Arsenic, Inorganic

HEAVY METAL INDEX · REFERENCE

November 2026

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CITE AS

Pendergrass, K. (2026). Arsenic, Inorganic. Heavy Metal Index. https://heavymetalindex.com/metals/arsenic-inorganic

CORRESPONDENCE

Corrections are logged publicly on the article page, each with its date, the affected value, and the source that resolved it.

KEYWORDS

heavy metals, food safety, dietary exposure

PUBLICATION HISTORY

This revision 2026-11-05.

Abstract

Inorganic arsenic drives dietary arsenic risk assessment worldwide. Rice and rice-derived products dominate exposure for most populations not relying on contaminated groundwater.

1 | Overview

Inorganic arsenic (iAs) denotes the trivalent arsenite (As(III)) and pentavalent arsenate (As(V)) oxyanions arising primarily from geogenic mineral dissolution and agricultural soil uptake. It is classified by the International Agency for Research on Cancer as a Group 1 human carcinogen and is the fraction of dietary arsenic that governs regulatory posture in most jurisdictions worldwide. The distinction between inorganic and total arsenic is toxicologically and regulatorily essential: in marine fish the organic arsenical arsenobetaine predominates and accounts for over 95% of total arsenic, while in rice the inorganic fraction typically represents 55 to 70% of total arsenic and is the form associated with carcinogenic and systemic health risk (Farruggia et al. 2025, Sadee et al. 2024). See arsenic-total for the companion total arsenic page.

This page synthesises evidence from 20 open-access peer-reviewed papers deposited in evidence unit HMI-METAL-ARSENIC-INORGANIC-1, together with 2 sources from the previous scaffold. The evidence covers occurrence in rice, rice-based beverages, seafood, food additives, and vegetables; toxicology and biomonitoring; speciation methods; and birth-outcome epidemiology.

2 | Regulatory Limits

JURISDICTION / BODY	INSTRUMENT	MATRIX	VALUE (IAS)
EU	Regulation (EU) 2023/915	Non-parboiled milled rice	150 ug/kg
EU	Regulation (EU) 2023/915	Parboiled rice / husked rice / rice flour	250 ug/kg

EU	Regulation (EU) 2023/915	Rice cakes, crackers, flakes, popped rice	300 ug/kg
EU	Regulation (EU) 2023/915	Rice destined for infant and young-child food	100 ug/kg
EU	Regulation (EU) 2023/915	Non-alcoholic rice-based beverages	30 ug/kg
EU	Regulation (EU) 2023/915	Powdered infant formula	20 ug/kg
EU	Regulation (EU) 2023/915	Liquid infant formula (ready-to-feed)	10 ug/kg
EU	Regulation (EU) 2023/915	Baby food	20 ug/kg
EU	Regulation (EU) 2023/915	Fruit juices and nectars	20 ug/kg
EU	Regulation (EU) 2025/1891	Fish muscle and other seafood	Category-specific; see regulation page
US FDA	Final guidance	Infant rice cereal	100 ug/kg
US FDA	Final guidance	Apple juice	10 ug/kg

The EU rows are binding maximum levels. The FDA rows are final guidance action levels, not binding limits, and should be labelled as such on product pages. Sources: Farruggia et al. 2025, D'Amato et al. 2026.

3 | Toxicology

Inorganic arsenic is classified as an IARC Group 1 human carcinogen. The primary evidence base for carcinogenicity is occupational inhalation and high-dose groundwater drinking exposures; epidemiological associations also exist for dietary exposure in the general population. Carcinogenicity operates through multiple mechanisms including oxidative DNA damage, inhibition of DNA repair, and chromosomal instability; As(III) is more toxic than As(V) because trivalent arsenite directly inhibits multiple enzymes including pyruvate dehydrogenase and suppresses DNA repair proteins more potently than the pentavalent form (Farruggia et al. 2025, Tanaka 2025).

The principal target organs of chronic inorganic arsenic exposure are the skin, lung, urinary bladder, and kidney. Characteristic skin manifestations of chronic exposure include hyperkeratosis, hyperpigmentation, and Bowen disease; skin cancer (both squamous cell and basal cell carcinoma) is the canonical endpoint for dose-response modelling of inorganic arsenic (Farruggia et al. 2025). Peripheral neuropathy, cardiovascular effects (peripheral vascular disease, hypertension), and adverse reproductive outcomes including spontaneous abortion and low birthweight have been reported in populations with high groundwater arsenic exposure, though the epidemiological evidence for birth outcomes at lower general-population dietary exposures is inconsistent (see Birth Outcomes section below).

