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A Critical Review of Arsenic Contamination in Sri Lankan Foods

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HIGHLIGHTS

- A comprehensive review and assessment of arsenic contamination was presented in Sri Lankan foods.
- Arsenic levels in most of the food types were lower than the allowable level.
- The review also identified gaps in arsenic assessments in Sri Lanka.

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Acronyms and abbreviations
As=Arsenic
CKDu=Chronic Kidney Disease of unknown aetiology
IAs=Inorganic Arsenic

ABSTRACT

Numerous studies have shown growing information indicating the contribution of food to the dietary exposure of arsenic (As) through consumption of different food items in many different regions over the world. However, few review papers with regard to As in Sri Lankan foods are available in databases. Thus, a critical review and assessment of a number of local studies on total As concentrations has been made in rice, fish and fisheries products, vegetables, and other food products from Sri Lanka. From a limited comparison of freshwater fish with two marine species, the tuna and rays have substantially higher total As concentrations than all the freshwater species analyzed. One of the more important findings is that rice, the staple food of the country, is a major contributor to total As exposure of the population. Hence, based on the assessment of available data for total As levels in the various foods analyzed, it is suggested that a shift in a staple food diet of rice to one of maize and multi-cereal grains could lead to a reduction in total As exposure to the general population. Furthermore, important information gaps were identified such as a total lack of corresponding data for total As in Sri Lankan fruit crops, and a major one being the present lack of any information on the various inorganic and organic As species in local foods. Finally, some suggestions are made for giving guidance in agricultural practices which will lead to a reduction in As inputs to the local farmlands. This data compilation and assessment serves as an initial baseline for comparison with As results from future monitoring and research studies in Sri Lanka.

Introduction

Arsenic (As) is one of the most significant toxic environmental hazards which can threaten human life and health. As is present naturally at trace levels in air, water, soil. However, natural concentrations of As can be elevated mainly by human activities as well as natural phenomena such as geological events which may pose serious health issues (Antonova and Zakharova, 2016; Baig et al., 2011; Balouch et al., 2017).

Using arsenical compounds in the agrochemicals industry began from 1970s as a wood preservative, and since

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then it has been used as a principal ingredient of insecticides, pesticides, and herbicides (Bencko and Foong, 2017). At present, As is commonly used in the electronics industry in the form of gallium arsenide and arsine gas in the production of components of semiconductors. Moreover, As is used in algaecides, desiccants for mechanical cotton harvesting, glass manufacturing, nonferrous alloys, and in the feed industry as a feed additive (ATSDR, 2013). In addition, As has been used as a drug for over 2000 years in the treatment of leukemia and other cancer therapy (da Rosa et al., 2019), as a remedy of naturopathic or homeopathic medicine (Belon et al., 2007), and as an ingredient in traditional medicine in some countries, especially Asian ones (Garvey et al., 2001).

The toxicity and bioavailability of the element depend on the concentration and chemical form (Meharg et al., 2008). As can be present in food and the environment in several forms which are summarized in Table 1. In general Inorganic As (IAs), mainly the As (III) and As (V) oxidation states, is more toxic than organic As. Furthermore, As (III) is more toxic than As (V), and dimethyl arsenic and monomethyl arsenic are more toxic than their parent compounds (Hulle et al., 2004; Rahman et al., 2012). The arsenobetaine and arsenosugar compounds are more commonly found in marine animals and generally contribute about 80% of total As in fish and seafood. Hence, the determination of As speciation in food is an important factor to consider in human health and risk assessment studies (Rahman et al., 2012).

Enhanced levels of As in groundwater is a problem in many countries, especially in Asian countries such as Bangladesh, India, and China (Bandara et al., 2018). The As contaminated waters are mainly used for drinking and agricultural purposes (Perera et al., 2016). From the contaminated water, As gets its entry into the food chain. Food and water are basic requirements for humans and, hence, they are the main pathways for aggregate As exposure in human populations. The As concentrations in food vary widely depending on the food type and growing conditions such as type of soil, water, geochemical activity, use of As pesticides, and the food processing techniques used (Molin et al., 2015); whereas the degree of human exposure also varies with the consumption volume, season, age, sex, and food choice (e.g. rice, cereals, vegetables, meat, fish, and fruit).

