

1 **Inorganic arsenic determination in food: A review on analytical proposals and**
2 **quality assessment over the last six years**

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13 **ABSTRACT**

14 Here we review recent developments in analytical proposals for the assessment of the
15 inorganic arsenic (iAs) content in food products. Interest in the determination of iAs in
16 products for human consumption such as food commodities, wine and seaweed among
17 others is fueled by the wide recognition of its toxic effects on humans, even at low
18 concentrations. Currently, the need for robust and reliable analytical methods is
19 recognized by various international safety and health agencies, and by organizations in
20 charge of establishing acceptable tolerance levels of iAs in food. This review
21 summarizes the state of the art of analytical methods while highlighting tools for the
22 assessment of quality assessment of the results, such as the production and evaluation of
23 certified reference materials (CRMs) and the availability of specific proficiency testing
24 (PT) programs.

25 Since the number of studies dedicated to the subject of this review has increased
26 considerably over recent years, the sources consulted and cited here are limited to those
27 from 2010 up to the end of 2015.

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29 *Index headings:* Inorganic arsenic; Food analysis; Analytical techniques; Quality
30 assessment; Proficiency testing; Certified Reference Materials.

31

32 **1. INTRODUCTION**

33

34 The determination of inorganic arsenic (iAs) in food is considered a subject of
35 paramount importance. Of the great number of known arsenic species that have been
36 identified in different types of food, arsenic health concerns are derived primarily from
37 the inorganic forms of this element. Moreover, food is the main contributor to human
38 arsenic intake (excluding occupational exposure and drinking contaminated water). This
39 interest is supported by a huge number of publications in the literature over many years
40 ¹. The causal effect of arsenic with regards to cancer has been well studied more twenty
41 years ago. The most recent reviews highlight new research concerning both the toxic
42 and carcinogenic character of iAs ²⁻⁵, and many proposals have been made on the
43 possible arsenic-induced carcinogenic molecular mechanisms ⁶⁻⁹. Two reviews use the
44 meta-analysis of toxicity data^{10,11} to obtain information concerning the assessment of
45 iAs exposure risk or the possible dose–response relationship, among other approaches.
46 Mechanisms involved in the pathogenesis of arsenic-induced toxicity have been
47 reviewed¹². Among the studies of the toxicity of iAs, vulnerable groups are especially
48 considered, such as children¹³⁻¹⁵ and pregnant women¹⁶.

49 The toxic effects of inorganic arsenic forms led the Joint Commission
50 FAO/WHO (Food and Agriculture Organization of the United Nations/ World Health
51 Organization) in 1989 to set a provisional tolerable weekly intake (PTWI) for inorganic
52 arsenic of 15 $\mu\text{g kg}^{-1}$ of body weight (equivalent to 2.1 $\mu\text{g kg}^{-1}$ bw per day)¹⁷. Recently,
53 the European Food Safety Authority (EFSA)¹⁸ and the JECFA (Joint FAO/WHO Expert
54 Committee on Food Additives) ¹⁹ evaluated dietary exposure to iAs. Both concluded
55 that the PTWI parameter is no longer appropriate and should no longer be used and it is
56 thus withdrawn. The EFSA and JECFA evaluations provided estimates of toxic intake
57 limits for iAs as a benchmark dose level (BMDL): 0.3–8 μgkg^{-1} b.w. per day for cancers
58 of lung, skin and bladder as well as for skin lesions (EFSA BMDL₀₁¹⁸); and 3.0 $\mu\text{g kg}^{-1}$
59 b.w. per day (2-7 $\mu\text{g kg}^{-1}$ b.w. per day based on the estimated range of total dietary
60 exposure) for lung cancer (JECFA BMDL_{0.5}¹⁹). Also, both reports emphasized the need
61 to produce speciation data, particularly iAs data, for different food products to estimate
62 the health risk associated with dietary As exposure. EFSA and JECFA highlighted the
63 need for a robust, validated analytical method for the determination of iAs in a range of
64 food items; and the need for certified reference materials (CRMs) for iAs. In 2014,
65 EFSA evaluated dietary exposure to iAs in the European population ²⁰. It concluded that
66 for all ages except infants and toddlers, the main contributor to dietary exposure to iAs

67 is the food group: “grain-based processed products (non-rice-based)”. Other food
68 groups that were important contributors to iAs exposure were rice, milk and dairy
69 products (the main contributor in infants and toddlers), and drinking water.
70 Furthermore, in order to reduce the uncertainty in the assessment of exposure to iAs,
71 more analytical data on iAs are needed. This mainly refers to speciation data in fish and
72 seafood, and for food groups that contribute substantially to dietary exposure to iAs
73 (e.g., rice and wheat-based products). Many of the statements in the present paragraph
74 are summarized recently in ²¹. Rice and rice-based products are the type of food in
75 which iAs toxicity is of most concern in many countries ^{22–28} especially in countries,
76 such as those in Southeast Asia, where irrigation practices increasingly include flooding
77 with water containing arsenic ²⁹. This can lead to an increase of the arsenic contents of
78 rice and so control of such practices is frequently called for ³⁰. The other type of food
79 product that merits special interest regarding iAs toxicity is those with a marine origin
80 ^{31–34} and in lesser extent other food commodities such as apple juice³⁵ or mushrooms³⁶.
81 Furthermore, the assessment of iAs concentrations in food products aimed particularly
82 at children deserves special interest ^{37–40}. Other studies also reveal that knowledge of
83 iAs content is important in the control of processes of biotransformation in marine
84 organisms that constitute a food source, after exposure to iAs compounds ⁴¹. Lynch et
85 al. ⁴² considered four food groups, in accordance with their iAs contents, reporting
86 estimated mean values as: *seaweed/algae/seafood*, 11,000 $\mu\text{g kg}^{-1}$ for seaweed/algae
87 and 130 $\mu\text{g kg}^{-1}$ for seafood; *rice*, 130 $\mu\text{g kg}^{-1}$; *apple juice*, 5.8 $\mu\text{g kg}^{-1}$; and *infant food*,
88 rice, other cereals and related products, 92 $\mu\text{g kg}^{-1}$ and vegetables, 20 $\mu\text{g kg}^{-1}$.

89 The establishment of maximum levels (MLs) regulating iAs are emphasized in
90 Directives and Regulations^{43–51}. Meharg and Raab⁵² discusses several proposals and
91 relates them with detection capacities and the availability of measurement techniques,
92 highlighting the assessment of iAs contents. Among the regulations proposing MLs of
93 arsenic tolerated in food, few establish specific levels for iAs. Table I summarizes the
94 ML for inorganic arsenic or total arsenic in food established by several countries. The
95 maximum tolerable level of total arsenic (tAs) in drinking water defined by the World
96 Health Organization (WHO) is 10 $\mu\text{g L}^{-1}$ ⁶⁰. Very recently, the European Union
97 published Regulation (EU) 2015/1006 ⁵⁸amending Annex to Regulation (EC) No
98 1881/2006 ⁶¹regarding the maximum levels of iAs in foodstuffs, especially rice and
99 rice-based products. The new MLs of iAs range from 0.10 to 0.3 mg As kg^{-1} depending
100 of the rice product. Furthermore, the EU established a maximum levels for iAs in

101 animal feeds, contents of below 2 mg kg⁻¹ are recommended, especially those based on
102 the seaweed species *Hizikiafusiforme*⁶². The Ministry of Health of China established a
103 maximum level of iAs in food products depending on type of food⁵⁶. The CODEX
104 Alimentarius Commission in a draft report on contaminants in food accepts a ML of 0.2
105 mg kg⁻¹ of iAs for polished rice and analysis of tAs as a screening method⁶³; the same
106 document states that no agreement was reached for a ML of iAs in husked rice, but a
107 value of 0.4 mg kg⁻¹ is ongoing discussed^{63,64} and may be adopted at the next session of
108 the Committee. The Australia New Zealand Food Standard Code(FSANZ) ⁵⁴ established
109 a limit of 1 mg kg⁻¹ for seaweed and mollusks; while for crustacean and fish, iAs is not
110 allowed to exceed 2 mg kg⁻¹. Meanwhile, the authorities in the UK have advised
111 consumers to avoid consumption of hijiki seaweed ⁶⁵while the Canadian Food
112 Inspection Agency (CFIA) advises consumers to avoid that seaweed ⁶⁶. Specific
113 regulations for iAs in edible seaweed have been established in some countries: 3 mg kg⁻¹
114 ¹ (dw) as the maximum permitted level in the USA ⁶⁷ and France ⁵⁷. The content of iAs
115 in apple juices is considered a matter of concern by the U.S Food Drug and
116 Administration (FDA) ⁶⁸ and by the FSANZ ⁵⁴. The FDA recommends 10 ppb (as in
117 drinking water) as a ML for iAs adequate to protect public health. The Canadian
118 government, thorough Health Canada, established 0.1 ppm as the maximum tolerated
119 limit for arsenic in fruit juices, fruit nectar and ready-to-serve beverages⁶⁹; furthermore,
120 this organization is currently considering establishing a specific lower tolerance of 0.01
121 ppm for apple juice. Several national initiatives and authorities have advised against
122 consumption of rice drinks for infants and toddlers because it can increase the intake of
123 iAs. The UK Food Standards Agency ⁷⁰does not recommend substitution of breast milk,
124 infant formula, or cows' milk by rice drinks for toddlers and young children up to 4.5
125 years, whereas the Swedish National Food Agency⁷¹recommends no rice-based drinks
126 for children younger than 6 years and, in Denmark⁷², children are advised against
127 consuming rice drinks and biscuits.

