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The Level of Heavy Metal in Fresh and Processed Fruits: A Study Meta-analysis, Systematic Review, and Health Risk Assessment

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Abstract
Intake of fruits is important for health. However, it can be a contamination source of potentially toxic elements (PTEs). The present study aimed to investigate the concentration of PTEs such as arsenic (As), lead (Pb), cadmium (Cd), copper (Cu), nickel (Ni), and Iron (Fe) in various fresh and processed fruits. All the studies related to the concentration of PTEs in fresh and processed fruits by international databases including were included and non-carcinogenic risks assessment was evaluated based on the total hazard quotient (TTHQ). According to findings highest concentrations of As, Cd and Pb were observed in pineapple, mango, and cherry, while the lowest concentrations of these metals were found in berries, pineapple, and berries. Regarding trace elements, peach and cucumber represented the highest and lowest concentrations of Fe, respectively. Moreover, the highest and lowest concentrations of Cu were related to plum and banana, respectively. Considering the type of continents, the highest concentrations of As, Cd, Pb, Fe, Ni, and Cu among fresh and processed fruits belonged to Pan American Health Organization (EMRO), EMRO, African Region (AFRO), European Region (EURO), AFRO, and Western Pacific Region (SEARO). Eventually, the non-carcinogenic risk assessment of the heavy metal in fresh and processed fruits indicated that the risk pattern was different in various countries and the calculated TTHQ level in infants was below 1. Overall, the consumption of fresh and processed fruits is safe and does not pose a risk to the health of consumers.

Keywords Fresh and processed fruits · Meta-analysis · PTEs · Risk assessment

Introduction

Nutrition security is one of the main global concerns in the last decades. The Ministry of Health has suggested a healthy diet, including different fruits and vegetables abundantly [1]. A fruit-enriched diet in addition to being the main source of essential vitamins, trace elements, fiber, and antioxidants has a vital role in human nutritional health [2, 3]. It also acts as a neutralizing agent for acidic substances formed during digestion [4]. According to the estimations of the World Health Organization (WHO), the daily consumption of 400 g of fruits and vegetables is recommended for human health [5]. The American dietary guidelines recommend five servings of fruits and vegetables per day based on an intake of 2000 cal [6]. Moreover, daily consumption of fruit reduces the risks of diabetes, ischemic heart disease, obesity, stroke, hypertension, and also cancers of the colorectal gastric, lung, and esophageal body [7, 8]. Despite the undoubted health benefits of fruits in a food diet, these compounds may be contaminated by mycotoxins, pesticides, and toxic metals [9, 10]. Potentially toxic

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elements (PTEs) such as toxic metals and trace elements are substances that naturally exist in nature. Human activities (industrialization and urbanization) can change their concentrations, thus leading to harmful impacts on human health [11, 12]. Contamination induced by toxic metals can occur through anthropogenic activities (volcanic activities, traffic density, mines, motor vehicles, pesticides, and fertilizers) and other remarkable sources (closeness to highways and irrigation with contaminated water) [2, 13–15]. Due to the biodegradable, thermostable, and long biological half-lives of metals, they are prone to accumulation in the different body organs of fruits, which lead to various unwanted side effects on health if consumed by humans and animals [16]. In order to confirm the health of fruits by consumers, different guidelines have been set by some countries for assessing the concentration of toxic metals in different food products [17]. Based on previous studies, metals such as Cu, Ni, and Zn are considered essential for human health. However, As, Pb, and Cd were identified as toxic or non-essential metals causing nutritional problems and serious risks to health [4]. The toxicity of metals is different based on the type, intensity, duration, frequency, and exposure routes to metals [18]. The occurrence of toxic elements in different fruit can cause problems for health. Diarrhea, vomiting, sleep disturbances, dizziness, and loss of appetite are the symptoms of heavy metal poisoning. Heavy metals can cause neurological and immune system disorders, cardiovascular disease, decreased fertility, and increased abortion [19]. Exposure to high concentrations of Pb can disturb kidneys, red blood cells, reproductive systems, and the central nervous system; thus, the memory disorder and delays in response times [9]. Furthermore, Cd can damage the lung and kidney tissue [2]. Long chronic exposure to zinc can result in impairment and disruption of protein metabolism and arteriosclerosis. Brain damage, iron deficiency, and destruction of membranes cells are the well-known side effects of the elevated levels of copper [20]. It is reported that exposure to a higher level of nickel can also lead to the deficiency of Zn or Fe and enzymes malfunctioning [21]. In recent years, there have been several reports on different metal contamination in fruits. For example, Bagdatlioglu et al. reported the concentration of Fe, Cu, Zn, Pb, and Cd in samples of Turkey as 0.56 to 329.7, 0.01 to 5.67, 0.26 to 30.68, 0.001 to 0.97, and 0 to 0.06 l mg/kg, respectively [21]. Elbagermi et al. indicated the level of Pb, Cu, Zn, Co, Ni, and Cd in samples of Libya as 0.02 to 1.824, 0.75 to 6.21, 0.042 to 11.4, 0.141 to 1.168, 0.19 to 5.143, and 0.01 to 0.362 mg/kg, respectively [22]. In another similar study, Pb, Cd, Cu, Zn, Co, and Ni were identified in samples of Nigeria within the range of 0.072 to 0.128, 0.003 to 0.005, 0.002 to 0.015, 0.039 to 0.082, 0.014 to 0.026, and 0.070 to 0.137 mg/kg, respectively [23]. Meta-analysis is a new technique for merging the data obtained from preliminary research. Recently, this technique has been used in food safety, particularly in the evaluation of the overall concentration of different contaminants such as toxic metals in food to measure the health risk [24]. Considering the importance of the presence of metals in the fruits, and their side effects on health, it is needed to investigate their levels in these products as a quality factor. To date, no meta-analysis and review systematic have assessed the content of metals and their probabilistic health risk for health. Therefore, the present study aimed to evaluate the concentration and the non-carcinogenic risks of PTEs (Cd, Pb, As, Cu, Fe, and Ni) in various fresh and processed fruits (apple, cherry, banana, grape, peach, pineapple, berries, citrus, cucumber, mango, and plum & prune) using review systematic and meta-analysis and risk assessment.