Considering the above facts, an attempt is made here to document and assess the As levels in Sri Lankan fish, rice, vegetables, and certain other food products for the first time. This assessment was synthesized from key published researches related to As levels in foods such as vegetables, cereals, fruits, fish, meat, milk, etc. in Sri Lanka.

As toxicity and human health

As has been categorized as number one in their substances priority list of 2017 by Agency for Toxic Substances and Disease Registry of USA; furthermore it has also been categorized as a human carcinogen by the International Agency for Research on Cancer (ATSDR, 2017; IARC, 2018).

Risk associated with exposure of As is a significant global health issue and is affecting millions of people in the world. As exposure is associated with cancer, skin diseases, developmental effects, morphological alterations, cardiovascular disease, neurotoxicity, increasing the risk of diabetes mellitus, adverse pregnancy outcomes, and a variety of complications in body organ systems (Hsueh et al., 2016; Mohammed Abdul et al., 2015; Upadhyay et al., 2019).

Various factors may affect As toxicity in humans such as age, gender, race, lifestyle, inherited genetic characteristics, socio-economic status, exposure route, As species, and dietary factors (Hsueh et al., 2016). Once contaminated food or drink are ingested, approximately 70% of As is excreted through the kidney and a small amount is excreted through skin, hair, nail, and feces (Ghosh et al., 2013; Mohammed Abdul et al., 2015). A higher urinary As excretion was detected in the USA, UK, and in pregnant Bangladeshi women who consumed a high amount of rice in their diet (Upadhyay et al., 2019). Serious toxic pregnancy outcomes were also observed in the women who drank As contaminated water in Bangladesh (Ahmad et al., 2001), West Bengal, India (Von Ehrenstein et al., 2006), and Taiwan (Yang et al., 2003) such as spontaneous abortions, stillbirths, and preterm birth rates.

As regulation

The globalization of the food trade has raised the issue regarding the assurance of “safe food”. The assurance of food and water safety is a wide-ranging task which includes a number of participants such as food producers, processors, food scientists, toxicologists, technologists, and food regulators. To control food-borne outbreaks, several international, national, and regional level organizations are reinforcing their food regulations. Given the importance of the contaminated drinking water problem, the World Health Organization (WHO) and United States Environmental Protection Agency (USEPA) set the maximum contaminant level for As in drinking water as a 10 µg/L (Almberg et al., 2017).

The As regulatory limit is different from that for the food type and for a standard body. For monitoring purposes, the European Union (Commission Regulation, 2015) has set the limits for IAs at 0.20 mg/kg for non-

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parboiled milled rice (i.e. polished or white rice); 0.25 mg/kg for parboiled rice and husked rice; 0.30 mg/kg for rice waffles, wafers, crackers, and cakes; and 0.10 mg/kg for rice destined for the production of food for infants and young children. As another example of regulatory differences for food, the maximum limit for As (w/w) in fish is 0.5 µg/g in China, 1.1 µg/g in India, 2 µg/g in Australia and New Zealand while it is 3.5 µg/kg in Canada (Bhupander and Mukherjee, 2011; Chiocchetti et al., 2017). The Joint FAO/WHO Expert Committee on Food Additives (JECFA, 2017) also introduced the maximum contaminant level for As at 0.1 mg/kg for edible fats and oils, fat spreads and blended spreads, and 0.5 mg/kg for food grade salt.

As contamination of water and soil in Sri Lanka

During the last two decades, increasing numbers of patients with a Chronic Kidney Disease of unknown aetiology (CKDu) was reported from rural Sri Lanka especially from the North Central Province (Jayasumana et al., 2015a). Still, no obvious cause has been identified for CKDu, however, some researchers suspect that the main reason is probably As (Jayasumana et al., 2013b; Perera et al., 2016; Rajapakse et al., 2016). Hence, a number of studies have been conducted on the water and soil quality of these areas with special attention to the As content. Although, the main objective of this review is assessing the As content in Sri Lankan foods, in the context of human health issues, a brief discussion of the As levels in water and soil is given here.

