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OCCURRENCE OF ARSENIC IN FOOD AS A CURRENT HEALTH CONCERN®

Występowanie arsenu w żywności jako aktualny problem zdrowotny®

Key words: arsenic, inorganic arsenic, dietary exposure, risk assessment, rice, rice based products.

The health-related food quality is determined by, among others, the content of undesirable elements such as arsenic (As). It is a widespread environmental pollutant, naturally occurring in the earth's crust and as a result of anthropogenic human activities. As is a metalloid that occurs as inorganic (iAs) and organic arsenic species. The inorganic forms of As are more toxic as compared to the organic arsenic. Most As compounds are water soluble, therefore there is also a high possibility of arsenic penetrating from rocks and soil into the hydrosphere, which to some extent also causes its inclusion in the food chain. Contaminated groundwater used for irrigation of crops, in particular rice, is a major source of exposure to iAs. This is especially important for consumers for whom rice is a staple food in their diet. In contrast, fish and other seafood contain the most of less toxic organic arsenic. Diet is the major route of As exposure, and rice and rice-based products are food groups with relatively high iAs levels.

Dietary iAs exposure may have long-term effects on health. It is of particular importance to apply the requirements of EU legislation on maximum levels of iAs in rice and rice-based products, as well as to define these requirements in products for infants and young children. Inorganic arsenic contamination levels in food have decreased significantly in European countries over the past years. Current European exposures according to the EFSA Opinion of 2021 show no or little the margin of exposure (MoE) in relation to the lower confidence limit of the benchmark dose (BMDL). Based on this data, the potential health risk by iAs for certain infants and toddlers by the consumption of rice and rice-based products cannot be excluded. Therefore, it is necessary to control iAs levels in certain products, especially in infants and children, and individuals with celiac disease and/or gluten intolerance.

As a result, this article presents potential health risks of exposure to arsenic as well as the occurrence and consumption of arsenic in rice and rice-based products, fish, fish products and seafood. Dietary exposure to iAs in light of the scientific opinion of EFSA and regulatory policies concerning As in food is also covered. Additionally, the effect of technological treatment on the reduction of iAs levels in rice is also presented.

Słowa kluczowe: arsen, arsen nieorganiczny, pobranie z dietą, ocena ryzyka, ryż, produkty na bazie ryżu.

O jakości zdrowotnej żywności decyduje między innymi zawartość pierwiastków niepożądanych, takich jak arsen (As). Jest on szeroko rozpowszechnionym zanieczyszczeniem środowiskowym obecnym naturalnie w skorupie ziemskiej oraz na skutek antropogenicznej działalności człowieka. Arsen jest metaloidem występującym zarówno w formie nieorganicznych (iAs), jak i organicznych związków, przy czym formy iAs są bardziej toksyczne dla organizmu niż związki organiczne. Większość związków arsenu jest łatwo rozpuszczalna w wodzie, dlatego też istnieje duża możliwość przenikania arsenu ze skał i gleby do hydrosfery, co w pewnym stopniu powoduje również jego włączenie w łańcuch żywnościowy. Zanieczyszczone wody gruntowe wykorzystywane do nawadniania upraw, w szczególności ryżu, są głównych źródłem narażenia na iAs. Szczególnie ważne jest to w przypadku konsumentów, u których ryż w diecie jest podstawnym produktem. Ryby i inne owoce morza zawierają najwięcej mniej toksycznej formy arsenu. Dieta jest główną drogą narażenia na As, a ryż i produkty ryżowe stanowią grupę żywności o stosunkowo wysokim poziomie iAs.

Pobranie z dietą iAs może mieć wpływ na zdrowie w dłuższej perspektywie. Szczególne znaczenie ma objęcie wymaganiami w ustawodawstwie UE w zakresie najwyższych dopuszczalnych poziomów iAs w ryżu i produktach na bazie ryżu, jak również określenie tych wymagań w produktach dla niemowląt i małych dzieci. Poziomy zanieczyszczenia iAs w żywności znacznie się zmniejszyły w krajach europejskich. Obecne narażenia w Europie według Opinii EFSA z 2021 roku wykazują brak lub niewielkie marginesy w stosunku do dolnej granicy ufności dawki referencyjnej (BMDL). Odnosząc się do tych danych margines narażenia (MoE) jest niewielki lub żaden, w związku z tym nie można wykluczyć możliwości wystąpienia ryzyka zdrowotnego spowodowanego przez iA w przypadku niektórych małych dzieci w wyniku spożycia produktów na bazie ryżu. Dlatego konieczne jest kontrolowanie poziomów iAs w żywności, szczególnie dla niemowląt i małych dzieci oraz osób z celiakią i/lub nietolerancją glutenu.

W związku powyższym w niniejszym artykule przedstawiono potencjalne zagrożenia zdrowotne związane z narażeniem organizmu na As, jak również omówiono zawartość i pobranie As głównie z ryżem i produktami na bazie ryżu, rybami, przetworami rybnymi i owocami morza. Przedstawiono również wyniki oszacowania pobrania iAs z żywnością w świetle opinii naukowej EFSA oraz regulacje prawne w zakresie maksymalnych dopuszczalnych limitów. Ponadto omówiono wpływ obróbki technologicznej na obniżenie w ryżu poziomu iAs.

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INTRODUCTION

Food safety, in particular its inextricable link with human health, is a high priority issue for global sustainable development. In recent decades, heavy metal pollution has spread around the world, disrupting the environment and posing a serious risk to human health. One of such pollutants widespread in the environment is arsenic (As) [7, 8, 12, 14–16, 51, 52]. In nature, arsenic is found in the earth's crust and is a component of various minerals. It is part of rocks, from where it penetrates into unconfined groundwater. However, human activity causes its increased emission, and therefore anthropogenic factors largely contribute to the increase in the concentration of As in nature, which to some extent also causes its inclusion in the food chain [6, 9, 21, 38, 46, 50, 52].

For humans, the main source of As is food, which is sometimes contaminated as a result of environmental pollution (soil, water) with arsenic compounds. Arsenic occurs in both organic and inorganic forms (iAs). Organic forms have relatively low toxicity, while inorganic forms pose a greater risk and may cause cancer [3, 5, 8, 12, 24, 38, 46, 50, 51].

The highest concentrations of arsenic are found in rice and rice-based products (inorganic As) compared to other products of plant origin, and in fish and seafood (organic As). Due to environmental pollution, apart from essential nutrients, the aforementioned products can also be a source of harmful substances. Therefore, it is imperative to control arsenic levels in foods to protect human health [5, 13, 14-17, 19, 20, 26, 39, 44, 52].

The European Food Safety Authority's (EFSA) Expert Panel on Contaminants, recommended limiting exposure to inorganic arsenic. As a result, EU legal regulations have been established and introduced for maximum allowable levels of iAs in rice and rice-based products, including products for infants and young children. Furthermore, EFSA recommends that various foods are subject to monitoring to assess dietary exposure to inorganic arsenic [14, 15].

The latest Scientific Report conducted by EFSA from 2021 on the assessment of the complete diet has shown that the average exposure to inorganic arsenic is below the reference range set by EFSA. Regarding the consumption of products considered to be the main source of iAs, in particular on specific populations (e.g. infants and toddlers, individuals with coeliac disease and/or gluten intolerance) that might have a higher consumption of rice and/or rice-based products and, therefore, higher dietary exposure to iAs [16].

The aim of the review is to characterize the occurrence and causes of arsenic in foodstuffs, as well as to present the toxicity and health effects associated with the exposure to arsenic, and its recognized public health problems.

GENERAL CHARACTERISTICS AND ROUTES OF ARSENIC EXPOSURE

Arsenic (As) is a metalloid that occurs naturally in varying concentrations in various compounds in many parts of the earth's crust, depending on geological conditions. In the environment, it occurs in inorganic compounds as As (III) (arsenic trichloride, arsenic oxide, arsenite sodium, etc.) and As (V) (arsenic pentoxide, arsenic acid and arsenate, e.g. lead arsenate and calcium arsenate, etc.), and in organic compounds (arsanilic acid, methylarsonic acid, dimethylarsinic acid, arsenobetaine) [12, 14, 23, 24, 49].

Human exposure to As occurs mainly via three main routes, including inhalation, oral ingestion and dermal exposure. Oral ingestion is the major route of exposure to arsenic due to its water solubility. According to WHO [51, 52], water and food contaminated with arsenic are considered the main source of exposure. The estimated daily intake is between 20 and 300 µg/day depending on the type of food, cultivation method and conditions, and food processing [24]. Inhalation is an important route for inorganic arsenic, causing nausea and skin irritation. The risk of lung cancer is also increased due to exposure to inorganic arsenic [8, 14, 23, 24, 38, 51].

