Exposure and Health (2020) 12:641–655
https://doi.org/10.1007/s12403-019-00324-w

ORIGINAL PAPER

Dietary Estimated Intake of Trace Elements: Risk Assessment in an Italian Population

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Received: 23 August 2019 / Revised: 14 September 2019 / Accepted: 21 September 2019 / Published online: 9 October 2019

Abstract

Dietary intake to trace elements may represent the most relevant source of exposure for the general, non-occupationally population, but some of them have been rarely evaluated. We measured content of fifteen trace elements (antimony, barium, beryllium, boron, cobalt, lithium, molybdenum, nickel, silver, strontium, tellurium, thallium, titanium, uranium, and vanadium) in 908 food and beverage samples through inductively coupled plasma mass spectrometry. We estimated their dietary intake using a validated semi-quantitative food frequency questionnaire collected from a population of the Emilia-Romagna Region in Northern Italy. We compared our estimates with tolerable upper intake levels reported by international agencies and we assessed the non-carcinogenic risk through calculation of total hazard quotient for each trace element according to the US-EPA approach. Overall, estimates of their dietary intake were substantially similar to those reported from other countries, and they fell below the tolerable upper intake levels provided by international agencies. The total hazard quotient for each trace element was below 1. Our findings provide updated estimates of food levels and dietary intake of trace elements far frequently evaluated in a sample of Italian adult consumers. They also suggest that any non-carcinogenic risk associated with intake of investigated trace elements may be ruled out in our population.

Keywords Trace elements · Dietary intake · Food contamination · Food safety · Risk assessment

Introduction

A comprehensive assessment of dietary intake of chemical contaminants is needed to evaluate the long-term risk for public health and food risk assessment (European Food Safety Authority 2006; US-EPA; WHO 1996), considering that diet represents the most relevant source of majority of trace elements for non-occupationally exposed populations (Reilly 2002). In order to assess the possible health risk to the consumers, it seems necessary to evaluate trace element content in foods and beverages that are consumed by the general population and to estimate their actual dietary intake for comparison with tolerable levels (European Food Safety Authority 2006). In recent years, a few studies assessed the levels of rare or 'neglected' trace elements, especially in the Italian population (Filippini et al. 2018a; Turconi et al. 2009), and for some elements results are lacking also for Europe and other Western population (European Food Safety Authority 2011; Reilly 2002). In addition, the relevance of trace elements in human health and disease is well documented. Depending also of their role within the metabolism, they present an intriguing relation with human health, showing either nutritional and toxicological effects (Nordberg and Nordberg 2016; WHO 1996). Being diet most relevant source of exposure to the above-mentioned trace elements, a periodic and updated evaluation of their content in foods represents a key element for a comprehensive assessment of

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Electronic supplementary material The online version of this article (https://doi.org/10.1007/s12403-019-00324-w) contains supplementary material, which is available to authorized users.

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their intake levels and of possible consequent health risks (Kim et al. 2015).

To do this, in this study, we aimed to estimate the dietary intake of a large number of trace elements (namely antimony, barium, beryllium, boron, cobalt, lithium, molybdenum, nickel, silver, strontium, tellurium, thallium, titanium, uranium, and vanadium) in a Northern Italy population, in order to assess their exposure level through diet and evaluate whether these levels are safe for human health.

Methods

Food Collection and Analysis

We determined the content of trace elements in food samples available and collected in the area of the study. Food collection lasted from October 2016 to February 2017. We purchased a total of 908 food and beverage samples in local markets, large supermarkets, and grocery stores as well as in community canteens from Reggio Emilia and Modena provinces. Relevant food items characterizing the diet of this community were selected from previous population-based studies addressing the dietary habits of subjects from Northern Italy, with particular reference of Emilia-Romagna Region (Filippini et al. 2018a). In order to avoid cross contamination with metals and trace element under investigation, we used plastic food containers (i.e. 50 ml volume plastic tubes or jars) as well as plastic cutlery or stainless knives when handling and collecting food samples. Using a clean stainless-steel knife, we cut solid foods by collecting samples from six different points in the plate. Then, we homogenized the samples using a food blender equipped with a stainless-steel blade and we placed a portion of 0.5 g in quartz containers previously washed with MilliQ water (MilliQPlus, Millipore, MA, USA) and HNO_3. We liquid-ashed the samples with 10 ml solution (5 ml HNO_3 + 5 ml·H_2O) in a microwave digestion system (Discover SP-D, CEM Corporation, NC, USA) and we finally stored them in plastic tubes, and diluted to 50 ml with deionized water before analysis. Using an inductively coupled plasma mass spectrometer (Agilent 7500ce, Agilent Technologies, CA, USA), we performed trace element determination. All the analyses were performed in duplicate, implementing quality controls including both blanks (solution of MilliQ water) and a control solution of tap water additionally enriched with 22 ppb of each element under investigation (Filippini et al. 2018b, 2019b). Limits of detection (LOD) are presented in Table 1 and values below the LOD were set equal to LOD/2.

Table 1 Limit of quantification (LOQ) and limit of detection (LOD) of investigated elements

Element	LOQ	LOD
Antimony (Sb)	0.00390	0.00130
Barium (Ba)	0.79092	0.26364
Beryllium (Be)	0.00012	0.00004
Boron (B)	0.95640	0.31880
Cobalt (Cb)	0.04956	0.01652
Lithium (Lt)	0.02322	0.00774
Molybdenum (Mo)	0.05424	0.01808
Nickel (Ni)	0.31800	0.10600
Silver (Ag)	0.00012	0.00004
Strontium (Sr)	0.54096	0.18032
Tellurium (Te)	0.00210	0.00070
Thallium (Tl)	0.00300	0.00100
Titanium (Ti)	0.43914	0.14638
Uranium (U)	0.00096	0.00032
Vanadium (V)	0.05298	0.01766

All values are in µg/kg

We report the contamination levels of selected trace elements according to the food consumption patterns and food categories typical of this Italian population, as assessed through the European Prospective Investigation into Cancer and Nutrition-EPIC food frequency questionnaire implemented for dietary habits evaluation (Filippini et al. 2017a, 2017b; Turrini et al. 2001). The final list of main food categories includes cereals and cereal products, meat and meat products, milk and dairy products, eggs, fish and seafood, vegetables, legumes, potatoes, fresh fruits, dry fruits, sweets, and beverages.

Study Population and Assessment of Dietary Habits

We assessed dietary habits in sample population in Emilia-Romagna Region, Northern Italy. Detailed information of participant identification and recruitment has been previously reported in detail (Malavolti et al. 2013; Malavolti et al. 2017). To sum up, after the approval of the provincial ethical committee, and through the access to the National Health Service directory including all residents of the Emilia-Romagna Region, namely from the provinces of Bologna, Ferrara, Modena, Parma, and Reggio Emilia, we invited to participate to the study 2825 subjects, and eventually 747 (26.4%) agreed to participate and provided their written consent. The participants returned both a lifestyle questionnaire and the EPIC food frequency questionnaire (FFQ) which we had mailed to them. The EPIC FFQ is a validated semi-quantitative FFQ specifically developed for the Central-Northern Italy population (Pala et al. 2003; Pasanisi et al. 2002) within the 'European Prospective Investigation into Cancer and Nutrition' project. This FFQ was designed to estimate frequency and amount of consumption of 188 food items over the previous year, also using photos of serving sizes to help proper completion by participants.