Several sources of As contamination in soil and water in Sri Lanka have been identified. Most researches have pointed to the long term use of agrochemicals as potentially being the main reason for this contamination (Jayasumana et al., 2013a, 2015a). The soil geochemistry near some agricultural sites of Sri Lanka was analyzed by Jayawardana et al. (2014) who concluded that there was no significant threat from As in the soil.

Groundwater is the main source of drinking water of the most of Sri Lanka. Dug well or tube well water is mainly used for cooking and drinking purposes. International and Sri Lankan standard guidelines also propose that the maximum allowable level of As is 10 µg/L in drinking water (Herath et al., 2017). In the study of Herath et al. (2018), 1435 dug well and tube well water samples were analyzed from all districts in Sri Lanka, and the highest As concentration (66 µg/L) was recorded in the water samples from the Mannar district. The drinking water quality of the Ulagalla cascade was studied by Wanasinghe et al. (2018) who found a range of ground water As concentrations of 0.03-0.44 µg/L, with a range in the surface water samples between 0.02-0.19 µg/L.

Rango et al. (2015) analyzed As concentration in the different water sources (i.e. shallow and deep wells, springs, piped, and surface water) from the CKDu-affected areas and reported that total As levels were well below the 10 µg/L limit. Furthermore, Wickramaratne et al. (2016) examined 71 groundwater and 26 surface water samples from CKDu-affected areas and reported that the As level in most cases was negligible. A high As concentration (0.4 mg/L) was reported by Rajasooriyar et al. (2013) in the groundwater from Southern Sri Lanka with the authors noting that the source of As was not clear. Finally, Diyabalanage et al. (2016a) measured the As levels in the three river waters including the longest river in Sri Lanka, and recorded relatively low As level of 1.44 µg/L, 0.37 µg/L, and 0.22 µg/L in the Mahaweli, Maha Oya, and Kalu Ganga rivers, respectively. Given the existing database on total As in soils and drinking water, except for a few potential hot spots, As levels in Sri Lanka are generally below the recognized guideline maximum limits.

As contamination in Sri Lankan foods

-Rice

According to the World Bank and the Food and Agriculture Organization (FAO), Sri Lanka is among the top 10 countries with the highest per capita cooked rice consumption at 105 kg/year or about 300 g/day (Hu et al., 2016). The accumulation of As in rice and rice-based products is a global problem (Majumder and Banik, 2019; Meharg et al., 2008). The concentration of As in rice depends on a number of factors such as geographical variation (Chen et al., 2018; Majumder and Banik, 2019), irrigation systems (Hu et al., 2015; Islam et al., 2017b), soil type and fertilizer (Vithanage et al., 2014), rice varieties (Cheng et al., 2006; Kumarathilaka et al., 2018), and various processing and cooking techniques (Sharafi et al., 2019).

The available literature on As in Sri Lankan rice is shown in Table 2. Some studies are based on field sample collections and others are from market-based samples. The JECFA set a maximum permissible level for IAs at 0.2 mg/kg for white rice and at 0.4 mg/kg for red rice (Upadhyay et al., 2019). Though, all the above standards mentioned IAs, the Chinese legislation has established a maximum allowable concentration for total As in rice at 0.7 mg/kg (Qian et al., 2010). None of the studies in Table 2 analyzed the As speciation and none exceed the maximum allowable concentration based on the Chinese regulation.

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Table 1: Chemical forms of arsenic speciation found in food and determined in a wide variety of aquatic species (Molin et al., 2015; Rahman et al., 2012; Werner et al., 2018)