The EFSA 2024 updated risk assessment for inorganic arsenic established a benchmark dose lower confidence limit for a 5% excess skin cancer benchmark response (BMDL05) of 0.06 ug iAs per kilogram bodyweight per day. This value replaces the previously used EFSA 2009 BMDL0.1 of 0.3 ug/kg bw/day and applies across all EU dietary exposure assessments. Using this benchmark, the margin of exposure (MOE) at the 95th percentile

dietary exposure for infants and toddlers fell below 1 in all 23 EU member states for which data were assessed, indicating a health concern cannot be excluded (D'Amato et al. 2026, Farruggia et al. 2025).

The toxicity ranking of arsenic species from most to least toxic is: As(III) greater than As(V) greater than dimethylarsinic acid (DMA) greater than monomethylarsonic acid (MMA) greater than arsenobetaine (AsB, essentially non-toxic). The thioarsenical dimethylthioarsinic acid (DMTA), produced by intestinal bacteria from DMA, was classified by IARC as Group 2B (possible human carcinogen) in the 2024 reassessment and is an emerging concern for gut microbiome interactions (Tanaka 2025).

After dietary ingestion, inorganic arsenic is absorbed from the gastrointestinal tract and undergoes hepatic methylation: As(V) is first reduced to As(III), then sequentially methylated to MMA and DMA by arsenic methyltransferase (AS3MT) using S-adenosylmethionine as the methyl donor. DMA is the dominant urinary excretion product in populations with rice-based diets and groundwater arsenic exposure, typically accounting for 60 to 80% of total urinary arsenic; MMA 10 to 20%; iAs 10 to 30% (Farruggia et al. 2025, Cheng et al. 2026).

4 | Occurrence by Matrix

Rice and rice products

Rice is the dominant food-chain source of inorganic arsenic for most populations globally, arising from the uptake of arsenate from paddy soils during flooded cultivation. The inorganic fraction of total rice arsenic typically ranges from 55 to 70% and is higher in brown rice and parboiled rice than in polished white rice due to the higher arsenic burden of the outer bran layer.

A market surveillance study of 58 rice samples from Croatian supermarkets (primarily Italian and other EU origin) found mean total arsenic of 142 +/- 57 ug/kg dry weight and mean iAs of 89.3 +/- 41.0 ug/kg dry weight, with iAs representing 62.8 +/- 22.1% of total arsenic (range 18 to 89% across individual samples); parboiled rice (mean iAs 118 ug/kg) was higher than white (72 ug/kg) and brown (106 ug/kg). No sample exceeded EU regulatory limits, but a single serving accounted for 56 to 92% of the EFSA 2024 reference point (Rumora Samarin et al. 2025).

A Malaysian study of 15 white rice and 15 brown rice samples found that some samples exceeded EU Commission iAs limits, with all samples exceeding a threshold hazard quotient of 1 (non-carcinogenic risk) and all samples showing lifetime carcinogenic risk estimates above 10^-3 (Navaretnam et al. 2025).

A Saudi Arabian study of 24 imported rice samples (predominantly from India) and 9 locally grown Hassawi rice samples found mean iAs of 73 +/- 8 ug/kg (imported) and 43 +/- 5 ug/kg (Hassawi) on a dry weight basis. The difference was statistically significant; estimated daily iAs intake from imported rice (0.3 ug/kg bw/day) exceeded the EFSA BMDL05 of 0.06 ug/kg bw/day, with excess lifetime carcinogenic risk estimates of 3 x 10^-5 to 4 x 10^-4 (Alrashdi et al. 2024).

A national survey across 30 Indonesian provinces found mean total arsenic 106 +/- 93 ug/kg dry weight in cooked rice; two provinces with mining histories (Lampung and Bangka Belitung) exceeded the Codex 2023 iAs ML of 200 ug/kg, with values of 267 and 211 ug/kg respectively. Inorganic arsenic in this study was estimated by regression from total arsenic rather than directly speciated, which is a methodological limitation (Ramadhani et al. 2025).