128 The analytical technology to be applied for the assessment of arsenic species,
129 highlighting iAs, is continuously updated and reviewed^{43,73–84}. Nearing et al. ⁸⁵ reviewed
130 additional analytical methods suitable for obtaining data to complement the information
131 on arsenic speciation obtained when applying the methods commonly used. Among
132 such complementary methods, electrospray mass spectrometry (ESI-MS) is most useful
133 for identifying or complementing information on several arsenic compounds with more

134 complex molecular structures than those corresponding to iAs species. Some articles
135 report the use of some supplementary methods for iAs, among them Nearing et al. ⁸⁶
136 report X-ray absorption near edge structure (XANES) for As speciation in solid samples
137 to obtain information on which As species cannot be extracted, provided that enough mass
138 remains after extraction, as a complementary information of HPLC-ICPMS technique,
139 and Whaley-Martin ⁸⁷ in a study on arsenic species distribution in marine periwinkle
140 tissues samples by HPLC-ICPMS, uses X-ray Spectroscopy (XAS) for the estimation of
141 inorganic arsenic species and to reveal their high concentrations in contaminated
142 samples. Some other general reviews of element speciation provide broad information
143 on arsenic speciation, including analytical methodology and types of food ^{77,88-92}.
144 Moreover the importance of maintaining the integrity of arsenic species during the
145 overall analytical process, with final measurement by HPLC-ICPMS and HPLC-HG-
146 AFS, is emphasized widely in a recent Review ⁹³.

147 Efforts have also been made in the last decades by Research scientists,
148 government agencies (FDA and EPA), and commercial laboratories to establish
149 methodologies for the specific determination of iAs in food products. The validation of
150 such methods is mandatory to demonstrate their suitability for routine analysis in
151 control laboratories. Reliable analytical methods are currently available and it can be
152 expected that they will be considered in future Regulations from Government Agencies.
153 For this, the European Committee for Standardization (CEN) (CEN TC 327/WG 4)
154 standardized a method (EN 16278:2012) for the determination of iAs in animal feeding
155 stuffs by HG-AAS after microwave extraction and off-line separation of iAs by solid
156 phase extraction (SPE) ⁹⁴. Other two standards are published, such as: Chinese Standard
157 Method GB/T 5009.11-2003 ⁹⁵; and EN 15517:2008 ⁹⁶. Currently, there is an ongoing
158 proposal for CEN method to determine iAs in foodstuffs by HPLC coupled to
159 inductively coupled plasma mass spectrometry (HPLC-ICPMS) (CEN TC275/WG10).
160 The AOAC, through the AOAC International, invited method authors and developers to
161 submit methods for quantitation of arsenic species in selected foods and beverages, that
162 propose to meet the AOAC Standard Method Performance Requirements SMPR's.
163 2015.006 for quantitation of arsenic species in selected foods and beverages, and the
164 preferred analytical technique for quantitation is HPLC-ICPMS, this proposal is
165 currently in its fourth draft version ⁹⁷. Furthermore, for future implementation of
166 analytical methods for iAs determination in food control laboratories, the availability of
167 validated methods as well as participation in proficiency testing (PT) and the analysis of

168 CRMs is mandatory, according to the ISO/IEC 17025 standard ⁹⁸. Obviously, this is
169 applicable to speciation of iAs in food; considering its toxicity and the need to develop
170 methods that can be applied in routine analysis.

171 The present review summarizes recent analytical proposals, including the use of
172 CRMs and the availability of specific PT for the determination of iAs in the most
173 widely consumed food products, covering the period 2010-end of 2015. Increasing
174 interest in the iAs contents of food products has led to a large number of studies being
175 published on subjects such as: the evaluation of toxicity, bioaccessibility and
176 bioavailability studies; the estimation of dietary intake; and estimations of iAs
177 consumed by populations in different geographical areas. Such studies and the data they
178 generate are beyond the scope of the present review; thus they are not included in it.

179

180 **1.1. Overview of the literature**

181

182 Due to the vast number of scientific publications on the subject of the present
183 Manuscript, the authors have been selected the Web of Science database, widely
184 accepted by the scientific community, as a basis to reflect the information. This
185 database includes 50.2 million journal articles. A preliminary search provided us with
186 more than 18,000 papers and reviews whose titles contain the term “arsen*” between
187 1985 and 2014. Refining the search and including the search terms “speci*” or
188 “compo*” or “inorg*” in the titles, led to 3301 publications (Figure 1). The distinction
189 between “species” and “compounds” is not entirely clear and several authors use the
190 terms as though they were synonyms; so both terms could be found interchangeably in
191 the titles, meaning the same. From the search reported above and the data obtained,
192 Figure 1, representing the rate of publication related to As speciation, clearly shows a
193 significant increase, making evident the interest in arsenic speciation within the
194 scientific community over the last fifteen years. The blue plot in Figure 1 reveals a peak
195 in interest in arsenic species over 2011-2014, which could be related to the increased
196 focus on iAs in food by authorities and institutions ^{18,19}. It seems that this call could have
197 encouraged researchers to produce more data on arsenic species in different food
198 products and hence the number of publications has increased from 2010 to the present.

199 Refining the initial search and including “arsenite” or “arsenate” or “food”, or
200 food synonyms as well as types of food (rice, seaweeds, fish, etc.), in the title led to
201 approximately 500 which are represented by the red plot in Figure 1. A tendency can be

202 observed in the literature related to arsenic and dealing with several subjects such as
203 speciation, compounds, inorganic or food; this is an increase of the publication rate over
204 recent years (2009-2014).

205 Finally, the terms “speci*” and “compo*” were excluded from the last search
206 and a more specific search was performed. Hence, we searched for papers and reviews
207 including “arsen*” and either “inorg*”, “arsenite” or “arsenate” in the title as well as
208 including several terms in the title such as “food” or “nutrit*” and several types of food.
209 This provided us with 250 approximately (Figure 1). The green plot in Figure 1 shows
210 the same tendency: a rise in the numbers of publications dealing with iAs in food, surely
211 due to the increasing emphasis on iAs in food by the authorities and institutions
212 mentioned above.

213 Focusing on the period 2010-2015, 115 publications were found in the Web of
214 Science database that deal with iAs in foodstuffs. These papers were sorted according to
215 the research area of the publication and the Web of Science classification criteria
216 (Figure 2a). A wide variety of fields was obtained and as can be seen, areas such as
217 “chemistry”, “environmental sciences ecology”, “food science technology”, and
218 “toxicology” are the most cited in these publications related to iAs in food. From the
219 data consulted, a detailed distribution of these publications, according to type of food
220 analyzed, was elaborated and is represented in Figure 2b. It can be seen that more than
221 50% are related to “cereal-based food” and specifically “rice and rice products”, which
222 accounted to 43%. This means that research on iAs in the last five years focused on rice
223 and its products; which is not surprisingly since rice is the main food of over half the
224 world’s population, owing to its nutritive properties and its relatively low cost. It is
225 estimated that in many countries, rice may contribute as much as 50% of the daily
226 intake of protein, and in Asian countries it is a staple food. Furthermore, it is estimated
227 that the As content of rice is over 10 times greater than that found in other cereals^{99,100}.
228 As stated above, cereal-based food and especially rice and its products are among the
229 foods that contribute most to iAs exposure in the European population. It seems quite
230 clear that speciation research focused on cereals and rice, motivated by the
231 recommendations of the EFSA¹⁸ and JECFA¹⁹ reports. The second and the third
232 groups are “fish and shellfish” and “seaweed and algae” which represent 17% and 10%,
233 respectively (Figure 2b). Marine foods usually have higher tAs (in the range of mg As
234 kg⁻¹) than rice or cereals (in the range of µg As kg⁻¹); however, the proportion of iAs in
235 such food is very low compared to that in terrestrial foodstuffs. The non-toxic

236 arsenobetaine is the major compound in fish and shellfish; while it is the so-called
237 “potentially toxic” arsenosugars in “seaweed and algae”¹⁰¹. Other minor groups (3%)
238 are “vegetables and tubers”, “mushrooms” and “dietary supplements”.

239

240 **2. ANALYTICAL METHODS AND MEASUREMENT TECHNIQUES**

241

242 In analytical element speciation the best way to ensure there are no alterations of
243 the species across the overall analytical process, including sampling, in general consists
244 of the use of techniques capable of performing the measurements *in situ*. Nevertheless,
245 very few techniques are selective and sensitive enough to determine individual
246 elemental species at trace levels. In practice, analytical speciation involves two main
247 steps: extraction and measurement. Figure 3 summarizes an overall scheme including
248 the most important steps in element speciation, and highlights specific information for
249 iAs determination in food products. The steps need proper optimization to guarantee
250 minimal changes to the original species, especially in complex matrices, such as
251 different foodstuffs. The challenge is greater when a single group of species has to be
252 determined, as in the case of iAs, from among other arsenic species that are present in
253 the samples. Some reviews focus on specific analytical aspects, such as sampling and
254 sample pre-treatment^{82,102–106}. From the large number of proposals for arsenic speciation
255 within the field of food analysis, we summarize here those developed with the aim of
256 determining iAs contents. Two groups of methods are reported here, based on either
257 direct measurement techniques (2.1) or on the use of coupling systems between
258 separation and detection (2.2). In both cases, preliminary steps of extraction or selective
259 separation are also reported.

260

261 **2.1 Methods involving non-coupled techniques**

262

263 The vast majority of these methods are based on selective separation of arsenic
264 species and spectroscopic detection; they are designed to determine only iAs species,
265 the most toxic, and many of them are presented as alternatives to the use of ICPMS,
266 which is more costly than other element detection techniques. Methods and applications
267 based on such techniques are reported here by separately summarizing those that use
268 direct measurement (A) and those that use HG, as a previous derivatization technique
269 (B).