ARSENIC METABOLISM, TOXICITY AND HEALTH HAZARD

Arsenic metabolism is complex, and its metabolites depend on the type of arsenic compounds taken, the route of administration, and the mechanisms used to eliminate arsenic. Inorganic As (iAs) is methylated in the liver, to form monomethyl (Monomethylarsonic acid) and dimethyl (Dimethylarsinic acid) arsenical species, which facilitate the elimination of As from urine. However, it is known that some metabolites are more likely to be toxic. Higher concentrations of monomethylarsonic acid in the urine are associated with the risk of many adverse effects on health [12, 14, 23, 24].

The degree to which arsenic is hazardous to health depends on the compound and the level of oxidation. Among the two chemical forms of arsenic (organic and inorganic), inorganic arsenic is highly acutely toxic. Long-term exposure to iAs may lead to chronic arsenic poisoning. Effects which may develop depending on the level of exposure include skin lesions, peripheral neuropathy, developmental toxicity, as well as diabetes, cardiovascular diseases, and cancer of the skin and internal organs. The most toxic iAs compounds are found in the trivalent oxidation state [12, 14, 23, 38, 49, 51.

Human exposure to iAs can also occur through the consumption of groundwater that contains naturally high levels of iAs, including foods prepared with iAs, and rice irrigated with arsenic-rich water [6, 14, 38, 46, 50, 51, 52,

Among the various forms of As, i-AsIII (arsenite) is the main form found in rice and also the most toxic to humans. In contrast, organic arsenic compounds, which are present in greater amounts in fish and seafood, are less harmful to health and are quickly excreted from the body. Organic As is considered toxic only after metabolic conversion to the trivalent form of As [5, 12, 17, 19–21, 26, 39, 44, 54].

EFSA's Scientific Panel on Chemical Pollutants (CONTAM) has adopted a scientific opinion on the risks to human health related to the presence of arsenic in food. In place of the dose of tolerated weekly intake of arsenic, the range of the lowest dose of iAs determining the harmful effect (Benchmark Dose Lower Confidence Limit) of $BMDL_{01}$ was established in the range of 0.3-8.0 µg/kg bw/day [14].

A similar approach was used in 2010 by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), which - instead of the PTWI value for inorganic arsenic – proposed the lowest determining dose ($BMDL_{0.5}$) causing a 0.5% increase in lung cancer incidence, determined on the basis of epidemiological studies at the level of 3.0 µg/kg bw/day [51].

The International Agency for Research on Cancer (IARC) has established the causal role of oral iAs exposure in skin, lung and bladder cancer and demonstrated evidence of kidney cancer, liver cancer, and prostate cancer. Arsenic and inorganic arsenic compounds are carcinogenic to humans (Group 1) [24].

Table 1 adverse effects based on which tolerable intake levels of iAs are determined [14, 15, 51]. In addition to adverse effects an association was also found between exposure to As, and for example, infertility, other harmful consequences for the reproductive system. In addition, the studies analysed in the EFSA reports also show that iAs is genotoxic. The mechanism of genotoxicity due to oxidative stress, however, is that it can be expected that there is a threshold, and therefore inorganic arsenic is considered potentially carcinogenic through dietary exposure [14, 15].

Table 1. Adverse effects and reference value of iAs

Tabela 1. Działalnie niepożądane oraz wartości referencyjne dla iAs

Reference value / BMDL*	Health effect	Reference
$BMDL_{01}$ 0.30 – 8.0 µg/kg bw per day	Cancer risk, especially lung cancer	[14]
$BMDL_{0.5}$ 3.0 µg/kg bw per day	Cancer risk (lung cancer)	[51]

*BMDL is the Benchmark Dose Lower confidence limit and its subscript shows the percent change from baseline level.

Source: [14, 51]

Źródło: [14, 51]

Most of the data on arsenic exposure relates to an increased risk of lung, skin and bladder cancer, and these links are mainly found in studies that assessed the effects of contaminated drinking water [14, 23, 24].

Children are particularly susceptible to exposure to As, and exposure early in life may induce long-term metabolic changes and possibly, through increased insulin resistance, increase the risk of diabetes in adulthood. The nutritional status of the mother also influences the metabolic effects associated with arsenic. Exposure to As is associated with an increased risk of diabetes, atherosclerosis, and cardiovascular diseases [4, 6, 14, 23, 24, 35, 49, 52]. It should also be emphasized that the metabolites of arsenic, formed during its biotransformation, may also cross the placental barrier, exposing the foetus to this carcinogen at a level similar to that in the mother. The concentration of As found in the placenta correlates with both maternal and infant levels and with household drinking water levels. Gestational exposure to arsenic is also associated with health effects occurring in the pre- and perinatal stages, including childhood, and an increased risk of developing certain diseases in adulthood [12, 14, 24, 28, 32, 52, 53].

In recent years, research to assess the potential impact of levels of arsenic exposure on the risk of breast cancer, which is the most commonly diagnosed cancer in women, with an increasing number of new cases each year, is also interesting. However, to date, the relationship between arsenic exposure and breast cancer risk remains unclear, and the results do not give a definite answer [37]. In the evaluation carried out in a cohort of 1,703 Polish women, in contrast to other studies, a highly significant, 13-fold higher risk of breast cancer in women with the highest quartile of arsenic concentration in the blood compared to the reference group (Hazard ratio quartile 4 vs. quartile 1 = 13.2; 95% CI: 4.02–43.0 p-trend <0.0001) was observed. Moreover, the results were similar for arsenic levels and all cancer cases [31].

OCCURRENCE AND CAUSE OF AS IN FOODSTUFFS, AND SOURCES OF EXPOSURE TO ARSENIC

Arsenic (As) is an environmental pollutant, which is commonly found in the earth's crust and is a component of many minerals. It can come from natural sources, e.g. from rocks, volcanic eruptions, forest fires, as well as from anthropogenic sources such as mining, metallurgy (including copper), coal and fossil fuel combustion and inappropriate waste management. It is a metalloid with a very high accumulation factor in the natural environment, therefore its persistence in the environment is very long. Identification of soil pollutants, their sources and groundwater is essential due to their close relationship with human health [6, 8, 12, 14, 23, 24, 49].

Arsenic in rice and rice-based food products

The concentration of iAs in rice is high and can reach 85-90% of the total As content. The concentration varies according to the soil and type of rice. The high concentration of As in rice compared to other grains reflects the anaerobic growing conditions of irrigated rice fields and the specific physiology of the plant, which allows arsenic to be absorbed from the environment, accumulating it to a greater extent in rice grains than in soil. Since iAs tends to accumulate especially in the outer layers of the rice grain, the concentration in the finished product also depends on how the rice is processed [13, 15, 16, 19, 21, 26, 36, 39].

The content of arsenic in rice varies depending on rice variety, where it is grown and how it is processed. Brown rice has a higher concentration than white rice. Most of iAs in rice is stored in the outer layer - bran, which contains 10 to 20 times higher concentrations than the whole grain [14]. In addition, the risk associated with the consumption of products such as rice drinks are much higher than with raw but polished white rice. The EFSA report found that rice and rice-based products contained high average levels of total arsenic, ranging from 0.14 to 0.17 mg/kg [14].

Several studies have been carried out in different countries and it has been found that rice contains significant levels of iAs [5, 13, 14–16, 19–21, 26–28, 54]. Studies involving the assessment of the occurrence of (As) in infant food showed that 75% of the samples were contaminated with inorganic arsenic above the EU maximum levels for infants and children (0.1 mg/kg), and the average total iAs was almost 85%. The highest concentrations of As were recorded in whole grain rice, rice pasta and crackers [14–15, 20, 39].

The contamination with As was also shown in other studies of rice-based products, with the exception of ready-to-eat rice, all others exceeded the EU recommended value for young children. Estimated consumption of As was within the range of the $BMDL_{01}$ value indicated by EFSA [15–16], which means that the risk to young children and adults cannot be avoided considering arsenic levels in rice-based products [26].

Another study also assessed the consumption of rice and rice-based products as a group of products with relatively high As levels. It was found, as in other studies, that brown rice varieties showed higher As levels than white rice [5, 13, 19, 20 26, 27, 54]. The highest total arsenic intake was recorded in the group of infants and children, but unlike the rest of the population groups, it was mainly organic arsenic. In product evaluation, rice is the main factor of exposure to inorganic As in the adult population, while rice flakes and breakfast cereals are the most important factors of exposure in the case of infants. However, none of the studied population groups exceeded the lower limit of BMDL established by EFSA [15–16]. To reduce arsenic exposure, the authors of these studies recommend consuming white rice varieties or pre-cooked rice, as well as washing rice before cooking [2, 9, 19, 27, 51, 52].

