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Dietary exposure assessment and risk characterization of lead based on lead contaminant research (online) in Indonesia and Indonesian Individual Food Consumption Survey (IFCS)

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Abstract. An exposure assessment was performed to estimate the potential of lead dietary intake in the Indonesian population. Dietary exposure assessment requires information on lead concentration in food and food consumption data. The data of lead concentration in food was a secondary data obtained through online research from several online scientific resources with keywords "lead in food, lead contamination". Food consumption data were obtained from Indonesian Individual Food Consumption Survey. Lead dietary intakes were estimated with a deterministic approaches that used lead concentration in food and maximum level (ML) of lead in food based on Indonesia Nation Agency of Drug and Food Control (INA-DFC) regulation with the average value of food consumption. Risk characterization was conducted by comparing dietary intakes with a Provisional Tolerable Weekly Intake (PTWI). The results have shown that the infant group (0-59 months) had highest lead dietary intakes. Lead dietary intakes of mean concentration of lead from references are lower than lead dietary intake of INA-DFC ML of lead in all age groups. Risk characterization results showed that lead dietary intake of average level data and ML are at high risk (>100% PTWI) in all age groups. Major contributors to lead dietary intakes are fish and seafood.

Keywords: dietary, food, lead contamination

1. Introduction

Lead (Pb) is a heavy metal which commonly contaminates our environment (air, water, and soil). Lead contaminations in environments can be caused by oil combustion, gas emission of vehicles as well as, industrial and domestic waste. Lead was mostly used as material in packaging, water piping, household equipment, and crafters [1]. As in the form of lead dioxide, it was used as pigment or colorants in ceramics and cosmetics industries. Its characteristic is that it is soft in texture, easy to be formed, and has good electrical conductivity, making it one of the most popular metals used in any electronic industries. The result of measurement by Environmental Impact Management Agency of North Sumatra Province in 2003 showed that the lead level of air pollution in Medan City was 3.5 µg/Nm3. That level had exceeded the maximum standard set by the government in PP RI No. 41/1999, which is 2.0 µg/Nm^3 [2]. Lead concentration on the water surrounding Jakarta was around 0.013–0.117 µg/mL on rainy season and around 0.03–0.067 µg/mL on the dry season [3]. That concentration had exceeded maximum standard level (0.008 µg/mL) governed by Environmental Ministry.

Lead exposure to human occurred in two ways which are through the respiratory and digestive systems. Lead exposure through the digestive system is caused by contaminated food and water. Accumulation of lead in the human body can harm human's health. WHO had identified lead as one of ten chemicals of major public health concerns, needing action by member states to protect especially the health of workers, children, and women of reproductive age [4]. Lead toxicity depends on the exposure route, dosage, and growth stage of the organism [3]. Lead exposure on children can affect brain development resulting in reduced intelligence quotient (IQ) and brain damage. Meanwhile, on adults, it can trigger nausea, loss of appetite, anemia, sleep disorder, weaken, high blood pressure, and miscarriage [1]. Based on the Health Ministry of Indonesia, the correlation between dietary exposure and intelligence decrease is for every exposure of 12 µg/day will reduce one IQ point [5]. Codex regulated Provisional Tolerable Weekly Intake (PTWI) as the tolerance threshold of lead exposure on human body per day was 25 µg/kg of body weight (BW) [6].

Dietary exposure assessment is the qualitative and/or quantitative evaluation of the likely intake of a biological, chemical and physical agent via food [7]. Dietary exposure assessment could be conducted using deterministic or probabilistic approaches. The deterministic approach uses point values to produce a point estimate of exposure (either high-end or typical exposure). Probabilistic approach uses more complicated modeling that relies on distributions of data as inputs in place of point values for key parameters. The data needed for conducting lead exposure assessment was the lead concentration in food and food consumption data. Lead exposure assessment that was conducted by the Health Ministry of Indonesia showed that lead intake ranges between 0.4724-1.7355 µg/kg BW/day [5]. Risk characterization was then conducted to evaluate the risk value of lead exposure in Indonesia and to identify the major contributor to lead dietary exposure.

The lead exposure assessment in this study was conducted using consumption data from Indonesian Individual Food Consumption Survey (IFCS) year 2014, lead concentration data (minimum, maximum and mean) based on online scientific literature from 2004 to 2017, and lead maximum level based on INADFC Regulation No 23 - 2017. Based on the types of data used, lead exposure assessment was conducted using a deterministic approach.