Out of those who returned study materials, we excluded twenty-eight subjects from subsequent analysis because of incomplete data or extreme and implausible values of energy intake derived from the FFQ (assessed though the ratio of total energy intake:calculated basal metabolic rate lower than the 0.5th percentile or higher than the 99.5th percentile). The final population sample comprised 719 (men/women 319/400) adult subjects, with age ranging from 18 to 87 years, with 499 subjects (male/female 190/309) aged <65 years and 220 (male/female 129/91) aged ≥ 65 years. Mean age was 55.2 (standard deviation 14.5) years in overall sample with slightly higher values in men than women with mean age of 59.1 (14.0) year and 52.3 (14.1) years, respectively. (Filippini et al. 2019a; Malagoli et al. 2019). The median energy intake was 1906 kcal/day (interquartile range-IQR 1538–2364 kcal/day) in all subjects, 2024 kcal/day (IQR 1649–2462 kcal/day) in men and 1800 kcal/day (IQR 1455–2296 kcal/day) in women, respectively.

Dietary Intake Estimates of Trace Elements

We combined data from the determination of contamination levels of trace elements in foods and the dietary habits assessed using the FFQ to compute trace element daily intake, by using the equation presented below.

$$\text{Daily dietary estimate}\left(\frac{\mu g}{\text{day}}\right) = \sum \frac{\text{level in food}\left(\frac{\mu g}{\text{kg}}\right) \times \text{food intake}\left(\frac{\text{g}}{\text{day}}\right)}{1000}$$

We multiplied the element contents measured in food (μg/kg) with the intake as estimated by the FFQ (g/day). Accordingly, we estimated the daily dietary intake of the rare trace elements for the diet as a whole and for each food category, by reporting median and interquartile ranges (IQR). We also estimated the dietary intake by kilogram (kg) of body weight (bw), by dividing for weight of participants.

Finally, we implemented the human health risk assessment method as suggested by the US-Environmental Protection Agency (US-EPA) in order to evaluate the probability of adverse health effects in humans exposed to selected trace element through diet (Adel et al. 2016; Bonsignore et al. 2018; Copat et al. 2018; Ferrante et al. 2018). In particular, the safety risk assessment using target hazard quotient (THQ) promoted by US-EPA describes the non-cancer risk of contaminants by the ratio between exposure dose (i.e. dietary intake) and the reference dose (RfD) (US-EPA). Detailed expression is as follows:

$$\sum \text{THQ} = \sum \frac{\text{DI}}{\text{RfD}}$$

where THQ is the target hazard quotient, DI is the dietary daily intake in μg/kg bw/day, and RfD is the reference dose in μg/kg bw/day. A THQ <1 indicates that the trace element exposure level is no harmful, while a THQ >1 indicates that it has potential harm to the human body (US-EPA).

Results and Discussion

Only a few elements show values below the LOD of a large amount of food (Supplemental Table S1), in particular silver (48.6%), thallium (35.8%), tellurium (22.2%), and partially beryllium (14.1%) and antimony (11.0%). Tables 2 and 3 present the levels of trace element contamination in foods and the estimates of their dietary intake according to the main food categories, respectively, showing their median and interquartile range. Corresponding figures according to subcategories are presented in Supplemental Tables S2-S3, and dietary estimates in subjects aged <65 and ≥ 65 years are presented in Supplemental Tables S4 and S5, respectively. Table 4 compares the estimated median and the highest level we estimated in study population with the tolerable intake suggested by international regulatory agencies. Detailed results are presented for each trace element separately. Overall, our findings are similar compared to data on dietary intake reported in other countries when available.

Antimony

Antimony occurs mainly in a trivalent (as antimony trioxide) or pentavalent state (antimony potassium tartrate) (WHO 2003b). Antimony trioxide is considered a food contaminant due to its use as additive and initiator in the manufacture of polyethylene terephthalate and other polymers. Food contamination follows migration from food contact materials in which they are used (ECHA 2008; European Food Safety Authority 2004b). Antimony is also a naturally occurring element, therefore, its presence in the environment, and thereby also indirectly in water and in foods and beverages produced from agricultural goods, may also be attributed to natural sources (WHO 2003b). Antimony shows higher concentration in sweets products, followed by meat and fish (Table 2). Foods showing the highest antimony content are biscuits, dry cakes, chocolate, and candy bars among sweet products, but also mushrooms, processed meat, crustaceans, molluscs, and preserved and tinned fish demonstrated concentration above 2 μg/kg (Supplemental Table S2). The antimony daily dietary intake is 3.471 μg/day (IQR 2.801–4.395 μg/day) (Table 3), with main contribution from fresh fruits (particularly citrus fruits), cereal products (mainly bread), and meat (red and processed ones) (Supplemental Table S3). Our results are consistent with previous