Arsenic in fish and seaweed and other foods

Arsenic found in fish is the less harmful organic form of arsenic, on the contrary, iAs is present in very low concentrations. As found in fish is the less harmful organic form of As, although, there are some exceptions in the case of blue mussels [47], and some types of seaweed [25] that contain higher concentrations of iAs.

Certain seafood and seaweed products (e.g. Hijiki) can contain high levels of inorganic arsenic. The dietary exposure levels of pregnant women and children were studied in a group of Japanese consumers, where the intake of Hijiki seaweed is relatively high compared to European countries. Intakes of total and inorganic arsenic have been shown to be higher among frequent consumers of Hijiki, both in pregnant women and children. Although rice and rice-based products, which constitute staple food, are considered the main sources of exposure to inorganic arsenic in Japan, research results indicate that the consumption of Hijiki seaweed increases the levels of inorganic arsenic consumption in Japanese children and pregnant women [33].

While there are measures to protect people from high levels of arsenic, for people who regularly consume large amounts of Hijiki seaweed, along with other foods that may contain arsenic, this may result in higher arsenic intake and therefore greater potential health risk than in the general population [14, 15, 21, 51, 52].

REGULATORY POLICIES CONCERNING ARSENIC IN FOOD

In order to protect human health, the content of pollutants with documented toxic effect in food is limited.

On an international scale, issues associated with health-related food quality are dealt with by the Codex Alimentarius Commission (established by FAO/WHO members), which tries to establish the acceptable limits of contamination, being of particular importance for the import and export of food [9].

The issues related to the supervision of food quality are based on the legal regulations in force in the EU [10, 11]. Due to the potential exposure of certain population groups, maximum levels of iAs have been set in some food products. Rice and rice-based products belong to the group of food products accumulating large amounts of As and they are also highly consumed. As a result, maximum permissible levels of inorganic arsenic [10] have been set for this group of products pursuant to Commission Regulation (EU) 2015/1006 of June 25, 2015 [Commission Regulation (EU), 2015]. So far, the limitation and maximum permissible levels of this element in food include only rice and rice-based products (0.20–0.30 mg/kg) and a much lower maximum level (0.10 mg/kg) for rice intended for the production of food for infants and young children. It should be emphasized that the requirements for this type of food are much more restrictive; the permissible limits are almost three times lower compared to food intended for general consumption (Table 2). Maximum levels are one of the many risk management strategies we use to keep arsenic exposure at a safe level.

Table 2. The maximum permissible levels of iAs in food as sum of As(III) and As(V)

Tabela 2. Maksymalny dopuszczalny poziom iAS w żywności jako suma As(III) and As(V)

Food	Maximum levels (mg/kg)
Non-parboiled milled rice (polished or white rice)	0.20
Parboiled rice and husked rice	0.25
Rice waffles, rice wafers, rice crackers and rice cakes	0.30
Rice destined for the production of food for infants and young children	0.10

Source: Commission Regulation (EU) 2015/1006 [11]

Źródło: Rozporządzenie Komisji Europejskiej (UE) 2015/1006 [11]

An important source of As may be water intended for human consumption, when water with an As concentration significantly above 10 μg/L is used for drinking and cooking. The limit value for drinking water is <10 μg/L [51, 52].

According to the regulation of the Minister of Health, the total concentration of As should not exceed 0.010 mg/litre [40, 41]. The maximum permissible level of As for natural mineral, table and spring waters is also similar [40]. In the light of the latest data of the State Sanitary Inspection, which supervises the quality of drinking water, for arsenic only in 1 case (Lower Silesian Voivodeship) a deviation from the normal range was noted [18].

The European Commission, in cooperation with EFSA, has developed a specific recommendation on As monitoring in food (Commission Recommendation (EU) 2015 [10]. According to EFSA, it is important to collect more representative data on iAs contamination of different food groups in order to provide a more complete risk assessment in this regard. Moreover, targeted research, including the monitoring of iAs in seaweed, has been recommended in recent years [11].

The available data on the occurrence of As indicate that seaweed is characterized by the accumulation of elements harmful to health. They belong to a group of foods that, according to EFSA, can contribute significantly to dietary As intake. However, there are currently no maximum levels of As in seaweed, halophytes or products based on seaweed. In 2018, the EU Commission made recommendations to monitor the presence of heavy metals, including As, in these products. The above recommendations are not binding but may be helpful in determining actions for food control authorities [11].

THE CONCENTRATIONS OF INORGANIC AS IN RICE AND RICE-BASED PRODUCTS ON THE POLISH MARKET

Inorganic arsenic concentrations in rice and rice-based products were also tested in Poland. An assessment by monitoring authorities has shown that rice and rice-based products contain high concentrations of iAS compared to other grains [29].

The average concentration of total As and iAs in white rice was 0.10 mg/kg (90-percentile: 0.19 mg/kg) and 0.03 mg/kg (90-percentile: 0.06 mg/kg). Brown rice contained higher concentrations than white rice, most of which had been removed from the outer layer of the grain. The average concentration of total As was 0.18 mg/kg (90th percentile: 0.32 mg/kg), while of iAs it was 0.05 mg/kg (90th percentile: 0.07 mg/kg). Higher concentrations than those in white rice have also been shown in rice cakes and rice flakes, especially rice wafers, 0.24 mg/kg and 0.13 mg/kg, respectively. In the group of products for infants, the obtained results were low, i.e. total As concentration was 0.06 mg/kg, and iAs concentration was 0.02 mg/kg. Regarding adults and children, the estimated average iAs exposure for rice and rice-based products was less than 1% of the lowest dose determining $BMDL_{05}$. On the basis of the obtained results, it was found that As contamination of rice and rice-based products does not pose a health risk [29].

Fish, seafood and seaweed belong to a group of foods that, according to EFSA, can contribute significantly to dietary As intake. In this product group, the major forms of As are the less toxic organic compounds [30]. The national monitoring studies showed that the average content of total As in the tested fish samples was 0.46 mg/kg, while the content of the inorganic form did not exceed the detection limit of the method used, i.e. 0.025 mg/kg. In seafood, the concentrations for total As were: 0.87 mg/kg, for inorganic arsenic the 90th percentile was determined, which was 0.043 mg/kg. The average exposure estimated for iAs for adults was less than 0.5% of the lowest dose determining BMDL0.5 for fish and seafood. Based on the above results, it was found that the intake of As as a result of the consumption of fish and seafood does not pose a significant risk to people consuming these products [30].

DIETARY EXPOSURE TO INORGANIC ARSENIC IN THE EUROPEAN POPULATION

In their scientific opinion, EFSA assessed the exposure to iAs from food and water in nineteen European countries, using lower (LB) and upper (UB) concentrations. The estimated iAs intake was from 0.13 to 0.56 µg/kg bw/day for average consumers and between 0.37 and 1.22 µg/kg bw/day for the 95-percentile consumers. This dietary exposure estimate is in the range of BMDL values, indicating that a risk of toxicity cannot be excluded [14].

Infants and young children have 2 to 3 times greater exposure to iAs arsenic than adults [14]. The greater risk of exposure to iAs from rice is not only limited to those traditionally consuming great amounts of rice, but also to those with special intake habits (consumption of algae and algae products; the levels of iAs can be two to ten times the median) [14, 15]. Moreover, for certain population groups, for example people with allergies or celiac disease, where the consumption of rice and rice-based products is much higher, the exposure to As is also greater [14, 15, 16].

In 2014 EFSA [15], the re-evaluation of dietary intake of inorganic arsenic based on more recent data reported lower exposure values compared to the previous EFSA scientific opinion [14]. The highest estimated daily exposure was found in infants and young children, from 0.20 to 0.45 µg/kg bw/day (min – max LB) and from 0.47 to 1.37 µg/kg bw/day (min – max UB), with the maximum value for infants. In the same age groups, 95-percentile dietary exposure ranged from 0.36 to 1.04 µg/kg bw/day (min – max LB) and from 0.81 to 2.09 µg/kg bw/day (min – max UB), with the highest level estimated in young children [14].

For adults, the average exposure level was 0.11 to 0.38 µg/kg bw/day (min LB to max UB) and 0.18 to 0.64 µg/kg bw/day (min LB to max UB) UB) for the 95th percentile, which is the lower limit of the BMDL01 value from 0.3 to 8 µg/kg/day [14].