Method and Material

Search Strategy

Searching was performed based on Cochrane protocols (Fig. 1). The current study was conducted to collect articles that detected concentration of PTEs (As, Pb, Cd, and Cu, Ni, and Fe in various fresh and processed fruits, including (apple, cherry, banana, grape, peach, pineapple, berries, citrus, cucumber, mango, and plum& prune). The searching was done among the international databases such as Scopus, PubMed, and Web of Science 8/May/1975 to 24/January/2021. The MESH terms was performed using the following keywords: key search terms included terminology for Scopus: ((ti/ab (“trace element”)OR((ti/ab(“metals”) ORti/ ab (“metal(oid)s”))) OR ti/ab (“heavy metals”)AND ((ti/ab fresh and Process fruits ((ti/ab (“Apple”) OR ti/ab (“Banana”) OR ti/ab (“Grape”) OR ((ti/ab (“Peach”) OR ti/ab (“Pineapple”) OR ti/ab (“Berries”) OR ((ti/ab (“Citrus”) OR ((ti/ab (“Mango”) OR ((ti/ab (“Plum& Prune”); PubMed: search (((“Metals”[Mesh([OR(((trace element [Ti/Ab]) OR(((heavy metals [Ti/Ab([OR metals [Ti/Ab]) OR metal(oid)s [Tit_Abs]))) AND))))))) fresh and Process fruits, including [Ti/Ab]) Apple [Ti/Ab]) OR Banana [Ti/Ab]) OR Grape [Ti/Ab]) OR Peach [Ti/Ab) OR Pineapple [Ti/Ab]) OR Berries [Ti/Ab]) OR Citrus [Ti/Ab]) OR Mango [Ti/Ab]) OR Plum& Prune [Ti/Ab]); Embase: (‘metals’:abt OR ‘heavy metals’:abt OR’ metal(oid)s: abt) AND’ fresh and Process fruits:abt OR Apple’:abt OR Banana’:abt OR Grape’ OR Peach abt.’ abt OR Peach’:abt OR Pineapple’:abt OR Berries’ OR Citrus abt.’:abt OR Mango OR Plum& Prune abt.’was applied to import all citations found.

Data Extraction, Inclusion, and Exclusion Criteria

The abstract and title of all obtained records according to keywords were investigated by two researchers, FM and

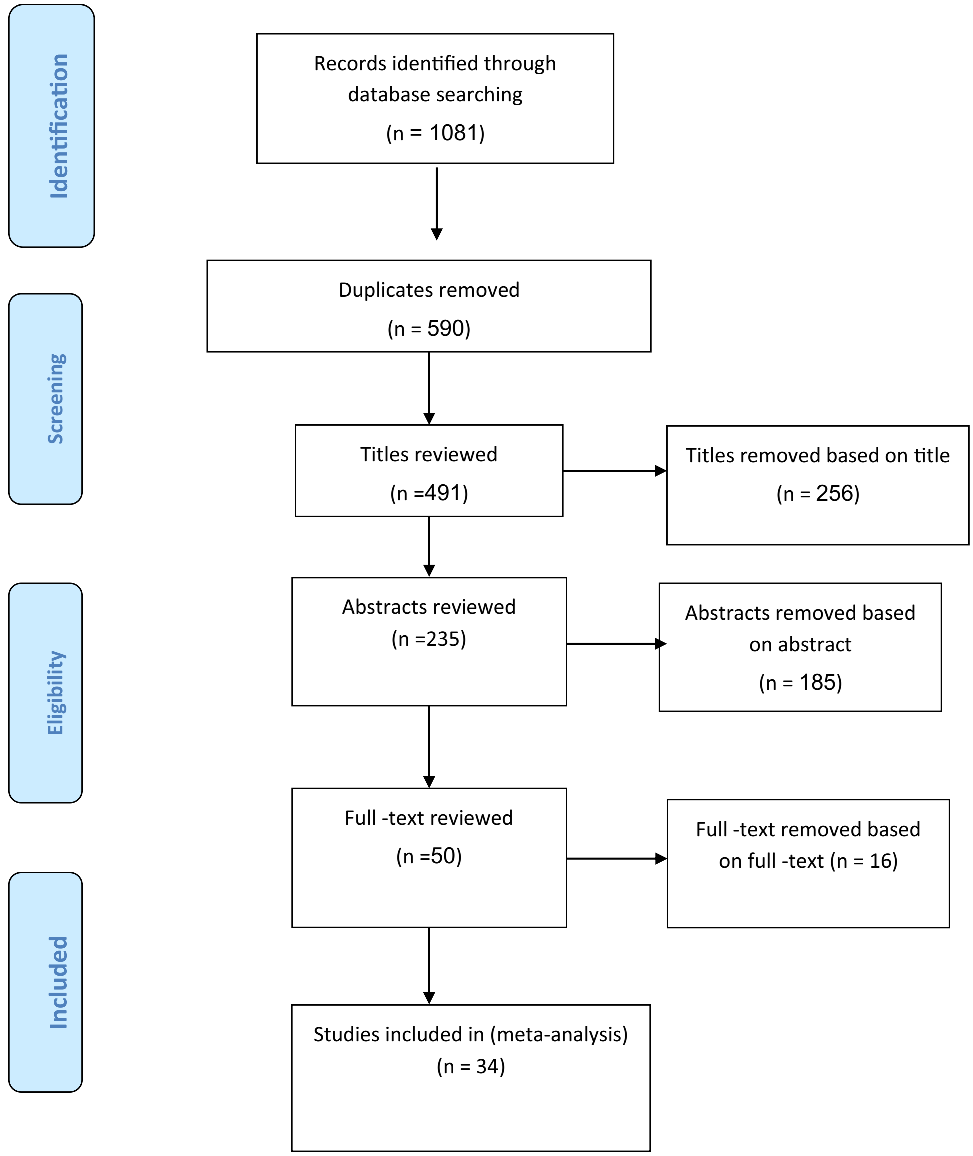

Fig. 1 Selection process evidence searches and inclusion

ME, based on exclusion and inclusion criteria and any disagreement between the two authors was discussed to reach a consensus. To detect the inter-author trustiness, the kappa statistics (95%) were used. Regarding troubled documents, the agreement was reached by the other researcher. Inclusion criteria applied in this study were (1) full-text available articles published in the English language, (2) recording of average concentration of PTEs, (3) original and cross-sectional articles, and (4) research specially conducted online between 8/May/1975 and 24/January/2021. In this regard, clinical trials, qualitative studies, review articles, case reports, letters to editors, and duplicates were excluded. It also should be revealed that documents that did not mention mean values, raw data, name of authors and journal, standard deviations, year of article publication, country, and type of brand of fruits, studies that assessed the role of climate change on metal in fruits, and studies that described the fate of metals in fruits were excluded. The composed data of each study is including the name of author, year and country of study, type of fruit, sample size, average concentration, and standard deviation of toxic metals. In order to unify the units, all units reporting the level of metals, including µg/kg, ppb, and ng/g, were changed to mg/kg.

Statistical Investigation

The combined concentration of PTEs in fresh and processed was evaluated using standard and error mean (SE) [25].

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

In the current study, the I^2 and Q-test were conducted to measure between-study, and kappa statistics (95%) was applied to find the inter-authors reliability. $I^2 > 50\%$ was considerable as heterogeneity. From the random effect, the model was used to investigate the concentration of metals in fruits based on sub-groups (continent and fruits type). Analysis data was used from the Stata software, version 14 (StataCorp, College Station, TX, USA).