Name	Chemical structure
Arsenite	$As(OH)_3$
Arsenate	AsH_3O_4
Monomethylarsonous acid	$CH_3As(OH)_2$
Dimethylarsinous acid	$(CH_3)_2AsOH$
Monomethylarsonic acid	$AsO(OH)_2CH_3$
Dimethylarsinic acid	$AsO(OH)(CH_3)_2$
Trimethylarsine acid	CH_3As_3
Arsenocholine	$(CH_3)_3As(CH_2)_2OH$
Arsenobetaine	$(CH_3)_3AsCH_2COOH$
Arsenosugar	$C_{10}H_{21}AsO_7$
Sulfate arsenoribose	R=SO3H
Sulfonate arsenoribose	R=OSO3H
Phosphate arsenoribose	$R=OP(O)(OH)OCH_2CH(OH)CH_2OH$
Trimethylarsoniopropionate	$(CH_3)_3As(CH_2)_2COOH$
Tetramethylarsonium ion	$(CH_3)_4As$
Trimethylarsine oxide	$(CH_3)_3AsO$
Thiodimethylarsinate	$(CH_3)_2AsS$
Arsenolipids	$(CH_3)_2AsO(R)COOH$
Roxarsone	$AsO(OH)_2(C_6H_6)OHNO_2$
Phenylarsonic acid	$AsO(OH)_2(C_6H_6)$
Triphenylarsine	$As(C_6H_6)_3$
Triethylarsine	$(CH_3)_3(CH_2)_3As$
2-chlorovinylarsonous acid	$(CH_2)_2AsCH_2CHCl$
2-chlorovinylarsonous oxide	$OAs(CH)_2Cl$
2-chlorovinyldichloroarsine	$Cl_2As(CH)_2Cl$

Table 2: Total arsenic concentrations in rice grains (w/w) of different rice varieties from Sri Lanka [§]

Rice type	Sampling areas and remarks	Sample no.	As level (μg/kg)	Reference
Newly improved variety	Throughout country	226	2.5-213 [*]	Diyabalanage et al., 2016b
Indigenous/Traditional variety	Throughout country	21	2.5-143 [*]	Diyabalanage et al., 2016b
Raw	Unknown	2	34±6 [*]	Jayasekera and Freitas, 2005
Parboiled	Unknown	2	65±12-92±1 [*]	Jayasekera and Freitas, 2005
Rice flour	Unknown	2	35±1-61±6 [*]	Jayasekera and Freitas, 2005
Newly improved variety	Dry and wet zones [a]	120	20.6-540.4 [*]	Jayasumana et al., 2015b
Indigenous/Traditional variety	Agrochemicals not used	50	11.6-64.2 [*]	Jayasumana et al., 2015b
Indigenous/Traditional variety	North Central Province	44	<LOQ-575.94	Jayasumana et al., 2015b
Indigenous/Traditional variety	Organic farm	Unknown	<20	Kariyawasam et al., 2016
Unknown	Sri Lankan rice from Qatar market	4	19.4-59.8 [*]	Rowell et al., 2014
Red raw	Throughout country	42	<14-159.843	Perera, 2018
White raw	Throughout country	27	<14-221.066	Perera, 2018
Parboiled	Throughout country	2	51.331-121.622	Perera, 2018
Unknown	Dry zone [c]	10	0.90-260 [*]	Chandrajith et al., 2011

[§] According to rainfall pattern, Sri Lanka is divided into dry, wet, and intermediate zones
[*] d/w basis
LOQ: Limit of Quantification
[a] Authors compared the sample from dry zone (Anuradapura, Polonnaruwa district), and wet zone (Gampaha district)
[b] Authors compared the sample from dry zone (Padaviya, Medawachchiya, Anuradhapura, Samanturai and Ambalantota) and wet zone (Colombo, Bombuwala, Labuduwa and Bathalagoda)
[c] Sample collected from dry zone (Giradurukotte, Nikawewa and Medwachchiya)

The As concentration in rice varies in field and market samples for a number of reasons. For example, the As in rice grains is elevated as follows: concentrations in polished rice<raw rice<brown rice<bran rice<hull, and furthermore non-parboiled rice has a higher As content than parboiled rice (Rahman et al., 2007). Even in rice grains, the As is not evenly distributed throughout the grain, with the highest concentration in germ and some

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hot spots in the coating up to 13 mg/kg (Kramar et al., 2017). Therefore, the individual data given in Table 2 are not really comparable with each other, because the sampling locations, rice variety, farming systems, and water sources are different.