2. Materials and Methods

2.1. Data

This study used three types of secondary data. They are food consumption data based on Total Diet Study Diet: Indonesian Individual Food Consumption Survey (IFCS) year 2014, lead concentration from national and/or international scientific publications such as journals, thesis, dissertation, research report, and proceeding during 2004-2017 also data of lead maximum level in food in Indonesia based on INAFDC Regulation Number 23-2017. Data were analyzed using Microsoft Excel 2013.

2.2. Secondary data extraction

From IFCS report data of food consumption level for 17 food groups and six age groups, as well as body weight data of respondents, were obtained [8]. Lead maximum levels in food in Indonesia were extracted from INAFDC Regulation Number 23 - 2017 about the Maximum level of heavy metals in processed food. Lead concentration data were collected and analyzed in five steps as follows:

a. Lead concentration data were collected through online research from several online scientific resources with keywords "lead in food, lead contamination". The data collection process was performed using internet search engines, journal sites, and university repository. The total collection of results was: 377 references in detail we sampled 114 scientific journals, 208 theses, and 55 other scientific references.
b. Reference selection was done using the following criteria: 1) Lead concentration was tested using Atomic Absorption Spectrophotometer (AAS), 2) and test samples taken were from Indonesian territory, 3) Samples were eligible for consumption and 4) As results reasonable data were presented. Total selection results were 293 references in detail we sampled 86 scientific journals, 165 theses and 42 other scientific references.

c. Data mapping of lead concentrations was conducted to obtain lead concentration level for all food groups and lead concentrations in all Indonesia.
d. Lead concentration data were processed using Microsoft Excel 2013 to obtain minimum, maximum, and mean values for all food groups. The standard deviation was calculated in order to know the data distribution.
e. Evaluation of lead contamination levels was conducted by comparing the mean of lead concentrations from references with INADFC maximum level of lead

2.3. Food groups matching process from lead references and Indonesian regulation with IFCS report 2014
Food group matching process was conducted by comparing food types from lead references and food categories of INADFC regulation with 17 food groups in IFCS report 2014. If there are differences, then the food groups would follow IFCS report 2014.

2.4. Dietary exposure assessment of lead
Lead dietary intakes were obtained by multiplying lead concentration with food consumption level as below:

$$\text{Dietary Intakes} = \frac{\Sigma(\text{Food consumption level x lead concentration})}{\text{Body weight}} \quad (1)$$

Lead dietary intakes are calculated in µg/kg body weight/day. The lead dietary intakes were calculated for the minimum, maximum and means of lead concentrations from references and maximum level of lead from INADFC regulation. The food groups which have no lead concentration and/or mean of food consumption value of zero (0) were excluded from dietary intakes calculation.

2.5. Risk characterization of lead from food in Indonesia
Risk characterization was performed by calculating the risk values of lead intakes, IQ decline in children and identification of food groups that contribute to lead intakes in the following way:

a. Risk values of lead intakes were calculated by comparing lead dietary intakes with Provisional Tolerable Weekly Intake (PTWI) of lead. The risk was stated as high or unsafe if it exceeds 100% PTWI.
b. The calculation of IQ score decrements due to lead intakes was based on estimation in table 1.

Table 1. The estimation of lead intakes relationship with IQ score (using bilinear and hill method [9].

No	IQ score decrement in children	Lead dietary intakes (µg/day)*
1	0.5	17 (2-194)
2	1	30 (4-208)
3	1.5	40 (5-224)
4	2	48 (7-241)
5	2.5	55 (9-261)
6	3	63 (11-296)

Notes: *Median estimation by 5-95 percentile confidence interval in brackets

c. The contribution of food groups to dietary lead intakes was calculated in percentage and sorted by the highest to lowest contribution. Food groups which contribute less than five percent were grouped as other food.

3. Results and Discussion

3.1. Respondent profile
The number of respondents surveyed in the IFCS report 2014 is 145,360 [8]. The respondents were divided into six age groups. The comparison between the body weight of Indonesian respondents in the IFCS report 2014 and body weight of respondents from various countries (table 2) shows the mean of

Indonesians body weight is lower than that of the Americans and Europeans in all age groups. The difference is influenced by heredity, race, culture, and consumption pattern.

Table 2. The weight comparison of Indonesian and various countries.

