi et al. 2008)
Portugal	5	NM	NM	NM	0.09±0.01	0.08±0.03	197.00±35.60	NM	1.66±0.30	AAS	(Alves et al. 2015)
Portugal	5	NM	NM	NM	0.10±0.01	0.06±0.03	85.40±35.61	NM	1.27±0.30	NM	(Alves et al. 2015)
Serbia	5	NM	NM	NM	0.03±0.02	0.07±0.03	47.40±32.51	NM	2.36±0.25	NM	(Alves et al. 2015)
Serbia	5	NM	NM	NM	0.02±0.02	0.04±0.04	38.90±39.81	NM	1.48±0.30	NM	(Alves et al. 2015)
Serbia	5	NM	0.01±0.01	1.01±0.01	3.05±0.00	0.490.01 ±0.010.00	172.410.01 ±0.010.00	65.55±0.02	110.90±0.01	NM	(Alves et al. 2015)
Iran	30	NM	5.70±2.57	53.50±24.08	NM	NM	5.70±2.57	NM	NM	AAS	(Abedi et al. 2011)
Saudi Arabia	10	NM	3.33±0.17	15.43±1.22	NM	3.33±0.17	242.443.33 ±0.1712.09	65.43±2.06	18.51±0.54	AAS	(Alturiqi and Albedair 2012)
China	19	90.00±28.00	5.90±1.30	154.00±50.00	280.00±0.0.00	200.005.90 ±1.30110.00	537.005.90 ±1.30294.00	20.70±1.20	14.41±2.06	ICP-MS	(Dermience et al. 2014)
Poland	30	NM	2.71±0.87	26.64±9.32	51.63±5.09	2.71±0.87	7800.002.71 ±0.87450.00	2977.00±1600.00	1293.57±182.99	AAS	(Halagarda et al. 2018)
Turkey	3	NM	0.83±0.70	135.00±9.90	95.10±9.00	161.000.83 ±0.7014.00	1564.000.83 ±0.70147.00	600.00±21.00	88.30±2.00	ICP-OES	(Demirezen and Uruç 2006)

NM not measured, *ICP-EOS* inductively coupled plasma-optical emission spectrometry, *AAS* atomic absorption spectroscopy, *ICP-MS* inductively coupled plasma mass spectrometry

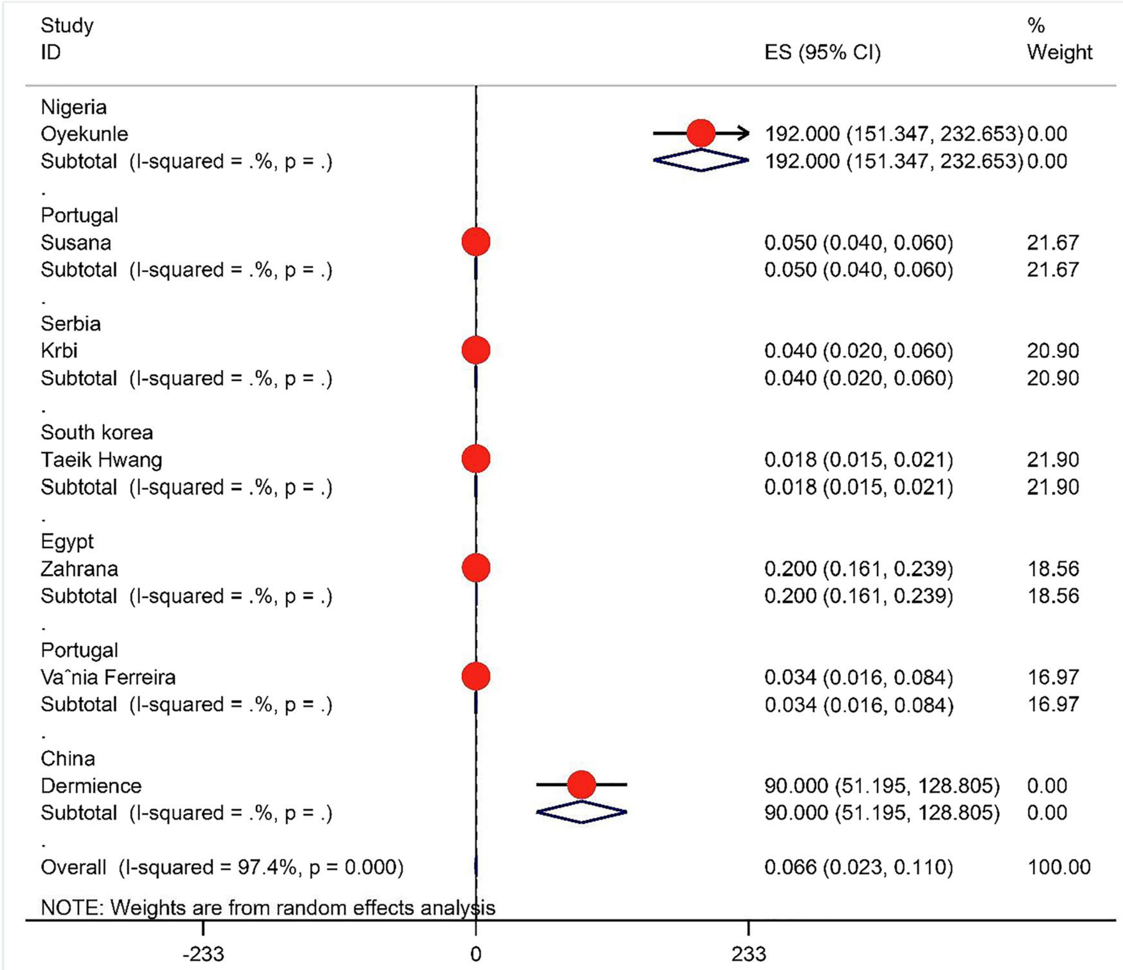


Fig. 2 The meta-analysis of As concentration in sausage (μg/kg). EF: effect size

Korish and Attia (2020) reported that As principally accumulates in the gizzards and the liver, and its accumulation in meat is low (Korish and Attia 2020). Therefore, it could be a possible reason for lower As in the sausages than other elements (Khaneghah et al. 2020). Moreover, Cd absorption is relatively low (about 3 to 5%), and its significant part is efficiently accumulated in the kidney and liver compared to muscle in animals and the human body after food ingestion (Zahrana and Hendy 2015). Therefore, Cd concentration in sausage is the lowest heavy metals, except inorganic As.

Generally, the concentration of PTEs in meat and meat products like sausages relates to factors including the environmental situations (dose of PTEs), the kind of fodder, and the animal's genetic properties. Technical processing is also essential for PTE concentration in this product (Abedi et al. 2011). In some cases, as the grounding machine is damaged, the leaching of heavy metals like Cu and Fe into the meat occurs during the processing (Logochura et al. 2020). Manea et al. (2017) noted that the concentrations of several PTEs in meat products manufactured by conventional methods were higher than those produced by traditional methods, probably due to the application of additives and water containing these metals (Manea et al. 2017).