The As levels in traditional varieties have also been analyzed by some researchers. Diyabalanage et al. (2016b) have reported a mean As level of 74 µg/kg in indigenous rice samples from the wet zone of Sri Lanka. The authors concluded that the As content in an indigenous variety was higher than the newly improved varieties, while the As concentration was not significantly different between the rice types or climatic zones. From 50 different indigenous rice varieties in Sri Lanka, Jayasumana et al. (2015b) studied As levels in 6 indigenous rice varieties and reported values ranging from 11.6-64.2 µg/kg dry weight basis. A similar lower As level (<20 µg/kg) was recorded in traditional rice varieties by Kariyawasam et al. (2016) using only organic farming techniques. This may result from organic farming using only the organic fertilizer and biological pest control methods, etc.

Rowell et al. (2014) determined the As concentrations in rice from a Qatar market in which the rice originated from nine countries including Sri Lanka. The lowest mean As concentration was found in the imported Sri Lankan rice (41.3 µg/kg) while the highest reported value was in the rice from Vietnam (169 µg/kg). Nevertheless, other researchers found much higher As levels in Bangladesh rice, i.e. <40-920 µg/kg (Williams et al., 2006) and 610 µg/kg (Meharg et al., 2008). Rice contains mainly IAs, especially As (III) and As (V), whereas there are also organic As species present such as dimethyl arsenic and monomethyl arsenic (Chen et al., 2018; Meharg et al., 2008). In this regard, Ma et al. (2016) have reported the dominant order of the different species of As in Chinese rice from Hunan Province as: As (III)>dimethyl arsenic>As(V)>monomethyl arsenic.

-Fish, oysters, and other foods of animal origin

Foods of animal origin are among the other principal pathways for human exposure to As (Azevedo et al., 2018; Hashemi et al., 2019). It should be noted that religious, cultural, and economic factors basically drive the development of the meat industry in Sri Lanka. As one example, the per capita consumption of different meat such as poultry, beef, mutton, and pork in 2013 were 7.09, 1.80, 0.10, and 0.32 kg/year, respectively (Alahakoon et al., 2016). Although, this has shown an upward trend in recent decades, still fish and certain seafoods provide most of the animal-based proteins. Per capita fish consumption in Sri Lanka was 15.8 kg in 2016 (Jinadasa et al., 2018). The largest contributors to As exposure in many human populations are seafood species such as finfish, shellfish, and seaweed (Taylor et al., 2017). In general, the total As concentration in fish is usually below 5 mg/g w/w (Chiocchetti et al., 2017). The nontoxic arsenobetaine is the most abundant As species in fish and shellfish (Moreda-Piñeiro et al., 2008), while arsenosugars are the major As compounds in marine algae (Whaley-Martin et al., 2012). Hence, the guidelines do not specify total As concentration as a maximum level for fish and fishery products, since speciation is the important toxicological endpoint, especially in the fish and seafood sector. However, in some other national regulations, total As is specified as the maximum level. For example in Hong Kong, it is 6 mg/kg w/w for fish and fish products and 10 mg/kg w/w for shellfish and shellfish products, and for the Food Standards Australia and New Zealand the maximum limit is 2 mg/kg for fish and crustacea and 1 mg/kg for molluscs and seaweed (Anacleto et al., 2009; FSANZ, 2017).

Table 3 illustrates the As concentrations in animal-based foods in Sri Lanka. A lower As concentration was observed in the freshwater fish species than in the two marine fish including tuna and rays. Many authors have noted the low As concentration in the freshwater environment (Kumari et al., 2017). Tilapia is the most popular freshwater aquaculture species in Sri Lanka, with 50065 tons produced in 2017 and comprising 61% of the total freshwater fish production (MOFAR, 2018). In comparison with the As levels in Tilapia from some other countries, e.g., 0.13-1.45 mg/kg dry (Han et al., 1998), 0.94-15.1 mg/kg dry (Liao and Ling, 2003), and 85.77±14.81 mg/kg dry in Taiwan (Liao et al., 2008), As concentrations in Sri Lankan Tilapia are considerably lower, assuming an average 80% moisture content in these fish.