Table 2 Trace element concentrations in main food categories

Food category		Antimony (μg/kg)		Barium (mg/kg)		Beryllium (μg/kg)
	50th	(IQR)	50th	(IQR)	50th	(IQR)
Cereals and cereal products	1.361	(0.263–3.438)	1.034	(0.724–1.400)	0.135	(0.033–0.269)
Meat and meat products	2.025	(0.836–4.284)	0.038	(0.022–0.072)	0.042	(0.007–0.106)
Milk and dairy products	1.031	(0.294–2.800)	0.539	(0.125–0.801)	0.048	(0.005–0.113)
Eggs	0.756	(0.158–0.941)	0.214	(0.031–1.096)	0.001	(0.000–0.048)
Fish and seafood	1.838	(0.551–3.783)	0.056	(0.026–0.165)	0.077	(0.024–0.226)
All vegetables	1.179	(0.276–3.897)	0.217	(0.081–0.532)	0.082	(0.020–0.220)
Legumes	1.185	(0.001–2.698)	0.893	(0.519–2.010)	0.342	(0.146–0.578)
Potatoes	1.489	(0.170–3.468)	0.088	(0.065–0.174)	0.109	(0.019–0.376)
Fresh fruits	0.526	(0.097–2.070)	0.169	(0.081–0.344)	0.059	(0.006–0.174)
Dry fruits, nuts, and seeds	1.535	(0.634–4.403)	0.927	(0.568–2.445)	0.277	(0.037–0.355)
Sweets, chocolate, cakes, etc.	2.101	(1.086–5.842)	0.693	(0.269–2.145)	0.145	(0.031–0.333)
Oils and fats	0.352	(0.150–1.285)	0.007	(0.002–0.015)	0.003	(0.000–0.022)
Beverages	0.363	(0.124–0.745)	0.039	(0.014–0.087)	0.067	(0.013–0.280)
		Boron (mg/kg)		Cobalt (μg/kg)		Lithium (μg/kg)
	50th	(IQR)	50th	(IQR)	50th	(IQR)
Cereals and cereal products	0.368	(0.188–0.751)	7.08	(4.03–13.11)	14.83	(7.16–29.15)
Meat and meat products	0.143	(0.059–0.256)	2.87	(2.01–5.52)	3.41	(2.01–6.05)
Milk and dairy products	0.164	(0.081–0.266)	6.88	(3.60–12.24)	4.78	(2.75–9.43)
Eggs	0.202	(0.181–0.331)	2.49	(0.94–5.48)	3.87	(1.50–6.51)
Fish and seafood	0.306	(0.097–0.554)	4.91	(2.98–7.45)	19.10	(10.49–38.80)
All vegetables	1.415	(0.956–2.427)	6.05	(3.71–13.92)	8.23	(2.37–23.26)
Legumes	7.756	(3.537–11.090)	72.84	(39.28–104.29)	15.43	(6.19–35.66)
Potatoes	0.796	(0.616–1.077)	9.72	(5.07–12.80)	8.99	(5.21–11.92)
Fresh fruits	2.009	(0.982–4.198)	3.45	(1.97–6.43)	1.87	(0.95–4.73)
Dry fruits, nuts, and seeds	11.131	(7.548–17.035)	38.07	(16.64–89.51)	4.48	(1.29–11.53)
Sweets, chocolate, cakes, etc.	0.696	(0.212–3.805)	6.99	(3.32–69.53)	7.08	(5.16–13.94)
Oils and fats	0.022	(0.000–0.123)	0.43	(0.01–1.77)	0.35	(0.004–1.48)
Beverages	0.671	(0.077–3.491)	1.29	(0.52–3.06)	2.36	(0.66–9.58)
		Molybdenum (μg/kg)		Nickel (μg/kg)		Silver (ng/kg)
	50th	(IQR)	50th	(IQR)	50th	(IQR)
Cereals and cereal products	421.06	(289.66–639.36)	109.06	(67.03–183.42)	374.85	(0.02–1026.00)
Meat and meat products	22.14	(12.70–41.98)	27.07	(12.78–46.73)	0.02	(0.02–234.00)
Milk and dairy products	77.10	(50.22–147.73)	30.22	(16.27–95.61)	0.02	(0.02–39.54)
Eggs	81.22	(34.81–203.03)	4.90	(3.30–7.21)	0.02	(0.02–0.02)
Fish and seafood	9.82	(3.91–26.09)	23.27	(13.06–50.22)	376.00	(0.02–2319.00)
All vegetables	48.56	(20.29–101.79)	64.75	(39.22–159.63)	87.62	(0.02–550.00)
Legumes	2531.86	(1022.62–5399.85)	896.13	(347.66–1660.21)	3.00	(0.02–1778.00)
Potatoes	44.67	(40.48–199.30)	97.14	(75.89–194.37)	282.00	(92.93–494.00)
Fresh fruits	9.19	(5.19–26.41)	31.53	(13.39–59.45)	0.02	(0.02–224.82)
Dry fruits, nuts, and seeds	163.32	(90.95–394.09)	1096.59	(486.95–2087.37)	734.00	(0.02–1881.00)
Sweets, chocolate, cakes, etc.	177.75	(79.66–244.11)	98.45	(39.39–695.49)	116.47	(0.02–537.32)
Oils and fats	1.87	(1.14–16.56)	7.13	(2.67–16.82)	0.02	(0.02–32.00)
Beverages	1.53	(0.70–3.76)	14.31	(6.16–24.83)	0.02	(0.02–0.15)

Table 2 (continued)

		Strontium (mg/kg)		Tellurium (μg/kg)		Thallium (μg/kg)
	50th	(IQR)	50th	(IQR)	50th	(IQR)
Cereals and cereal products	1.262	(0.867–1.810)	0.168	(0.000–1.022)	0.055	(0.001–0.494)
Meat and meat products	0.222	(0.083–0.580)	0.686	(0.292–1.605)	0.052	(0.001–0.374)
Milk and dairy products	2.459	(0.851–3.975)	0.937	(0.354–2.009)	0.044	(0.001–0.210)
Eggs	0.317	(0.178–0.825)	0.399	(0.142–0.482)	0.442	(0.001–0.516)
Fish and seafood	1.286	(0.659–4.294)	0.803	(0.283–1.631)	0.006	(0.001–0.217)
All vegetables	1.846	(0.564–3.644)	0.246	(0.000–0.674)	0.256	(0.001–1.542)
Legumes	2.338	(1.477–3.669)	0.382	(0.000–0.989)	0.001	(0.001–0.343)
Potatoes	0.280	(0.208–0.630)	0.189	(0.049–0.955)	0.046	(0.001–0.509)
Fresh fruits	0.453	(0.197–1.722)	0.185	(0.000–0.652)	0.001	(0.001–0.134)
Dry fruits, nuts, and seeds	4.078	(1.797–7.432)	1.072	(0.500–1.983)	0.648	(0.054–2.002)
Sweets, chocolate, cakes, etc.	1.145	(0.472–4.363)	0.435	(0.082–1.040)	0.300	(0.031–1.478)
Oils and fats	0.017	(0.000–0.141)	0.304	(0.000–1.451)	0.001	(0.001–0.135)
Beverages	0.193	(0.046–0.580)	0.048	(0.010–0.094)	0.077	(0.020–0.230)

		Titanium (μg/kg)		Uranium (μg/kg)		Vanadium (μg/kg)
	50th	(IQR)	50th	(IQR)	50th	(IQR)
Cereals and cereal products	395.84	(258.44–1109.75)	0.470	(0.197–0.901)	7.00	(3.28–12.92)
Meat and meat products	550.60	(333.29–2225.50)	0.220	(0.068–0.429)	3.46	(1.81–7.65)
Milk and dairy products	1100.75	(667.31–4800.02)	0.340	(0.113–0.746)	2.92	(1.59–7.44)
Eggs	450.00	(26.31–973.21)	0.043	(0.039–0.178)	1.41	(0.97–3.50)
Fish and seafood	453.96	(286.80–1342.46)	0.790	(0.226–2.367)	6.28	(3.05–17.67)
All vegetables	163.73	(65.93–471.55)	0.185	(0.051–0.944)	2.78	(1.12–9.12)
Legumes	790.47	(490.35–1031.42)	0.301	(0.188–0.627)	12.20	(3.22–26.60)
Potatoes	207.16	(85.09–447.81)	0.133	(0.048–0.437)	1.32	(0.97–2.37)
Fresh fruits	56.87	(30.32–152.52)	0.051	(0.017–0.088)	1.04	(0.59–1.72)
Dry fruits, nuts, and seeds	1222.86	(711.37–6671.81)	0.170	(0.050–1.122)	4.45	(1.91–9.80)
Sweets, chocolate, cakes, etc.	941.98	(414.39–1922.09)	0.594	(0.262–1.383)	8.62	(4.37–23.75)
Oils and fats	35.26	(10.87–111.97)	0.003	(0.000–0.110)	2.84	(1.07–3.79)
Beverages	76.67	(41.95–132.50)	0.132	(0.050–0.304)	1.90	(0.61–7.76)