Non-carcinogenic Risk Assessment

The risk assessment of metals through the consumption of various fruits was assessed based on this equation:

$$EDI = C \times IR \times ED \times EF/BW \times ATn \quad (2)$$

where *C* displays the average content of the metals in various fruits (mg/kg); IR is the ingestion rate of various fruits in various countries as shown in Table 3 (kg/n-day). ED shows exposure duration (adults = 30 years); EF indicates exposure frequency (365 days/year); ATn (ED × EF) expresses mean time exposure (adults = 10,950 days); and BW is body weight (adults = 70 kg) [26]. Target hazard quotient (THQ) because of intake of toxic metals in different fruits was calculated based on the stated equation:

$$THQ = EDI/RfD \quad (3)$$

where EDI and RfD show daily intake and oral reference dose respectively. The RfD values of Cd, Pb, As, Ni,Cu, and Fe, were 0.001, 0.0036, 0.0003, 0.02 0.04, and 0.7, mg/kg/day, respectively [26, 27]. TTHQ displays the entirety of each THQ for the whole mentioned metal in various fruits, If TTHQ obtain lower than 1, the non-carcinogenic risk of metals was considered safe for health [28].

Uncertainty Analysis

To increase the precision of risk assessment, Monte Carlo simulated (MCS) method was used. For this aim, the Oracle Crystal Ball software (version 11.1.2.4.600) was used. According to this method, the factors such as the content of metals (*C*), body weight (BW), and ingestion rate (IR) were considered as a lognormal distribution [29, 30], and the cut point of health risk was considered as the amount of repetitions 10,000 and percentile 95% of TTHQ [31].

Results and Discussion

Characteristics of Study

Next, in an initial screening in various databases, including Web of Science, PubMed, and Scopus of 1081 articles, 590 were removed as duplicates using EndNote citation manager (vX7.4, Thomas Reuters, New York, USA) and 491 documents were selected for more investigation. Based on Fig. 1, according to the titles, 256 articles were excluded due to the unrelated title. Then, 185 articles were selected due to suitable abstracts. Subsequent, the full texts of the 50 articles were downloaded, and 34 published from 1975 to 2021 were included in the current study. The studies were done all over the world. The summary of the selected papers about the level of Pb, Cd, As, Zn, Cu, Ni, and Fe in fresh and processed fruits in different regions of the world are presented in Table1-S.

The Study Characteristics

Results have been shown in Tables 1–7 S. The included studies were published between 2011 and 2019 for As, between 1989 and 2021 for Cd, between 1986 and 2021 for Cu, between 1989 and 2021 for Fe, between 1990 and 2021 for Ni, and between 1975 and 2021 for Pb. Moreover, the sample size of included articles varied from 3 to 150 with a total of 1315 samples for As, from 1 to 150 with a total of 3580 samples for Cd, from 3 to 333 with a total of 4727 samples for Cu, from 1 to 333 with a total of 2995 samples for Fe, from 1 to 150 with a total of 2225 samples for Ni, and from 3 to 333 with a total of 4138 samples for Pb. The ranking of countries based on number of study was Egypt (4 studies) ~ Pakistan (4 studies) > Turkey (3 studies) > Bangladesh (2 studies) ~ Jordan (2 studies) ~ Nigeria (2 studies) ~ Romani (2 studies) ~ South Africa (2 studies) ~ South Korea (2 studies) > Algeria (1 study) ~ Armenia (1 study) ~ Brazil (1 study) ~ China (1 study) ~ England (1 study) ~ Greece (1 study) ~ Iran (1 study) ~ Italy (1 study) ~ Japan (1 study) ~ Poland (1 study) ~ Serbia (1 study) (Table 1).

PTEs Level in Fresh Fruits Based on the Type of Metals

As seen in Table 1, the ranking of metal concentration in fresh fruits was Fe > Cu > Pb > As > Ni > Cd in apple, Fe > Cu > Ni > Pb > As > Cd in banana, Fe > Cu > Ni > Pb > As > Cd in grape, Fe > Cu > Ni > Pb > Cd in cherry, Fe > Cu > Ni > Pb > Cd > As in peach, Fe > Cu > Pb > Ni > Cd in cucumber, Fe > Ni > Cu > Pb > Cd in citrus, Cu > Ni > Pb > Cd > As in mango, Fe > Cu > Pb > Ni > Cd in pear, and Fe > Cu > Ni > Pb > Cd > As in plum. According to the findings, the maximum concentrations of As, Cd, and Pb were detected in pineapple, mango, and cherry (3.75, 4.13, and 2.01 mg/kg, respectively), while the minimum concentrations of these metals were found in berries, pineapple, and berries (0.001, 0.002, and 0.06 mg/kg, respectively). Regarding the trace elements, peach and cucumber represented the highest and lowest concentrations of Fe (50.49 and 2.22 mg/kg, respectively). Moreover, the highest and lowest concentrations of Cu were related to plum and banana (5.83 and 0.269 mg/kg, respectively). Based on the obtained data, the maximum and minimum concentrations of Ni were observed in citrus and cucumber (2.38 and 0.06 mg/kg, respectively). The results revealed a significant difference in the concentration of metals between the different fruits. This was consistent with the findings of previous studies. For example, various studies have reported different concentrations of metals in fresh and processed fruits. Compared to our findings, Altarawneh, R. M.. et al. reported the mean

Table 1 Meta-analysis of concentration of toxic metal (PTEs) (mg/kg) in fresh and processed fruits based on fruit

Metal	Fruit	Kind	N of studies	ES (95% CI)	Weight	Heterogeneity Statistics	df	*P*. value	I^2 (%)
As	Apple	Processed	–	–	–	–	–	–	–
		Fresh	14	0.309 (0.139, 0.478)	100	93,790.91	13	< 0.001	100.0
	Banana	Processed	–	–	–	–	–	–	–
		Fresh	2	0.076 (0.000, 0.221)	100	389.36	1	< 0.001	99.7
	Grape	Processed	–	–	–	–	–	–	–
		Fresh	8	0.027 (0.000, 0.054)	100	188.03	7	< 0.001	96.3
	Peach	Processed	–	–	–	–	–	–	–
		Fresh	13	0.009 (0.002, 0.016)	100	152.86	12	< 0.001	92.1
	Pineapple	Processed	1	3.750 (2.722, 4.778)	48.99	–	–	–	–
		Fresh	1	0.002 (0.001, 0.003)	51.01	–	–	–	–
	Berries	Processed	–	–	–	–	–	–	–
		Fresh	1	0.001 (0.000, 0.002)	100	–	–	–	–
	Citrus	Processed	–	–	–	–	–	–	–
		Fresh	12	0.080 (0.059, 0.101)	100	6395.46	11	< 0.001	99.8
	Mango	Processed	–	–	–	–	–	–	–
		Fresh	2	0.008 (0.000, 0.018)	100	405.52	1		99.8
	Plum& prune	Processed	–	–	–	–	–	–	–
		Fresh	6	0.002 (0.000, 0.009)	100	0.05	5	0.999	0.0
Cd	Apple	Processed	7	0.145 (0.075, 0.214)	18.68	2382.71	6	< 0.001	99.7
		Fresh	22	0.014 (0.010, 0.019)	81.32	14,513.58	21	< 0.001	99.9
	Banana	Processed	1	0.080 (0.069, 0.091)	11.09	–	–	–	–
		Fresh	11	0.021 (0.015, 0.026)	88.91	711.53	6	< 0.001	100.0
	Grape	Processed	2	0.134 (0.000, 0.395)	9.97	133.66	1	< 0.001	99.3
		Fresh	16	0.012 (0.000, 0.034)	90.03	2.2e + 05	15	< 0.001	100.0
	Cherry	Processed	1	2.889 (2.685, 3.093)	2.18	–	–	–	–
		Fresh	11	0.040 (0.012, 0.069)	97.82	1826.49	7	< 0.001	100.0
	Peach	Processed	3	0.250 (0.000, 0.547)	11.89	4585.14	2	< 0.001	99.7
		Fresh	21	0.016 (0.011, 0.021)	88.11	5906.64	20	0.999	0.0
	Pineapple	Processed	6	0.692 (0.476, 0.907)	63.95	1927.94	5	< 0.001	99.7
		Fresh	2	0.002 (0.001, 0.003)	36.05	0.00	1	0.999	0.0
	Berries	Processed	12	0.199 (0.115, 0.284)	43.07	20,464.37	11	< 0.001	99.9
		Fresh	10	0.021 (0.011, 0.030)	56.93	1627.73	9	< 0.001	99.4
	Cucumber	Processed	1	0.930 (0.896, 0.964)	2.32	–	–	–	–
		Fresh	36	0.048 (0.036, 0.060)	97.68	1.3e + 05	35	< 0.001	100.0
	Citrus	Processed	3	0.144 (0.006, 0.283)	3.88	57.42	2	< 0.001	96.5
		Fresh	27	0.019 (0.015, 0.022)	96.12	7855.19	26	< 0.001	99.7
	Mango	Processed	2	4.132 (2.302, 5.962)	0.09	49.49	1	< 0.001	98.0
		Fresh	3	0.006 (0.002, 0.010)	99.91	518.98	2	< 0.001	99.6
	Pear	Processed	3	0.009 (0.000, 0.022)	24.88	1513.81	2	< 0.001	99.9
		Fresh	7	0.018 (0.009, 0.028)	75.12	140.12	6	< 0.001	95.7
	Plum	Processed	–	–	–	–	–	–	–
		Fresh	9	0.009 (0.004, 0.013)	100	193.12	8	< 0.001	95.9