No	Age groups	Mean of body weight (kg)			
		Indonesia [10]	World [11], [12]	European [13]	American [14]
1	Infant (0-59 months)	11.67	6.1 (0-6 months) 8.6 (7-11 months) 11.9 (1-3 months)	6.1 (0-6 months) 8.6 (7-11 months) 11.9 (1-3 months) 19.0 (4-6 months)	4.8 (0-1 months) 5.9 (1-3 months) 7.4 (3-6 months) 9.2 (6-12 months) 11.4 (1-2 yr.) 13.8 (2-3 yr.) 18.6 (3-6 yr.)
2	Children (5-12 yr.)	27.50	15	28.7 (7-10 yr.) 44.6 (11-14 yr.)	31.8 (6-11 yr.)
3	Adolescence (13-18 yr.)	46.33	-	60.3 (15-17 yr.)	56.8 (11-16 yr.)
4	Adults (19–55 yr.)	57.87	60 55 (Asia)	63.3 (≥ 18 yr.)	71.6 (16-21 yr.) 78.4 (21-30 yr.) 80.8 (30-40 yr.) 83.6 (40-50 yr.)
5	Elderly (>55 yr.)	52.30	-	-	83.4 (50-60 yr.) 82.6 (60-70 yr.) 76.4 (70-80 yr.) 68.5 (>80 yr.)
6	All age	50.78	-	-	-

3.2. Food consumption levels

Food consumption levels in the IFCS report 2014 showed the highest mean of food consumption is edible water (60-67%), cereals and its products (11-15%) and fish, seafood and their products (3-4%). figure 1 showed the mean of Indonesian's consumption levels are higher than global food consumption in cereals, peanut and fish and lower in fruit, vegetables, and meat.

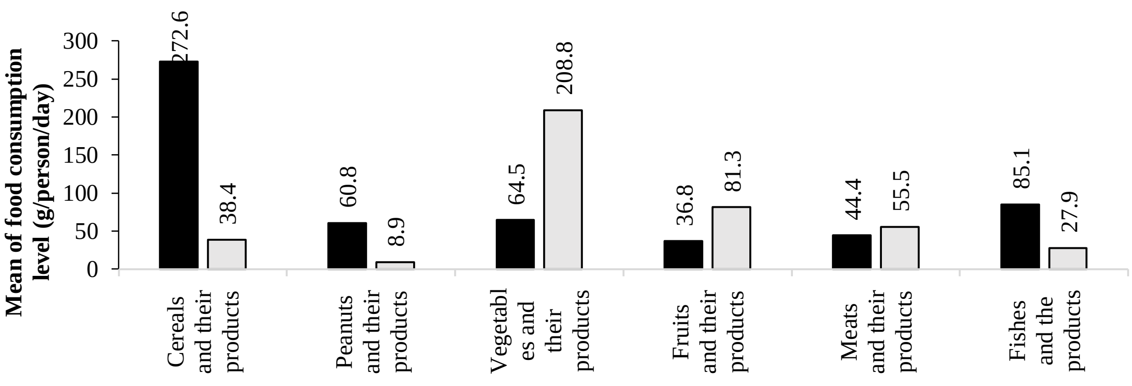

Figure 1. Comparison of major food groups consumption levels in Indonesia (Health Ministry of Indonesia 2014) with global consumption level [15] ■ Indonesian; ■ global.

3.3. Food groups matching

There are 15 of 17 food groups on IFCS report 2014 which display available lead concentration data. They are 1) cereals and their products, 2) tubers and their products, 3) peanuts, bean and their products, 4) vegetables and their products, 5) fruits and their products, 6) meat and their products, 7) visceras and their products, 8) fishes, seafood and their products, 9) milks and their products, 10) oil, fat and their products, 11) sugars, syrups, and confectioneries, 12) spices and their products, 13) beverages, 14) composite foods and 15) edible water [8].

3.4. Lead concentration from food in Indonesia

Lead concentration was processed from 293 references with the most references about fishes, seafood, and their products. Lead concentration data were obtained for 27 of 34 provinces in Indonesia. Those are Bali, Banten, Bangka Belitung Islands, Central Java, Central Kalimantan, Central Sulawesi, East Java, East Kalimantan, Gorontalo, Jakarta, Lampung, Maluku, Nangroe Aceh Darussalam, North Maluku, North Sulawesi, North Sumatera, Riau, Riau Islands, Southeast Sulawesi, South Kalimantan, South Sulawesi, South Sumatera, West Java, West Kalimantan, West Sumatera and Yogyakarta. table 3 shows the highest mean of lead concentration from references in beverages, fishes, seafood and their products. In Riyadh City, Saudi Arabia, the highest lead concentration was found in confectionaries, beverages, and peanuts [16].