results showing similar main sources of antimony content in food categories as well as our results show comparable (ANSES 2011; Arnich et al. 2012; Iyengar et al. 2000; Noel et al. 2003; Ysart et al. 1999) or slightly higher (Gibson and Scythes 1984; Gimou et al. 2014; Leblanc et al. 2005; Marcussen et al. 2013; Rose et al. 2010; Wappelhorst et al. 2002) or lower (Domingo et al. 2012) dietary intake respect to other European and non-European populations.

Barium

Barium compounds are present in nature due to leaching and erosion of natural deposits and subsequent contamination of groundwater sources. Foods showing higher barium content are cereals products, followed by legumes and dry fruits (Table 2). Particularly, among cereals, rice presents negligible content compared with pasta, bread, and other cereals products, while nuts and seeds, chocolate products, and other confectioneries show high concentration above 1 mg/kg (Supplemental Table S2). The estimated median dietary barium intake is 0.84 mg/day (IQR 0.62–1.12 mg/day) (Table 3) due to higher contribution from milk and dairy products (mainly aged cheese), cereal products, followed by vegetables (particularly leafy ones), and fruits (Supplemental Table S3). We found comparable intake (Gonzalez-Weller et al. 2013; Marcussen et al. 2013), or little higher than previous studies (ANSES 2011; Rose et al. 2010; Turconi et al. 2009; Ysart et al. 1999) and in one case lower (Gimou et al. 2014).

Beryllium

Main sources of beryllium and beryllium compounds are industrial processing and fossil fuel combustion (especially coal) resulting in emission of beryllium to the atmosphere, surface waters, and soil. In non-occupationally

Table 3 Daily estimated trace element intake by food category

		Antimony (µg/day)		Barium (µg/day)		Beryllium (ng/day)
	50th	(IQR)	50th	(IQR)	50th	(IQR)
Total intake (µg/day)	3.471	(2.801–4.395)	844.96	(618.13–1123.00)	237.74	(179.06–319.22)
Cereals and cereal products	0.523	(0.303–0.765)	177.52	(117.78–259.18)	37.98	(23.07–56.11)
Meat and meat products	0.496	(0.319–0.678)	11.06	(7.44–17.50)	8.94	(5.93–12.54)
Milk and dairy products	0.358	(0.213–0.579)	251.11	(131.14–432.29)	9.46	(5.36–13.95)
Eggs	0.010	(0.005–0.015)	7.22	(3.90–11.34)	0.37	(0.20–0.59)
Fish and seafood	0.081	(0.042–0.134)	3.00	(1.57–5.03)	4.42	(2.03–9.59)
All vegetables	0.396	(0.259–0.574)	65.18	(42.06–100.70)	49.78	(32.32–77.62)
Legumes	0.029	(0.013–0.054)	18.89	(8.75–35.14)	7.00	(3.24–13.03)
Potatoes	0.033	(0.020–0.060)	2.78	(1.65–4.94)	3.69	(2.19–6.56)
Fresh fruits	0.607	(0.387–0.870)	78.55	(51.15–110.81)	28.26	(17.81–40.82)
Dry fruits, nuts, and seeds	0.001	(0.001–0.006)	13.38	(13.32–86.62)	0.13	(0.08–0.69)
Sweets, chocolate, cakes, etc.	0.323	(0.179–0.581)	44.42	(20.87–84.86)	8.68	(3.92–15.22)
Oils and fats	0.162	(0.072–0.335)	0.18	(0.13–0.25)	0.47	(0.35–0.65)
Beverages	0.096	(0.042–0.191)	28.46	(15.66–47.58)	37.14	(7.66–103.82)
		Boron (µg/day)		Cobalt (µg/day)		Lithium (µg/day)
	50th	(IQR)	50th	(IQR)	50th	(IQR)
Total intake (µg/day)	2037.18	(1511.17–2760.72)	19.680	(14.822–25.170)	18.151	(14.638–22.868)
Cereals and cereal products	112.99	(76.37–156.77)	1.729	(1.122–2.527)	3.651	(2.445–5.289)
Meat and meat products	40.56	(27.15–56.36)	0.516	(0.334–0.730)	0.750	(0.496–1.071)
Milk and dairy products	45.18	(25.16–70.42)	1.115	(0.694–1.735)	1.079	(0.617–1.605)
Eggs	3.44	(1.86–5.41)	0.043	(0.023–0.068)	0.087	(0.047–0.137)
Fish and seafood	11.55	(5.56–19.57)	0.271	(0.129–0.537)	0.792	(0.382–1.475)
All vegetables	238.99	(162.30–344.08)	5.889	(3.593–9.684)	4.912	(3.263–6.951)
Legumes	115.51	(53.51–214.89)	1.253	(0.580–2.330)	0.669	(0.310–1.245)
Potatoes	19.44	(11.56–34.56)	0.285	(0.169–0.506)	0.164	(0.097–0.291)
Fresh fruits	676.60	(428.84–973.63)	1.437	(0.918–2.053)	1.723	(1.098–2.456)
Dry fruits, nuts, and seeds	3.70	(2.75–20.20)	0.022	(0.018–0.130)	0.033	(0.006–0.091)
Sweets, chocolate, cakes, etc.	86.66	(40.56–149.54)	1.832	(0.913–3.534)	0.714	(0.398–1.192)
Oils and fats	4.36	(3.19–6.00)	0.018	(0.012–0.026)	0.008	(0.004–0.014)
Beverages	326.13	(83.81–934.67)	1.806	(1.002–3.336)	1.677	(0.715–3.330)
		Molybdenum (µg/day)		Nickel (µg/day)		Silver (ng/day)
	50th	(IQR)	50th	(IQR)	50th	(IQR)
Total intake (µg/day)	196.28	(150.31–**260.36)**	130.92	(102.80–168.94)	908.14	(679.09–1146.63)
Cereals and cereal products	74.36	(50.38–104.76)	24.53	(16.04–34.99)	226.10	(140.84–325.60)
Meat and meat products	4.07	(2.56–6.06)	3.92	(2.55–5.34)	43.70	(23.87–87.08)
Milk and dairy products	12.70	(7.31–18.71)	8.03	(4.49–11.75)	11.41	(6.55–18.98)
Eggs	2.15	(1.16–3.38)	0.08	(0.04–0.12)	0.01	(0.01–0.01)
Fish and seafood	0.58	(0.28–1.03)	2.10	(1.15–3.57)	86.65	(39.07–208.52)
All vegetables	12.91	(8.73–18.87)	13.62	(8.94–20.21)	73.95	(48.68–113.36)
Legumes	51.99	(24.09–96.72)	16.61	(7.70–30.90)	18.18	(8.42–33.82)
Potatoes	2.48	(1.48–4.41)	2.50	(1.49–4.45)	8.00	(4.76–14.22)
Fresh fruits	5.91	(3.77–8.49)	14.15	(9.04–19.96)	173.03	(107.74–251.37)
Dry fruits, nuts, and seeds	0.18	(0.17–1.17)	0.43	(0.41–2.69)	1.37	(0.53–5.09)
Sweets, chocolate, cakes, etc.	9.31	(3.44–15.99)	13.82	(5.64–30.39)	36.23	(16.52–72.89)
Oils and fats	0.30	(0.16–0.58)	1.23	(0.91–1.68)	38.13	(12.26–85.62)
Beverages	1.78	(0.96–3.39)	9.29	(5.36–15.32)	3.04	(2.00–4.67)