270

271 **2.1.A Techniques involving direct measurement**

272

273 *Electrothermal atomic absorption spectrometry (ETAAS)*

274 Electrothermal atomic absorption spectrometry (ETAAS), including its different
275 atomization systems, is considered one of the most sensitive Atomic Absorption
276 Spectrometric techniques, and several proposals have been made for As speciation in
277 different matrices of interest, among them food samples. The determination of arsenic
278 species can be considered a challenge when using ETAAS, since accurate optimization
279 of the operational parameters, as well as the type of chemical modifiers, is required.

280 Lopez-Garcia et al. proposes arsenic speciation in fish-based baby foods using
281 ETAAS¹⁰⁷. According to those authors, iAs, MA (monomethylarsonate), DMA
282 (dimethylarsinate) and AB (arsenobetaine) can be determined using sample suspensions
283 in TMAH (tetramethyl ammonium hydroxide) and by means of several injections using
284 three different chemically modified ETAAS atomizers: cerium (IV), palladium salts and
285 a zirconium-coated tube. This approach is qualified by those authors as semi-
286 quantitative due to the incomplete discrimination among arsenic species; but they claim
287 it is suitable for food products where AB is the predominant compound, compared to
288 methylated arsenic species. The same authors¹⁰⁸ applied dispersive liquid-liquid micro
289 extraction for extracting the water-soluble arsenic species from organic phases (oils of
290 animal or plant origin), achieving a pre-concentration and using ETAAS for final
291 measurement; according to the authors although a reliable arsenic speciation is not
292 achieved, the toxicity of water-soluble arsenic species: As(III), As(V) and MA present
293 in edible oils can be assessed. Arsenic species and total iAs in rice is determined by
294 using microwave-assisted dispersive liquid-liquid microextraction and measurement by
295 ETAAS¹⁰⁹. Dos Santos Costa et al.¹¹⁰ determine arsenic species in rice by CPE (cloud
296 point extraction) and ETAAS, using graphite tubes with different modifiers. Shah et al.
297¹¹¹ determines total As and iAs in samples of edible fish from the arsenic-contaminated
298 Manchar Lake, Pakistan, and evaluated the estimated daily intake (EDI) of iAs. The
299 method adopted allows the measurement of total As, after prior acidic digestion;
300 whereas As(III) and As(V) are separated by two sequential steps with chloroform as the
301 extracting agent and reducing As(V) to As(III). The corresponding extracts, as well as
302 total As, are measured by ETAAS, using Mg (NO₃)₂ + Pd as a modifier. Pasiadis et al.¹¹²
303 develops and fully validates a method to determine total As and iAs in rice. The method

304 is then applied to determine total As and its inorganic forms in several varieties of rice
305 and rice flour samples from local markets in Lamia (Greece). The authors applies two
306 selective extraction procedures: total iAs is extracted with EDTA in acidic media (1M
307 HNO₃) whereas the determination of As(III) is performed by extraction with 1M HNO₃
308 and further addition of EDTA (as masking agent to prevent interferences of divalent
309 cations) at pH 4.8, followed by addition of APDC at this pH, to form the complex with
310 As(III), extracting it with MIBK and back extracting in HNO₃; Pd is chosen, among
311 other chemical modifiers, for the ETAAS measurement of As in all extracts. Accuracy
312 is assessed against the certified Reference Material IRMM 804 through the IMEP-107
313 PT (Proficiency Test).

314 In a study of As speciation in mono-varietal wines purchased in Mendoza
315 (Argentina) Escudero et al.¹¹³ determines total As and iAs in samples of Malbec and
316 Sauvignon Blanc varieties using ionic liquid (IL) dispersive micro extraction as a pre-
317 concentration technique, coupled with ETAAS. This system is applied to each separate
318 fraction previously obtained of As(III), total iAs and total As. Zmozinski et al.¹¹⁴
319 proposes direct solid sample analysis with a graphite furnace (SS-ETAAS) as a
320 screening method for iAs determination in fish and seafood. A method for the
321 determination of arsenate and total iAs in rice samples is proposed by Dos Santos Costa
322 et al.¹¹⁰; after whole extraction with HNO₃, arsenate is determined by cloud point
323 extraction (CPE) of the complex formed with molybdate and As(V) in a sulfuric acid
324 medium; while total iAs is extracted by the same CPE method, after previous oxidation
325 of As(III) to As(V). In both cases, the final measurement is performed by ETAAS using
326 Ir as the modifier.

327 Interest in the use of nano materials as sorbents to separate and preconcentrate
328 trace elements is currently increasing, among them and a recent review¹¹⁵ summarizes
329 some applications of these materials as sorbents for arsenic complexes, applied to
330 arsenic species determination with final measurement by spectroscopic techniques,
331 among them ETAAS. Hassanpoor et al.¹¹⁶ describes a new sorbent based on aluminium
332 oxide nanoparticles functionalized by a ligand, applied as preconcentration system for
333 inorganic arsenic speciation in spiked food samples, with final measurement by GFAAS
334

335 *Inductively coupled plasma mass spectrometry (ICPMS)*

336 ICPMS has been widely used as a system for arsenic determination at very low
337 levels and fundamental studies are frequently published.

338 D'Ilio et al. ¹¹⁷ reports and discusses the most common interferences found in As
339 measurements, and proposals for correction. Rajakovic et al. ¹¹⁸ reports a study focused
340 on estimating the limits of detection (LOD) for arsenic at trace levels, when using
341 ICPMS. Those authors review current approaches and discuss them, supporting the
342 conclusions with their experimental work. Bolea-Fernandez et al. ¹¹⁹ reports information
343 concerning performance mechanisms, interferences and new proposals dealing with the
344 use of such detection systems applied to arsenic determination.

345 Among the applications of ICPMS as a technique for iAs determination in food,
346 differences arise in the pre-treatment of the sample and the extraction system applied.
347 Kucuksezgin et al. ¹²⁰, in a study on risk assessment based on the consumption of some
348 edible marine organisms from Izmir Bay (eastern Aegean Sea), uses acidic digestion to
349 determine total As; whereas separation of iAs is carried out in an alkaline medium with
350 further oxidation of the arsenate. In both cases, final measurement of As is performed
351 by ICPMS. Lewis et al. ¹²¹ develops a study of the stability of fish (megrim) samples
352 over time, under different conditions, to ascertain whether some variability of arsenic
353 species can occur. Within the study, iAs, obtained by applying the method using
354 extraction with chloroform after acidification and further reduction, and final back-
355 extraction, is measured by an HR-ICPMS detector with Ga as the internal standard.

356

357

358 **2.1.B Techniques involving hydride generation (HG) as a derivatization step**

359 The use of HG as a tool may improve selectivity and sensitivity in elemental
360 analysis and different proposals are frequently reviewed¹²²⁻¹²⁵. Such system can easily
361 be combined with spectroscopic and ICPMS detectors. Regarding arsenic, volatile
362 arsines generated by reduction can be transported to the detector, avoiding chemical
363 interference, thus achieving a very low LOD. The boiling points of the volatile arsines
364 generated by reduction of inorganic and methylated forms of arsenic are sufficiently
365 different to allow their separation. Nevertheless, HG is not suitable for arsenic
366 compounds which cannot generate volatile hydrides by reduction; among such
367 compounds arsenobetaine and arsenocholine, both usually present in fish-based food
368 products, require transformation into iAs, capable of generating arsines by reduction.
369 Moreover, efficiency in the formation of volatile arsines strongly depends not only on
370 the type of original arsenic compounds in the sample, but on the matrix composition.
371 The mechanisms of arsine generation, the gas transport systems leading to the detector

372 and detection conditions are frequently discussed. Sodium tetrahydroborate, NaBH₄, in
373 acidic media, which is probably the most commonly used reducing agent for the
374 generation of volatile arsines, is required in substantial amounts; and some alternatives
375 have been proposed. Several specific conditions have been proposed and reviewed.

376 Thus, Wu et al.¹²² reviews applications of several reducing systems other than
377 tetrahydroborate; while D'Ulivo et al.¹²⁶ discusses the mechanisms of hydrides forming
378 from iAs and from methylated arsenic species, by using NaBH₄ and the formation of
379 intermediate byproducts. Anawar¹²⁷ discusses the advantages and disadvantages of the
380 combined HG-ETAAS system, in a review focused on this combined technique applied
381 to arsenic speciation. Lehmann et al.¹²⁸ proposes the determination of iAs by
382 controlling the medium of reduction and detection by FI-HG-MF-AAS (flow injection–
383 HG–metal furnace–atomic absorption spectrometry) as the final measurement
384 technique. Leal et al.¹²⁹ and Chaparro et al.¹³⁰ in studies using flow systems as on-line
385 pre-concentration systems, propose a multi-commutation flow system coupled to HG
386 atomic fluorescence spectrometry (AFS) for the analysis of As. The method is applied
387 to arsenic speciation and the determination of DMA and iAs using multi-syringe flow
388 injection analysis (MSFIA) coupled to an HG-AFS system. Yang et al.¹³¹ uses a low-
389 temperature plasma-assisted chemical vapor generation method to avoid the use of large
390 amounts of sodium tetrahydroborate for the generation of volatile arsines, with
391 detection by HG-AFS. Chen et al.¹³² proposes a method for selective separation of
392 As(III) from As(V) based on adsorption on multi-wall carbon nanotubes functionalized
393 with branched cationic polyethyleneimine (BPEI-MWNTs) and measurement by HG-
394 AFS. Matousek et al.¹³³ develops a method for arsenic speciation based on selective
395 HG-cryotrapping-ICPMS, based on cryotrapping of arsines and desorption at their
396 boiling points. Dados et al.¹³⁴ proposes a system to trap *in situ* arsenic hydrides
397 previously generated using a nano-sized ceria-coated silica-iron oxide and final
398 measurement of the slurry by ICPOES.