The EFSA scientific opinion [14] on the assessment of exposure to inorganic arsenic via food consumption has shown that, for the European population, also food with significantly lower levels of inorganic arsenic compared to rice may affect arsenic exposure due to the high amounts consumed.

For infants, milk, dairy products, drinking water and baby formula constitute the main sources of exposure to inorganic arsenic. For other age groups, non-rice grain products (mostly wheat) constitute the main source of exposure to inorganic arsenic, according to most nutritional studies. In contrast, rice, milk, dairy products and drinking water also have a significant impact on arsenic consumption [14].

Upon request of the European Commission, EFSA has recently assessed chronic dietary exposure to iAs in the European population [15]. The highest average dietary exposure estimates at the lower limit (LB) occurred in young children (0.30 µg/kg body weight/day) and in infants and young children (0.61 µg/kg bw/day) in the upper limit (UB). In the 95th percentile, the highest estimated exposure (LB-UB) was 0.58 and 1.20 µg/kg bw/day, respectively, and concerned young children and infants. In different age classes, the main causes of dietary exposure to iAs were rice and rice-based products, grains and grain-based products (without rice), and drinking water. Different exposure scenarios showed dietary exposure estimates on average and for large consumers near or in the value range of $BMDL_{01}$.

Compared to the 2014 EFSA scientific report, the estimated dietary exposure to iAs was lower, with the average, maximum and 95-percentile being approximately 1.5–3 times lower in the different age classes [15]. Risk groups were identified including people with celiac disease and/or gluten intolerance, as they consume higher amounts of rice and processed grains, and therefore have a higher dietary exposure to iAs [14, 15].

EFFECT OF TECHNOLOGICAL TREATMENT ON THE REDUCTION OF ARSENIC LEVELS

Reduction in the content of As in rice can be achieved by various methods and practices after harvest and during cooking. Polishing rice and removing the outer layer (50––70%), washing raw rice (13–84%) and boiling in excess of water (28–66%) significantly reduce the content of arsenic in rice grains (Table 3). The listed methods can be implemented almost at no extra cost [2, 27].

Table 3. Effects of different removal methods and cooking practices on As concentration in rice

Tabela 3. Wpływ różnych metod oraz sposobu gotowania na stężenie As w ryżu

Methods	Arsenic removal (%) from cooked rice
Polishing grains	50–70
Washing of raw rice	13–84
Cooking (in excess water)	28–66
Rinsing rice grains (3 cycles) and then cooking it in excess water	83%

Source: Reference [2, 27]

Źródło: [2, 27]

In studies evaluating the effect of rinsing and cooking on the As content, it was shown that the treatment consisting of rinsing rice grains (3 cycles) followed by cooking in excess of water resulted in a significant decrease by as much as 83% of the tAs content compared to raw rice [2].

In order to reduce exposure to As and cadmium at the same time, attempts are being made to develop a method of simultaneous reduction of arsenic and cadmium from rice. The use of food-safe citric acid and calcium carbonate to pre-soak white rice grains reduces the level of iAs by as much as 80% [36].

In order to look for methods to reduce As, some studies also investigate genetically modified rice that would accumulate less arsenic in rice grains [2, 27]. To reduce exposure to As, some authors recommend eating white rice varieties or pre-cooked rice, and washing rice before cooking to minimize arsenic exposure [19, 42, 54].

THE ROLE AND PROTECTIVE EFFECT OF NUTRITION IN ARSENIC METABOLISM

The nutritional status of the body is one of the important factors related to the frequency or severity of health effects related to arsenic exposure, and malnourished people are particularly vulnerable [1, 4, 35, 43, 45, 55].

Research results indicate that there is a wide variation in the body's susceptibility to arsenic toxicity, which is probably related to factors such as: variability in arsenic metabolism, nutritional status, body defence mechanisms and genetic predisposition [4, 35, 43, 45].

Research results indicate that some dietary nutrients show the so-called protective effect against the harmful effects of toxic metals. Diet rich in vegetables containing antioxidants and folic acid may contribute to minimizing some arsenic-induced toxic effects [4, 43, 45].

The main mechanisms of arsenic-nutrition interaction include arsenic-induced oxidative stress, which requires nutrient-dependent defence systems, and arsenic metabolism (methylation), which requires folic acid, vitamin B_{12}, and choline for the remethylation of homocysteine to methionine. In particular, low consumption of these ingredients may reduce the efficiency of this process [1, 4, 43, 45].

Methyl groups for As methylation are ensured by a one-carbon metabolism, and it is influenced by folic acid and other micronutrients, such as vitamin B_{12}, choline, betaine and creatine. There is increasing scientific evidence confirming the effect of folic acid on As methylation, and some evidence from case-control studies suggests that poor folate nutritional status influences the risk of As-induced skin lesions and bladder cancer [1, 4, 43, 45].

Arsenic is eliminated as a result of methylation mediated by folic acid. Providing folic acid through folic acid supplements can facilitate methylation and arsenic excretion, thereby reducing arsenic toxicity. It is also possible that people with a genotype associated with less efficient arsenic methylation may be more sensitive to interactions with deficient nutrition [1, 4, 43, 45].

Another important aspect is that selenium, if dosed excessively, can intensify the harmful effects of inorganic As by inhibiting As methylation. Therefore, one of the therapeutic strategies to counteract its toxicity is the simultaneous administration of selenium with plant antioxidants [55].

In addition to the protective role of trace elements such as zinc and selenium, food-derived bioactive compounds that can alleviate oxidative stress and inflammation have the potential to protect against arsenic-induced tissue damage. Noteworthy of the natural ones are curcumin, quercetin, gallic acid, genistein, resveratrol and thymoquinone, whose protective effect against arsenic toxicity has been confirmed in numerous animal studies. A high-protein diet will also help reduce arsenic toxicity [43, 45].

In general, it can be concluded that a wholesome diet rich in antioxidants and folic acid as well as zinc and selenium, providing nutrients in the recommended amounts, protects the body against the harmful effects of toxic substances consumed with food [1, 4, 35, 43, 45, 55].

RICE AND RICE-BASED PRODUCTS IN THE NUTRITION OF SELECTED POPULATION GROUPS – RECOMMENDATIONS

The Codex Alimentarius Commission (FAO/WHO) has published a code of practice for preventing and reducing arsenic contamination in rice, which provides guidelines for rice cultivation and the production of rice-based products [9].

For its nutritional value, rice should continue to be part of a balanced diet. However, when choosing food, consumers should follow a varied diet and, if possible, vary the types of grains they consume [16, 52].

In the case of infants and young children, parents are advised not to use only rice drinks. National and international authorities advise against this form of nutrition not only because of the high concentration of arsenic in these products, but also because of the inadequate composition of nutrients that does not meet the needs of infants [22, 28, 34, 48].

When it comes to rice-based snacks, it is recommended to consume foods such as rice cakes or rice flakes or other snacks in moderation or occasionally, and to diversify diet with those based on other grains such as corn or wheat [9, 10, 16, 22, 34].

For consumers with celiac disease, the same recommendations should be followed as for the general population. If possible, avoid a diet that is based solely on rice and rice-based products. Instead, eat other gluten-free grains, such as corn, buckwheat, amaranth, and quinoa [22, 34, 48].

The Nutrition Committee of the European Society of Gastroenterology, Hepatology and Nutrition in Paediatrics (ESPGHAN) issued a statement in 2015 recommending that the intake of inorganic arsenic during infancy and childhood should be as low as possible, and the content of inorganic arsenic in products intended for infants and young children was regulated by law. It also points out that, although infant formulas based on rice proteins constitute an alternative for infants allergic to cow's milk proteins, the content of inorganic arsenic in them should be taken into account, and the potential risks associated with this should be considered when using these products [22].

Rice drinks should not be used in the nutrition of infants and young children, and exposure to inorganic arsenic from food may be lowered by the use of other types of grains, including oats, barley, wheat and corn. ESPGHAN also notes that the content of arsenic in rice should be widely monitored around the world, and that rice with the lowest arsenic content should be used in the production of food intended for infants and young children and food for special medical purposes [34]. To reduce the risk of exposure to inorganic arsenic, it is recommended to choose other types of grains. Rice drinks should not be used in the nutrition of infants [48].

SUMMARY

For humans, the main sources of arsenic (As) is food and drinking-water, as a result of the environmental pollution and anthropogenic human activities. Inorganic arsenic (iAs) forms are potentially harmful to human health. Rice is the largest dietary source of inorganic arsenic (iAs) that the plant accumulates from the soil and water. Therefore, a diet based on rice and its products, in particular for the young population (infants, toddlers and other children), as well as individuals with celiac disease and/or gluten intolerance, may constitute an important health issue. In the adult population, food groups such as rice and rice-based food, algae formula and fish and other seafood were also apparent sources of iAs. Diet quality is becoming a key determinant on the environment-water-soil-food-human health axis.