Table 3 (continued)

		Strontium (µg/day)		Tellurium (ng/day)		Thallium (ng/day)
	50th	(IQR)	50th	(IQR)	50th	(IQR)
Total intake (µg/day)	1931.99	(1543.32–2390.35)	2698.06	(1921.86–3752.08)	533.69	(414.58–676.04)
Cereals and cereal products	248.66	(162.64–361.39)	177.77	(111.81–255.98)	65.87	(39.14–99.96)
Meat and meat products	43.72	(28.49–65.50)	339.40	(217.28–499.84)	73.64	(46.41–109.50)
Milk and dairy products	212.45	(132.59–323.31)	1089.56	(605.00–1863.86)	28.58	(12.89–44.78)
Eggs	6.38	(3.45–10.02)	6.91	(3.73–10.84)	6.53	(3.53–10.25)
Fish and seafood	70.68	(34.05–129.31)	36.17	(18.63–64.91)	4.83	(2.03–9.87)
All vegetables	405.23	(259.54–612.72)	106.63	(72.36–151.16)	123.22	(67.33–200.73)
Legumes	37.51	(17.38–69.78)	9.03	(4.18–16.80)	4.92	(2.28–9.16)
Potatoes	9.70	(5.77–17.25)	11.01	(6.55–19.58)	9.49	(5.64–16.87)
Fresh fruits	400.95	(251.58–562.46)	245.29	(155.58–354.65)	51.86	(33.03–73.21)
Dry fruits, nuts, and seeds	3.13	(2.65–19.03)	0.54	(0.42–3.09)	1.13	(0.63–5.70)
Sweets, chocolate, cakes, etc.	93.08	(46.63–159.51)	48.00	(27.39–76.21)	42.75	(20.27–77.95)
Oils and fats	1.31	(0.67–2.39)	309.04	(123.69–626.20)	0.56	(0.38–0.86)
Beverages	155.96	(77.35–292.84)	42.38	(26.89–61.84)	48.25	(23.53–87.42)
		Titanium (µg/day)		Uranium (ng/day)		Vanadium (µg/day)
	50th	(IQR)	50th	(IQR)	50th	(IQR)
Total intake (µg/day)	881.90	(705.58–1135.53)	790.18	(600.52–1121.22)	10.363	(7.822–13.426)
Cereals and cereal products	140.37	(93.06–198.58)	154.95	(98.57–224.00)	1.646	(1.010–2.463)
Meat and meat products	155.74	(107.32–219.56)	31.67	(20.58–44.52)	0.645	(0.425–0.925)
Milk and dairy products	283.99	(167.35–407.48)	59.46	(35.03–96.26)	0.370	(0.229–0.528)
Eggs	7.64	(4.13–12.00)	3.30	(1.79–5.19)	0.032	(0.017–0.050)
Fish and seafood	33.13	(18.73–52.28)	48.97	(20.37–116.35)	0.560	(0.270–1.081)
All vegetables	51.81	(36.36–77.02)	117.53	(77.26–175.57)	2.025	(1.330–3.131)
Legumes	11.02	(5.10–20.49)	7.31	(3.39–13.61)	0.255	(0.118–0.474)
Potatoes	4.94	(2.94–8.78)	6.57	(3.91–11.68)	0.188	(0.112–0.335)
Fresh fruits	32.05	(20.45–44.86)	19.51	(12.29–28.19)	0.355	(0.226–0.510)
Dry fruits, nuts, and seeds	0.91	(0.80–5.63)	0.46	(0.25–2.23)	0.005	(0.002–0.015)
Sweets, chocolate, cakes, etc.	57.30	(29.02–108.07)	71.74	(39.63–128.74)	0.860	(0.474–1.515)
Oils and fats	5.19	(0.00–19.75)	1.33	(0.83–2.25)	0.064	(0.042–0.097)
Beverages	2.23	(1.34–3.57)	135.17	(53.23–332.62)	1.516	(0.479–3.681)

exposed population, ingestion through foods and beverages is the main route of exposure (WHO 2009). We found higher beryllium concentration in legumes, dry fruits, and sweet products (Table 2), with also substantial content in all cereal products but rice, leafy vegetables, red wine, and chocolate and biscuits/dry cakes (Supplemental Table S2). Beryllium daily intake is of 0.24 µg/day (IQR 0.18–0.32 µg/day) (Table 3) with main contribution from leafy vegetables, cereals (pasta and bread), beverages (particularly wine), and citrus fruits (Supplemental Table S3). We found comparable intake (ATSDR 2007; Domingo et al. 2012; Marcussen et al. 2013) or in such cases little higher (Llobet et al. 1998; Turconi et al. 2009) than previous studies.