399 The recent applications of HG-spectroscopic detection, focused on the
400 determination of iAs in food samples, are briefly summarized in the next few
401 paragraphs, grouped by techniques.

402

403 ***Hydride generation–atomic absorption spectrometry (HG-AAS)***

404 Several studies propose previous sample extraction and concentration before
405 measurement of iAs. Among them Uluzolu et al.¹³⁵ develops a method based on solid-

406 phase extraction (SPE) using *Streptococcus pyogenes* loaded on Sepabeads SP70 resin,
407 for the speciation of As(III) and As(V). The method is applied to food samples of
408 animal and plant origin. A method involving selective separation of As(III) and As(V)
409 is proposed by Tuzen et al. ¹³⁶. That method is based on the selective adsorption of
410 As(III) onto Diaion HP-2MG resin coated with *Alternaria solani*. The method is applied
411 to CRMs of plant origin. Rasmussen et al ¹³⁷ develops a method to determine iAs in
412 food and feed samples of marine origin. The method involves off-line aqueous
413 extraction and separation by SPE followed by HG-AAS (silica cell) detection.
414 Optimized conditions during the extraction permit the selective separation of iAs from
415 organic arsenic species such as AB, MA and DMA; the method is validated in-house.
416 The same author¹³⁸also develops and validates another method based on the same
417 extraction–pre-concentration system, optimized to obtain lower LOD and a higher
418 throughput of sample extraction, to determine iAs in rice and rice products. Cerveira et
419 al.¹³⁹ applies HG-AAS to measure iAs in several types of rice samples, after selective
420 extraction with HNO₃. Sun and Liu ¹⁴⁰ develops a method for analysis of As(III) and
421 total iAs in dietary supplements by using a slurry in the presence of 8-hydroxyquinoline.
422 After generation of hydride, As(III) is determine with HG-AAS using a gas–liquid
423 separator and an electrothermal quartz atomizer. Total iAs is measured after reduction
424 of As(V) to As(III). The authors check the recovery in the determination of total iAs by
425 comparing it with the Chinese Standard Method ⁹⁵ using HG-AFS for As measurement.
426 The same method was applied for speciation of iAs in wheat and rice flours ¹⁴¹.

427 Among the applications of methods that already exist, several studies report iAs
428 determination in food across different fields of interest. A method based on the
429 determination of total As via dry ashing mineralization and quantification by FI-HG-
430 AAS together with acidic digestion and chloroform extraction determines iAs from the
431 back extraction¹⁴². This method is applied in Diaz et al. ¹⁴³ to determine total As and iAs
432 in several algae species, for both human consumption and production of phytocolloids,
433 harvested from different regions of the Chilean coast. Several research groups in
434 Thailand apply a similar analytical method in several studies with different objectives,
435 but all based on the assessment of total As and iAs in samples collected from different
436 regions of Thailand. Those studies include: marine fish, mollusks and crustaceans ¹⁴⁴;
437 freshwater fish and prawns ¹⁴⁵; and a comparative study of total As in fresh water fish
438 sampled from natural water sources and aquaculture systems ¹⁴⁶. Three types of rice and
439 rice bran produced from them are also analyzed and the results compared¹⁴⁷. Ubonnuch

440 et al.¹⁴⁸ analyzes rhizomes of Zingiberaceae, a family of plants collected in Thailand, as a
441 preliminary assessment of the risk of consuming natural products. Ruangwises et al.
442 (2010)¹⁴⁹ and Ruangwises et al. (2011)¹⁵⁰ evaluate the intake of total As and iAs within
443 populations from two contaminated areas of Thailand. Also, a study is developed to
444 assess the risk of cancer due to exposure to iAs in Ronphibun, Thailand¹⁵¹, by applying
445 the guidelines in USEPA 2001. Mania¹⁵² reports a method for the determination of tAs
446 and iAs in fish products, seafood and seaweeds; iAs is determined by reduction with
447 hydrobromic acid and hydrazine sulphate, followed by extraction with chloroform,
448 back-extraction and ashing. Measurement of iAs in the dissolved ash is performed by
449 HGAAS. A recent Review on recent progress on vapor-generation-atomic as pre
450 concentration in spectrometric techniques from Gil¹⁵³ include arsenic speciation,
451 among other elements.

452

453 ***Hydride generation–atomic fluorescence spectrometry (HG-AFS)***

454 Several studies report using HG-AFS to measure total As and iAs in different
455 food samples. In a study of the arsenic content of several commercial Spanish garlic
456 samples, Sousa Ferreira et al.¹⁵⁴ proposes a method for screening of As(III) and As(V)
457 based on extraction with H₂SO₄. In that study As is further measured in two aliquots in
458 which the differences in the efficiency of HG with and without previous reduction is
459 evaluated by means of two equations relating to the two oxidation states of As. G. Chen
460 and T. Chen¹⁵⁵ proposes the quantification of iAs in rice via initial extraction with
461 HNO₃ and H₂O₂ after which the resulting As(V) is selectively retained in a SPE
462 cartridge (silica-based SAX) and iAs determined after elution and generation of arsine.
463 The experimental conditions for acid-oxidizing extraction, absorption in an SPE
464 cartridge and the generation of arsine are carefully optimized and discussed in depth.
465 B.Chen et al.¹⁵⁶ describes a fast screening method for total As and iAs in a wide variety
466 of rice grains of different geographic origins, with the different matrices having no
467 significant influence on the final measurements. For total As, UV-HG-AFS is used
468 since the oxidative photolysis ensures quantitative oxidation of all the As species to
469 As(V).

470

471 ***Hydride generation–inductively coupled plasma mass spectrometry (HG-ICPMS)***

472 Several methods are proposed to suitable screening of iAs in food samples using
473 an oxidative acidic extraction. Musil et al.¹⁵⁷ reports a method based on the extraction of

474 iAs with HNO₃ and H₂O₂, and then on the use a selective HG coupled to ICPMS. To
475 achieve this, HCl and NaBH₄ concentrations are optimized to volatilize almost
476 exclusively arsines from the iAs, while minimizing possible volatile compounds
477 generated from other organoarsenic compounds present in the samples. The method is
478 applied to rice and seafood samples. The same method is further applied by
479 Pétursdóttiret al.¹⁵⁸ for the analysis of a wide number of rice samples. Moreover, both
480 methods are compared with the more widely used one involving HPLC-ICPMS for
481 measurement and the results are shown to be comparable.

482

483 **2.2 Methods using coupled techniques**

484

485 Many proposals have been made for arsenic speciation by combining techniques
486 that provide efficient separation of the species with suitable detection and
487 quantification. These coupled techniques provide a high degree of automation, good
488 reproducibility and offer application in different fields. Among them, here we mention
489 some reviews that are specifically dedicated to arsenic speciation with coupled
490 techniques^{73,78,79,83,105,159}. In addition, some more general reviews of analytical
491 techniques include arsenic speciation. Some of them describe food samples or
492 summarize such aspects as pre-treatment, extraction and preservation of the arsenic
493 species, pre-concentration, how to overcome matrix interference and specific
494 instrumental conditions (such as types of nebulizers, the use of a dynamic reaction cell
495 and internal standards)^{76,77,82,88,90,91,160-162}. Some studies treat and discuss a specific
496 subject in depth, as in the work of Pétursdóttiret al.¹⁶³ concerning the influence of the
497 extraction step on the analysis of iAs in seafood, with measurement by coupled
498 techniques. Next we summarize studies of applications of coupled techniques for iAs
499 determination in several types of food, according to the separation technique.

500

501 **2.2.A Coupled techniques that use HPLC as the separation technique**

502

503 Most information corresponds to coupling techniques that use HPLC to separate
504 As species. We consider applications based on HPLC-AAS, HPLC-HG-AFS and
505 HPLC-ICPMS. No applications have been found of HPLC-ICPAES. Based on these
506 coupling options, most studies use HPLC-ICPMS. Nevertheless, we also include studies
507 using HPLC and detection systems other than ICPMS and that report iAs contents,

508 along with some other species, to highlight interest in its toxicity. The vast majority of
509 studies based on HPLC use strong anion exchange columns (SAX) and $\text{NH}_4\text{H}_2\text{PO}_4$,
510 NH_4NO_3 or NaHCO_3 as the mobile phase. Thus, in the following information, the type
511 of chromatographic system is only reported in studies that use a system other than these.

512 The coupled technique HPLC-MS or HPLC-MS/MS, proposed for arsenic
513 speciation in samples containing more complex compounds than those considered as
514 iAs, has been applied to obtain molecular structure information on arsenic compounds
515 of interest, although in general with no proved toxic effects, and has been shown not to
516 be suitable for small molecules such as arsenate, arsenite and their methylated
517 compounds.

518

519 ***HPLC–atomic absorption spectrometry (HPLC-AAS)***

520 Since very few applications of this technique were found, each is mentioned
521 here. Tian et al.¹⁶⁴ develops a gas–liquid separator for gradient arsenic HG, interfaced
522 between HPLC coupled to the AAS detector, using a reversed-phase column and using
523 sodium 1-butanefulfonate, malonic acid, tetramethylammonium hydroxide, MeOH and
524 ammonium tartrate as the mobile phase. After optimizing the transport of the hydrides
525 to the detector, the method is applied to the determination of arsenic species in hijiki
526 algae. Niedzielski et al.¹⁶⁵ aims to determine iAs and DMA in species of mushrooms
527 collected from forests in Poland with different degrees of contamination, as well as
528 some that are commercially available. The extraction of arsenic species is performed
529 with phosphoric acid with Triton X100 and the species are measured by HPLC-HG-
530 AAS with a quartz atomizer and Ar as the carrier gas. HPLC-HG-AAS is used by
531 Mleczek et al.¹⁶⁶ for inorganic arsenic determination in edible mushrooms and
532 cultivation substrates. Bergés-Tiznado et al.¹⁶⁷ analyzes cultured oyster samples from
533 the SE Gulf of California in Mexico; although a non-coupled technique is used, since
534 the corresponding fractions are collected from two HPLC columns (anionic and
535 cationic) are finally measured by ETAAS. Only two samples are reported to have very
536 low contents of iAs.