Table 1 (continued)

Metal	Fruit		N of studies	ES (95% CI)		Heterogeneity			
		Kind			Weight	Statistics	df	*P*. value	I^2 (%)
Cu	Apple	Processed	7	1.840 (0.654, 3.025)	33.47	24,430.35	6	< 0.001	100.0
		Fresh	14	1.398 (1.119, 1.678)	66.53	3443.79	13	< 0.001	99.6
	Banana	Processed	1	0.269 (0.212, 0.326)	12.54	–	–	–	–
		Fresh	7	2.665 (0.000, 6.483)	87.46	2.5e + 05	6	< 0.001	100.0
	Grape	Processed	4	2.373 (0.000, 4.977)	20.28	24,395.57	3	< 0.001	100.0
		Fresh	16	2.378 (1.660, 3.097)	79.72	12,536.46	15	< 0.001	99.9
	Cherry	Processed	1	0.594 (0.549, 0.639)	11.13	–	–	–	–
		Fresh	8	2.208 (1.027, 3.389)	88.87	10,754.52	7	< 0.001	99.9
	Peach	Processed	7	4.953 (3.350, 6.555)	35.21	21,405.88	6	< 0.001	99.7
		Fresh	13	2.838 (2.093, 3.583)	64.79	4283.49	12	< 0.001	100.0
	Pineapple	Processed	5	1.022 (0.770, 1.274)	55.56	451.07	4	< 0.001	99.1
		Fresh	4	2.830 (0.000, 8.654)	44.44	63,273.67	3	< 0.001	100.0
	Berries	Processed	6	1.477 (0.913, 2.041)	26.75	7517.79	5	< 0.001	99.9
		Fresh	17	2.714 (2.470, 3.012)	73.25	9.9e + 05	16	< 0.001	100.0
	Cucumber	Processed	–	–	–	–	–	–	–
		Fresh	36	0.417 (0.383, 0.450)	100	17,226.43	35	< 0.001	99.8
	Citrus	Processed	4	1.047 (0.815, 1.278)	10.61	252.84	3	< 0.001	98.8
		Fresh	36	1.396 (0.000, 3.232)	89.39	1.1e + 07	35	< 0.001	100.0
	Mango	Processed	9	1.919 (1.707, 2.131)	69.47	9458.15	8	< 0.001	99.9
		Fresh	4	2.796 (0.000, 6.178)	30.53	5502.85	3	< 0.001	99.9
	Pear	Processed	–	–	–	–	–	–	–
		Fresh	8	1.454 (1.139, 1.768)	100	917.28	7	< 0.001	99.2
	Plum& prune	Processed	2	5.838 (0.000, 11.816)	21.13	257.89	1	< 0.001	99.6
		Fresh	7	1.410 (0.585, 2.235)	78.36	2700.24	6	< 0.001	99.8
Fe	Apple	Processed	9	19.619 (0.000, 41.398)	60.09	1.1e + 05	8	< 0.001	100.0
		Fresh	6	8.330 (5.616, 11.044)	39.91	405.12	5	< 0.001	98.8
	Banana	Processed	–	–	–	–	–	–	–
		Fresh	3	6.217 (0.768, 11.667)	100	29.82	2	< 0.001	93.3
	Grape	Processed	3	41.669 (0.000, 94.708)	29.99	41,106.69	2	< 0.001	100.0
		Fresh	16	5.517 (4.100, 6.934)	70.01	3551.56	6	< 0.001	99.8
	Cherry	Processed	–	–	–	–	–	–	–
		Fresh	6	7.886 (6.364, 9.409)	100	352.58	5	< 0.001	98.6
	Peach	Processed	6	50.490 (30.118, 70.861)	42.97	54,418.52	5	< 0.001	100.0

concentrations of Pb, Ni, and Cd as 0.37, 1.5, and 0.08 mg/kg in the fresh banana samples in Jordan, respectively [32]. Similarly, Chen et al. concluded that the mean concentrations of Cd, Pb, and As in the fresh apple samples in China were 0.005 0.008 0.003 mg/kg, while they were 0.008, 0.081, and 0.003 respectively in fresh grape samples in China [28]. In another study, Esposito et al. reported that the mean concentration of Ni and Cu was 1.25 0.036 mg/kg in the peach of Italy, respectively [33]. Fathabad et al. reported Cd, Pb, and As concentrations in the studied samples of processed fruit (juice) as 0.0037, 0.0012, and 0.04 mg/kg, respectively [34]. Additionally, Habte et al. observed that the mean concentration of Cu, Ni, As, Cd, and Pb was 0.91, 0.109, 0.002 0.002, and 0.012 mg/kg in the banana samples of South Korea, respectively [35]. Furthermore, Hong et al. found that the mean concentrations of Fe, Ni, Cu, As, and Cd in different types of processed fruit (juice) were 0.33, 0.056, 0.569, 0.0083, and 0.0012 mg/kg, respectively [36]. The different concentrations of metals between fresh and processed fruits in the current study and other studies can be related to various reasons such as the physiology or nature of the fruit, the source of contamination, the presence of industrial

Table 1 (continued)