Mobulid ray is one of the target fisheries in the Indian Ocean, due to the use of its branchial plates in Chinese medicine. Ooi et al. (2015) indicated that the total As level was higher in Mobulid ray fish caught from Sri Lanka (20±15 mg/kg w/w) than those caught from Australia (0.53±0.56 mg/kg w/w). Moreover, some other studies have also recorded high As concentrations in ray fish, e.g. 31 mg/kg w/w in the Southern North sea (Luten et al., 1982) and 6.2-35.9 mg/kg w/w in the North sea channel (de Gieter et al., 2002). Considering the previous mentioned studies carried out by some researchers, it is obvious that As levels in fish depends mainly on type of the fish.

In general bivalve molluscs including oysters can accumulate metals present at very low levels in water to very high concentrations in their tissues (Lu et al., 2017). In this regard, the As level range in *Crassostrea gigas* from Taiwan was 7.90-10.68 µg/kg w/w (Liu et al., 2006).

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Table 3: Total arsenic concentration (mg/kg w/w) in different marine and freshwater biota and various foods of animal origin from Sri Lanka

Sample type	Sampling area	Body length (cm) §	No. of samples	As level (mg/kg w/w)	Reference
Freshwater species					
Tilapia	Ridiyagama (1)	23	-	0.3	Allinson et al., 2002
Tilapia	Ridiyagama (1)	22-23	-	0.3	Allinson et al., 2002
Tilapia	Ridiyagama (1)	20-22	-	0.1	Allinson et al., 2002
Tilapia	Ridiyagama (1)	17-20	-	0.3	Allinson et al., 2002
Tilapia	Ridiyagama (2)	17-20	-	0.3	Allinson et al., 2002
Tilapia	Ridiyagama (2)	15-17	-	0.1	Allinson et al., 2002
Tilapia	Ridiyagama (2)	13-15	-	0.4	Allinson et al., 2002
Tilapia	Badagiriya	13-20	-	0.2	Allinson et al., 2002
Tilapia	Meegahajadura	17-20	-	<0.002	Allinson et al., 2002
Tilapia	Meegahajadura	15-17	-	0.4	Allinson et al., 2002
Tilapia	Meegahajadura	13-15	-	0.3	Allinson et al., 2002
Tilapia	Meegahajadura	11-13	-	0.1	Allinson et al., 2002
Tilapia	Chandrikawewa	15-17	-	0.2	Allinson et al., 2002
Tilapia	Chandrikawewa	13-15	-	0.1	Allinson et al., 2002
Tilapia	Kiriibbanwewa	14-15	-	0.3	Allinson et al., 2002
Tilapia	Medawachchiya and Medirigiriya	-	11	3.39-11.9*	Levine et al., 2016
Tilapia	North Central Province	23.3±4.2	145	ND	Jinadasa et al., 2013
Stinging catfish	North Central Province	22.6±3.2	39	ND	Jinadasa et al., 2013
Tank goby	North Central Province	22.5±3.6	26	0.004	Jinadasa et al., 2013
Striped snakehead	North Central Province	38.8±6.2	13	ND	Jinadasa et al., 2013
One-stripe spiny eel	North Central Province	40.5±7.1	6	ND	Jinadasa et al., 2013
Orinoco sailfin catfish	Eastern Province	30-48	44	ND	Jinadasa et al., 2014
Marine and brackish water species					
Mobulid rays	-	70-121	15	10-66	Ooi et al., 2015
Skipjack tuna	-	36-56	44	0.85±1.08	Jinadasa et al., 2015
Other animal-based products					
Cow milk	-	-	35	ND	Perera et al., 2019

§ body length given as mean value or range or mean±standard deviation
*dry weight
ND: Not Detected
Ridiyagama (1 and 2) are sampling site number

Perera et al. (2019) found As in 35 milk samples including powdered and pasteurized milk from Colombo and Gampaha supermarkets of Sri Lanka, and stated that the As level in all samples was below the detection limit. Nevertheless, some researchers have reported As in cow's milk in Mexico as <0.9-27.4 ng/g (Rosas et al., 1999), in Bangladesh as 0.031-0.038 µg/ml (Jolly et al., 2017), and in China as 0.05-15.77 µg/L (Zhou et al., 2019).