537

538 ***HPLC–Hydride generation–atomic fluorescence spectrometry (HPLC-HG-AFS)***

539 A review by Y-W Chen et al.¹⁶⁸ describes relevant chemical and instrumental
540 aspects, as well as applications, of this coupled technique for the speciation of some
541 elements; among them arsenic. For this element, the literature on speciation in some

542 food materials is included, among a wide number of matrices. Extraction systems as
543 well as the stability of the chemical species throughout the overall chemical process are
544 also included. Jesus et al. ¹⁶⁹ proposes a method for arsenic speciation by adding
545 sequential injection analysis: SIA-HPLC-AFS. In such a system, while the
546 chromatographic detection operates in the usual way, the SIA module is programmed to
547 inject sequentially the standard additions of the arsenic species. The method is applied
548 to the analysis of seafood extracts to quantify the most toxic species: As(III),As(V), MA
549 and DMA. Garcia-Salgado et al. ¹⁷⁰ applies HPLC-HG-AFS using both anionic and
550 cationic columns, which includes a photo oxidation step, resulting in HPLC-(UV)-HG-
551 AFS, to carry out arsenic speciation in edible algae extracts. The same authors in
552 Garcia-Salgado et al. ¹⁷¹use the same technique in a study of the stability of toxic
553 arsenic species and arsenosugars in hijiki alga samples under several storage conditions.
554 They highlight the predominance of As(V)in such food. Cano-Lamadrid et al. ¹⁷²
555 applies HPLC-HG-AFS to determine iAs, together with MA and DMA, in rice samples
556 collected from different provinces of Iran. Extraction of the arsenic species is carried
557 out using TFA and the iAs levels are found to be below the maximum FAO residue
558 limit of 200 μgkg^{-1} for rice ⁶³.

559

560 ***HPLC–inductively coupled plasma optical emission spectrometry (HPLC-ICPAES)***

561 In a study of interference to the determination of iAs in seaweed by ion
562 chromatography (IC)-ICPAES, Cui et al. ¹⁷³ assays two extractants: HNO₃ and MeOH.
563 That study concludes that suitable performance was not obtained with either system and
564 the authors propose an alternative method for the determination of total iAs from
565 seaweed. They add concentrated HCl and after separation, HBr and hydrazine sulfate
566 are added to reduce As(V) to As(III); extraction of iAs with chloroform is finally carried
567 out and measured by ICPAES.

568

569 ***HPLC–inductively coupled plasma mass spectrometry (HPLC-ICPMS)***

570 As mentioned above, this technique has been the most commonly used over the
571 last decade to determine arsenic species in several matrices. Here we summarize studies
572 whose aim is the specific determination of iAs in food products. Furthermore, some
573 studies to determine other arsenic species but that highlight the importance of obtaining
574 information on iAs contents are also considered, reporting the suitability of this
575 technique for arsenic speciation.

576 Thus, Prinkler et al.¹⁷⁴ compares different methods of signal treatment to
577 improve the LOD of the different species, as an attempt to decrease the noise signal.
578 The study obtained different signal-to-noise ratios according to the convolution of the
579 signal treatment systems with Gaussian distribution curves, for the noise reduction via
580 Fourier transform or wavelet transform. The study concludes that the last method was
581 the most appropriate. Ammann¹⁷⁵ used a narrow-bore chromatographic system with low
582 flow rates to optimize the efficiency of the nebulizers when using high resolving sector-
583 field ICPMS as the detection system. Chromatographic performance for arsenic species
584 separation and interference with the detection are discussed. Amaral et al.¹⁷⁶ uses ICP-
585 QMS in the coupled system and proposes the use of $^{83}\text{Kr}^+$ instead of Ar for the
586 interference standard method (ISM) to overcome the most common sources of
587 interference that occur in Ar plasma. The system improved both the accuracy and
588 sensitivity of arsenic species determination. Some reviews and studies report sample
589 preparation and extraction methods for arsenic speciation in food as a preliminary step
590 before measurement¹⁰³. Grotti et al.¹⁷⁷ discuss the influences of the arsenic species on
591 the ICPMS signal when working at a low liquid flow rate ($\mu\text{HPLC-ICPMS}$). In general,
592 different ICPMS responses are originated by differences in the volatility of the
593 elemental species, as discussed by several authors. After assaying and comparing
594 different nebulizers/spray chamber systems, this study supports this assumption and
595 recommends species-specific calibration for the quantification of arsenic species.
596 Jackson et al.¹⁷⁸ proposes a general approach for arsenic speciation by modifying the
597 existing method and using carbonate eluents for a small particle size, short Hamilton
598 PRP-X100 column which is interfaced with an ICPMS triple quadrupole, Agilent 8800
599 ICP-QQQ, using oxygen as the reaction gas and detection of AsO at m/z 91.

600 Among the types of food to which HPLC-ICPMS is applied for the
601 determination of toxic iAs compounds, rice and rice-based products, and to a lesser
602 extent other cereals, are the focus of increasing interest; as reported in studies this
603 decade. Among the applications, the optimization of extraction systems to obtain
604 selective extraction of iAs is one of the main objectives, but when applying a
605 separation–detection coupled system, information on methylated arsenic species in
606 those types of samples is also obtained and reported. Thus, the studies using this
607 technique report results for iAs as well as DMA and MA, and they differ mainly in the
608 extraction systems for arsenic species. The variety of extraction systems and
609 measurement conditions are summarized next, according to the target food type.

610

611 *Rice and rice products*

612 Huang et al.¹⁷⁹ studies several extraction systems that ensure suitable extraction
613 of iAs compounds while preserving any possible transformation between As(III) and
614 As(V) during the process, and finally proposes extraction with 0.28 mol L⁻¹ HNO₃ at
615 95°C for 90 min. The method was applied to several types of rice samples. Narukawa
616 and Chiba¹⁸⁰ develops heat-assisted extraction with water for arsenic speciation in rice
617 flour at 90°C for 3h. The authors discuss optimization of the extraction parameters in
618 depth, as well as the influence of sample particle size on the extraction conditions, by
619 considering information obtained from SEM (scanning electron microscopy) analysis of
620 the surface of samples. For separation of arsenic species, a C18ODS L-column was used
621 with sodium 1-butanefulfonate/malonic acid/tetramethylammonium hydroxide/MeOH
622 as the mobile phase. Nishimura et al.¹⁸¹ develops a partial digestion method using 0.15
623 mol L⁻¹ HNO₃. After assaying 80°C and 100°C, the latter temperature was adopted for
624 extraction, for 2 h, of iAs, MA and DMA from several varieties of rice from Japan. Paik
625 et al.¹⁸² proposes and validates a method based on ultrasonic extraction with
626 MeOH:water (1:1) containing 1% HNO₃ in a study of arsenic speciation in eleven
627 polished rice samples cultivated near areas of South Korea polluted by mining and for
628 iAs finds a mean value of 25.5 µg kg⁻¹. Huang et al.¹⁸³ validates the method established
629 before for iAs determination¹⁷⁹ by applying it to rice CRMs and through participation
630 in the PT IMEP-107^{46,184}, dedicated to the determination of iAs in rice. The validated
631 method is applied to twelve types of rice samples of different origins. The
632 concentrations of As(III) and As(V) increased with increasing total grain As
633 concentration, and As(III) was predominant in almost all the samples analyzed,
634 independent of the rice origin. Narukawa et al.¹⁸⁵ proposes specific monitoring test for
635 iAs in rice, based on a previously developed and validated method, using water as the
636 iAs extractant¹⁸⁰. The method is applied to 20 white rice flour samples. For separation, a
637 C18 column with sodium 1-butanefulfonate/malonic acid/tetramethylammonium
638 hydroxide/MeOH as the mobile phase was used and arsenobetaine was used as the
639 internal standard. Different percentages of iAs, with respect to total As, were found,
640 depending on the geographical origin of the samples. In a further publication¹⁸⁶ the
641 same research group develop a similar method after the study of several eluents and
642 elution conditions and adopting for separation a C18 column with sodium 1-
643 butanefulfonate/malonic acid/tetramethylammonium hydroxide/MeOH as the mobile