As noted previously, contamination of sausages with PTEs can occur throughout the handling, transport, processing of meats, contact with equipment and containers, storage, and packaging, actually from land to table (Khalafalla et al. 2016). Several studies indicated that the PTE concentrations are higher in the sausages than in the initial meat used in their production, probably due to the high contamination of the meat processing spices (Gaya and Ikechukwu 2016; Hoha et al. 2014). Ways of pollution by PTEs are altered from one metal to another and most associated with the kind of soil, environmental contamination, animal species, feeds, and the geographic area (Korish and Attia 2020; Singh et al. 2016).

The primary sources of sausages' contamination with PTEs are a mineral presence in commercial feeds for animal diet and spices added to these products (Hoha et al. 2014). Undesirably, considerable amounts of PTEs have been found in the spices like pepper (black and red), turmeric, mint, cinnamon, and mustard (Bazargani-Gilani and Pajohi-Alamoti 2017). It should bear in mind that the accumulation of PTEs in the spices

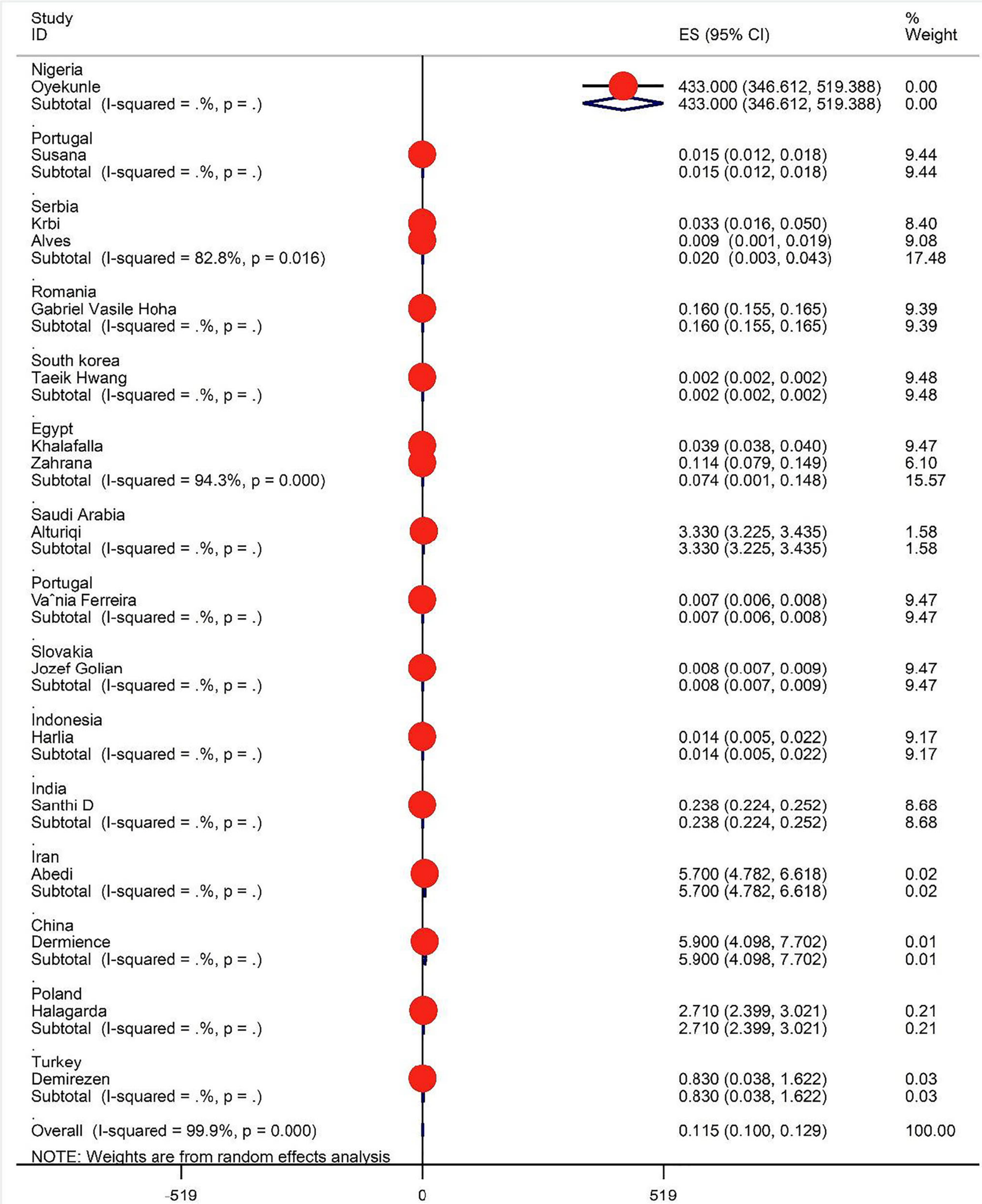


Fig. 3 The meta-analysis of Cd concentration in sausage (μg/kg). EF: effect size

depends on the type of plant (Bazargani-Gilani and Pajohi-Alamoti 2017; Gaya and Ikechukwu 2016; Khan et al. 2014).

PTE concentration in animals is also tissues related. For example, Darwish et al. (2015) reported that cattle and sheep