Boron

The collective body of evidence has yet to establish a clear biological function for boron in humans, since no specific biochemical function has been identified (Institute of Medicine 2001). Adverse health effects due to low boron intake have been consistently accompanied with deficiency of other elements such as calcium, copper, or magnesium (Nielsen 2014; WHO 2003d). The greatest amount of boron exposure in the general population occurs through food intake in the form of borate and boric acid (European Food Safety Authority 2004c). We found higher boron concentration in dry fruits/seeds, legumes, and fruits (Table 2), with also high content among all vegetables from leafy and other vegetables, cabbage, chocolate and candy bars, and wine

Table 4 Dietary daily intake (DI) and tolerable upper intake levels (UI) of trace elements reported by this study compared with data reported by international agencies

Element		This study		EU	WHO	US-EPA	THQ
	DI (µg or mg/day)	DI (µg or mg/kg bw/day)	DI (µg or mg/kg bw/week)	UI (µg or mg/kg bw/week)	UI (µg or mg/kg bw/week	RfD[a] (µg or mg/kg bw/day)	
Antimony (Sb) (µg)	3.47	**0.050**	0.352	6 (European Food Safety Authority 2004b)	6 (WHO 2003b)	**4**	**0.013**
Barium (Ba) (mg)	0.84	**0.012**	0.084	0.2 (SCHER 2012)	0.21 (WHO 2016)	**0.2**	**0.060**
Beryllium (Be) (µg)	0.24	**0.003**	0.024	Not assessed	2 (Bruce et al. 2001; WHO 2009)	**3**	**0.001**
Boron (B) (mg)	2.05	**0.029**	0.206	0.14 (European Food Safety Authority 2004c)[b]	0.19 (WHO 1996)[b]	**0.2**	**0.150**
Cobalt (Co) (µg)	19.68	**0.277**	1.938	1.6 (European Food Safety Authority 2012)	Not derived (Kim et al. 2006)	**5**[c]	**0.560**[e]
Lithium (Li) (µg)	18.15	**0.258**	1.807	Not derived (European Food Safety Authority 2009a)	Not derived (WHO 1996)	**2**[d]	**0.130**
Molybdenum (Mo) (mg)	0.20	**0.003**	0.020	0.009 (European Food Safety Authority 2013)[b]	0.029 (Institute of Medicine 2001; WHO 2003a)[b]	**0.005**	**0.560**
Nickel (Ni) (µg)	130.92	**1.844**	12.906	2.8 (European Food Safety Authority 2015)	22 (WHO 2005)	**20**	**0.092**
Silver (Ag) (µg)	0.91	**0.013**	0.089	Not derived (European Food Safety Authority 2016b)	Not derived (WHO 2003c)	**5**	**0.003**
Strontium (Sr) (mg)	1.93	**0.027**	0.191	Not derived (European Food Safety Authority 2009c)	0.13 (WHO 2010)	**0.6**	**0.045**
Tellurium (Te) (µg)	2.70	**0.039**	0.271	Not derived (ANSES 2011)	Not assessed	**210**	**0.0002**
Thallium (Tl) (µg)	0.53	**0.007**	0.052	0.14 (German Federal Institute for Risk Assessment (BfR) 2004)[b]	Not derived (WHO and International Programme for Chemical Safety 1996)	**0.01**[e]	**0.744**
Titanium (Ti) (mg)	0.88	**0.126**	0.885	Not derived (European Food Safety Authority 2016a; European Food Safety Authority 2018; European Food Safety Authority 2019)[f]	Not derived (FAO/WHO 1969)	**Not assessed**	**–**
Uranium (U) (µg)	0.79	**0.012**	0.081	0.6 (European Food Safety Authority 2009b)	0.6 (WHO 2004)	**3**	**0.004**
Vanadium (V) (µg)	10.36	**0.146**	1.021	Not derived (European Food Safety Authority 2004a; Tiesjema and Baars 2009)[g]	Not derived (Institute of Medicine 2001; WHO 1996; WHO 2000)[g]	**9**	**0.017**

Data for target hazard quotient (THQ) calculation reported in bold

bw body weight, *DI* estimated dietary intake, *EFSA* European Food Safety Authority, *UI* upper intake daily intake, *US-EPA* US-Environmental Protection Agency, *RfD* reference dose, *THQ* target hazard quotient, *WHO* World Health Organization

[a] Reference dose (RfD) provided by US-Environmental Protection Agency (US-EPA) (US-EPA)

Table 4 (continued)

[b] 70 kg of body weight considered for the comparison. Original values for boron were 10 mg/day (European Food Safety Authority 2004c) and 13 mg/day (WHO 1996), for molybdenum 0.6 mg/day (European Food Safety Authority 2013) and 2 mg/day (Institute of Medicine 2001; WHO 2003a) and for thallium 10 mg/day (German Federal Institute for Risk Assessment (BfR) 2004)

[c] Using the subchronic p-RfD of 3 mg/kg/day, the THQ is 0.093 (Finley et al. 2012)

[d] For lithium, we used the subchronic and chronic p-RfD of 2 µg/kg-day since RfD is not available

[e] Since RfD was not derived, we used the value of 0.01 µg/kg bw/day for thallium salts, observed for hair follicle atrophy

[f] Upper limit not derived for elemental titanium, but for titanium dioxide (TiO_2) a No Observed Adverse Effect Level (NOAEL) of 2250 mg TiO2/kg bw/day was reported

[g] Upper limit not derived, although the lowest intake with reported adverse effects was 200 µg/kg bw/day. The Institute of Medicine proposed a values of 1.8 mg/day as upper limit for elemental vanadium (Institute of Medicine 2001), approximately corresponding to 0.18 mg/kg bw/week for an adult of 70 kg of body weight

(Supplemental Table S2). Estimated dietary boron intake is 2.05 mg/day (IQR 1.51–2–76 mg/day) that is comparable or little higher compared to the data reported in previous studies (Biego et al. 1998; Hunt and Meacham 2001; Iyengar et al. 2000; Meacham and Hunt 1998; Rainey and Nyquist 1998; Shimbo et al. 1996; Turconi et al. 2009; Ysart et al. 1999).

Cobalt

Cobalt owes its essentiality as central bonding atom for the vitamin B12 (also called cobalamin), which is necessary for the metabolism of folates and fatty acids. In the general population, the largest source of cobalt exposure is through diet, ingested in its inorganic form by plants, while only a small fraction of total cobalt intake occurs in the form of cobalamin from foods of animal origin (Gambelli et al. 1999; Kim et al. 2006). In our study, foods showing the highest cobalt content are legumes, dry fruits/seeds, and potatoes (Table 2), with also high levels in sweets (particularly chocolate products), leafy vegetables, offal, and cheese (Supplemental Table S2). The daily cobalt intake is 19 µg/day (IQR 14.82–25.17 µg/day), driven by vegetables, with also substantial contribution from sweets, beverages, cereals, but also fresh fruits, legumes, and dairy products. Dietary intake was similar (Domingo et al. 2012; Reilly 2002) or slightly higher than other populations (ANSES 2011; Arnich et al. 2012; Marcussen et al. 2013; Ysart et al. 1999), but alternatively higher (Leblanc et al. 2005; Noel et al. 2003; Shimbo et al. 1996) and lower intake (Biego et al. 1998; Turconi et al. 2009) are also reported.