A mouse bioassay study measured three rice varieties with iAs ranging from 170 to 280 ug/kg dry weight and demonstrated that dietary fruit supplementation (guava, kiwifruit, apple, banana, grape, pitaya at 16% by

weight of diet) reduced tissue arsenic accumulation by approximately 30 to 40% and increased urinary and fecal excretion, with the mechanism attributed to short-chain fatty acid-producing gut bacteria strengthening intestinal barrier integrity and increasing methylation capacity (Liu et al. 2026).

Rice-based beverages

A study of 25 rice-based beverages from the Italian retail market found mean iAs of 15 ug/kg (median 15; range 7 to 24 ug/kg) and mean total arsenic of 23 ug/kg. All 25 samples complied with the EU ML of 30 ug/kg iAs for non-alcoholic rice-based beverages. The mean iAs fraction was 84% of the sum of arsenic species (range 33 to 97%), confirming that iAs is overwhelmingly the predominant arsenic species in rice drinks (D'Amato et al. 2026).

Seafood

In marine fish, arsenic occurs predominantly as arsenobetaine, a non-toxic organic species. The inorganic arsenic fraction in marine fish muscle is typically 1 to 5% of total arsenic. A review of arsenic speciation in marine organisms compiled published concentration ranges: total arsenic in marine fish typically 100 to 2,500 ug/kg wet weight; iAs fraction 1 to 5% corresponding to approximately 1 to 50 ug/kg wet weight in muscle tissue (Sadee et al. 2024). A second review covering arsenic determination in vegetables and other matrices confirmed the same pattern and noted that hijiki seaweed (Hizikia fusiforme) is an exception with elevated iAs proportions of up to 60% of total arsenic, which has led to consumption advisories from UK FSA and EFSA (Sadee et al. 2023).

A Hungarian study of 40 European seabass (Dicentrarchus labrax) muscle samples from Adriatic Sea origin found mean total arsenic of 1.44 +/- 0.90 mg/kg wet weight, with all mercury results below the LOD (0.50 mg/kg). No arsenic speciation was performed; the study applied a conservative 5% iAs fraction estimate for risk calculation. By contrast, cadmium (32.5% of samples exceeding EU ML of 0.05 mg/kg) and lead (15% exceeding EU ML of 0.30 mg/kg) were the dominant risk drivers; combined hazard index from arsenic, cadmium, and lead exceeded 1 for mean adult consumption and all high-consumer scenarios (Lehel et al. 2026).

A study of crayfish (Procambarus clarkii) from 7 Chinese cities (Yangtze River basin; n=112 samples) found mean iAs of 0.0125 mg/kg wet weight in abdominal muscle. At average consumption rates, all non-carcinogenic hazard quotients were below 1; at high consumption rates with the maximum-iAs sample, carcinogenic risk approached or exceeded 10^-3. The bioaccessibility of iAs in crayfish under simulated gastrointestinal digestion was essentially 100%, confirming that bioavailability corrections do not reduce iAs risk substantially for crustacean matrices (Zhuang et al. 2026).

A study from Brunei Darussalam applied a simultaneous microwave digestion method to measure total arsenic and inorganic arsenic in local shrimp and prawn commodities, confirming that the iAs fraction in crustaceans is small relative to total arsenic and validating the method for routine regulatory monitoring (Ibrahim et al. 2024).

Food additives

A Belgian probabilistic dietary exposure study measured 17 food additives by ICP-MS/MS and LC-ICP-MS. Among all additives tested, algae-derived additives carried the highest arsenic levels: sodium alginate (E401) median total arsenic 474 ug/kg with iAs 6.8 ug/kg (approximately 1.4% inorganic); carrageenan (E407) median total arsenic 354 ug/kg with iAs 152 ug/kg (approximately 32% inorganic). Most other additives (gums, mineral salts, ascorbic acid, citric acid) had arsenic concentrations below 13 ug/kg. The MOE for iAs from food additives was approximately 2 to 6 for children, indicating that health concern from this pathway cannot be excluded for children who regularly consume foods containing algae-derived additives (Vansnick et al. 2026).

Chicken

An analytical method development study from Trinidad and Tobago validated HG-AAS with selective KI reduction for speciation of As(III) and As(V) in chicken thigh and breast muscle. The study achieved LOD of 0.003 mg/kg iAs and LOQ of 0.010 mg/kg. The method was validated against DORM-5 fish protein CRM with 96 to 97% recovery. The regulatory total arsenic limit for poultry meat in the US, China, and Canada is 0.5 mg/kg (Alvarez and Mohammed 2026).