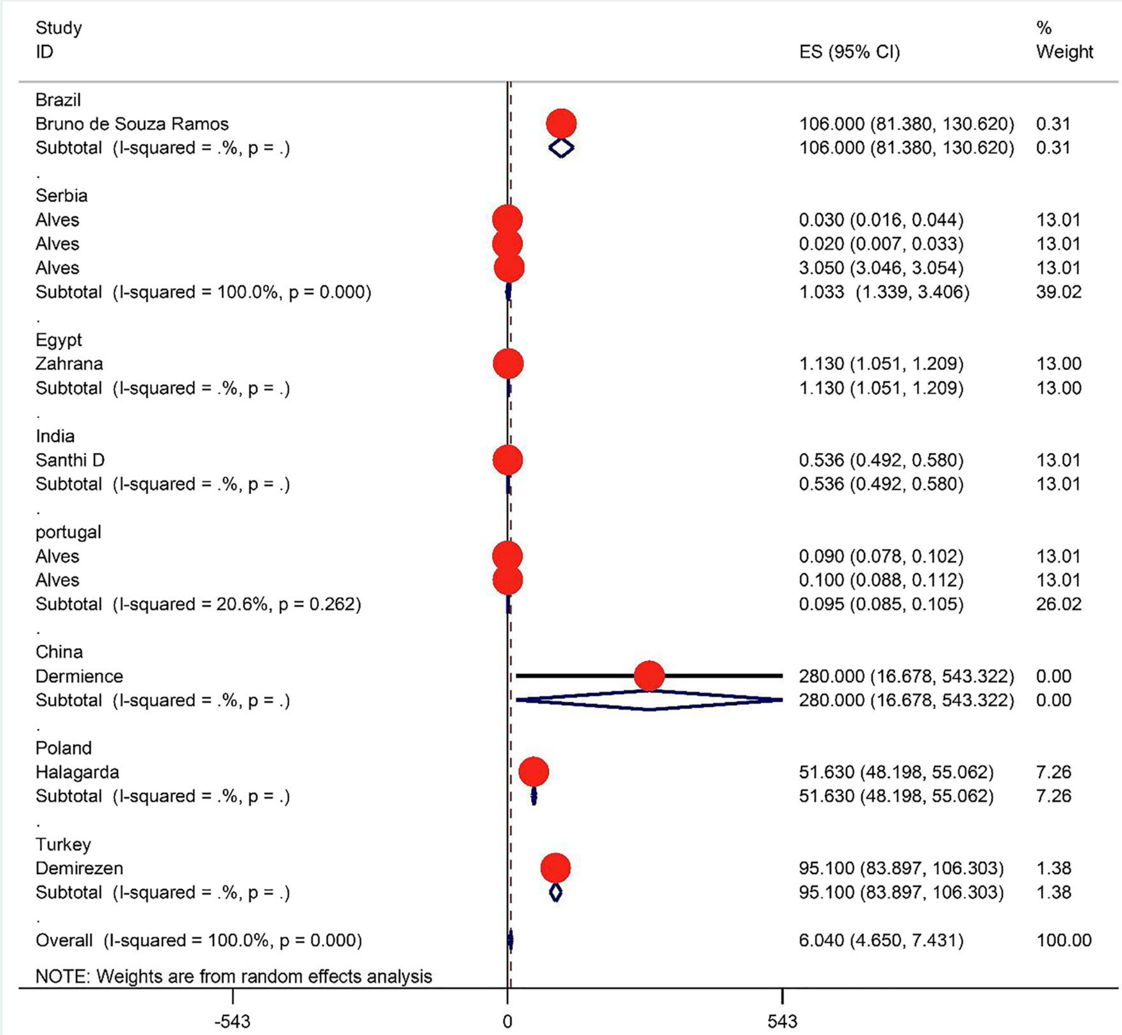


Fig. 4 The meta-analysis of Cr concentration in sausage (μg/kg). EF: effect size

muscle had a lower amount of toxic metals than that in the liver and kidneys (Darwish et al. 2015). Furthermore, Korish and Attia (2020) reported that the liver had the highest concentrations of PTEs, except for Cr and Ni (Korish and Attia 2020). As shown in the results, the Cd concentration in sausages is low because Cd accumulates in the animals' kidneys due to free protein-thiol groups in the kidneys' texture (Bortey-Sam et al. 2015).

Age is also an important factor influencing PTE accumulation in animals (Darwish et al. 2015). It is reported that Cd levels in the meat of older animals are more significant than that in younger ones and also depend on its levels in the feed (Alturiqi and Albedair 2012; Hoha et al. 2014; Sathyamoorthy et al. 2016).

The concentration of different PTEs in meat also depends on the type of meat. For instance, Alturiqi and Albedair (2012) noticed that Fe levels in the chicken and camel meats were considerably higher than those in the other meats, while the highest Zn levels were found in sheep meat (Alturiqi and Albedair 2012). Humaeda and Ahmed (2108) also found a difference in Fe concentration among several species although the Fe level in the same kind of meat product may differ probably due to the age of the animal used for meat, the feed of the animal, and agricultural practices (Humaeda and Ahmed 2018). Wafaa Abid and Daoud El-Zubair (2018) reported that beef sausages had a higher Ni level than goat and camel sausages (Wafaa Abid and Daoud El-Zubair 2018).

The season is also another factor affecting PTEs' concentration in meat and meat products. For instance, Zeinali et al. (2019) reported that the concentration of PTEs in cattle was compared during the summer and winter seasons (Zeinali et al. 2019). For instance, Ni concentration in plants also alters in different seasons so that its level is lower in summer than in spring and autumn (Manea et al. 2017).

There are considerable differences in the concentrations of the PTEs in sausages of different countries (Abedi et al. 2011). The meat contamination generally depends on the nature, place, and environment of an animal, dietary habits,