Metal	Fruit	Kind	N of studies	ES (95% CI)	Weight	Heterogeneity Statistics	df	*P*. value	I^2 (%)
Ni		Fresh	8	10.432 (9.062, 11.801)	57.03	157.64	7	< 0.001	95.6
	Pineapple	Processed	6	35.207 (16.688, 53.726)	80.09	17,541.95	7	< 0.001	100.0
		Fresh	2	6.412 (0.000, 16.264)	19.91	11.39	1	0.001	91.2
	Berries	Processed	5	11.510 (2.624, 20.396)	31.44	5489.49	4	< 0.001	99.9
		Fresh	11	10.897 (9.313, 12.481)	68.56	38,720.48	10	< 0.001	100.0
	Cucumber	Processed	–	–	–	–	–	–	–
		Fresh	36	2.222 (2.135, 2.310)	100	46,095.75	35	< 0.001	99.9
	Citrus	Processed	3	3.266 (0.000, 6.752)	13.54	973.58	2	< 0.001	99.8
		Fresh	26	2.997 (2.814, 3.181)	86.46	1.4e+05	25	< 0.001	100.0
	Mango	Processed	2	4.481 (3.786, 5.176)	100	9.72	1	0.002	89.7
		Fresh	–	–	–	–	–	–	–
	Pear	Processed	–	–	–	–	–	–	–
		Fresh	5	4.914 (2.626, 7.202)	100	280.69	4	< 0.001	98.6
	Plum	Processed	2	25.695 (12.563, 38.826)	40.00	1244.48	1	< 0.001	99.9
		Fresh	3	6.895 (4.085, 9.750)	60.0	237.43	2	< 0.001	99.2
	Apple	Processed	1	2.000 (1.378, 2.622)	0.13	–	–	–	–
		Fresh	18	0.262 (0.240, 0.285)	99.87	47,986.47	17	< 0.001	100.0
	Banana	Processed	1	1.660 (1.207, 2.113)	1.79	–	–	–	–
		Fresh	8	0.159 (0.096, 0.221)	98.21	1609.17	7	< 0.001	99.6
	Grape	Processed	–	–	–	–	–	–	–
		Fresh	13	0.226 (0.192, 0.261)	100.0	5260.69	12	< 0.001	99.8
	Cherry	Processed	–	–	–	–	–	–	–
		Fresh	7	0.270 (0.180, 0.359)	100.0	5304.75	6	< 0.001	99.9
	Peach	Processed	–	–	–	–	–	–	–
		Fresh	10	0.481 (0.405,0.557)	100.0	6469.09	9	< 0.001	99.9
	Pineapple	Processed	1	1.640 (1.191, 2.089)	4.22	–	–	–	–
		Fresh	3	0.065 (0.003, 0.127)	95.78	30.73	2	< 0.001	93.5
	Berries	Processed	–	–	–	–	–	–	–
		Fresh	5	0.060 (0.033, 0.088)	100	1305.52	4	< 0.001	99.7
	Cucumber	Processed	1	1.180 (1.022, 1.338)	0.61	–	–	–	–
		Fresh	18	0.060 (0.047, 0.073)	99.39	8755.73	17	< 0.001	99.8
	Citrus	Processed	1	2.380 (1.893, 2.867)	0.76	–	–	–	–
		Fresh	36	0.212 (0.167, 0.256)	99.24	4630.71	27	< 0.001	99.4
	Mango	Processed	9	–	–	–	–	–	–
		Fresh	4	0.300 (0.124, 0.476)	100	6492.95	3	< 0.001	100.0
	Pear	Processed	–	–	–	–	–	–	–
		Fresh	4	0.234 (0.122, 0.347)	100	110.47	3	< 0.001	97.3
	Plum& prune	Processed	–	–	–	–	–	–	–
		Fresh	4	0.293 (0.055, 0.531)	100	1653.63	3	< 0.001	99.8

Table 1 (continued)

Metal	Fruit		N of studies	ES (95% CI)		Heterogeneity			
		Kind			Weight	Statistics	df	*P*. value	I^2 (%)
Pb	Apple	Processed	8	0.685 (0.508, 0.861)	24.19	400.90	7	< 0.001	98.3
		Fresh	25	0.577 (0.000, 1.179)	75.81	1.3e + 07	24	< 0.001	100.0
	Banana	Processed	2	0.348 (0.093, 0.602)	12.97	22.53	1	< 0.001	95.6
		Fresh	7	0.112 (0.085, 0.138)	87.03	2290.74	6	< 0.001	99.7
	Grape	Processed	4	0.244 (0.057, 0.431)	12.87	29.10	3	< 0.001	89.7
		Fresh	20	0.148 (0.112, 0.185)	87.13	6572.81	19	< 0.001	99.7
	Cherry	Processed	1	2.010 (1.970, 2.050)	10.96	–	–	–	–
		Fresh	9	0.212 (0.175, 0.246)	89.04	2258.49	8	< 0.001	99.6
	Peach	Processed	3	0.149 (0.000, 0.356)	16.54	186.0	2	< 0.001	98.9
		Fresh	22	0.177 (0.124, 0.231)	83.46	11,206.79	21	< 0.001	99.8
	Pineapple	Processed	6	1.005 (0.677, 1.332)	73.09	959.74	8	< 0.001	99.2
		Fresh	2	0.383 (0.010, 0.756)	26.74	10,221.87	2	< 0.001	100.0
	Berries	Processed	21	0.117 (0.102, 0.131)	52.83	2870.93	20	< 0.001	99.3
		Fresh	12	0.065 (0.048, 0.081)	47.17	3230.20	11	< 0.001	99.7
	Cucumber	Processed	1	0.960 (0.779, 1.141)	9.69	–	–	–	–
		Fresh	35	0.295 (0.262, 0.328)	98.44	36,342.71	8	< 0.001	99.9
	Citrus	Processed	2	0.683 (0.332, 1.034)	4.07	6.43	1	0.011	84.4
		Fresh	28	0.250 (0.215, 0.285)	95.93	11,151.18	27	< 0.001	99.8
	Mango	Processed	6	1.803 (0.700, 2.905)	67.56	5139.66	5	< 0.001	99.9
		Fresh	3	0.081 (0.007, 0.156)	32.44	1145.58	2	< 0.001	99.8
	Pear	Processed	3	0.028 (0.016, 0.040)	36.22	9.70	2	0.008	79.4
		Fresh	7	0.561 (0.477, 0.465)	63.78	3790.93	6	< 0.001	99.8
	Plum	Processed	2	–	–	–	–	–	–
		Fresh	11	0.292 (0.160, 0.424)	100	4046.69	10	< 0.001	99.8