Vegetables

A systematic review of arsenic speciation in vegetables compiled literature data showing that arsenic species profiles vary substantially by plant family and growth conditions. As(V) predominates in oxidising soil conditions and As(III) in reducing conditions. Leafy vegetables typically contain iAs as a minor fraction of total arsenic (organic forms and DMA may predominate); the arsenic entry pathway via phosphate transporters means high soil phosphate competitively reduces As(V) uptake. Hijiki seaweed remains a notable exception with elevated iAs (Sadee et al. 2023).

5 | Speciation Methods

Arsenic speciation (the analytical separation and quantification of individual arsenic species) is essential for food safety and risk assessment because total arsenic measurements cannot distinguish the high-toxicity inorganic fraction from the low-toxicity organic arsenicals that dominate in seafood. Anion-exchange HPLC-ICP-MS is the validated reference method for iAs in food, achieving LODs below 1 ug/kg for most species in a single 10 to 15 minute run (Tanaka 2025, Sadee et al. 2023).

Key method advances described in this evidence unit include a simultaneous water- and fat-soluble arsenic speciation method on a reversed-phase C8 column capable of detecting arsenolipids alongside iAs and DMA in a single run (Nawrocka et al. 2026); a 4-minute reversed-phase HPLC-ICP-MS method validated for rice speciation (Navaretnam et al. 2025); and a selective reduction HG-AAS method for distinguishing As(III) from As(V) in chicken muscle (Alvarez and Mohammed 2026).

For urinary biomonitoring, anion-exchange HPLC-ICP-MS is the gold standard. The HEALS cohort study (1,873 urine samples, Bangladesh) found that summing iAs, MMA, and DMA accounted for 99.6% of total urinary arsenic (R2 = 0.996), but identified uncharacterised arsenic species in 40% of samples (mean 1.8 ug/L), consistent with findings from a clinical laboratory study that also reported two unknown species in routine monitoring (Cheng et al. 2026, De Simone et al. 2026). These uncharacterised species represent residual uncertainty in mass balance calculations when speciated sums are compared to total urinary arsenic.

6 | Biomonitoring and Exposure Markers

Urinary arsenic speciation is the established biomarker of chronic inorganic arsenic exposure. The HEALS cohort (Araihazar, Bangladesh; groundwater As 0.1 to 864 ug/L) demonstrated the following urinary profile in a high-exposure groundwater setting: mean DMA 79.2 ug/L (71.7%), MMA 12.1 ug/L (11.0%), iAs 16.4 ug/L (14.8%), AsB 2.1 ug/L (1.9%), total urinary As mean 114.3 ug/L. Participants with arsenic-induced skin lesions had significantly higher concentrations of all speciated urinary arsenic forms compared to matched controls without lesions (Cheng et al. 2026).

The general-population urinary methylation profile in populations with lower exposure (dietary rice plus background sources, no contaminated groundwater) is typically DMA 60 to 80%, MMA 10 to 20%, iAs 10 to

30% (Farruggia et al. 2025). Interindividual variation in methylation efficiency (reflected in the MMA/DMA ratio and the proportion of urinary iAs) is determined partly by AS3MT genetic polymorphisms, partly by nutritional cofactors (folate, methionine, choline as methyl donors; selenium as a cofactor in arsenite reduction), and partly by the composition of the gut microbiome.

7 | Birth Outcomes

A harmonised multi-cohort study of 3,222 US pregnant women across three cohorts (NBCS Navajo Nation, NHBCS New Hampshire, PROTECT Puerto Rico) found no consistent statistically significant associations between total urinary arsenic or speciated iAs during pregnancy and birth outcomes (birthweight, length, head circumference, gestational age, preterm birth, small or large for gestational age). Effect estimates varied substantially in direction and magnitude across the three cohorts; between-cohort heterogeneity was high (I2 = 79.96% for the association of iAs sum with preterm birth). The geometric mean total urinary arsenic of 6.03 ug/L across the pooled sample was similar to the NHANES general female population benchmark of 6.8 ug/L, indicating that this study operates at background rather than high-exposure levels (Feric et al. 2026). The null finding is consistent with the broader epidemiological literature showing inconsistent birth-outcome associations at low-to-moderate arsenic exposures; high-exposure groundwater contexts consistently show adverse associations, but the evidence at dietary background levels remains mixed.