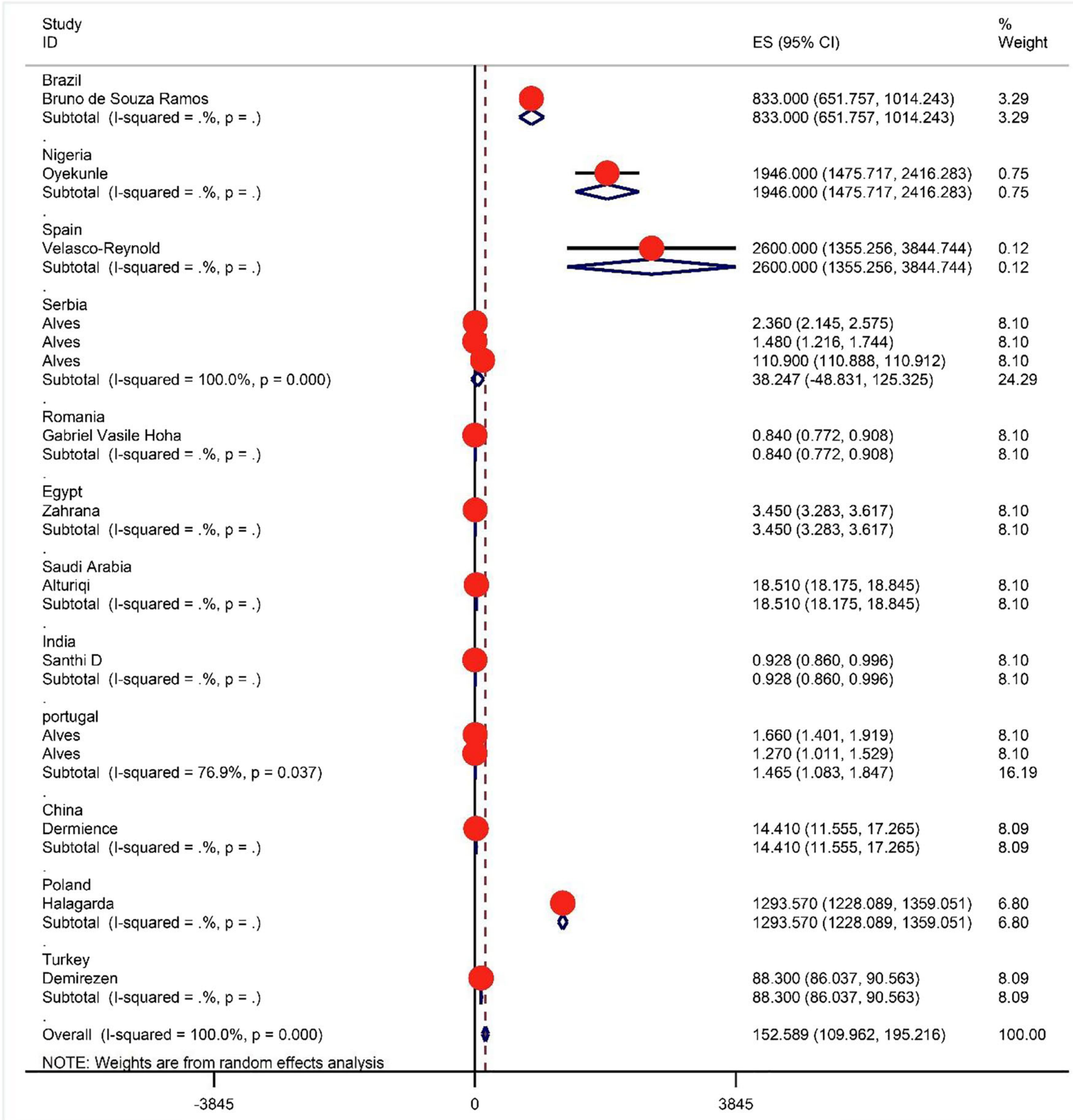


Fig. 5 The meta-analysis of Cu concentration in sausage (μg/kg). EF: effect size

butchering, shipping conditions, and contact period with animals' dust and age. Furthermore, these differences could be associated with processing approaches, the kind and level of meat, spices, gluten, starch, ice, oil, salt, and other fillers and seasonings (Khan et al. 2015).

In the case of plants, it is also observed that growing in lands with raised soil pollutions increased PTE uptake, thus affecting their concentration in the meat of animals pasturing in such lands (Ahmadi et al. 2019). For example, higher amounts of PTEs in some meat products of a distinct area may occur because of the pasturing cattle on the polluted soil by fertilizers and insecticides containing heavy metals and feeding animals by contaminated diet (Sabir et al. 2003).

The agricultural practices employed in meat product manufacturing will be a critical factor in the level of the PTEs in sausages analyzed in different studies de Souza et al. (2019). In this regard, one study by Sathyamoorthy et al. (2016) revealed a high concentration of PTEs in the cattle fed contaminated fodder and drunk the sewage water (Sathyamoorthy et al. 2016). The high PTE concentrations in the sausages can also result from applying agrochemicals (pesticides and fertilizers) in farming land and rainwater precipitation on the plants (Sathyamoorthy et al. 2016). According to Halagarda et al. (2018) study, it should note that differences in the concentrations of PTEs in the sausages from different studies may be ascribed to differences in their content in animal meats as a result of the incidence of these natural metals in the soil, influencing the nutrition of animals and consequently the meat components (Halagarda et al. 2018). It is worth mentioning that different species and forage plants

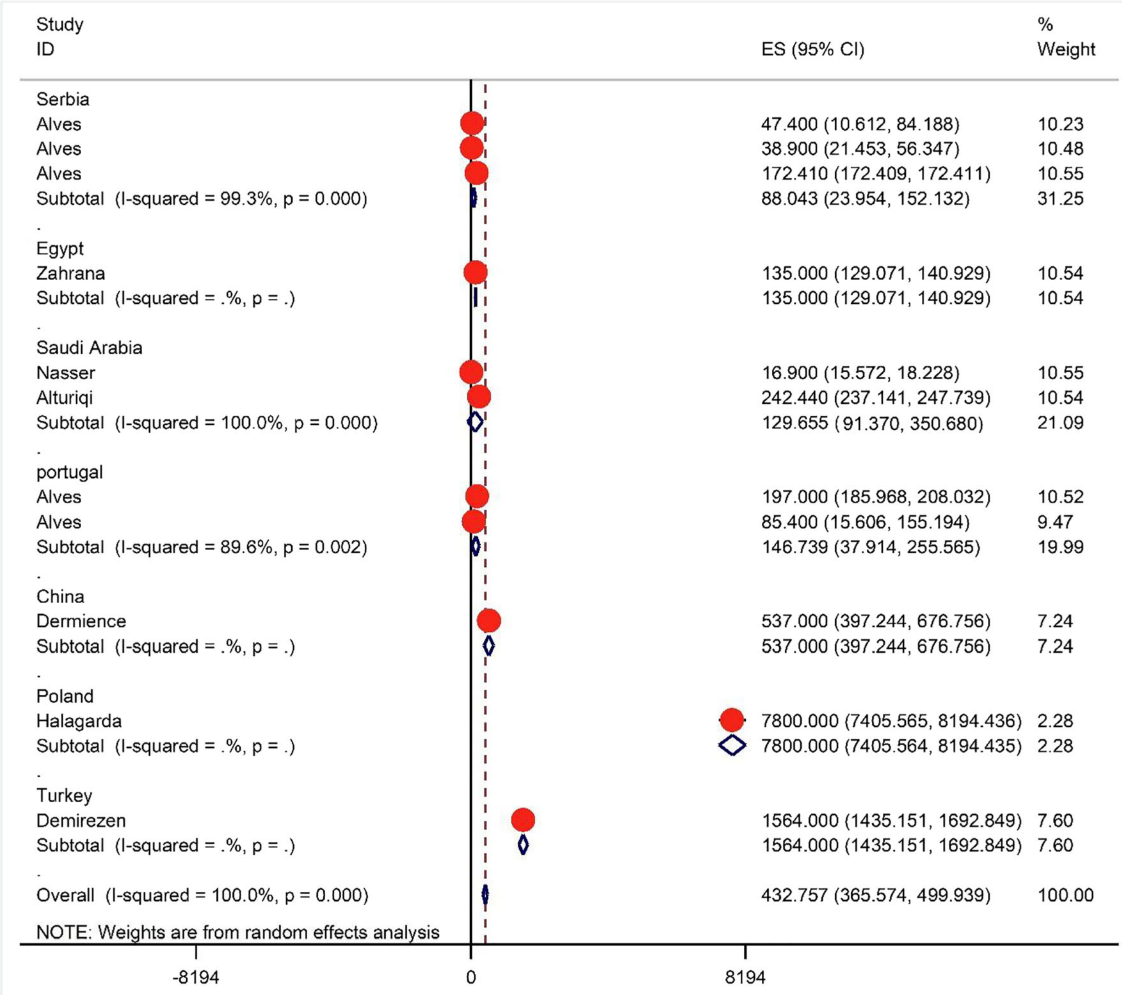


Fig. 6 The meta-analysis of Fe concentration in sausage (μg/kg). EF: effect size

have different selectivity of PTE absorption from the soil, resulting in different metallic levels in plants and animals used for sausage production (Sathyamoorthy et al. 2016).