areas near fruit-growing sites, contamination of irrigation areas, the agricultural activities (the type and amount of the applied fertilizers), storage conditions, method of metals detection (ICP-OES, ICP-MS, or AAS), and processing technologies [32, 37, 38]. The physicochemical properties of soil and climatic conditions in different regions should not be ignored in this regard [16, 28, 33]. For example, considering the plants growing in acidic soils, the solubility of toxic metals such as As, Cd, and Pb is increased. Thus, they become readily available for uptake by plants. Radwan et al. (2006) and Moyo (2020) reported that acidification of the soil increased the dissolution of Cd thus increasing their absorption by fruits. Therefore, soil pH has an important role in controlling the bioavailability of heavy metals, especially for Cd [16, 39]. Cadmium, unlike other toxic metals, is highly mobile in the soil, easily absorbed by roots, and transported to stems. Hence, it is evenly distributed in plants [40]. Therefore, the soil pH, solubility of the metal, and the organic matter content are among the important factors affecting the metal contents in soil [41]. Concentrations of heavy metals in different species of fruits vary due to their different bioavailability of metals and plant species. Based on the reports, the low accumulation of heavy metals in fruits can be caused by the absorption of large amounts of heavy metals by trees and their storage in other organs, especially in the leaves [40, 42]. De Las Torres et al. (2020) indicated that the level of arsenic (As) in the roots and stems of many fruits was higher than in leaves and seeds [43]. Semple et al. (2015) reported that metals like Fe and Cu are high-mobility and quickly move from soil into aerial plants. However, other metals such as Pb and Cd are low-mobility and accumulated with higher concentrations in plants root [44]. Another important factor influencing the observed changes is the type of water and fertilizer used for plant cultivation. Al-Busaidi et al. (2005) found that soil irrigated with wastewater had higher pH and metals concentration as compared to the soil irrigated with groundwater [45]. In two separate studies performed by Xue et al. and Gupta et al., it was indicated that long and frequent irrigation with wastewater compared to the clean water and groundwater led to a significant increase in total organic content, bioavailability, and concentration of metals in the soil and the following various crops [46, 47]. According to the study by Roba et al. (2016), the highest level of copper in various studies can be caused by using micronutrient fertilizers and copper-based fungicides in agricultural activities [40]. Compared to the agricultural soils, high levels of Cu, Fe, and Pb metal are found in soils of areas related to engine mechanical work [48].

PTEs Content in Processed Fruits Based on the Type of Metals

According to the statistical results and our meta-analysis, the concentrations of different metals in processed fruits were significantly different. As seen in Table 1, the ranking of metal concentration in processed fruits was Fe > Ni > Cu > Pb > Cd > As in apple, Ni > Pb > Cu > Cd in banana, Fe > Cu > Pb > Cd in grape, Cd > Pb > Cu in cherry, Fe > Cu > Pb > Cd in peach, Fe > As > Ni > Cu > Pb > Cd in pineapple, Fe > Cu > Cd > Pb in berries, Ni > Pb > Cd in cucumber, Fe > Cu > Pb > Ni > Cd > As in citrus, Fe > Cd > Cu > Pb in mango, Pb > Cd in pear, and Fe > Cu in plum. According to the results, despite the significant differences in metal concentrations between kinds of processed fruits such as juices, jams, and dried fruits, it was observed that the concentration of metals in processed fruits was significantly higher than in fresh fruits ($p < 0.05$). Massadeh et al. reported that Cd, Cu, Ni, and Pb concentration in pineapple juice of Jordan was 0.56 (mg/kg), 0.91 (mg/kg), 1.64 (mg/kg), and 2.80 (mg/kg), respectively [49]. Sattar et al. reported Pb, Cu, and Fe concentration in dried Fig of Pakistan as 0 0.20 (μg/kg) 3.90 (μg/kg) 32.33 (μg/kg), respectively [50]. Rusin et al. studying the effect of processed on level of different metals in Poland indicated the Cd and Pb concentration in dried and fresh apple as 0.023 (mg/kg), 0.127 (mg/kg), 0.001 (mg/kg), and 0.009 (mg/kg), respectively [42]. In a similar study, Altarawneh et al. indicated the level of Pb, Ni, and Cd in fresh bananas. However, in the stored banana, it was 0.37 mg/kg, 1.50 mg/kg, 0.08 mg/kg, and 0.48 mg/kg, 1.66 mg/kg, and 0.08 mg/kg, respectively [32]. Based on our findings and other reports, there were significant differences in metal concentrations between the kinds of processed fruits. Washing fruit is one of the influential factors in this regard. According to Oteef et al. (2015), there is an insignificant difference between the washed and unwashed fruits [1]. These fruits could be also contaminated by heavy metals as farmers wash them with wastewater before bringing them into the market [23]. Another important factor is the technology and processes used to produce the fruit. Abasi et al. (2020) indicated that wide use of Fe in steel containers or machinery in processing industries foods can increment iron concentration in processed foods. Also, the presence of acids in different fruits can cause the leaching of iron in fruits stored or packed with iron or steel containers [51]. Various studies showed that drying the leafy fruits near roads, mines, and polluting industries increase the concentration of lead and cadmium metals as a result of aerosol transport to these crops [23, 50]. Fathabad et al. (2018) represented the contamination of processed fruits with heavy metals, in addition to the problems that may occur during fruit planting. Among other sources of metal pollution are the quality of water and air, as well as the soil used, failure in the safety of juice and canning equipment, transportation and storage containers, and the leakage, and release of more heavy metals from the packaging. It seems that using the stainless steel containers for proper packaging, storage of fruit,s and using the crops grown in environments with the least pollution of metals may play a main role in reducing various metals in the processed fruits [34]. Studies have also stated other causes of metal contamination in processed products including the deposition of metals in the atmosphere and soil, the use of fertilizers, harvesting techniques, storage conditions, transportation, and processing machinery. However, the presence of acid in various fruits and their packaging may cause the leaching of lead (Pb) in canned fruits [51]. Unfortunately, the complete removal of metals such as Cd or Pb from processed fruits is almost impossible since their processing is effective in changing the level of heavy metals. Moreover, the technological processes used in the production of these products can only remove a small part of impurities from selected products or even help increase their pollution [42]. Thus, to reduce and prevent the level of heavy metals in various fruits, regular control should be considered on the environmental condition of cultivation (especially drinking water and irrigation, soil, and vegetation) and proper processed techniques, as well as methods and agricultural management including time of harvest and post-harvest, and product storage [32].

Level of Metals in Fresh and Processed Fruits According to the Classification of the World Health Organization

Based on the data in Table 2, the concentration of metals in the fresh and processed fruits was different among the studied countries in the present study. Our results indicated that the highest concentrations of As (3.75 mg/kg), Cd (0.65 mg/kg), Pb (4.57 mg/kg), Fe (50.37 μg/kg), Ni (4.57 μg/kg), and Cu (4.41 μg/kg) among fresh and processed fruits belonged to EMRO, EMRO, AFRO, EURO, AFRO, and SEARO. Based on the findings, the lowest concentrations of As (0.021 mg/kg), Cd (0.016 mg/kg), Pb (0.018 mg/kg), Fe (2.18 mg/kg), Ni (0.06 mg/kg), and Cu (0.507 mg/kg) were related to WPRO, EURO, WPRO, EMRO, WPRO, and PAHO. The results of the present meta-analysis were interesting and showed the difference in the concentration of the metals between countries in different regions of WHO. The wide variation range of the reported data in the literature and also our study regarding the fresh and processed fruits between countries could be probably related to the climatic conditions of different countries and regions, type of industries and active mines, type and amount of chemical fertilizers, and use of different methods as traditional and industrial of cultivation and harvesting the plants [52]. We found that many previous studies reported different amounts of Pb, Cd, Ni, Cu, and Fe in fresh and processed fruits in various countries. For example, Pb and Cd concentrations in the studies (Ikebe et al., Japan; Kandil et al., Egypt; Keskin et al., Turkey) were 0.002 mg/kg and 0.02 mg/kg in apple, 0.02 mg/kg and 0.05 mg/kg in orange, and 0.05 mg/kg and