Due to its chemical stability and the tendency to bioaccumulate, iAs is considered a persistent pollutant that is still present in the environment, including in food and drinking water. Rice (brown husked rice that retains the bran) and rice-based products (wafers, crackers, biscuits, rusks, cookies, flakes, flour and rice popped), contains high levels of iAs.

Rice protein-based infant formulas and products young children (including rice drinks) constitute an option in case of an allergy to cow's milk protein, therefore levels of these contaminants should be carefully controlled. Rice drinks as substitutes for cow's milk should not be used in infants and young children.

When choosing food, consumers should follow a varied diet and, if possible, vary the types of grains they consume. In order to look for methods to reduce iAs, some studies also investigate genetically modified rice that would accumulate less arsenic in rice grains. To reduce exposure to iAs, it is recommended to polish grains, and rinse rice grains under water and then cooking it in excess water.

According to the latest EFSA opinion of 2021, to ensure consumers' health safety, it is recomended to introduce further limits for inorganic arsenic and to constantly monitor the content of arsenic in foodstuffs available on the market.

PODSUMOWANIE

Dla człowieka głównym źródłem arsenu (As) jest żywność i woda, z powodu zanieczyszczenia środowiska oraz działalności antropogenicznej człowieka. Nieorganiczne formy arsenu (iAs) są najbardziej szkodliwe dla zdrowia. Spośród różnych produktów, największe stężenia iAs stwierdzane są w ryżu i produktach na bazie ryżu. Dieta oparta na ryżu i jego przetworach, szczególnie w populacji niemowląt i małych dzieci, a także osób z celiakią i/lub nietolerancją glutenu, może stanowić istotny problem zdrowotny. Wśród dorosłych osób ryż i produkty na bazie ryżu, preparaty z alg oraz ryby i inne owoce morza, również są ważnymi źródłami iAs. Jakość produkowanej żywności staje się kluczowym wyznacznikiem w systemie środowisko-woda-gleba-żywność a zdrowie człowieka.

Ze względu na stabilność chemiczną i tendencję do bioakumulacji, iAs jest uważany za trwałe zanieczyszczenie, które nadal występuje w środowisku, w tym w żywności i wodzie pitnej. Ryż (brązowy ryż łuskany, który zachowuje otręby) i produkty na bazie ryżu (wafle, krakersy, herbatniki, sucharki, ciastka, płatki, mąka i ryż preparowany) zawierają wysoki poziom iA.

Preparaty dla niemowląt i małych dzieci na bazie białka ryżu (m.in. napoje ryżowe) są opcją dla niemowląt z alergią na białko mleka krowiego, dlatego należy objąć szczególną kontrolą poziomy zanieczyszczeń iAs. Pobranie z dietą iAs

przez małe dzieci prawdopodobnie może wpłynąć na zdrowie w dłuższej perspektywie. Napojów roślinnych ryżowych jako substytutów mleka krowiego nie należy stosować u niemowląt i małych dzieci.

Konsumenci przy wyborze żywności powinni stosować urozmaiconą dietę i, jeśli to możliwe, zróżnicować rodzaje spożywanych zbóż. Niektóre badania wskazują na możliwość zastosowania genetycznie zmodyfikowanego ryżu, który gromadziłby mniej arsenu w ziarnach. Aby zmniejszyć narażenie na iAs, technologicznie zalecane się polerowanie ziaren ryżu, jak również płukanie pod bieżącą wodą, a następnie gotowanie w większej ilości wody.

Zgodnie z najnowszą opinią EFSA z 2021 r aby zapewnić bezpieczeństwo zdrowotne konsumentów zalecane jest wprowadzenie limitów dla arsenu nieorganicznego dla kolejnych produktów oraz stałe monitorowanie zawartości arsenu w środkach spożywczych dostępnych na rynku.

REFERENCES

[1] **ABUAWAD A., A.K. BOZACK, S. ROHEENI, M.V. GAMBLE. 2021.** "Nutrition, one-carbon metabolism and arsenic methylation". Toxicology 457: 152803.

[2] **ATIAGA O, L.M. NUNES, X.L. OTERO. 2020.** "Effect of cooking on arsenic concentration in rice". Environmental Science and Pollution Research International 27(10): 10757–10765.

[3] **BABAR M., A. TARIQ. 2018.** "Status of Arsenic Toxicity in the World". Mechanisms of Arsenic Toxicity and Tolerance in Plants 457–481.

[4] **BAE S., E. KAMYNINA, H.M. GUETTERMAN, A.F. FARINOLA, M.A. CAUDILL, R.J. BERRY, P.A. CASSANO, P.J. STOVER. 2021.** "Provision of folic acid for reducing arsenic toxicity in arsenic-exposed children and adults". Cochrane Database of Systematic Reviews 10:CD012649.

[5] **BISWAS, J.K., M. WARKE, R. DATTA. 2020.** "Is Arsenic in Rice a Major Human Health Concern?". **Human** Health Effects of Environmental Pollution 6: 37–42.

[6] **BORAH G., P. MUDOI, P. BORAH. 2021.** Arsenic contamination in water resources and its health risk assessment". Contamination of Water: 187–198.

[7] **CARLIN D.J., M.F. NAUJOKAS, K.D. BRADHAM, J. COWDEN, M. HEACOCK, H.F. HENRY, J.S. LEE, D.J. THOMAS, C. THOMPSON, E.J. TOKAR. 2015.** "Arsenic and environmental health: State of the science and future research opportunities". Environmental Health Perspectives 124: 890–899.

[8] **CHENGJUN L.I., J. WANG, B. YAN, M. AI-JUN, H. ZHONG, W. ZHANG, L.Q. MA. 2021.** "Progresses and emerging trends of arsenic research in the past 120 years". Critical Reviews in Environmental Science and Technology 51:13, 1306–1353.

[9] **Codex Alimentarius FAO/WHO. 2017.** Code of Practice for the prevention and reduction of arsenic contamination in rice. CXC 77-2017, https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B77-2017%252FCXC_077e.pdf

REFERENCES

[1] **ABUAWAD A., A.K. BOZACK, S.ROHEENI, M.V. GAMBLE. 2021.** "Nutrition, one-carbon metabolism and arsenic methylation". Toxicology 457: 152803.

[2] **ATIAGA O, L.M. NUNES, X.L. OTERO. 2020.** "Effect of cooking on arsenic concentration in rice". Environmental Science and Pollution Research International 27(10):10757–10765.

[3] **BABAR M., A. TARIQ. 2018.** "Status of Arsenic Toxicity in the World". Mechanisms of Arsenic Toxicity and Tolerance in Plants 457–481.

[4] **BAE S., E. KAMYNINA, H.M. GUETTERMAN, A.F. FARINOLA, M.A. CAUDILL, R.J. BERRY, P.A. CASSANO, P.J. STOVER. 2021.** "Provision of folic acid for reducing arsenic toxicity in arsenic-exposed children and adults". Cochrane Database of Systematic Reviews 10:CD012649.

[5] **BISWAS, J.K., M. WARKE, R. DATTA. 2020.** "Is Arsenic in Rice a Major Human Health Concern? ". Human Health Effects of Environmental Pollution 6: 37–42.

[6] **BORAH G., P. MUDOI, P. BORAH. 2021.** Arsenic contamination in water resources and its health risk assessment". Contamination of Water: 187–198.

[7] **CARLIN D.J., M.F. NAUJOKAS, K.D. BRADHAM, J. COWDEN, M. HEACOCK, H.F. HENRY, J.S. LEE, D.J. THOMAS, C. THOMPSON, E.J. TOKAR. 2015.** "Arsenic and environmental health: State of the science and future research opportunities". Environmental Health Perspectives 124: 890–899.

[8] **CHENGJUN L.I., J. WANG, B. YAN, M. AI-JUN, H. ZHONG, W. ZHANG, L.Q. MA. 2021.** "Progresses and emerging trends of arsenic research in the past 120 years". Critical Reviews in Environmental Science and Technology 51:13, 1306–1353.