Wafaa Abid and Daoud El-Zubair (2018) suggested that the absence of Pb and As in the investigated samples may be determined because raw meat and sausages' additives were free of these elements. Furthermore, the lower presence of Ni, Cr, Cu, Fe, and Zn might be because of the lower level of these metals in grazing fodders (Wafaa Abid and Daoud El-Zubair 2018). Moreover, Goswami and Mazumdar (2014) reported relatively considerable Pb contents in some spices, probably resulting from uptake through air contamination, distribution course, and some pesticides, including Pb, used during farming (Goswami and Mazumdar 2014). Blanco-Penedo et al. (2209) found that the Cu concentrations in calves' bodies from different farms were altered considerably, mainly due to different ratios of materials that cattle were fed (concentrate or forage). In this regard, they observed that the Cu concentration in concentrate was much higher than that in the forage, which can probably be generalized to other heavy metals (Blanco-Penedo et al. 2009).

Sathyamoorthy et al. (2016) also mentioned that PTE pollution of plants and animals from industrial parts and close to highways was greater than that in plants from farming lands (Sathyamoorthy et al. 2016). PTE concentrations are lower in natural environments than those in large cities or industrial regions (Logochura et al. 2020). Wang et al. (2019) also reported that in some areas like Mongolia, Shaanxi provinces, and Qinghai-Tibet Plateau city, increasing urbanization, discharge of industrial wastewater, metal-containing pesticides, and fertilizers could result in soil contamination with PTEs and subsequent contamination of meat products (Wang et al. 2019). The high concentration of toxic heavy metals in some samples probably results from unsuitable processing (pollution) or food manufacturing in polluted areas (Halagarda et al. 2018). Moreover, Roggeman et al. (2014) also observed a higher Cd and Pb concentration in cows' tissues from contaminated areas than cleaner areas.

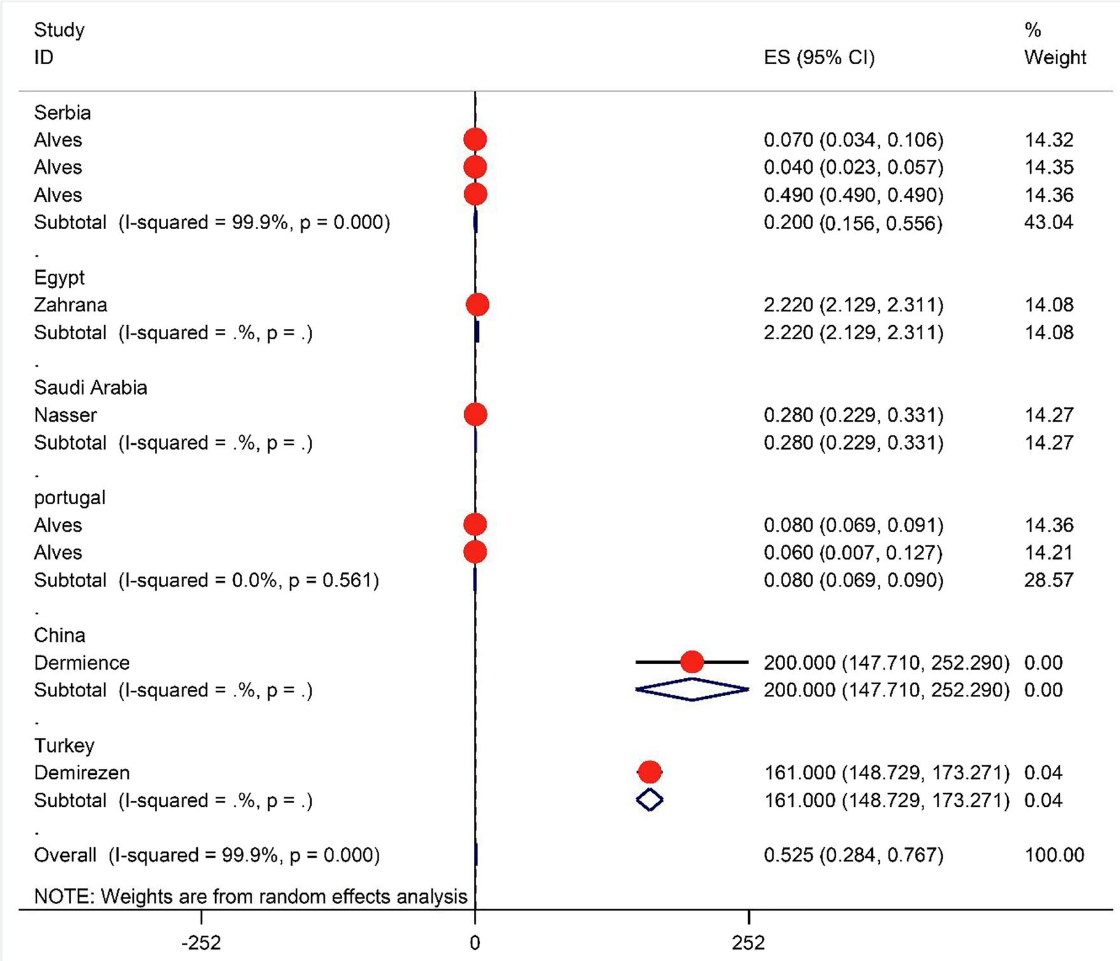


Fig. 7 The meta-analysis of Ni concentration in sausage (μg/kg). EF: effect size

Furthermore, their results showed that Galloways accumulate more PTEs than dairy cows due to the differences in cattle breeds' grazing and nutrition (Roggeman et al. 2014).

In some countries, the concentration of PTEs may be declined by better selecting raw material, further controlling and processing ingredients and raw material (Abedi et al. 2011). For instance, Logochura et al. (2020) observed that the concentrations of Pb in sausages from the Tamale metropolis were lower than detectable levels because the animals applied for the sausages' production may probably do not expose to water, feed, and air polluted by Pb before the production process (Logochura et al. 2020).

Turning to additives used in sausage production, applying different spices with different backgrounds in sausage production may also result in divergences in PTE concentration in samples investigated in different countries (Sathyamoorthy et al. 2016).

The type of sausages investigated in different studies is also a vital factor influential in PTE concentration. In this sense, Djinovic-Stojanovic et al. (2017) suggested that pork products are better sources of Zn than chicken meat products (Djinovic-Stojanovic et al. 2017).