Table 2 Meta-analysis of concentration of toxic metal (PTEs) (mg/kg) in fresh and processed fruits based on WHO region

Metal	Fruit		N of studies	ES (95% CI)		Heterogeneity			
		Kind			Weight	Statistics	df	*P*. value	I^2 (%)
AS	SEARO[3]	Processed	–	–	–	–	–	–	–
		Fresh	6	0.668 (0.380, 0.956)	100	92,350.91	5	< 0.001	100.0
	EURO[2]	Processed	–	–	–	–	–	–	–
		Fresh	2	0.115 (0.000, 0.340)	100	609.44	1	< 0.001	99.8
	EMRO[4]	Processed	1	3.750 (2.722, 4.778)	0.02	–	–	–	–
		Fresh	33	0.025 (0.012, 0.038)	99.98	1144.39	32	< 0.001	97.2
	WPRO[1]	Processed	–	–	–	–	–	–	–
		Fresh	18	0.021 (0.017, 0.024)	100	6257.77	17	< 0.001	99.7
Cd	AFRO[5]	Processed	–	–	–	–	–	–	–
		Fresh	1	0.230 (0.005, 0.455)	100	–	–	–	–
	SEARO	Processed	–	–	–	–	–	–	–
		Fresh	6	0.018 (0.010, 0.025)	100	4650	5	< 0.001	99.9
	EURO	Processed	11	0.024 (0.022, 0.026)	75.57	3550.27	10	< 0.001	99.7
		Fresh	41	0.016 (0.013, 0.019)	24.43	3971.64	40	< 0.001	99.0
	EMRO	Processed	29	0.657 (0.567, 0.747)	16.59	31,788.14	30	< 0.001	99.9
		Fresh	89	0.034 (0.027, 0.042)	83.41	7.5e + 05	90	< 0.001	100.0
	WPRO	Processed	–	–	–	–	–	–	–
		Fresh	30	0.003 (0.003, 0.004)	100.0	295.47	29	< 0.001	90.2
Cu	AFRO	Processed	1	4.000 (3.758, 4.215)	5.19	–	–	–	–
		Fresh	19	2.339 (2.038, 2.641)	94.81	4.5e + 05	18	< 0.001	100.0
	PAHO	Processed	–	–	–	–	–	–	–
		Fresh	4	0.507 (0.287, 0.728)	100.0	1.6e + 05	3	< 0.001	100.0
	SEARO	Processed	–	–	–	–	–	–	–
		Fresh	2	4.418 (0.000, 11.224)	100.0	6022.98	1	< 0.001	100.0
	EURO	Processed	8	4.302 (3.346, 5.168)	12.14	7046.08	7	< 0.001	99.9
		Fresh	58	2.793 (2.267, 3.319)	87.86	4.5e + 05	57	< 0.001	100.0
	EMRO	Processed	7	1.583 (1.429, 1.738)	38.15	63,646.57	36	< 0.001	99.9
		Fresh	13	0.513 (0.482, 0.543)	61.85	21,237.50	60	< 0.001	99.7
	WPRO	Processed	–	–	–	–	–	–	–
		Fresh	26	0.587 (0.453, 0.720)	100.0	982.15	25	< 0.001	97.5
Fe	AFRO	Processed	–	–	–	–	–	–	–
		Fresh	6	6.216 (0.000, 13.096)	100.0	4054.57	5	< 0.001	99.9
	PAHO	Processed	–	–	–	–	–	–	–
		Fresh	4	9.925 (7.258, 12.591)	100	32,892.21	3	< 0.001	100.0
	EURO	Processed	6	8.606 (7.752, 9.461)	86.61	44,440.87	5	< 0.001	100.0
		Fresh	39	50.317 (30.873, 69.761)	13.39	6.4e + 05	38	< 0.001	99.9
	EMRO	Processed	32	22.094 (18.924, 25.265)	30.29	69,096.62	31	< 0.001	100.0
		Fresh	42	2.189 (2.103, 2.275)	69.71	46,224.27	41	< 0.001	99.9
	WPRO	Processed	–	–	–	–	–	–	–
		Fresh	22	0.557 (0.426, 0.688)	100.0	11.39	21	< 0.001	100.0

Table 2 (continued)

Metal	Fruit		N of studies	ES (95% CI)		Heterogeneity			
		Kind			Weight	Statistics	df	*P*. value	I^2 (%)
Ni	AFRO	Processed	–	–	–	–	–	–	–
		Fresh	6	2.023 (1.406, 2.640)	100.0	23.12	5	< 0.001	79.4
	SEARO	Processed	–	–	–	–	–	–	–
		Fresh	7	0.383 (0.331, 0.434)	100.0	74,231.28	6	< 0.001	100.0
	EURO	Processed	–	–	–	–	–	–	–
		Fresh	34	0.323 (0.301, 0.344)	100.0	18,004.81	33	< 0.001	99.8
	EMRO	Processed	5	1.740 (1.267, 2.213)	0.05	28.90	4	< 0.001	86.2
		Fresh	49	0.071 (0.068,0.074)	99.95	49,916.13	48	< 0.001	99.9
	WPRO	Processed	–	–	–	–	–	–	–
		Fresh	26	0.062 (0.044, 0.080)	100.0	251.79	25	< 0.001	90.1
Pb	AFRO	Processed	1	0.020 (0.019, 0.021)	25.0	–	–	–	–
		Fresh	3	4.573 (0.000, 9.362)	75.0	3.0e + 05	2	< 0.001	100.0
	SEARO	Processed	–	–	–	–	–	–	–
		Fresh	7	0.618 (0.224, 1.011)	100.0	1.3e + 05	6	< 0.001	100.0
	EURO	Processed	19	0.042 (0.033, 0.051)	25.81	795.06	18	< 0.001	97.7
		Fresh	49	0.267 (0.249, 0.285)	74.19	43,799.80	48	< 0.001	99.9
	EMRO	Processed	40	0.961 (0.731, 1.191)	22.48	22,150.56	39	< 0.001	99.8
		Fresh	93	0.225 (0.212, 0.239)	77.52	88,330.99	92	< 0.001	99.9
	WPRO	Processed	–	–	–	–	–	–	–
		Fresh	30	0.018 (0.015, 0.021)	100.0	296.72	29	< 0.001	90.2