8 | Geogenic Contamination Scenarios

A probabilistic risk assessment from the Taal volcano region of the Philippines following the January 2020 eruption (Batangas province) illustrates the extreme end of the iAs exposure range. Monte Carlo simulation across 10,000 iterations estimated an aggregate daily iAs dose of 3.0 to 4.0 ug/kg bw/day (mean), more than 50-fold above the EFSA BMDL05. Rice contributed 30.4% and freshwater clams 26.2% of aggregate dietary dose in this volcanic contamination scenario; all simulated individuals faced hazard quotients far exceeding 1 and excess carcinogenic risks above 10^-6 (Perez et al. 2026). This scenario is not representative of background dietary exposure but illustrates multi-pathway dominance of rice and freshwater shellfish under severe geogenic contamination.

9 | Open Questions

The identification of uncharacterised urinary arsenic species in clinical and epidemiological cohorts introduces residual uncertainty in mass balance calculations and in the completeness of biomonitoring panels (Cheng et al. 2026, De Simone et al. 2026). The toxicological significance of arsenolipids (particularly AsHC 360) in oily fish and algae-derived food products is not yet reflected in regulatory limits; cell model data suggest neurotoxic potential comparable to iAs, but in vivo dose-response data for dietary exposure are lacking (Nawrocka et al. 2026). The gut microbiome modulates both arsenic methylation efficiency and potentially bioavailability; evidence from the fruit consumption mouse study (Liu et al. 2026) provides mechanistic support for gut-mediated reduction in iAs bioaccumulation, but translation to human dietary patterns is not yet established.

10 | Frequently asked questions

What is inorganic arsenic and where does it come from in food?

Inorganic arsenic (iAs) refers to the trivalent and pentavalent arsenic oxyanions, which arise primarily from geogenic (naturally occurring geological) sources and agricultural uptake. Rice and rice-derived ingredients dominate population-level inorganic arsenic exposure from food, with apple juice and some root vegetables as secondary contributors.

Why does this wiki distinguish inorganic arsenic from total arsenic?

The distinction is maintained throughout the wiki because the toxicological and regulatory implications of the two quantities differ sharply. Inorganic arsenic is the fraction of dietary arsenic that governs regulatory posture in most jurisdictions, whereas total arsenic includes less-toxic organic forms. The page maintains a companion page for arsenic, total.

Is inorganic arsenic a carcinogen?

Yes. The page states that inorganic arsenic is classified as a human carcinogen. Toxicology context on the page, drawn from Ufelle & Barchowsky 2021, covers its absorption, methylation, urinary excretion, acute and chronic toxicity, and carcinogenicity.

What are the regulatory limits for inorganic arsenic in food?

The EU sets binding maximum levels under Regulation 2023/915, including 20 ug/kg for infant formula powder and baby food, 10 ug/kg for liquid infant formula, and higher levels for various rice categories (for example 100 ug/kg for rice destined for infant and young-child food). The US FDA has issued final guidance action levels of 100 ug/kg iAs for infant rice cereal and 10 ug/kg iAs for apple juice. See eu2023-contaminants-maximum-levels, fda2020-inorganic-arsenic-infant-rice-cereal, and fda2023-inorganic-arsenic-apple-juice.

What is the difference between the EU maximum levels and the FDA action levels for arsenic?

The EU rows are binding maximum levels enforceable in food. The FDA rows are final guidance action levels rather than binding limits, and the page notes they should be labeled as such on product pages.

How much biomarker and toxicology detail does this page currently provide?

The page is currently a scaffold. Regulatory rows for EU 2023/915 and the FDA infant rice cereal and apple juice action levels have been partially routed, but the full toxicology and occurrence synthesis still awaits corpus ingest. Textbook-level context on biomarkers in skin, hair, and nails and on treatment is attributed to Ufelle & Barchowsky 2021, which is a toxicology source rather than a food occurrence dataset.

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TEXTBOOK

STATUS AND LICENCE

Editorially reviewed in-house; no external peer review has been completed on this reference. Published as an institutional technical report with its review state tracked on the article page. Released under CC BY 4.0.

COMPETING INTERESTS

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DATA AVAILABILITY

Every source behind this reference is listed with its own source record at https://heavymetalindex.com/metals/arsenic-inorganic#sources.

PUBLICATION HISTORY

This revision 2026-11-05. The full dated record is maintained at https://heavymetalindex.com/metals/arsenic-inorganic.