Table 3. Comparison of the mean of lead concentration from references with lead maximum level from INADFC regulation.

No	Food groups	Lead concentration (mg/kg)			
		Minimum	Maximum	Mean ± SD*	ML**
1	Cereals and their products	0.001	0.71	0.2528±0.1879	0.25
2	Tubber and their products	0	0.4543	0.1499±0.1448	0.2
3	Peanuts, beans and their products	0.0038	0.0061	0.0053±0.0013	0.2
4	Vegetables and their products	0	1.97	0.7525±0.6208	0.2
5	Fruits and their products	0	0.72	0.2877±0.2002	0.2
6	Meats and their products	0	1.45	0.4394±0.3951	0.5
7	Visceras and their products	0	1.8	0.5849±0.5130	0.5
8	Fishies, seafood and their products	0	7	1.1191±1.5018	0.2
9	Eggs and their products	-	-	-	0.25
10	Milk and their products	0.0018	1.121	0.3660±0.3766	0.02
11	Oils, fats and their products	0.0004	0.533	0.1545±0.1464	0.1
12	Sugars, syrups, and confectionaries	0.05	1.5	0.51±0.4767	1
13	Spices and their products	0.004	1.14	0.4256±0.3861	1
14	Beverages	0.0034	4.7595	1.7056±1.6178	0.2
15	Composite foods	0.044	0.044	0.044±0	0.25
16	Edible water	0	0.128	0.0231±0.0279	0.01
17	Supplement	-	-	-	0.02

Notes: (-) = Not available, *Standard Deviation, **Lead Maximum Level from INADFC no 23 – 2017 [17].

The mean lead concentration is higher than Indonesian regulation's maximum level (table 3) in vegetables and their products; fruits and their products; visceras and their products; fishies, seafood and their products; milk and their products; oils, fats and their products; and beverages. The sources of lead contamination in beverage and packaged food are from packaging which uses lead in the production process. Lead contamination in fish products is sourced from the water system which can be contaminated by industrial and urban waste. Gas emission of vehicles on the farm and the distribution process are the main sources of lead contamination in agricultural products [18]. One of the most important sources of lead contamination in milk is water and other factors such as transhumance along roads and/or motorways, fodder contamination, climatic factors, such as winds, and the use of pesticide compounds [19].

The mean of lead concentration from references in fish, seafood and their products have a standard deviation value higher than mean values, it showed a wide range of data. This is caused by a variety of products, such as fish, shellfish, crustaceans, mollusks, fishery products and others. Shellfish and mollusks have the highest mean of lead concentration by 1.4464 mg/kg and the lowest mean of lead concentration is in the freshwater fish group by 0.4214 mg/kg. Shellfish and mollusks are a natural accumulator which made the high likelihood of lead accumulation in shellfish and mollusks.

3.5. Dietary intake of lead in Indonesia

Calculation on table 4 showed infants (0-59 months) and children (5-12 yr.) have the highest value of lead dietary intakes (based on the mean concentration of lead from the references). This results in accordance with lead dietary intake estimation of Health Ministry of Indonesia, where infants (36-59 months) have the highest lead dietary intake with the range 1.0577–3.6762 µg/kg BW/day [5]. FAO/WHO data also showed lead intakes of children in the world ranged from 0.03 to 9 µg/kg BW/day [9]. Another research in Jinhu, China, showed lead dietary intakes of children (11.84 µg/kg BW/week) is higher than in adults (7.70 µg/kg BW/week) [20]. Infants and young children are especially sensitive to low levels of lead which may contribute to behavioral problems, learning deficits and lowered IQ [21]. At high levels of exposure, lead affects the central nervous system, causing coma, convulsions, and death [22]. Based on table 4, lead dietary intakes in this study are 3 to 10 times higher than lead dietary intakes of Health Ministry of Indonesia, 10 to 15 times higher than the Europeans and 40 to 50 times higher than the Australians.

Table 4. Comparison of lead dietary exposure based on minimum, maximum and mean lead concentration from references, and INADFC maximum level of the lead with various studies.