[1]Western Pacific Region

[2]European Region

[3]South-East Asia Region

[4]The Pan American Health Organization

[5]African Region

0.00 mg/kg in grape, respectively [53–55]. Mansour et al. (2009) revealed that the concentrations of Cu, Fe, and Ni in cucumber in Egypt were 0.5 mg/kg, 8.23 mg/kg and, 14.10 mg/kg, respectively [56]. Okoye et al. (2001) showed the amount of Cu, Fe, and Ni, in the apple in Nigeria as 0.6 mg/kg, 1.8 mg/kg and, 1.4 mg/kg, respectively [48]. As mentioned, there are significant differences in metal concentrations in different countries. The observed discrepancy could be related to various contamination sources such as car traffic on the highways [16, 28, 33]. Therefore, plants growing along roads, factories, and other industrial environments contain higher levels of heavy metals [34]. Manea et al. (2020) found different patterns of heavy metal accumulation in vegetables and fruits collected from areas with varying levels of pollution and mine-related pollution [52]. In another study, it was found that there was a huge amount of emissions from vehicles or machinery during transportation or in places designated for sale in open roadside markets, which can affect the level of metals in various fruits [57]. Sobukola et al. reported that the atmospheric deposition of metals on the fruit surfaces has a stronger effect than uptake from the soils [23]. Other causes of fruit contamination with heavy metals in continents may be the climatic conditions such as temperature, humidity, rainy season, and rainfall as well as the agricultural method. Ahmed et al. (2019) indicated that in the wet season, heavy rains dilute the irrigation water, thus reducing the concentration of heavy metals in soil [58]. According to the report of Migut et al. (2019), large amounts of organic fertilizers were used in traditional rather than industrial agriculture, which is the main source of heavy metal contamination [59].

Health Risk Assessment

Fruits should be considered an important component of diet because of the existence of fiber, mineral salts, and vitamins. It is commonly identified that health problems can occur owing to the higher accumulation of metals such as Pb, Cd, and As in the human body. Table 3 represents the non-carcinogenic risk assessment of toxic metals based

Table 3 Uncertainty analysis for TTHQ of metals in adult due to consumption of fresh and processed fruits in various countries

	IR*			Fresh fruits (95%)								Processed fruits (95%)				
Country	25.28	AS	Cd	Cu	Fe	Ni	Pb	TTHQ		AS	Cd	Cu	Fe	Ni	Pb	TTHQ
Algeria	50.06	–	–	–	–	–	–	–	–	–	–	0.0730	–	–	0.0049	0.038
Armenia	17.76	0.0007	0.0013	0.0245	–	0.0037	0.0003	0.017		–	–	–	–	–	–	–
Bangladesh	19.87	0.0765	0.0056	0.0357	–	0.0109	0.0896	0.155		–	–	–	–	–	–	–
Brazil	36.59	–	–	0.0034	0.0051	–	–	0.003		–	–	–	–	–	–	–
China	23.11	0.0013	0.0062	–	–	–	0.0224	0.015		–	–	–	–	–	–	–
Egypt	19.51	–	0.0732	0.0084	0.0023	0.0055	0.0686	0.059		–	–	–	–	–	–	–
England	32.29	–	–	–	–	–	–	–		–	–	–	–	–	0.3160	0.139
Greece	40.82	0.0541	0.4732	0.0629	0.0549	0.0089	0.0279	0.237		–	–	–	–	–	–	–
Iran	40.82	0.0090	0.0096	–	–	–	0.0010	0.006		–	–	–	–	–	–	–
Italy	11.15	–	–	0.0476	–	0.0039	–	0.024		–	–	–	–	–	–	–
Japan	9.00	–	0.0018	0.0050	0.0057	0.0022	0.0034	0.008		–	–	–	–	–	–	–
Jordan	14.76	–	0.0546	–	–	0.0174	0.0334	0.072		0.3000	0.0702	0.0038	–	0.0200	0.1037	0.304
Nigeria	13.52	–	–	0.0285	0.0037	0.0462	0.4821	0.433		–	–	–	–	–	–	–
Pakistan	22.62	0.0125	0.0259	0.0026	0.0036	0.0479	0.0463	0.067		–	0.2462	0.0242	0.0088		0.0921	0.234
Poland	33.39	–	0.0080	–	–	–	0.0021	0.004		–	0.0201	–	–	–	0.0125	0.011
Romania	69.70	–	0.0275	0.0370	0.0077	0.0149	0.3805	0.177		–	–	–	–	–	–	–
Serbia	5.16	–	–	0.1447	0.1096	–	–	0.158		–	–	–	–	–	–	–
South Africa	21.30		0.0346	0.0031	–	0.0624	–	0.049		–	–	–	–	–	–	–
South Korea	31.62	0.0064	0.0031	0.0188	0.0002	0.0042	0.0015	0.011		–	–	–	–	–	–	–
Turkey	25.28	–	0.0190	0.0658	0.0065	0.0014	0.0114	0.082		–	–	0.0631	0.0412	–	–	0.082

*kg/capita/year

on the consumption of fresh and processed fruits in different countries. The TTHQ ranking of countries in the adult consumers was in the order of Nigeria > Greece > Romania > Serbia > Bangladesh > Turkey > Jordan > Pakistan > Egypt > South Africa > Italy > Armenia > China > South Korea > Japan > Iran > Poland > Brazil for fresh fruits and Jordan > Pakistan > England > Turkey > Algeria > Poland for processed fruits. The results of risk assessment of metals in different countries indicated different patterns, possibly owing to the difference in fresh and processed fruit consumption in various countries, and the concentration of metals in plants and water used for the production of various fruits [2, 3]. According to the findings, the reported amounts of TTHQ for adults were lower than 1, suggesting that the local inhabitants in all studied countries will not be exposed to the potential health risk from the consumption of fresh and processed fruits. However, there are also other sources of metal exposure such as dermal contact, dust inhalation, and ingestion of other foodstuff and water, which were not included in this study. Our results are consistent with the previous studies indicating that exposure to the metals through the consumption of other foods such as milk and its products, vegetable oils, and various fruit juices was safe while not endangering the consumers' health [9, 60, 61]. Thus, the health risks of heavy metals in fruits can be reduced by observing some issues such as monitoring the quality and health of water used to irrigate the crops, reducing the use of lead-containing fuels and wastewater treatment, and using plants with suitable genotypes [62].

Conclusion

This study was done to investigate the content of the metals in fresh and processed fruits based on sub-groups of metals and countries on different continents. Non-carcinogenic risk of toxic metals was also assessed based on the consumption of fresh and processed fruits and metals concentration in different countries. According to data, the highest concentrations of As, Cd, and Pb were detected in pineapple, mango, and cherry while the lowest concentrations of these metals were found in berries, pineapple, and berries respectively. Regarding the trace elements, peach and cucumber represented the maximum and minimum concentrations of Fe respectively. Besides, the highest and lowest concentrations of Cu were related to plum and banana, respectively. The risk assessment results showed that the highest and lowest non-carcinogenic risk of metals for fresh fruits was related to Nigeria and Poland and for processed fruits was related to Jordan and Poland respectively. Based on risk assessment, consumption of fresh and processed fruits was safe and does not pose risk to the health of consumers. Chemical characteristics of metals, climatic conditions, plant-growing situations (soil humidity, pH, and soil water level), type of industries and active mines, and type and amount of chemical fertilizers used for agricultural, traditional, and industrial use of different methods of cultivation have important roles on the level of metals in fresh and processed fruits.

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Declarations

Conflict of Interest All authors declare no competing interests.

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