644 phase with the addition of an additional buffer containing $\text{NH}_4\text{H}_2\text{PO}_4$ and 0.05%
645 acetonitrile, with final pH 2.7. Under such conditions an improvement of the sensitivity
646 for As(III) and As(V), with respect to the previous method, is achieved. The method is
647 applied to the determination of As(III), As(V), MA, DMA and AB in three rice-based
648 CRMs. Llorente-Mirandes et al.⁴⁰ optimizes and validates a method for the
649 determination of arsenic species in rice. The arsenic species were extracted with a
650 mixture of 0.2% HNO_3 and 1% H_2O_2 in a microwave (MW) system, to completely
651 oxidize As(III) to As(V). Full validation is performed and the relative expanded
652 uncertainty is estimated, based on the top-down method. The validated method is
653 applied to the determination of arsenic species in 20 samples of rice and rice products.
654 Sommella et al.¹⁸⁷ determines total As and iAs in several Italian rice samples. Extraction
655 is performed with 1% HNO_3 and further addition of H_2O_2 , while separation is by anion
656 exchange column and quadruple ICPMS is used for detection. The iAs contents varied
657 with the region of Italy the samples came from. Maher et al.¹⁸⁸ extracts arsenic species
658 using 2% HNO_3 before measurement by the coupled technique. Both cation and anion
659 exchange columns are used for separation. The analysis is also carried out by XANES
660 (X-ray absorption near edge structure) and the results of both measurement techniques
661 compared, showing general agreement.. The method is applied to rice samples from
662 different countries. Kim et al.¹⁸⁹ uses 1% HNO_3 at 80°C for 30 min for the extraction of
663 arsenic species from 30 samples of rice grain collected from regions in South Korea
664 known to contain arsenic, as well as 34 polished rice samples from the USA. The
665 As(III) concentration in the American rice samples was slightly lower than that in the
666 samples collected in Korea. Baba et al.¹⁹⁰ performs iAs, MA and DMA analysis by
667 extracting them with 0.15 mol L⁻¹ HNO_3 for 120 min at 100°C. The authors summarize
668 the chromatographic separation modes used for arsenic speciation; among them anion
669 exchange columns are the most widely used although several other chromatographic
670 systems are mentioned and discussed. They adopt the use of PFP (pentafluorophenyl)
671 columns, after assaying and comparing some systems. The best results were obtained
672 with a Discovery HS F5 column in isocratic mode and, after optimization of the elution
673 conditions, 0.1% HCOOH and 1% MeOH, the latter as an organic modifier to enhance
674 the signal. AB is used as the internal standard. The method is applied to several samples
675 of rice purchased from markets in Japan. Narukawa et al.¹⁹¹ assays various extraction
676 systems for arsenic speciation in rice flour and the efficiencies are discussed in depth.
677 Moreover, prevention of possible changes in the arsenic species during the processes, as

678 well as the effects of the most common sources of interference on the separation and on
679 the detection are also reported and discussed. A proposal for both As(III) and As(V)
680 extraction from rice flour is based on 0.15 mol L⁻¹ HNO₃ containing Ag in a heat block,
681 and if only iAs is required, the proposal is based on extraction with 0.5 mol L⁻¹ HNO₃
682 and H₂O₂ in a heat block. For separation, a C₁₈ column with sodium 1-
683 butanesulfonate/malonic acid/tetramethylammonium hydroxide/MeOH as the mobile
684 phase is used. Sinha ²⁹ uses LC-ICPMS, after extraction of arsenic species with 2 mol L⁻¹
685 TFA (trifluoroacetic acid) in a study to evaluate and compare contents of iAs in rice
686 samples grown in a contaminated area and the relationship with the arsenic content in
687 the irrigation waters.

688

689 *Cereal-based food*

690 As a part of a study of the distribution and speciation of arsenic in wheat grain
691 from field-grown crops from European countries, Zhao et al.¹⁹² determine iAs species in
692 whole meal and white wheat flour samples. The extraction of the species is performed
693 with HNO₃ and H₂O₂ under MW. Tsai and Jiang ¹⁹³ proposes an extraction system
694 based on that established by Mar et al.¹⁹⁴ (which uses MW-assisted enzymatic digestion
695 with Protease XIV and amylase) optimizing the conditions by extending the digestion
696 time with respect to the proposed by Mar et al. ¹⁹⁴, and applies it to the analysis of
697 cereals. The final measurement is performed by IC-DRC-ICPMS (IC–dynamic reaction
698 cell–ICPMS). D’Amato et al. ¹⁹⁵ focuses on the sample treatment to obtain a good yield
699 of arsenic species without degradation. After assaying different methods, MW
700 extraction with HNO₃ was the most effective. The conditions are detailed in depth,
701 including lyophilization and elimination of the residual humidity, and the method is
702 applied to wheat and wheat products. Llorente-Mirandes et al.³⁹ performs a fully
703 validated method, based on ⁴⁰, for the determination of arsenic species in a large number
704 and variety of samples of cereal-based food products and infant cereals. The method is
705 used by the Laboratory of the Public Health Agency of Barcelona under accreditation
706 by ENAC/Spanish National Accreditation Entity, according the ISO/IEC 17025
707 standard, for its application in cereal-based food products.

708

709 *Infant food*

710 The method of Llorente-Mirandes et al. ³⁹ mentioned above was applied to the
711 determination of arsenic species in 9 samples of infant cereal products. Brockman and

712 Brown IV ¹⁹⁶ proposes an initial extraction with water at 98°C for 3 h and later addition
713 of hydrogen peroxide to the aqueous filtrate obtained. The resulting arsenate, MA and
714 DMA from infant rice cereals are analyzed by this coupled technique. The authors
715 conclude that iAs was found in all of the infant rice products in a large range between
716 33% and 77% of total As. Jackson et al. ³⁷, in a broad study of iAs content in infant
717 formulas and first foods, used an extraction with 1% HNO₃ following a progressive
718 heating program with MW from 55°C to 95°C. For measurement, two chromatographic
719 systems were used: both based on two anionic exchange columns, and with either
720 phosphate at pH 6 as the mobile phase or with tetramethyl ammonium hydroxide. The
721 samples, purchased from supermarkets, included 15 infant formulas, 41 fruit purees, and
722 18 second- and third-stage foods. As concentrations < 23 ng/g were found. Juskelis et al.
723 ¹⁹⁷, in a study for a survey of arsenic in rice cereals for infants, applied an extraction
724 method for iAs, MA and DMA based on the use of 0.28 M HNO₃ at 95°C for 90 min in
725 a block digestion system. A total of 31 different samples of organic wholegrain rice,
726 mixed-grain flour, organic rice and rice flour were analyzed and the results showed that
727 the iAs levels varied among all the samples studied: values in the range of µg iAs per
728 serving, for all the samples are reported (considering 15 g per serving, according to the
729 reference amount customarily consumed (RACC) per 21 CFR 101.12). Recently
730 Signes-Pastor ³⁸ in a study on rice-based products for children, uses IC-Q-ICPMS after
731 extraction with HNO₃ 1% under MW, for the determination of iAs in a large number of
732 samples from the UK shops and supermarkets.

733

734 *Other types of food*

735 The coupled technique HPLC-ICPMS has also been applied for arsenic
736 speciation in types of food other than rice and cereals. In many cases, as for example in
737 several types of food of marine origin, the number of arsenic species could be high.
738 However, as mentioned above, in such samples there are drawbacks caused by the
739 presence of polyatomic sources of interference arising from chloride. Several correction
740 systems have been proposed such as high-resolution MS and quadrupole-based
741 instruments with a reaction cell or collision cell ¹⁶⁰; or the use of the interference
742 standard method (IFS)¹⁷⁶. In complex food matrices, the selective extraction of iAs is
743 more difficult than it is from rice and cereal samples. When analyzing complex
744 matrices, a shift in the retention time of the iAs species (As(III) and As(V)) may be
745 observed, and consequently co-elution with organic arsenic species (arsenobetaine,

746 arsenosugars and others) may occur. Moreover, not all extractant reagents
747 (MeOH/water, dilute HCl, HNO₃, TFA, NaOH, etc.) quantitatively extract iAs from the
748 matrix. As a consequence, the analytical proposals reported in the literature are scarcer
749 and here we summarize those applications in which the main goal is the selective
750 determination of iAs.

751 Dufailly et al.¹⁹⁸ validates a method using IC-ICPMS for measurement, after
752 ultrasound-assisted enzymatic extraction (UAEE) with protease XIV and α -amilase. The
753 method is validated for a variety of food samples including rice, infant food and fish.
754 Mao et al.¹⁹⁹ develops highly polar stir bar sorptive extraction (SBSE) for arsenic
755 species, coated with TiO₂-PPHF (polypropylene hollow fiber), coupled to HPLC-
756 ICPMS. A C₁₈ chromatographic column with MeOH/water, and sodium butane
757 sulfonate/malonic acid is used as the mobile phase. The method is applied to determine
758 arsenic species, including iAs, in chicken samples. Raber et al.²⁰⁰ proposes an extraction
759 method based on 0.02 mol L⁻¹ trifluoroacetic acid with 30% H₂O₂ under sonication. In a
760 second step, 95°C of heat is applied for 60 min in an Ultraclave MW system. The
761 method is applied to rice, wheat and tuna fish samples. Julshamn et al.²⁰¹ applies an
762 extraction method for iAs based on 0.07 mol L⁻¹ HCl and 3% H₂O₂ at 90°C for 20 min.
763 The method is applied to determine iAs in 25 fish samples from Norwegian seas.
764 Pétursdóttiret al.²⁰², in a study to establish a method to determine iAs in seafood,
765 assayed three extraction methods based on 0.07 mol L⁻¹ HCl in 3% H₂O₂; 2% HNO₃ or
766 NaOH in 50% EtOH. The results are discussed; pointing out that some of them could
767 influence the performance of the separation. HG was introduced for measurement in the
768 coupled technique, resulting in HPLC-HG-ICPMS. This additional step, which uses
769 NaBH₄ in an HCl medium as a reducing agent, enhances the sensitivity, since the
770 volatile hydrides generated enter quantitatively into the plasma in a measurable fashion,
771 and in this study LOD improved 10- to 100-fold, with respect to conventional
772 nebulization systems. Narukawa et al.²⁰³ studies extraction methods for As(III) and
773 As(V) from several edible algae, including 15 samples of *Hizikia fusiforme*. They assay
774 MeOH, HNO₃, THAH, pepsin and α -amylase, under three extraction conditions:
775 ultrasonic, heat-assisted and MW-assisted, and conclude that extraction with water
776 under ultrasonic conditions is the most useful for monitoring iAs in hijiki and the other
777 algae studied. For separation, a C₁₈ chromatographic column is used, with sodium 1-
778 butanesulfonate/malonic acid/tetramethylammonium hydroxide/MeOH as the mobile
779 phase. Contreras-Acuña²⁰⁴ from a study of ultrasonic and microwave-based extraction

780 methods, the authors chose the last option for the extraction of arsenic species, among
781 the inorganic forms, from anemones samples by final measurement by both HPLC-
782 ICPMS and HPLC-MS techniques. Khan ²⁰⁵ validate a method for the determination of
783 As(III), As(V), AB, AC, DMA and MA in a wide number of samples from five
784 seaweed species after extraction with MeOH in 1% HNO₃ under sonication and
785 measurement by LC-ICPMS. In a study about the contents of arsenic and arsenic
786 species in Belgian food ²⁰⁶ species of marine and freshwaters fish are analyzed; water
787 under MW assisted extraction followed by HPLC-ICPMS is used for arsenic speciation
788 analysis; in the discussion about the extraction of arsenic species the authors stated that
789 the method used is sufficiently suitable for the purpose of their study. Numerous studies
790 have been reported on arsenic speciation in marine fish if compared with those on
791 freshwater fish. To take some example Ciardullo et al. ²⁰⁷, in a study on several fish
792 species collected from the Tiber river reports extraction of arsenic species with
793 methanol:water (1:1) and measurement with HPLC-ICPMS. The study emphasizes on
794 the optimization of the conditions to achieve the best recovery in the extraction
795 efficiency.