No	Age Groups	The mean dietary intake of lead (µg/kg BW/day)						
		This Study				Indonesian [5]	European [13]	Australian [23]
		Min.	Max.	Mean	ML*			
1	Infant (0-59 months)	1.20	43.37	10.97	13.15	1.0054 - 3.2638 (0-35 months) 1.0577 - 3.6762 (36-59 months)	0.73 - 1.09 (infants) 1.10 - 1.54 (toddlers)	0.22-0.24 (9 months) 0.26-0.27 (2-5 yr.)
2	Children (5-12 yr.)	0.99	845.4	7.85	9.89	0.6926 - 2.6207	0.87 - 1.18	0.16-0.17 (6-12 yr.)
3	Adolescence (13-18 yr.)	0.53	881.9	4.92	6.24	0.4444 - 1.7016	0.46 - 0.63	0.12 (13-16 yr.)
4	Adults (19–55 yr.)	0.35	1056.8	4.52	5.47	0.4215 - 1.5145	0.43 - 0.57	0.12-0.13 (≥17 yr.)
6	Elderly (>55 yr.)	0.19	926.4	4.27	5.27	0.3332 - 1.3878	0.42 - 0.55	-
7	All age	0.39	975.11	4.78	5.85	0.4724 - 1.7355	0.58 - 0.78	-

Notes: (-) = Not available, *based on assumption Lead Maximum Level from INADFC no 23 – 2017 [17] as lead concentration

3.6. Lead dietary intake in Indonesia

3.6.1. Risk values. Risk values of lead dietary exposure based on the mean concentration of lead from references and INADFC maximum level of lead are high-risk (>100% PTWI) in all age groups. The highest risk value is in the infant group (0-59 month). The study of the Health Ministry of Indonesia showed high-risk values of lead dietary exposure is in infants (36-59 months) by 103% PTWI [5], while in another study in various countries (EFSA 2012; FSANZ 2011; Liu et al. 2010; Othman 2010) showed low-risk values, those are European (11-43 %PTWI) [13]; Australian (3-7 %PTWI) [23]; Jinhu, China (30-47 %PTWI) [20] and Riyadh City, Arab Saudi (24%PTWI) [16].

Table 5 displays the risk values of lead dietary exposure based on INADFC maximum level of lead are high-risk in all age groups and higher than the risk value of lead exposure based on the mean concentration of lead. Figure 2 shows risk values of INADFC maximum level of lead are shown to be higher than in other regulations in all age groups. This is due to INADFC regulating the maximum level of lead in all food groups, while others do not regulate them. For example, INADFC regulates the maximum level of lead for eggs and eggs products, while Codex, EU, and USDA do not regulate it.

Table 5. Comparison of risk values of lead dietary exposure based on the mean concentration of lead from reference and based on assumption INADFC maximum level of lead as lead concentration.

No	Types of data	Risk values (% PTWI)					
		Infants (0-59 months)	Children (5-12 yr.)	Adolescence (13-18 yr.)	Adults (19-55 yr.)	Elderly (>55 yr.)	All age
1	Mean concentration of lead	307.15	219.69	137.73	126.66	119.56	133.76
2	INADFC maximum level of lead	368.23	276.94	174.70	153.06	147.53	163.76

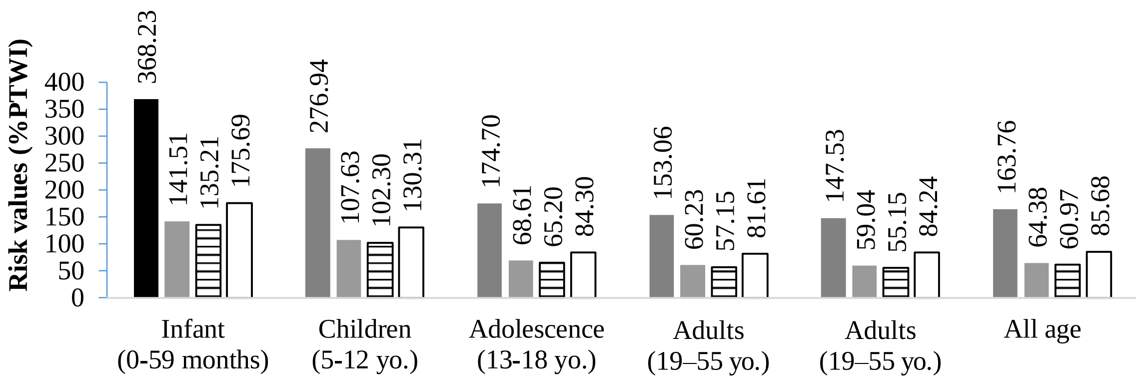

Figure 2. The comparison between risk values of lead dietary exposure of INADFC no 23-2017 with other regulation as lead level and IFCS report 2014 as food consumption data ■ = INADFC [17], ■ = codex [6], ⊟ = EU [24] □ = USDA [25].