Concentration of Cd

The ranking of total Cd concentrations (μg/kg) in sausage based on the countries studied was Nigeria (433.000 μg/kg) > China (5.900 μg/kg) > Iran (5.700 μg/kg) > Saudi Arabia (3.330 μg/kg) > Poland (2.710 μg/kg) > Turkey (0.830 μg/kg)> India (0.238 μg/kg) > Romania (0.160 μg/kg) > Egypt (0.074 μg/kg) > Serbia (0.020) > Indonesia (0.014 μg/kg) > Portugal (0.011 μg/kg) > Slovakia (0.008 μg/kg) > South Korea (0.002 μg/kg), respectively.

The maximum cadmium content in meat was 500 μg/kg by FAO (FAO 2002). Our result showed that Cd concentration in sausages from all investigated countries was less than the permitted level.

Cadmium has no biological role, and it is one of the most important toxic metals that cause kidney and skeletal damages and different kinds of cancer (group 1 human carcinogens)

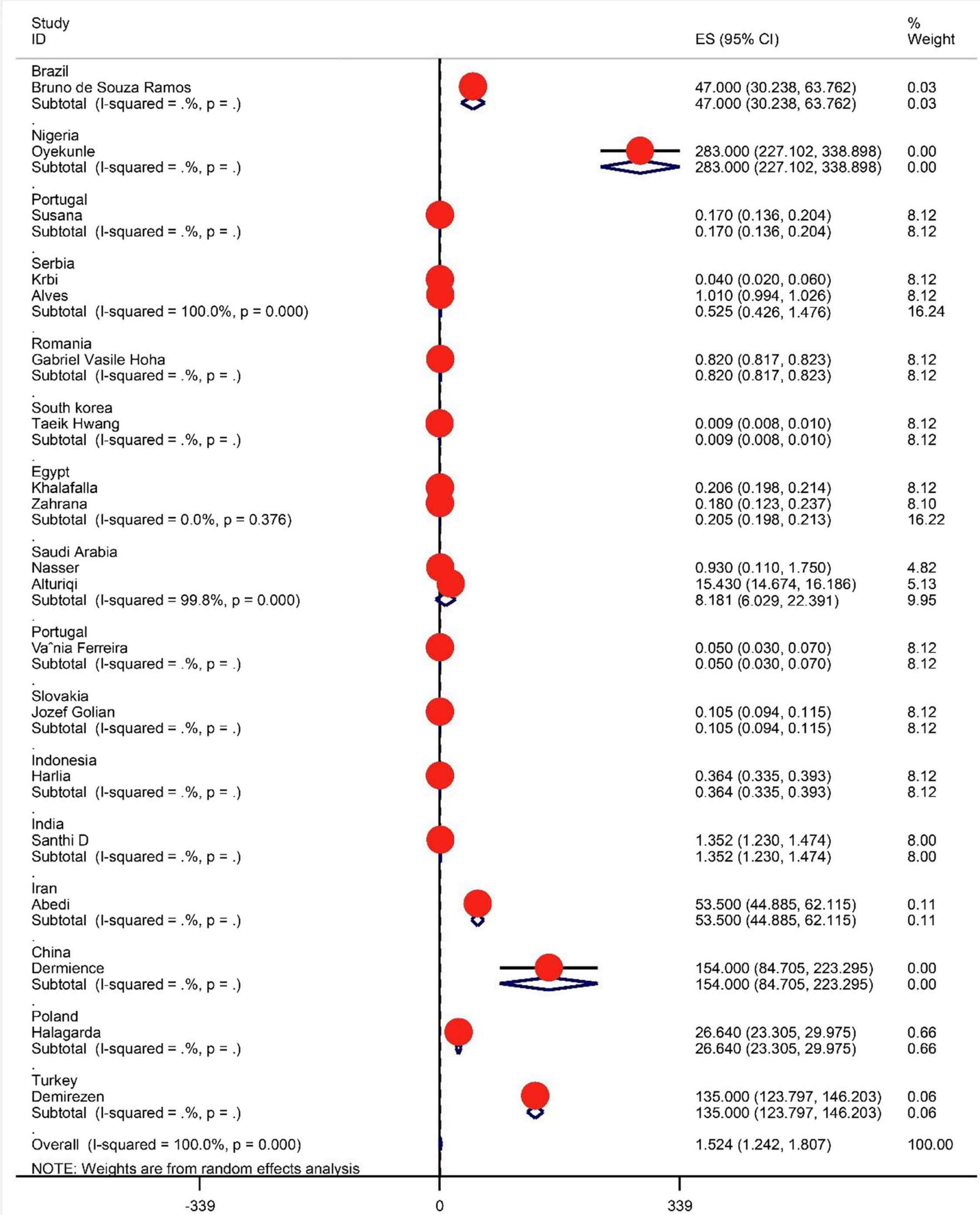


Fig. 8 The meta-analysis of Pb concentration in sausage (μg/kg). EF: effect size

(Nkansah and Ansah 2014; Zahrana and Hendy 2015). It is also a reproductive and embryonic toxin (Oyekunle et al. 2019).

Cadmium is present in low quantities in the Earth's crust (Korish and Attia 2020). It is also released from industrial activities like mining and smelting as well as electronic, plastic, and paint factories and agricultural practices like using chemical fertilizers and wastewater into the air and water and subsequently absorbed by plants and other organisms (Bortey-Sam et al. 2015; Humaeda and Ahmed 2018; Korish and Attia 2020; Nkansah and Ansah 2014; Zahrana and Hendy 2015). Furthermore, contamination of sausage formulation by Cd resulted from the application of spices, the production procedure, the apparatus applied during the process and packaging materials, and the storage of raw materials and the final product, which are other sources of Cd presence in meat products (Khalafalla et al. 2016).