796 In a study of the iAs content of dietary supplements, considering that no
797 maximum levels for As are included in the recent EU regulations, Hedegaard ²⁰⁸ studies
798 16 different dietary supplements based on herbs, other botanicals and algae collected
799 from stores in Denmark, with origins in China (9), Taiwan (1), Denmark (5) and the
800 USA(1). Extraction with 0.006 mol L⁻¹ and 3% H₂O₂ at 90°C for 20 min is applied. For
801 measurement, a polymer strong anion exchange column with 3% ammonium carbonate
802 adjusted to pH 10.3 is used. To estimate the exposure, the corresponding daily dose is
803 considered for each supplement. In work on the shiitake species *Lentinula edodes* ³⁶,
804 several types of edible shiitake mushrooms are extracted with 0.02% HNO₃ and 1%
805 H₂O₂ in a MW system; the results show that iAs is the predominant As species. Piras et
806 al. ²⁰⁹ determines tAs and iAs in samples of several marine organisms collected from the
807 Boi Cerbus Lagoon in Sardinia (Italy): an important fishing area. The iAs is determined
808 using HPLC-ICPMS after extraction with HCl 0.07 mol L⁻¹ and 3% H₂O₂.

809 Some studies determine iAs in fruit juices, following the recommendations of
810 the FDA ³⁵. Wang et al. ²¹⁰ proposes iron-pairing chromatography with a ODS column
811 and malonic acid/TBA/MeOH as the mobile phase, to determine iAs, MA and DMA in
812 fruit juice samples, and fruit-based beverages: iAs is the major arsenic compound
813 found.

814 Liu et al. ²¹¹ in a contribution on the arsenic species determination in chicken
815 meat treated and not treated with roxarsone, establishes and validates method based in
816 enzyme-assisted extraction of the arsenic species: As(III), As(V), AB, DMA, MA, 3-
817 nitro-4hydroxyphenylarsinic acid (Roxarsone) and N-acetyl-4-hydroxy-m-arsanilic acid
818 (NAHAA). After assaying some proteolytic enzymes and extraction systems, the
819 method using papain with ultrasonication is adopted due to the highest extraction
820 efficiency. For final measurement two techniques: LC-ICPMS and LC-ESIMS are used,
821 by splitting the eluent of the chromatographic column to the ICPMS and ESIMS
822 detectors simultaneously.

823 As a summary of results for iAs by HPLC-ICPMS in various types of food,
824 several chromatograms are shown in Figure 4 (a-f): a) rice, b) infant multicereals, c)
825 hijiki seaweed (*Sargassum fusiforme*), d) mushroom supplement (*Grifola frondosa*,
826 commercially known as Maitake) e) tuna fish, and f) mussel. The chromatograms are
827 unpublished results of research by our working group.

828

829 **2.2.B Coupled techniques that use capillary electrophoresis (EC) as the separation** 830 **technique**

831 Capillary electrophoresis (CE) has been proposed as a coupled technique for
832 element speciation, but fewer contributions are reported than for than HPLC. Previous
833 problems associated with the interface with the different detection systems have
834 recently been overcome²¹². Very few contributions have been found that deal with
835 arsenic speciation in general over the last five years ^{213,214}. We now summarize those
836 reports with applications to arsenic speciation in food samples; some of them include
837 iAs results, although with no specific determination of iAs species.

838 Hsieh et al. ²¹⁵ couples CE with dynamic reaction cell ICPMS as the detector for
839 arsenic speciation, with application to the CRM NRCC DOLT-3, in which the iAs value
840 found was lower than the LOD, and to dietary supplements. Niegel et al. ²¹⁶ develops a
841 method based on CE-ESI-TOF-MS (CE coupled to electrospray ionization time-of-
842 flight mass spectrometry) for arsenic speciation, with application to the analysis of some
843 algae extracts; although no results for iAs compounds are obtained. Liu et al. ²¹⁷
844 proposes a novel interface (the commercial CE-ESI-MS sprayer kit) for CE-ICPMS and
845 applies it to arsenic speciation in the CRMs TORT-2 and DORM-3, as well as to herbal
846 plants and chicken meat, the results from which include iAs compounds. More recently,
847 Qu et al. ²¹⁸ develops a method for arsenic speciation in rice and cereals. It is based on

848 the extraction of arsenic compounds by means of direct enzyme-assisted MW digestion,
849 to reduce matrix effects in the final measurement by CE-ICPMS. The method is
850 validated by applying it to the rice CRMs: NIST SRM 1568b and NMIJ CRM 7503-a.

851

852 **2.3 Other analytical techniques**

853 Some analytical techniques, other than those reported before have been reported
854 for inorganic arsenic speciation, although few of them report applications to food
855 samples. Here we summarize briefly few of them based on several analytical principles.

856 Among spectrophotometric analytical techniques Gürkan et al. ²¹⁹ describes a
857 method to determine iAs by means of a CPE (cloud point extraction) procedure based
858 on the formation of a complex with neutral red as the ion-pair reagent and using UV-vis
859 detection (CPE-UV-Vis). The method allows the determination of As(III), total As and
860 As(V), and is applied to alcoholic and non-alcoholic beverage samples. The same
861 authors ²²⁰ propose Acridine Orange, AOH⁺ using Triton X-114 with tartaric acid pH
862 5.0 as a new ion pairing complex formation of As(V), for applying it to the method
863 above described, which is applied to determine iAs in beverage and rice samples.

864 Some electrochemical techniques have been developed for the measurement of
865 iAs. Liu and Huang ²²¹ reviews recent contributions of voltammetric methods for the
866 determination of iAs. That review considers types of electrode systems, including
867 electrodes based on nanomaterials, and highlights the increased demand by researchers
868 for sensors to measure *in situ*. The vast majority of applications of such systems have
869 been applied to the analysis of iAs in water and waste water, or in some plant samples
870 ²²² and no applications to the measurement of iAs in food samples have been found. A
871 new arsenate selective electrode have been recently developed by Somer et al. ²²³,
872 prepared from solid salts: Ag₃AsO₄, Ag₂S, Cu₂S; the responses of some interfering
873 anions are studied, and it is applied to the determination of arsenate in beer.

874 Several biosensors for the detection iAs have been developed. They involve the
875 coupling of a biologically engineered system with a sensitive analytical technique; they
876 can be based on fluorescence ²²⁴, luminescence, electrochemical ²²⁵ or other analytical
877 response ²²⁶. Different developments in this field are reviewed by ^{227,228}. A novel
878 technique using Total-Reflection X-Ray Fluorescence Spectrometry (TXRF) have been
879 proposed for the measurement of arsenic species, by combining a pre-concentration
880 system based on dispersive microsolid phase extraction (DMSPE), by using a new
881 synthesized novel adsorbent ²²⁹. The literature warns that the application of these

882 techniques to complex matrices, such as environmental or food samples, is still a
883 challenge.

884 In the preceding paragraphs the proposals for the determination of iAs in food
885 were described, all of them based on instrumental analytical techniques, and therefore
886 laboratory based. Anyway some proposal, as that recently reported by Bralatei et al.²³⁰,
887 based on the well-known Gutzeit method, is proposed as screening method for iAs in
888 rice assuring quantification limits of about 50 µg kg⁻¹.

889

890 **3. ASSESSMENT OF QUALITY CONTROL**

891 Noticeable efforts have been made in recent years to develop strategies to
892 support the quality of results in speciation analysis. The preparation of suitable CRMs
893 of different types of food and the organization of PT form the basis of these efforts; the
894 use and application of both are mandatory in food control laboratories, as regulated by
895 ISO/IEC Standard 17025⁹⁸. A comprehensive scheme of QA in analytical chemistry
896 laboratories would include the following elements: validation of analytical methods; use
897 of CRMs; routine application of internal QC; and participation in PT²³¹. Method
898 validation is an essential component of the measures that a laboratory should implement
899 to allow it to produce reliable analytical data and demonstrate whether the method is fit
900 for a particular analytical purpose. Typical performance characteristics of analytical
901 methods are: applicability, selectivity, calibration, trueness, accuracy, precision,
902 recovery, operating range, LOD and limits of quantification (LOQ), sensitivity,
903 uncertainty, ruggedness and fitness-for-purpose²³².

904 The following subsections specifically focus on the evaluation of the accuracy of
905 the method by means of use of certified reference materials (CRMs) (3.1), and on
906 participation in PT (3.2) as external QC of method validation. Besides, section 3.1 is
907 subdivided and the text focuses on: CRMs available for iAs (3.1.1); other CRMs
908 available with a certified total arsenic value (3.1.2); other strategies to evaluate accuracy
909 (3.1.3).