[9] **Codex Alimentarius FAO/WHO. 2017:** Code of Practice for the prevention and reduction of arsenic contamination in rice. CXC 77-2017, https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B77-2017%252FCXC_077e.pdf

[10] **Commission Regulation (EU). 2015.** Commission Regulation 2015/1006 of 25 June 2015 amending Regulation (EC) No 1881/2006 as **regards maximum levels** of inorganic arsenic in foodstuffs. Official Journal of the EU,2015, L161/14 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02006R1881-20210919

[11] **Commission Recommendation (EU). 2018.** Commission Recommendation 2018/464 of 19 March 2018 on the **monitoring** of metals and iodine in seaweed**,** halophytes and products based on seaweed. Official Journal of the EU, 2018, L79/16; https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018H0464&from=PL

[12] **CUBADDA F., B. JACKSON, K. COTTINGHAM, Y. VAN HORNE, M. KURZIUS-SPENCER. 2017.** "Human exposure to dietary inorganic arsenic and other arsenic species: State of knowledge, gaps and uncertainties". Science of the Total Environment 579: 1228–1239.

[13] **DAVIS M., A. SIGNES-PASTOR, M. ARGOS, F. SLAUGHTER, C. PENDERGRAST, T. PUNSHON, A. GOSSAI, H. AHSAN, M. KARAGAS. 2017.** "Assessment of human dietary exposure to arsenic through rice". Science of The Total Environment 586: 1237–1244.

[14] **EFSA. 2009.** Scientific Opinion on Arsenic in Food. EFSA Journal: 7,10, 1351, 199 pp.

[15] **EFSA. 2014.** Scientific report. Dietary exposure to inorganic arsenic in the European population, EFSA Journal:12, 3, 3597, 68 pp.

[16] **EFSA. 2021.** Scientific report. Chronic dietary exposure to inorganic arsenic. EFSA Journal: 19, 1, e06380.

[17] **ESTHER F.A. P. J.C.M. BRANDON, J.L. DE WIT-BOS. 2014.** "Arsenic: bioaccessibility from seaweed and rice, dietary exposure calculations and risk assessment" Food Additives & Contaminants: Part A, 31:12: 1993–2003.

[18] **GIS. 2020.** Dane dotyczące jakości wody przeznaczonej do spożycia przez ludzi za 2020 r. https://dane.gov.pl/pl/dataset/36,dane-dotyczace-stanu-sanitarnego-jakosci-wody-przeznaczonej-do-spozycia/resource/33182/table

[19] **GONZÁLEZ N., J. CALDERÓN, A. RÚBIES, J. BOSCH, I. TIMONER, V. CASTELL, M. MARQUÈS, M. NADAL, J.L. DOMINGO. 2020.** "Dietary exposure to total and inorganic arsenic via rice and rice-based products consumption". Food and Chemical Toxicology 141: 111420.

[20] **GU Z., S. DE SILVA, S. M. REICHMAN. 2020.** "Arsenic Concentrations and Dietary Exposure in Rice-Based Infant Food in Australia". International Journal of Environmental Research and Public Health 17(2): 415.

[10] **Commission Regulation (EU). 2015.** Commission Regulation 2015/1006 of 25 June 2015 amending Regulation (EC) No 1881/2006 as regards maximum levels of inorganic arsenic in foodstuffs. Official Journal of the EU,2015, L161/14 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02006R1881-20210919

[11] **Commission Recommendation (EU). 2018.** Commission Recommendation 2018/464 of 19 March 2018 on the monitoring of metals and iodine in seaweed, halophytes and products based on seaweed. Official Journal of the EU, 2018, L79/16; https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018H0464&from=PL

[12] **CUBADDA F., B. JACKSON, K. COTTINGHAM, Y. VAN HORNE, M. KURZIUS-SPENCER. 2017.** "Human exposure to dietary inorganic arsenic and other arsenic species: State of knowledge, gaps and uncertainties". Science of the Total Environment 579: 1228–1239.

[13] **DAVIS M., A. SIGNES-PASTOR, M. ARGOS, F. SLAUGHTER, C. PENDERGRAST, T. PUNSHON, A. GOSSAI, H. AHSAN, M. KARAGAS. 2017.** "Assessment of human dietary exposure to arsenic through rice". Science of The Total Environment 586: 1237–1244.

[14] **EFSA. 2009.** Scientific Opinion on Arsenic in Food. EFSA Journal: 7,10, 1351, 199 pp.

[15] **EFSA. 2014.** Scientific report. Dietary exposure to inorganic arsenic in the European population, EFSA Journal:12, 3, 3597, 68 pp.

[16] **EFSA. 2021.** Scientific report. Chronic dietary exposure to inorganic arsenic. EFSA Journal: 19, 1, e06380.

[17] **ESTHER F.A. P. J.C.M. BRANDON, J.L. DE WIT-BOS. 2014.** "Arsenic: bioaccessibility from seaweed and rice, dietary exposure calculations and risk assessment" Food Additives & Contaminants: Part A, 31:12: 1993–2003.

[18] **GIS. 2020.** Dane dotyczace jakosci wody przeznaczonej do spozycia przez ludzi za 2020 r. https://dane.gov.pl/pl/dataset/36,dane-dotyczace-stanu-sanitarnego-jakosci-wody-przeznaczonej-do-spozycia/resource/33182/table

[19] **GONZALEZ N., J. CALDERON, A. RUBIES, J. BOSCH, I. TIMONER, V. CASTELL, M. MARQUES, M. NADAL, J.L. DOMINGO. 2020.** "Dietary exposure to total and inorganic arsenic via rice and rice-based products consumption". Food and Chemical Toxicology 141: 111420.

[20] **GU Z., S. DE SILVA, S. M. REICHMAN. 2020.** "Arsenic Concentrations and Dietary Exposure in Rice-Based Infant Food in Australia". International Journal of Environmental Research and Public Health 17(2): 415.

[21] **GUNDERT-REMY U., G. DAMM, H. FOTH, A. FREYBERGER, T. GEBEL, K. GOLKA, C. RÖHL, T. SCHUPP, K.M. WOLLIN, J.G. HENGSTLER. 2015.** "High exposure to inorganic arsenic by food: The need for risk reduction." Arch. Toxicol. 89: 2219–2227.

[22] **HOJSAK I. C., BRAEGGER, J. BRONSKY, C. CAMPOY, V. COLOMB, T. DECSI, M. DOMELLÖF, M. FEWTRELL, N. FIDLER; W. MIHATSCH, C. MOLGAARD, J. VAN GOUDOEVER, FOR THE ESPGHAN COMMITTEE ON NUTRITION. 2015.** "Arsenic in Rice". Journal of Pediatric Gastroenterology and Nutrition 60: 142–145.

[23] **HUGHES M.F., B.D. BECK, Y. CHEN, A.S. LEWIS, D.J. THOMAS. 2011.** "Arsenic Exposure and Toxicology. A Historical Perspective". Toxicological Sciences, 123(2): 305–332.

[24] **IARC 2012.** Monographs on the Evaluation of Carcinogenic Risks to Humans. A Review of Human Carcinogens: Arsenic, Metals, Fibres, and Dusts, vol. 100C. Lyon, France: International Agency for Research on Cancer, pp. 41–93.

[25] **ICHIKAWA S., M. KOMOSHIDA, K. HANAOKA, M. HAMANO, T. MAITANI, T. KAISE. 2006.** "Decrease of arsenic in edible brown algae Hijikia fusi forme by the cooking process". Applied Organometallic Chemistry 20: 585–590.

[26] **ISLAM S., M.M. RAHMAN, M.A. RAHMAN, R. NAIDU. 2017.** "Inorganic arsenic in rice and rice-based diets: health risk assessment". Food Control 82: 196–202.

[27] **KUMARATHILAKA P., S. SENEWEERA, Y.S. OKD, A. MEHARGE, J. BUNDSCHUH. 2019.** "Arsenic in cooked rice foods: assessing health risks and mitigation options". Environment International 127: 584–591.

[28] **LAI P.Y., K.L. COTTINGHAM, C. STEINMAUS, M.R. KARAGAS, M.D. MILLER. 2015.** "Arsenic and Rice: Translating Research to Address Health Care Providers' Needs". Journal of Pediatrics 167: 797–803.

[29] **MANIA M., M. REBENIAK, T. SZYNAL, K. STARSKA, M. WOJCIECHOWSKA-MAZUREK, J. POSTUPOLSKI. 2017.** „Ocena narażenia ludności Polski na toksyczne działanie związków arsenu obecnych w ryżu i produktach ryżowych". Roczniki Państwowego Zakładu Higieny 68: 339–346.

[30] **MANIA M., M. REBENIAK, T. SZYNAL, M. WOJCIECHOWSKA-MAZUREK, K. STARSKA, J. LENDZION, J. POSTUPOLSKI. 2015.** "Total and inorganic arsenic in fish, seafood and seaweeds - exposure assessment". Roczniki Państwowego Zakładu Higieny 66: 203–210.