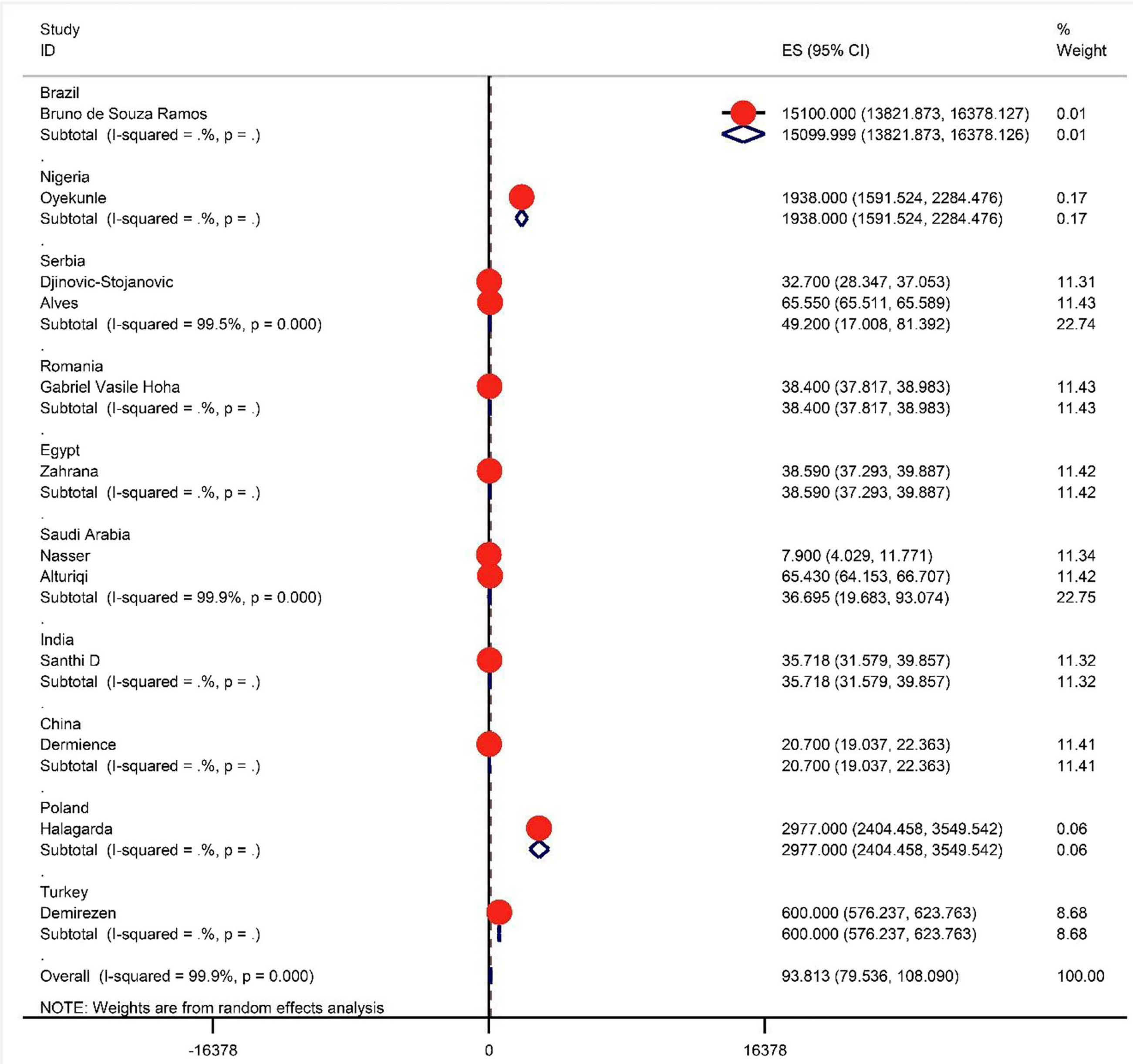


Fig. 9 The meta-analysis of concentration Zn in sausage (μg/kg). EF: effect size

Concentration of Pb

Pb could bind to several essential enzymes and other cellular compounds as a metabolic toxin and inactivates them (Khalafalla et al. 2016). Furthermore, lead is well known to provoke lowered cognitive growth and intellectual function in children and high blood pressure and other heart-related diseases in adults (Hoha et al. 2014; Manea et al. 2017). The United State Environmental Protection Agency (USEPA) has also classified Pb as a possible human carcinogen (category 2B) (Oyekunle et al. 2019). Pb is a toxic heavy metal without any known essential or useful impact on living organisms and its bioaccumulation in the human body can cause serious diseases during life time (Nkansah and Ansah 2014). The rank of Pb concentration in sausage was the following: Nigeria (283.000 μg/kg) > China (154.000 μg/kg) > Turkey (135.000 μg/kg) > Iran (53.500 μg/kg) > Brazil (47.000) > Poland(26.640 μg/kg) > Saudi Arabia (8.181 μg/kg) > India (1.352 μg/kg) > Romania(0.820 μg/kg) > Serbia(0.525 μg/kg) > Indonesia(0.364 μg/kg) > Egypt (0.205 μg/kg) > Portugal (0.109 μg/kg) > Slovakia (0.105 μg/kg) > South Korea (0.009 μg/kg), respectively.

WHO has set Pb's tolerable limit in meat products as 100 μg/kg (Nkansah and Ansah 2014). Pb concentration in sausages was lower than the permitted limit except in Nigeria, China, and Turkey. Pb may release into the environment through industrial applications, including refining, mining, smelting, production approaches, and Pb's application containing products like Pb containing fertilizers and pesticides (Goswami and Mazumdar 2014; Korish and Attia 2020). Generally, the source of lead contamination of cattle and poultry is the air, water, and feed (Nkansah and Ansah 2014). For instance, Humaeda and Ahmed (2018) reported that lead existence in meat products might result from Pb-contaminated forage or animal feeds (Humaeda and Ahmed 2018). Moreover, the application of spices in the sausage production and the leakage of substantial amounts of Pb from the equipment into the final product are considered additional sources (Khalafalla et al. 2016; Zahrana and Hendy 2015).

Concentration of As

The rank order of As was Nigeria (192.000 μg/kg) > China (90.000 μg/kg) > Egypt (0.200 μg/kg) > Portugal (0.049 μg/kg) > Serbia (0.040 μg/kg) > South Korea (0.018 μg/kg). The maximum permitted levels of As in meat and meat products are determined as 500 μg/kg by FAO (Oyekunle et al. 2019). According to the present study, concentration in all studied sausages was lower than the maximum level.

Arsenic is a toxic metal and not necessary for the life of humans (Püssa 2013). Inorganic As contains 65–70% of the total As in the red meat and can hurt the central and peripheral nervous system, heart, liver, and gastrointestinal tract functions (Korish and Attia 2020; Püssa 2013). It also can restrict chromosomes and the hematopoiesis systems (Püssa 2013). Furthermore, chronic exposure to As can lead to various kinds of cancer in the skin, lungs, and lymph glands (Oyekunle et al. 2019).

Arsenic may reach meat and meat products by several routes, including plants cultivating in naturally As-rich soil, water, and soil industrially contaminated with As (resulted from chemical and glass industries, mining, pesticides, insecticides, fossil fuels), supplements, and drugs containing As used in cattle production as well as processing procedures (Humaeda and Ahmed 2018; Nkansah and Ansah 2014; Püssa 2013).

Concentration of Ni

The rank order of Ni was China (200.000 μg/kg) > Turkey (161.000 μg/kg) > Egypt (2.220 μg/kg) > Saudi Arabia (0.280 μg/kg) > Serbia (0.200 μg/kg) > Portugal (0.080 μg/kg). According to FAO, the standard value determined for Ni in food is 5000 μg/kg (FAO 2002). Ni concentration in the sausages of all countries was under legal limit.

As an essential element, Ni can prevent anemia, regulate prolactin, and stabilize RNA and DNA structures in the body (Bazargani-Gilani and Pajohi-Alamoti 2017; Zahrana and Hendy 2015). However, its excessive intake can trigger cancer, respiratory drawbacks, and allergic reactions (Manea et al. 2017; Sathyamoorthy et al. 2016).