Lithium

Lithium is the lightest alkali metal, naturally present in soil and water. Due to its similarity to sodium and potassium and to a lesser extent to magnesium and calcium, it can compete with their intracellular targets and binding sites, although with different affinity (WHO 1996). In spite of lithium not yet considered an essential element (Schrauzer 2002), it has been demonstrated that lithium plays a role within the nervous system, and lithium salts are used in the treatment of psychiatric diseases, especially bipolar affective disorder (Mitchell and Hadzi-Pavlovic 2000). According to main categories, we found the highest lithium content in fish (especially crustaceans and molluscs), legumes, cereal products (all but rice), and potatoes (Table 2), with also high concentration in dry fruits, leafy vegetables and cabbage, sweet confectionery not chocolate, red wine, and fresh cheese (Supplemental Table S2). Our results show an estimated dietary lithium intake of 18.15 µg/day (IQR 7.16–29.15 µg/day) comparable or slightly higher to previous studies (Evans et al. 1985; Leblanc et al. 2005; Marcussen et al. 2013; Noel et al. 2003; Ysart et al. 1999), though also higher intake was reported (Gimou et al. 2014; Gonzalez-Weller et al. 2013; Iyengar et al. 2000; Turconi et al. 2009).

Molybdenum

Molybdenum is considered an essential trace element as it enters in a cofactor (molybdopterin) of certain enzymes that catalyse redox reactions (European Food Safety Authority 2013). Legumes, cereals (particularly rice), and offal are foods generally containing high concentration of molybdenum, similarly to what we found in our study (Table 2), and also chocolate, biscuits, dry cakes, and dry fruits/seeds present high content (Supplemental Table S2). Dietary daily intake is 196.28 µg/day (IQR 150.31–260.36 µg/day) due to substantial contribution from legumes, cereals (Table 3), particularly pasta and bread, but also vegetables, milk, and dairy products (Supplemental Table S3). Our estimates are similar (Gimou et al. 2014; Hunt and Meacham 2001; Leblanc et al. 2005; Shimbo et al. 1996) or slightly higher compared to other studies (ANSES 2011; Evans et al. 1985; Noel et al. 2003; Turconi et al. 2009; Ysart et al. 1999), while lower than other findings (Biego et al. 1998; Marcussen et al. 2013).

Nickel

Nickel is not essential for humans despite it plays an essential role in methionine metabolism in other animal species (WHO 2005). Conversely, nickel compounds are considered human carcinogens following exposure by inhalation (IARC 1990). However, there are no studies indicating any carcinogenic effects following oral exposure (IARC 1990). Beside raw foods, nickel levels in processed foods can be increased by pick-up from cooking materials and containers (Reilly 2002). Foods showing high nickel concentrations are mainly dry fruits/seeds and legumes (Table 2), with also very high levels in chocolate products, and partially also mushrooms, rice, and bread (Supplemental Table S2). The main foods contributing to the nickel daily intake of 130.92 µg/day (IQR 102.80–168–94 µg/day) are cereals, legumes, vegetables, fresh fruits, and sweets (Table 3), particularly leafy vegetables, other vegetables and tomatoes, citrus fruits, chocolate products, and coffee and tea (Supplemental Table S3). Similar intake is reported in previous studies (Alberti-Fidanza et al. 2002; Bocio et al. 2005; Pennington and Jones 1987; Shimbo et al. 1996; Ysart et al. 1999), while little lower (ANSES 2011; Arnich et al. 2012; Gimou et al. 2014; Larsen et al. 2002; Marcussen et al. 2013; Turconi et al. 2009), and alternatively higher was reported in other ones (Domingo et al. 2012; Leblanc et al. 2005; Santos et al. 2004).

Silver

Silver is a white metal generally having only trace amounts in foods, apart from its possible use as food additive (i.e. colouring agent) in cake decorations and confectionery (European Food Safety Authority 2016b). We found higher silver concentration in dry fruits, nuts, and seeds, followed by fish and seafood, cereals products, and eventually potatoes and sweets (Table 2). In particular, we found the highest values in crustaceans and molluscs, mushrooms, rice, and dry fruits. The estimated daily dietary intake is 0.908 µg/day (IQR 0.679–1.147 µg/day) with main contribution from cereals, fruits, and vegetables (mainly leafy ones), and fish, particularly crustaceans and molluscs (Table 3 and Supplemental Table S3). It should be pointed out that approximately half of the samples showed values below the LOD for silver (Supplemental Table S1), thus estimated could have been influenced by this large number of low results. Though limited dietary intake data are reported for silver (European Food Safety Authority 2011; Reilly 2002), our results show lower intake compared with other populations (ANSES 2011; Arnich et al. 2012; Dolara 2014; Evans et al. 1985; Gibson and Scythes 1984; Marcussen et al. 2013).

Strontium

Strontium occurs naturally in Earth's crust in the form of minerals such as celestite and strontianite and for humans non-occupationally exposed major sources are drinking water and foods (WHO 2010). Strontium can interfere with bone mineralization in the developing skeleton (WHO 2010), and a relationship between strontium exposure and childhood rickets has been suggested (Ozgur et al. 1996). We found the greater strontium content in dry fruits/seeds, dairy products, and legumes (Table 2) with the highest levels in crustaceans and molluscs, sweets products like confectionery made with and without chocolate, aged cheese, and some types of vegetables, particularly leafy, root, cabbage, and other types (Supplemental Table S2). The estimated dietary strontium intake was of 1.93 mg/day (IQR 1.54–2.39 mg/day), mainly driven by vegetables and fruits, followed by cereals (mainly bread and pasta) and dairy products (particularly cheese) (Table 3 and Supplemental Table S3). We found generally comparable (ANSES 2011; Gimou et al. 2014; Gonzalez-Weller et al. 2013; Iyengar et al. 2000; WHO 2010) or slightly higher estimated intake than previous studies (Evans et al. 1985; Marcussen et al. 2013; Turconi et al. 2009; Ysart et al. 1999).

Tellurium

Tellurium is a rare trace element with no biological function in human and generally its importance as a food contaminant is minor (Reilly 2002), as confirmed in our study demonstrating approximately 20% of samples below the LOD (Supplemental Table S1). In particular, we found higher tellurium concentrations in dry fruits, nuts and seeds, milk and dairy products, and fish (Table 2). Particularly in subgroup categories, we found the highest tellurium levels in processed meat, aged cheese, and mushrooms (Supplemental Table S2). The estimated daily dietary intake is 2.70 µg/day (IQR 1.92–3.75 µg/day) driven by foods of animal origin, namely dairy products, red and processed meat, oils and fats, followed by citrus fruits and cereals (Table 3 and Supplemental Table S3). Despite the limited data available (Reilly 2002), we found consistent findings with the most recent studies (ANSES 2011; Gimou et al. 2014), demonstrating a much lower intake than older data previously reported (Kron et al. 1991; Reilly 2002; Schroeder et al. 1967).

Thallium

Little information is available on levels of thallium in foods and diets. There is some evidence that thallium behaves like potassium in soil, thus it is readily absorbed by certain plants (Reilly 2002). In our study, we observed higher thallium concentration in dry fruits/seeds, vegetables, and eggs

(Table 2), with the highest levels in root vegetables, cabbages, and particularly chocolate products (Supplemental Table S2). Thallium dietary intake was estimated in 0.53 µg/day (IQR 0.41–0.68 µg/day), with main contribution from vegetables (mainly cabbages, root, and other vegetables), followed by meat (primarily white), cereal products (all but rice), and fresh fruits, particularly citrus ones (Table 3 and Supplemental Table S3). Also for thallium, we observed a consistent number (35.8%) of samples below the LOD (Supplemental Table S1), and also limited data about intake are available in other population. Nevertheless, our findings suggest that a lower dietary intake seems to be experienced compared with previous studies (Domingo et al. 2012; Rose et al. 2010; Ysart et al. 1999).