[21] **GUNDERT-REMY U., G. DAMM, H. FOTH, A. FREYBERGER, T. GEBEL, K. GOLKA, C. ROHL, T. SCHUPP, K.M. WOLLIN, J.G. HENGSTLER. 2015.** "High exposure to inorganic arsenic by food: The need for risk reduction". Arch. Toxicol. 89: 2219–2227.

[22] **HOJSAK I. C., BRAEGGER, J. BRONSKY, C. CAMPOY, V. COLOMB, T. DECSI, M. DOMELLOF, M. FEWTRELL, N. FIDLER; W. MIHATSCH, C. MOLGAARD, J. VAN GOUDOEVER, FOR THE ESPGHAN COMMITTEE ON NUTRITION. 2015.** "Arsenic in Rice". Journal of Pediatric Gastroenterology and Nutrition 60: 142–145.

[23] **HUGHES M.F., B.D. BECK, Y. CHEN, A.S. LEWIS, D.J. THOMAS. 2011.** "Arsenic Exposure and Toxicology. A Historical Perspective". Toxicological Sciences, 123(2): 305–332.

[24] **IARC 2012:** Monographs on the Evaluation of Carcinogenic Risks to Humans. A Review of Human Carcinogens: Arsenic, Metals, Fibres, and Dusts, vol. 100C. Lyon, France: International Agency for Research on Cancer, pp. 41–93.

[25] **ICHIKAWA S., M. KOMOSHIDA, K. HANAOKA, M. HAMANO, T. MAITANI, T. KAISE. 2006.** "Decrease of arsenic in edible brown algae Hijikia fusi forme by the cooking process". Applied Organometallic Chemistry 20: 585–590.

[26] **ISLAM S., M.M. RAHMAN, M.A. RAHMAN, R. NAIDU. 2017.** "Inorganic arsenic in rice and rice-based diets: health risk assessment". Food Control 82: 196–202.

[27] **KUMARATHILAKA P., S. SENEWEERA, Y.S. OKD, A. MEHARGE, J. BUNDSCHUH. 2019.** "Arsenic in cooked rice foods: assessing health risks and mitigation options". Environment International 127: 584–591.

[28] **LAI P.Y., K.L. COTTINGHAM, C. STEINMAUS, M.R. KARAGAS, M.D. MILLER. 2015.** "Arsenic and Rice: Translating Research to Address Health Care Providers' Needs". Journal of Pediatrics 167: 797–803.

[29] **MANIA M., M. REBENIAK, T. SZYNAL, K. STARSKA, M. WOJCIECHOWSKA-MAZUREK, J. POSTUPOLSKI. 2017:** „Ocena narazenia ludnosci Polski na toksyczne dzialanie zwiazkow arsenu obecnych w ryzu i produktach ryzowych". Roczniki Panstwowego Zakladu Higieny 68: 339–346.

[30] **MANIA M., M. REBENIAK, T. SZYNAL, M. WOJCIECHOWSKA-MAZUREK, K. STARSKA, J. LENDZION, J. POSTUPOLSKI. 2015.** "Total and inorganic arsenic in fish, seafood and seaweeds – exposure assessment". Roczniki Panstwowego Zakladu Higieny 66: 203–210.

[31] **MARCINIAK W., R. DERKACZ, M. MUSZYŃSKA, P. BASZUK, J. GRONWALD, T. HUZARSKI, C. CYBULSKI, A. JAKUBOWSKA, M. FALCO, T. DĘBNIAK, M. LENER, O. OSZUREK, K. PULLELLA, J. KOTSOPOULOS, P. SUN, S.A. NAROD, J. LUBIŃSKI. 2020.** "Blood arsenic levels and the risk of familial breast cancer in Poland". International Journal of Cancer 146(10): 2721–2727.

[32] **MARTINEZ V.D., W.L. LAM. 2021.** "Health Effects Associated With Pre- and Perinatal Exposure to Arsenic". Frontiers in Genetics 12: 664717.

[33] **MISE N., M. OHTSU, A. IKEGAMI, A. MIZUNO, X. CUI, Y. KOBAYASHI, Y. NAKAGI, K. NOHARA, T. YOSHIDA, F. KAYAMA. 2019.** "Hijiki seaweed consumption elevates levels of inorganic arsenic intake in Japanese children and pregnant women". Food Additives and Contaminants: Part A 36(1): 84–95.

[34] **MOJSKA H. 2016.** Arsen w ryżu: czy stanowi ryzyko dla zdrowia niemowląt i małych dzieci? Konsensus Komitetu Żywienia Europejskiego Towarzystwa Gastroenterologii, Hepatologii i Żywienia Dzieci ESPGHAN. Standardy Medyczne. Pediatria 13 (1): 18–20.

[35] **NAVAS-ACIEN A., M.I. SPRATLEN, A. ABUAWAD, N.J. LOIACONO, A.K. BOZACK, M.V. GAMBLE. 2019.** "Early-Life Arsenic Exposure, Nutritional Status, and Adult Diabetes Risk". Current Diabetes Reports 19(12):147.

[36] **POGOSON E., M. CAREY, C. MEHARG, A.A. MEHARG. 2021.** "Reducing the cadmium, inorganic arsenic and dimethylarsinic acid content of rice through food-safe chemical cooking pre-treatment". Food Chemistry 338: 127842.

[37] **PULLELLA K., J. KOTSOPOULOS. 2020.** "Arsenic Exposure and Breast Cancer Risk: A Re-Evaluation of the Literature". Nutrients 12(11), 3305.

[38] **RAHAMAN M, M. RAHMAN, N. MISE, T. SIKDER, G. ICHIHARA, M. UDDIN, M. KURASAKI, S. ICHIHARA. 2021.** "Environmental arsenic exposure and its contribution to human diseases, toxicity mechanism and management". Environmental Pollution 289:117940.

[39] **GUILLOD-MAGNIN R., B.J. BRÜSCHWEILER, R. AUBERT, M. HALDIMANN. 2018.** "Arsenic species in rice and rice-based products consumed by toddlers in Switzerland". Food Additives & Contaminants: Part A, 35:6, 1164–1178.

[40] **Rozporządzenie Ministra Zdrowia** z dnia 31 marca 2011 r. w sprawie naturalnych wód mineralnych, wód źródlanych i wód stołowych. Dz.U. 2011 nr 85 poz. 466 http://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20110850466/O/D20110466.pdf

[31] **MARCINIAK W., R. DERKACZ, M. MUSZYNSKA, P. BASZUK, J. GRONWALD, T. HUZARSKI, C. CYBULSKI, A. JAKUBOWSKA, M. FALCO, T. DEBNIAK, M. LENER, O. OSZUREK, K. PULLELLA, J. KOTSOPOULOS, P. SUN, S.A. NAROD, J. LUBINSKI. 2020.** "Blood arsenic levels and the risk of familial breast cancer in Poland". International Journal of Cancer 146(10): 2721–2727.

[32] **MARTINEZ V.D., W.L. LAM. 2021.** "Health Effects Associated With Pre- and Perinatal Exposure to Arsenic". Frontiers in Genetics 12:664717.

[33] **MISE N., M. OHTSU, A. IKEGAMI, A. MIZUNO, X. CUI, Y. KOBAYASHI, Y. NAKAGI, K. NOHARA, T. YOSHIDA, F. KAYAMA. 2019.** "Hijiki seaweed consumption elevates levels of inorganic arsenic intake in Japanese children and pregnant women". Food Additives and Contaminants: Part A 36(1): 84–95.

[34] **MOJSKA H. 2016.** Arsen w ryzu: czy stanowi ryzyko dla zdrowia niemowlat i malych dzieci? Konsensus Komitetu Zywienia Europejskiego Towarzystwa Gastroenterologii, Hepatologii i Zywienia Dzieci ESPGHAN. Standardy Medyczne. Pediatria 13 (1): 18–20.

[35] **NAVAS-ACIEN A., M.I. SPRATLEN, A. ABUAWAD, N.J. LOIACONO, A.K. BOZACK, M.V. GAMBLE. 2019.** "Early-Life Arsenic Exposure, Nutritional Status, and Adult Diabetes Risk". Current Diabetes Reports 19(12):147.

[36] **POGOSON E., M. CAREY, C. MEHARG, A.A. MEHARG. 2021.** "Reducing the cadmium, inorganic arsenic and dimethylarsinic acid content of rice through food-safe chemical cooking pre-treatment". Food Chemistry 338: 127842.

[37] **PULLELLA K., J. KOTSOPOULOS. 2020.** "Arsenic Exposure and Breast Cancer Risk: A Re-Evaluation of the Literature". Nutrients 12(11), 3305.