The contamination of meat with Ni results from pasturing cattle in polluted grass and cultivating plants and/or feeds in Ni-rich soils (Korish and Attia 2020). Environmental contamination by this trace element results from Ni producing and processing industries like petroleum factories (Humaeda and Ahmed 2018; Sabir et al. 2003).

Concentration of Cr

The rank order of Cr was China (280.000 μg/kg) > Brazil (106.000 μg/kg) > Turkey (95.100 μg/kg) > Poland (51.630 μg/kg) > Egypt (1.130 μg/kg) > Serbia (1.033 μg/kg) > India (0.536 μg/kg) > Portugal (0.095 μg/kg). The results of present study showed that Cr concentration in sausages of all countries were lower than permissible level.

Food is the most important source of chromium exposure by a human (Zahrana and Hendy 2015). Cr (III) is essential for human health with the increased tolerance to excessive glucose intake and metabolism of fat and protein in small amounts. However, Cr (VI) is carcinogenic and can damage biological regularities (Demirezen and Uruç 2006; Gaya and Ikechukwu 2016; Zahrana and Hendy 2015).

Cr present in dust and the use of farming technologies, including fertilizers and sewage and wastewater treatment in irrigation, have led to Cr release into nature, which finally enters into the meat and meat products (Korish and Attia 2020). Tolerable Cr in meat levels is 1000 μg/kg (de Souza et al. 2019; Humaeda and Ahmed 2018).

Concentration of Zn

Zn level of various countries was Brazil (15,000.000 μg/kg) > Poland (2977.000 μg/kg) > Nigeria (1938.000 μg/kg) > Turkey (600.000 μg/kg) > Serbia (49.200 μg/kg) > Egypt (38.590 μg/kg) > Romania (38.400 μg/kg) > Saudi Arabia (36.695 μg/kg) > India (35.718 μg/kg) > China (20.700 μg/kg) respectively. The upper allowable limit of Zn in meat products is 50 mg/kg (Hoha et al. 2014; Manea et al. 2017; Sobhanardakani 2018). Zn level in all sausages from different countries was below the allowed level. The main reason for Zn's presence in the meats and their products is soil, grasses, and animal feed supplementation with a high amount of Zn (Blanco-Penedo et al. 2009).

Zn is essential for good health and is the cofactors of numerous enzymes (over 300) (Zahrana and Hendy 2015). Zink deficiency has been associated with increased prostate swelling and cancer in the human body (Djinovic-Stojanovic et al. 2017; Oyekunle et al. 2019). Although Zn is essential for human health, the overload intake can result in some health problems, particularly gastrointestinal disorders, including nausea, vomiting, abdominal pain, cramps, and diarrhea (González Weller et al. 2014; Zahrana and Hendy 2015).

Concentration of Cu

Cu concentration in sausage was variable: Spain (2600.000 μg/kg) > Nigeria (1946.000 μg/kg) > Poland (1293.570 μg/kg) > Brazil (833.000 μg/kg) > Turkey (88.300 μg/kg) > Serbia (38.247 μg/kg) > Saudi Arabia (18.510 μg/kg) > China (14.410 μg/kg) > Egypt (3.450 μg/kg) > Portugal (1.465 μg/kg) > India (0.928 μg/kg) > Romania (0.840 μg/kg).

The maximum permitted Cu established by FAO and EC in meat products is 3000 μg/kg (Hoha et al. 2014). Cu concentration in the sausage of all countries was lower than the permitted level.

Cu is the cofactor in several enzymes, and it plays a vital role in bone structure, skeletal mineralization, and keeping the wholeness of the connective tissues (Humaeda and Ahmed 2018; Oyekunle et al. 2019). It serves as an antioxidant agent in the body, removes free reactive radicals, and prevents cell structure damage at moderate consumption (Zahrana and Hendy 2015). Although Cu is essential for human health, very high intakes negatively affect the main body organs' functions (like the brain, liver, and kidneys) (Alturiqi and Albedair 2012; Korish and Attia 2020; Zahrana and Hendy 2015).

The primary sources of copper in sausages could be industrial aerosols, contaminated feed, raw materials, and transport (Sobhanardakani 2018). Furthermore, the weathering of Cu-containing composites in pipes and processing equipment may add a high copper level into the water, meat, and finally processed meats (Sabir et al. 2003).

Concentration of Fe

The range order of Fe concentration in the sausages in different countries was the following: Poland (7800.000 μg/kg) > Turkey (1564.000 μg/kg) > China (537.000 μg/kg) > Portugal (146.739 μg/kg) > Egypt (135.000 μg/kg) > Saudi Arabia (129.655 μg/kg) > Serbia (88.043 μg/kg). Fe in all studied sausages was much lower than the permissible limit of iron in the food (30,000 to 150,000 μg/kg) (Ogwok et al. 2014).

Iron is an essential micronutrient. It is the most crucial element for creating blood cells within the body, and its deficiency causes anemia (Demirezen and Uruç 2006). Fe is present in hemoglobin and myoglobin, with an essential role in conveying oxygen throughout the human body (Bazargani-Gilani and Pajohi-Alamoti 2017). Fe also plays a vital role in macronutrient metabolism and xenobiotics' detoxification as the main part of oxidases like cytochrome P450 (Korish and Attia 2020; Mubeen et al. 2009). Iron overload may increase the risk of liver and heart diseases (Logochura et al. 2020) although the problems associated with a high Fe intake in the body are far lower than its deficiency (González Weller et al. 2014). Iron is the fourth most plentiful metal in the Earth's crust. The main route for Fe entrance into the meats and their products is soil, grasses, and supplementation of animal feeds with iron (Blanco-Penedo et al. 2009).

Conclusion

The present study was conducted to explain all studies on the concentration of PTEs, including inorganic As, Cr, Cd, Pb, Cu, Zn, Fe, and Ni in sausages. The concentration of PTEs was meta-analyzed in different countries. The sort of PTEs in the sausages based on their concentration was Fe > Cu > Zn > Cr > Pb > Ni > Cd > As. The main reasons for PTEs' presence in sausage are probably commercial feeds used in animal diets and spices used in the formulation. Although PTE concentration in sausages was lower than the permitted limit except for Pb in Nigeria, China, and Turkey, due to the increases in per capita consumption of meat products and also increasing sources of PTE contaminants, it is recommended to continuously monitoring the chemical quality of sausages as one of the most popular meat products.

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Data availability Data openly available in a public repository

Declarations

Ethics approval Ethical approval was approved by the Hormozgan University of medical sciences Ethics Committee (#IR.HUMS.REC.1546).

Consent to participate Not applicable.

Consent to publish Not applicable.

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