3.6.2. IQ decrement. High-risk values of lead dietary exposure to infants and children would increase the probability of IQ decrement. Each year, lead exposure causes an estimated 600,000 new cases of mental retardation in children and 143,000 deaths per year, mostly in developing regions [22]. A 6.9 IQ point decrement [95% confidence interval (CI), 4.2–9.4] associated with an increase in concurrent blood lead levels from 2.4 to 30 μg/dL [26]. The association of blood lead levels with lead dietary intakes are range from 0.052 to 0.16 μg/dL for every 1 μg/day lead dietary exposure [5]. Calculation of IQ decrement due to lead dietary exposure was conducted for infants and children with average body weight of 11.67 kg and 27.5 kg. Table 6 shows that IQ decrement in children is higher than infants. A study in a cohort born in New Zealand in 1972-1973 shows that childhood lead exposure was associated with lower cognitive functions and socioeconomic status at the age of 38 years and with declines in IQ and downward social mobility [27].

Table 6. IQ decrement in infants and children due to lead dietary exposure in this study.

Age groups	Lead dietary exposure in this study	IQ point decrement
Infants (0-59 months)		
Mean concentration of lead from references	10.97	4.27
INADFC maximum level of lead as lead concentration	13.15	5.16
Children (5-12 yr.)		
Mean concentration of lead from references	7.85	7.19
INADFC maximum level of lead as lead concentration	9.89	9.06

3.6.3. Food groups contribution. The dietary exposure assessment was conducted for 15 of 17 food groups from IFCS report 2014. From 15 food groups, the major contributors to lead dietary exposure in all ages were fish, seafood and their products; cereals and their products; edible water; and meats and their products. Another dietary exposure assessment in Catalonia, Spain states that cereals and grains are the major contributors to lead exposure in human consumption. Dietary exposure assessment of lead in Riyadh, Saudi Arabia displays vegetables and cereals as the major contributors [16] Figure 3 visualizes the comparison of major contributors to lead dietary exposure in this study differs with other exposure assessments. This is due to different sources of lead contamination and different levels of food consumption in each country.

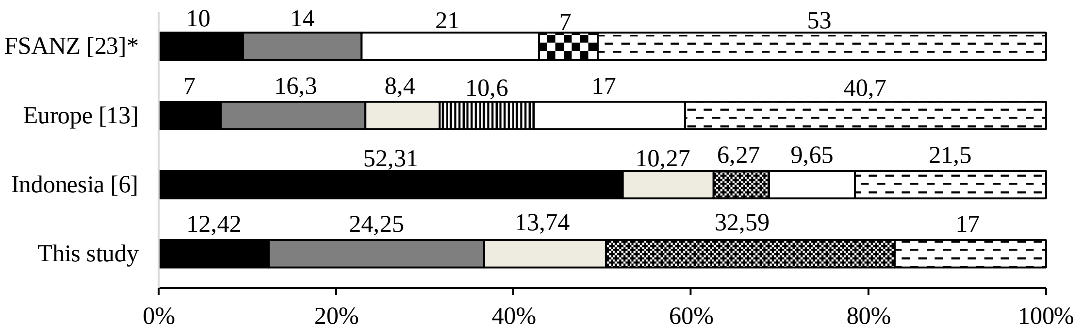

Figure 3. The Comparison of major contributors to lead dietary exposure in various references. Note: *Adults ≥ 17 years old. ■ Edible water, ■ Cereals and their products, □ Vegetables and their products, ▥ Milks and their products, ▩ Fishes and seafoods, □ Beverages, ⊠ Composite foods, ⊟ Others.

4. Conclusions

In this study, the highest level of food consumption belongs to edible water (60-67%) and then cereals and their products (11-15%) and fish, seafood and their products (3-4%). The highest mean concentration of lead is beverages by 1.7056 mg/kg. The mean of lead concentration of food from references is higher than INADFC maximum level of lead in vegetables, fruits, tuber, fishes, milk, oils, and beverages in all age groups. Infants (0-59 months) has the highest lead dietary exposure. Risk characterization results show that lead dietary exposures are high-risk in all age groups, especially in the group of infants and children. The lead dietary intakes of this study may result in reduced IQ scores in infants and children by 4.27 and 7.19 points. Major contributors to lead dietary intakes are fish and seafood (32.59%), cereals (24.25%) and vegetables (12.42%). The results of this study can be used as the initial prediction of health risks faced by Indonesians that are caused by lead exposure originating from food sources. Verification of this study's results is still needed with a dietary exposure assessment using the probabilistic approach with better outcomes.

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