[38] **RAHAMAN M, M. RAHMAN, N. MISE, T. SIKDER, G. ICHIHARA, M. UDDIN, M. KURASAKI, S. ICHIHARA. 2021.** "Environmental arsenic exposure and its contribution to human diseases, toxicity mechanism and management". Environmental Pollution 289:117940.

[39] **GUILLOD-MAGNIN R., B.J. BRUSCHWEILER, R. AUBERT, M. HALDIMANN. 2018.** "Arsenic species in rice and rice-based products consumed by toddlers in Switzerland". Food Additives & Contaminants: Part A, 35:6, 1164–1178.

[40] **Rozporzadzenie Ministra Zdrowia** z dnia 31 marca 2011 r. w sprawie naturalnych wod mineralnych, wod zrodlanych i wod stolowych. Dz.U. 2011 nr 85 poz. 466 http://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20110850466/O/D20110466.pdf

[41] **Rozporządzenie Ministra Zdrowia** z dnia 7 grudnia 2017 r. w sprawie jakości wody przeznaczonej do spożycia przez ludzi. Dz.U. 2017 poz. 2294 http://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20170002294/O/D20172294.pdf

[42] **SANYAL T, P. BHATTACHARJEE, S. PAUL, P. BHATTACHARJEE. 2020.** "Recent Advances in Arsenic Research: Significance of Differential Susceptibility and Sustainable Strategies for Mitigation". Frontiers in Public Health 8: 464.

[43] **SHARMA A., S.J.S. FLORA. 2018.** "Nutritional management can assist a significant role in alleviation of arsenicosis". Journal of Trace Elements in Medicine and Biology 45: 11–20.

[44] **SIGNES-PASTOR A.J., J. VIOQUE, E.M. NAVARRETE-MUÑOZ, M. CAREY, M. GARCÍA DE LA HERA, J. SUNYER, M. CASAS, I. RIAÑO-GALÁN, A. TARDÓN, S. LLOP, R. AMORÓS, P. AMIANO, J.R. BILBAO, M.R. KARAGAS, A.A. MEHARG. 2017.** "Concentrations of urinary arsenic species in relation to rice and seafood consumption among children living in Spain". Environmental Research, 159: 69–75.

[45] **SIJKO M., L. KOZŁOWSKA. 2021.** "Influence of Dietary Compounds on Arsenic Metabolism and Toxicity. Part II – Human Studies". Toxics 9(10): 259.

[46] **SINHA D., P. PRASAD. 2019**. "Health effects inflicted by chronic low□level arsenic contamination in groundwater: A global public health challenge". Journal of Applied Toxicology 40: 87–131.

[47] **SLOTH J.J., K. JULSHAMN. 2008.** "Survey of total and inorganic arsenic content in blue mussels (*Mytilus edulis* L.) from Norwegian fjords: Revelation of unusual high levels of inorganic arsenic". Journal of Agricultural and Food Chemistry 56, pp. 1269–1273.

[48] **SZAJEWSKA H., P. SOCHA, A. HORVATH I WSP. 2021.** „Zasady żywienia zdrowych niemowląt". Stanowisko Polskiego Towarzystwa Gastroenterologii, Hepatologii i Żywienia Dzieci. Standardy Medyczne/Pediatria 8: 805–822.

[49] **TSUJI J., K. LENNOX, H. WATSON, E. CHANG. 2021.** "Essential Concepts for Interpreting the Dose-Response of Low-Level Arsenic Exposure in Epidemiological Studies". Toxicology, 457: 152801.

[50] **WANG S. 2017.** "Accumulation of heavy metals in soil-crop systems: a review for wheat and corn". Environ. Sci. Pollut. Res., 24 (18), pp. 15209–15225.

[51] **WHO. 2011.** Joint FAO/WHO Expert Committee on Food Additives (JECFA). Arsenic (Addendum) [In:] Safety evaluation of certain contaminants in food; WHO Geneva, Food Additives Series, No 63, 153–316.

[52] **WHO. 2019.** "Preventing disease through healthy environments: Exposure to arsenic: a major public health concern". https://apps.who.int/iris/bitstream/handle/10665/329482/WHO-CED-PHE-EPE-19.4.1-eng.pdf

[41] **Rozporzadzenie Ministra Zdrowia** z dnia 7 grudnia 2017 r. w sprawie jakosci wody przeznaczonej do spozycia przez ludzi. Dz.U. 2017 poz. 2294 http://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20170002294/O/D20172294.pdf

[42] **SANYAL T, P. BHATTACHARJEE, S. PAUL, P. BHATTACHARJEE. 2020.** "Recent Advances in Arsenic Research: Significance of Differential Susceptibility and Sustainable Strategies for Mitigation". Frontiers in Public Health 8: 464.

[43] **SHARMA A., S.J.S. FLORA. 2018.** "Nutritional management can assist a significant role in alleviation of arsenicosis". Journal of Trace Elements in Medicine and Biology 45: 11–20.

[44] **SIGNES-PASTOR A.J., J. VIOQUE, E.M. NAVARRETE-MUNOZ, M. CAREY, M. GARCIA DE LA HERA, J. SUNYER, M. CASAS, I. RIANO-GALAN, A. TARDON, S. LLOP, R. AMOROS, P. AMIANO, J.R. BILBAO, M.R. KARAGAS, A.A. MEHARG. 2017.** "Concentrations of urinary arsenic species in relation to rice and seafood consumption among children living in Spain". Environmental Research, 159: 69–75.

[45] **SIJKO M., L. KOZLOWSKA. 2021.** "Influence of Dietary Compounds on Arsenic Metabolism and Toxicity. Part II – Human Studies". Toxics 9(10): 259.

[46] **SINHA D., P. PRASAD. 2019.** "Health effects inflicted by chronic low-level arsenic contamination in groundwater: A global public health challenge". Journal of Applied Toxicology 40: 87–131.

[47] **SLOTH J.J., K. JULSHAMN. 2008.** "Survey of total and inorganic arsenic content in blue mussels (Mytilus edulis L.) from Norwegian fjords: Revelation of unusual high levels of inorganic arsenic". Journal of Agricultural and Food Chemistry 56, pp. 1269–1273.

[48] **SZAJEWSKA H., P. SOCHA, A. HORVATH I WSP. 2021.** "Zasady zywienia zdrowych niemowlat". Stanowisko Polskiego Towarzystwa Gastroenterologii, Hepatologii i Zywienia Dzieci. Standardy Medyczne/Pediatria 8: 805–822.

[49] **TSUJI J., K. LENNOX, H. WATSON, E. CHANG. 2021.** "Essential Concepts for Interpreting the Dose-Response of Low-Level Arsenic Exposure in Epidemiological Studies". Toxicology, 457: 152801.

[50] **WANG S. 2017.** "Accumulation of heavy metals in soil-crop systems: a review for wheat and corn". Environ. Sci. Pollut. Res., 24 (18), pp. 15209–15225.

[51] **WHO. 2011.** Joint FAO/WHO Expert Committee on Food Additives (JECFA). Arsenic (Addendum) [In:] Safety evaluation of certain contaminants in food; WHO Geneva, Food Additives Series, No 63, 153–316.

[52] **WHO. 2019.** "Preventing disease through healthy environments: Exposure to arsenic: a major public health concern". https://apps.who.int/iris/bitstream/handle/10665/329482/WHO-CED-PHE-EPE-19.4.1-eng.pdf

[53] **YONG J.J., H.H. KYUNG, J.K. DAE. 2015.** "New risk factors for obesity and diabetes: Environmental chemicals". Journal Diabetes Investigation 6(2): 109–111.

[54] **ZHOU Z., G. YANG, P. XUN, W. QIANG, K. SHAO. 2021.** "Bioaccessibility of Inorganic Arsenic in Rice: Probabilistic Estimation and Identification of Influencing Factors". Food Reviews International 1970762.

[55] **ZWOLAK I. 2020.** "The Role of Selenium in Arsenic and Cadmium Toxicity: an Updated Review of Scientific Literature". Biological Trace Element Research 193(1): 44–63.

[53] **YONG J.J., H.H. KYUNG, J.K. DAE. 2015.** "New risk factors for obesity and diabetes: Environmental chemicals". Journal Diabetes Investigation 6(2): 109–111.

[54] **ZHOU Z., G. YANG, P. XUN, W. QIANG, K. SHAO. 2021.** "Bioaccessibility of Inorganic Arsenic in Rice: Probabilistic Estimation and Identification of Influencing Factors". Food Reviews International 1970762.

[55] **ZWOLAK I. 2020.** "The Role of Selenium in Arsenic and Cadmium Toxicity: an Updated Review of Scientific Literature". Biological Trace Element Research 193(1): 44–63.