Titanium

Titanium is the eighth most common element in Earth's crust and is commonly found in foods. In addition, in food industry, titanium dioxide is used as food additive for whitening and brightening purpose in flour, confection, and other sweets products, and non-dairy milk products (European Food Safety Authority 2016a; Reilly 2002) as well as in other personal care products, e.g. toothpaste, cosmetics, or sunscreens (Rompelberg et al. 2016; Weir et al. 2012; Winkler et al. 2018). Due to its wide-scale distribution in the environment, titanium is a frequent food contaminant, but at relatively low levels since it is poorly absorbed from soil (Reilly 2002). We found high metal concentrations in dry fruits/seeds, dairy products (particularly cheese), sweets, and also legumes (Table 2). In particular, we detected the highest titanium level in chocolate products and biscuits/dry cakes among sweets, and also white meat compared with overall content (Supplemental Table S2). We estimated a dietary intake of 0.88 mg/day (IQR 0.71–1.14 mg/day), with major contribution from milk and dietary products, meat, and cereals. In spite of its wide use, data on dietary intake of total titanium are scarce and not up-to-date. Our results showed more than double intake compared with a previous study carried out in Japan and US (Reilly 2002; Shimbo et al. 1996). Conversely, due to the large use in the most recent decades of titanium dioxide, many studies assessed its particular intake, showing intake levels approximately similar or slightly higher than our study (Bachler et al. 2015; Heringa et al. 2016; Rompelberg et al. 2016; Weir et al. 2012; Winkler et al. 2018), also considering that most of them accounted the contribution from other sources like toothpaste that could not be considered in our study.

Uranium

Uranium exposure in the general population is only marginally assessed. Excluding contamination from dumping sites, uranium is naturally present in soil at different levels depending on the geological origin, thus affecting the natural content in waters and foods and consequently human dietary intake (Anke et al. 2009; European Food Safety Authority 2009b). We found high uranium levels in fish, sweets products, and cereals (Table 2), with the highest levels in crustaceans and molluscs, mushrooms, dry fruits, and also leafy vegetables (Supplemental Table S2). We estimated a daily intake of 0.79 µg/day (IQR 0.60–1.12 µg/day) due to contribution by cereals (all but rice), beverages (particularly fruit juices, coffee/tea, and wine), and vegetables (leafy and other vegetables and tomatoes) (Table 3 and Supplemental Table S3). We found comparable intake compared with one previous study (Marcussen et al. 2013) while notably lower than those found in one Spanish survey (Domingo et al. 2012).

Vanadium

In spite of some indication for symptoms of deficiency in animals, vanadium has not been shown to be essential for humans and thus it has no nutritional value (European Food Safety Authority 2004a). Nevertheless, in the general population diet is the major source of the metal (Institute of Medicine 2001). Our findings show that legumes and sweets, cereals, and also fish are foods showing high vanadium content (Table 2), with the highest values in chocolate products, dry fruits, leafy vegetables, crustaceans and molluscs, and bread (Supplemental Table S2). The estimated daily intake is 10.36 µg/day (IQR 7.82–13.43 µg/day), due to major contribution from vegetables, cereals, and beverages (Table 3), particularly leafy vegetables, bread, and wine from subgroup analysis (Supplemental Table S3). Similar or slightly lower intake was found compared to previous studies (Arnich et al. 2012; Evans et al. 1985; Gimou et al. 2014; Pennington and Jones 1987; Shimbo et al. 1996; Turconi et al. 2009), except when comparing with findings from two Spanish studies reporting much higher intake (Bocio et al. 2005; Domingo et al. 2012).

Risk Assessment

For the considered elements, the target hazard quotient (THQ) shows no substantial risk when comparing the median intake in the study population with the RfD provided by US-EPA (Table 4). It should be noted that for titanium we are unable to evaluate the THQ since RfD was not provided, as well as no upper limits are derived from international agencies, considering the use of titanium substantially safe (European Food Safety Authority 2019; FAO/WHO 1969).

Conclusions

Overall, our study provides dietary estimated intake for a group of fifteen trace elements with generally scarce data and demonstrates that data from other countries, when available, are substantially similar. In addition, the estimated intakes are generally below the tolerable upper intake levels provided by international agencies. Thus, levels of trace elements in diet of the investigated population could be considered safe.

One of the strengths of our study is the collection and analysis of a large number of samples of foods and beverages that are actually purchased and consumed in the Emilia-Romagna Region. Secondly, we performed the estimation of dietary habits in a large population sample with overall dietary characteristics similar to those observed in other Italian populations (Agnoli et al. 2011; Malagoli et al. 2015). In addition, we used a detailed and validated food frequency questionnaire developed for the Northern Italian population (Pala et al. 2003; Pasanisi et al. 2002).

Our study also has some limitations which need to be acknowledged. We did not assess the bioavailability of trace elements after food ingestion by determining biological indicators of exposure, although previous studies suggested that only a fraction of total element intake is absorbed, especially in the presence of malabsorption disease (Reilly 2002). In addition, we did not carry out any speciation analysis for the selected elements, in spite of the increasing evidence of the importance of speciation analysis in the exposure assessment of trace elements possibly characterized by either toxicological and nutritional properties/features (Michalke et al. 2009, 2018; Ruzik 2012; Vinceti et al. 2017). Secondly, we did not differentiate between local and imported samples, hampering the ability to assess such a difference due to geographic origin of products. Finally, our study was carried out in adult population only, thus we could not evaluate dietary intake and safety levels in vulnerable population like children or pregnant women. With regard to some trace elements investigated, we did not evaluate the influence of other dietary sources of the metal such as cooking material and food containers, as well as other possible 'unconventional' dietary intake, e.g. toothpaste for titanium (Heringa et al. 2016; Perello et al. 2008; Ramos et al. 2016). Despite we limiting our assessment to dietary intake only, as the most relevant source in the general population (Reilly 2002), however, the evaluation of overall exposure in humans requires that additional sources be considered, particularly use of dietary supplements (which may represent the highest source of such trace elements in high consumers), dermal contact or air pollution (Rautiainen et al. 2016; Reilly 2002; WHO 1996). Dietary supplements consumption, however, is unlikely to have induced any substantial exposure misclassification in our investigation, since their use was very rare in the study population (Vinceti et al. 2011), as generally occurring in the Italian population.

Acknowledgements This work was supported by the and Reggio Emilia Local Health Authority of the National Health Service.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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