-Cereals, legumes, and other crops

Cereal grains, legumes, and pulses in general are very popular and make a large proportion of the Sri Lankan diet fulfilling the dietary requirements of the community (Silva et al., 2018). However, very little published information is available on the As level in these particular foods except for rice. Edirisinghe and Jinadasa (2019) analyzed nine kinds of cereal and legume varieties for As from the North Central Province, and the results are shown in Table 4. Maize (corn) is one of the major cultivated food staples worldwide. The total As concentrations in maize which have been reported for Tanzania, China, and Pakistan are <10-170 µg/kg dry weight (Marwa et al., 2012), 60±20 µg/kg dry weight (Neidhardt et al., 2012), and 302±50 µg/kg (Baig et al., 2010), respectively. Furthermore, sesame is one of the most consumed oilseed species, and the mean total As content analyzed in Iranian sesame was 54±26.21 ng/g dry weight (Khoshbakht Fahim et al., 2013). The As concentration in beans, as one of the main staple foods in Brazil, was reported to range between 0.005-0.223 mg/kg, and to contribute 11-23% of total As intake from food (Ciminelli et al., 2017). Compared with the above-published values, the As concentrations in Sri Lankan cereals and legumes are well below those. This difference

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is most likely due to the fact that most of the cereals and legumes cultivated in Sri Lanka are not grown using industrialized cultivation techniques (e.g. fertilizers, pesticides) like for rice.

-Vegetable and fruits

It is considered that fruits and vegetables are significant components of a well-balanced and healthy diet. However, the consumption of the fruit and vegetable component in the diet is relatively low worldwide (Bvenura and Sivakumar, 2017) and, from general observation, it is also the case in Sri Lanka. Table 5 indicates the available data regarding total As levels in Sri Lankan vegetables.

The potato, a common tuber, is one of the largest cultivated crops worldwide, and it is generally used as a base vegetable for curry in Sri Lanka. The reported values for the As content of Sri Lankan potatoes are 0.015±0.004 and 0.005±0.001 mg/kg w/w in the up country area and Kandy district, respectively. These values are relatively low compared with other published data such as those from Bangladesh as 0.17-0.47 mg/kg w/w (Islam et al., 2017a). In particular, Bhattacharya et al. (2010) reported As levels in brinjal (0.279 mg/kg), bitter gourd (0.021 mg/kg), capsicum (0.085 mg/kg), cabbage (0.209 mg/kg), and beans (0.091 mg/kg) from West Bengal, India, all of which are substantially higher than corresponding concentrations in those vegetables from Sri Lanka (Table 5). This variation may be due to higher As levels in Indian irrigation waters. Similar higher As levels were reported by Islam et al. (2017a) in vegetables from the Bogra district of Bangladesh, e.g., brinjal (0.17 mg/kg), carrot (0.25 mg/kg), beans (0.31 mg/kg), as well as capsicum (0.26 mg/kg). However, unfortunately, a local comparison cannot yet be made as comparable data for Sri Lankan fruit are presently lacking.

Table 4: Total arsenic concentration in cereals and legumes from the North Central Province of Sri Lanka (Edirisinghe and Jinadasa, 2019)

Type	No. of samples	As (μg/kg)	
		Mean	Range
Mustard	10	<18.17	<18.17-61.85
Maize	45	90.94	<18.17-475.72
Finger millet	50	52.67	<18.17-602.50
Sesame	26	105.23	<18.17-519.69
Cowpea	17	60.24	<18.17-502.53
Urad dal	11	47.94	<18.17-198.45
Foxtail millet	7	29.40	<18.17-127.07
Long bean	5	<18.17	<18.17
Green gram	10	46.69	<18.17-348.00

Table 5: Total arsenic concentration (mg/kg w/w) in various vegetables from Sri Lanka

Common name	Scientific name	Sampling area	No. of samples	As content (mg/kg w/w)	Reference
Carrot	*Daucus carota*	Up country	18	0.025±0.009	Silva et al., 2018
Potato	*Solanum tuberosum*	Up country	12	0.015±0.004	Silva et al., 2018
Beet	*Beta vulgaris*	Up country	12	0.012±0.002	Silva et al., 2018
Water spinach	*Ipomoea aquatica*	Kesbewa	5	ND	Wickramaratne et al., 2016
Lasia roots	*Lasia spinosa*	Kesbewa	5	ND	Wickramaratne et al., 2016
Lotus root	*Nelumbo nucifera*	Southern and North Central Province	3	ND	Wickramaratne et al., 2016
Lotus root	*Nelumbo nucifera*	North Central Province	-	0.413	Jayatilake et al., 2013
Bean	*Phaseolus vulgaris*	Kandy	26	0.003±0.0001	Silva et al., 2016
Beet	*Beta vulgaris*	Kandy	23	0.001±0.0002	Silva et al., 2016
Carrot	*Daucus carota*	Kandy	24	0.003±0.001	Silva et al., 2016
Cabbage	*Brassica oleracea*	Kandy	22	0.001±0.0001	Silva et al., 2016
Leeks	*Allium ampeloprasum*	Kandy	21	0.001±0.000	Silva et al., 2016
Potato	*Solanum tuberosum*	Kandy	16	0.005±0.001	Silva et al., 2016
Brinjal	*Solanum melongena*	Kandy	17	0.001±0.0002	Silva et al., 2016
Bitter guard	*Momordica charantia*	Kandy	15	0.001±0.0001	Silva et al., 2016
Capsicum	*Capsicum annum*	Kandy	18	0.003±0.001	Silva et al., 2016

ND: Not Detected

[DOI: 10.18502/jfqhc.6.4.1991]

Conclusion

This review summarized the As content in rice, fish, cereals, vegetables, and some other foods in Sri Lanka. Nevertheless, it should be noted that all the published studies discussed herein dealt exclusively with the analysis of total As concentrations. Furthermore, some researchers from Sri Lanka claimed that the cause of CKDu in some regions of Sri Lanka is due to the deposition of high levels of As compounds in the kidney. Since the main human exposure pathway for As is food and water, it is therefore necessary to analyze all food items for As types, especially IAs. As determination in foods should also include fruits, a key component of the Sri Lankan diet for which there are no data available at present. However, these expanded analyses will demand a large capital investment and new laboratory setups which is not a practical answer for a developing country like Sri Lanka. Hence, most countries are undertaking total diet studies to minimize costs and obtain a general picture of the nutrient and contaminant contents in foods. Therefore, it would be worthwhile for Sri Lanka to consider conducting in the near future such a complementary survey like total diet studies.

Research published to date on Sri Lankan foods has only focused on total As and neglected investigating the most toxic IAs species such as As (III) and As (V). Although only a few local laboratories are accredited for analyzing total As in some food products, none of them are accredited for measuring IAs or other As types. Furthermore, this is also a global challenge owing to the unavailability of As speciation reference materials for different food matrices, along with the capital cost of the more advanced instrumentation techniques. Considering the above drawbacks, it will be necessary to undertake more researches on developing a new cost-effective method for IAs analyses and instrumentation to be used.

Moreover, Sri Lanka is one of the top countries around the world that consume rice as the primary staple food. Most of the published studies have drawn their conclusions under the assumptions that the IAs accounts for a high percentage of the total As (e.g. 80% in rice) and that 100% of the IAs is bioavailable. Those assumptions are not always valid and it is now known that not all IAs is bioavailable, and that the IAs percentage in rice varies from country to country. Furthermore, it is necessary to make agricultural programs aware of findings and knowledge from different areas of sciences. For example, some studies have highlighted that Sri Lankan farmers use unnecessary amounts of fertilizers and pesticides in their agriculture activities. Therefore, proper guidance and programing of those agricultural practices are significant, and especially there should be a strict control on government subsidies for fertilizers. Also, some researchers have noted that total As can be significantly reduced by cooking and pre-processing practices. Therefore, more researches are recommended into the fundamental traditional practices in cooking and pre-processing techniques and a wide dissemination of that knowledge.

In addition, the total As concentrations in Sri Lankan maize and some cereals, which can potentially be used as a main staple food, are an order of magnitude lower than the corresponding total levels in rice. Thus, promoting a shift from a rice-based diet to a multi cereal-grain diet could substantially help reduce As exposure to the population of Sri Lanka.

Author contributions

Both authors contributed equally to the studying some literature, analysis, writing, and editing of the manuscript. Both authors read and approved the final manuscript.

Conflicts of interest

The authors have no conflicts of interests.

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