910

911 **3.1. Use of certified reference materials (CRMs)**

912 CRMs are useful to evaluate the accuracy of the analytical method; both for
913 validation and QC purposes. In any case the differences of matrix composition between
914 the sample and the CRM have to be carefully evaluated, since such differences may
915 prevent reach satisfactory results. Sample treatment (digestion, extraction, etc.),
916 separation and measurement processes are all subject to errors such as contamination,
917 degradation, matrix effects, instability and interconversion of arsenic species, and
918 calibration errors. Recovery, mass balance and QA/QC of the analytical method should
919 be determined in all the steps of the procedure (Figure 3). CRMs are traceable to
920 international standards with a known uncertainty and therefore can be used to address
921 all aspects of bias, assuming that there is no matrix mismatch. CRMs should be of
922 similar composition of real samples and have concentration levels similar to those of the
923 samples analyzed²³². CRMs are provided by various organizations, such as: the Institute
924 for Reference Materials and Measurements (IRMM), the National Institute for
925 Environmental Studies (NIES), the National Institute of Standards and Technology
926 (NIST), the National Metrology Institute of Japan (NMIJ), the National Research
927 Council of Canada (NRC-CNRC), the Chinese Academy of Geological Sciences
928 (CAGS), the China National Analysis Center for Iron and Steel (CNCIS), the Korea
929 Research Institute of Standards and Science (KRISS) and the Antarctic Environmental
930 Specimen Bank (BCAA) all produce CRMs for different matrices.

931 The first food CRMs were certified for tAs content and were produced several
932 decades ago. Later, since the toxicological effects of arsenic species differ markedly
933 between them, some analytical methods were developed to quantify the mass fraction of
934 the species in various matrices. The start was made with environmentally and food
935 matrices of relevant species. Feasibility studies of some arsenic species (e.g. AB and
936 DMA) were performed in the 1990s and 2000s. In the last years, efforts on the
937 production of CRMs with inorganic arsenic value in food, especially rice, are
938 performed. Although considerable progress has been made regarding the establishment
939 of specific and sensitive analytical methodology for arsenic species, few CRMs are
940 available with certified values for arsenic species in food samples.

941 As far as the authors know, few CRMs are available with certified values for
942 some arsenic species (AB and/or DMA). Among them the CRM BCR-627 Tuna Fish
943 was one of the first materials certified for As species and it was produced by IRMM in
944 1999²³³. The material was certified for tAs, DMA and AB values. Years after

945 certification, the material is still available from the IRMM website²³⁴, which means that
946 AB and DMA species are stable over time and no transformation or degradation is
947 produced²³⁵. More recently, three other marine food materials have been produced,
948 extending the availability of suitable fish and shellfish CRMs with certified AB value:
949 TORT-3 Lobster Hepatopancreas (NRC-CNRC), CRM 7402-a Cod Fish Tissue and
950 CRM 7403-a Swordfish Tissue(both from NMIJ).

951

952 *3.1.1 CRMs available for inorganic arsenic*

953 The commercially available food matrix CRMs with a certified iAs value are
954 summarized in this section. Although some advances have been made in specific
955 analytical methods for iAs determination in recent years, very few CRMs have been
956 developed. Only rice and seaweed CRMs are available with a certified value for the iAs
957 content. Five CRMs for iAs have been produced since 2009 by different institutions
958 including NMIJ, NIST and IRMM. Four of them are rice matrices: NIST SRM 1568b,
959 ERM-BC211, NMIJ CRM 7503a and NMIJ CRM 7532a, which are also certified for
960 tAs and DMA. The other is hijiki seaweed (NMIJ CRM 7405a) which is also certified
961 for tAs, and other arsenic species have been reported²³⁶. Inorganic arsenic results
962 available from the literature for these CRMs in the period 2010-2015 are shown in
963 Table II. The type of food, supplier, certified values, tAs reported, method and
964 measurement technique for iAs determination are also shown. Based on the information
965 provided in Table II, the need to produce more CRMs with a certified iAs value in
966 different food matrices can be appreciated. Some aspects should be considered to select
967 and analyze a representative CRM: the origin and type of the matrix, the type of As
968 species and the level of concentration.

969 Some thermal process is generally applied before the pre-treatment of the
970 CRMs. For example, SRM 1568b was dried for 24 h at 101°C while NMIJ 7532a was
971 dried at 60°C for 8 h; in contrast, BC-211 was stored at -20°C before being processed.
972 All the rice CRMs were milled and sieved or pulverized and mixed to ensure
973 homogeneity. The hijiki CRM was washed, freeze-dried, freeze-pulverized, sieved and
974 mixed for homogenization. For all of the CRMs, a sterilization step was applied by γ -
975 irradiating the material at a range of doses in order to eliminate active bacteria as a
976 potential source of instability for arsenic species. The producers of CRMs usually

977 recommend storing the materials shielded from sunlight or UV-radiation, in a clean
978 place at room temperature or below. Only in the case of BC211 is it specified that the
979 material should be stored at $-20^{\circ}\text{C} \pm 5^{\circ}\text{C}$, in the dark.

980 Different approaches have been adopted by the producers to express the iAs
981 mass fraction or concentration in the CRMs: three of the rice CRM (NIST 1568b, ERM-
982 BC211 and NMIJ 7532a) are certified with iAs values (the sum of As(III) + As(V)); the
983 other one is certified for As(III) and As(V) separately (NMIJ 7503a); and the seaweed
984 (NMIJ 7405a) as arsenate. The inorganic species present in these CRMs are of natural
985 origin, according to the certification reports, no spiking experiments were performed.
986 The iAs level in the four rice CRMs ranged from 0.084 to 0.298 mg As kg⁻¹; the typical
987 range for rice samples²⁴⁴. Typically, the iAs content in the brown rice CRM is higher
988 than in the white rice CRMs, as commonly reported²⁴⁵⁻²⁴⁷.

989 The first CRM released with a certified iAs value was CRM 7503-a rice and it
990 was produced by NMIJ. The certificate is dated August 2009 and it is the most analyzed
991 CRM. Several authors use it to assess the accuracy of iAs methods
992 ^{39,40,180,183,190,191,218,237-242}. The mean value for iAs content of the values reported in
993 Table II is 0.0823 ± 0.0037 mg As kg⁻¹ (mean value \pm standard deviation, n=16 reported
994 results) which is in perfect agreement with the certified value of iAs: $0.0841 \pm$
995 0.0030 mg As kg⁻¹ (the sum of the certified As(III) and As(V) values \pm the square root of
996 the sum of their squared uncertainties). Nine of the published values use different
997 extraction methods, such as MW-assisted extraction (MAE) or heating in a block with
998 several extractants such as HNO₃, HNO₃/H₂O₂, HClO₄, H₂O or enzymes; and with final
999 measurement via the coupled HPLC-ICPMS technique, which allows iAs to be
1000 separated from methylated species and the iAs species to be determined
1001 satisfactorily^{39,40,180,183,190,191,237,239,241}. A study of bioaccessible extracts (0.07 mol L⁻¹
1002 HCl and 0.01 % pepsin) was performed using (HPLC-ICPMS) with a high-efficiency
1003 photooxidation (HEPO) and HG system²⁴². A bioaccessible iAs value close to the
1004 certified one was obtained: 0.0821 ± 0.0024 mg As kg⁻¹. Two authors selectively
1005 extract the iAs with HCl and subsequent extraction with chloroform of the iAs present
1006 in the acid medium^{238,240}, based on the method of Muñoz et al.¹⁴². The final
1007 determination is performed by ICPMS and results comparable to the certified value
1008 were obtained. Although CE-ICPMS is not usual in iAs determination, Qu et al.²¹⁸

1009 extract iAs with an enzyme-assisted water-phase MAE and quantify by CE-ICPMS,
1010 reporting a satisfactory iAs value for the NMIJ 7503-a rice material.

1011 Very recently, EC-JRC-IRMM has produced a rice CRM (ERM-BC211) which
1012 is certified for DMA and iAs as well as for tAs. Six studies analyze
1013 this material^{36,139,155,156,172,243} and the mean value for the reported iAs results is $0.122 \pm$
1014 0.004 (mean \pm standard deviation, $n=6$ results) which is in agreement with the certified
1015 value: 0.124 ± 0.011 mg As kg^{-1} . Five studies use MAE with HNO_3 or $\text{HNO}_3/\text{H}_2\text{O}_2$ as
1016 the extractant solvent; two of them with determination of iAs by HPLC-ICPMS^{36,243} and
1017 two by HG-AFS^{155,156} and the other by HG-AAS¹³⁹. Another study extracts iAs with
1018 TFA and determination is by HPLC-HG-AFS¹⁷².

1019 SRM 1568b white rice was recently released by NIST and it is certified for
1020 arsenic speciation (DMA, MA and iAs). To date, two studies analyze it to evaluate the
1021 accuracy of their methods; one is based on As species in rice by CE-ICPMS²¹⁸ and the
1022 other is focused on rice-based products for infants and young children by HPLC-
1023 ICPMS²⁴⁸. Finally, only one study was found that analyzes the NMIJ 7405a hijiki and
1024 the reported iAs value is in agreement with the certified one²⁴². The high content of iAs
1025 (10.1 ± 0.5 mg As kg^{-1}) in this seaweed is usually found in studies of hijiki (*Hizikia*
1026 *fusiforme*), which is known to bioaccumulate arsenic as iAs^{33,249}.

1027

1028 ***3.1.2 Other CRMs available with certified total arsenic value***

1029 Due to the lack of CRMs with a certified iAs value, many authors perform
1030 arsenic speciation analysis on CRMs in which the tAs content or other arsenic species
1031 are certified. For validation purposes, the data obtained is compared with data reported
1032 in the literature by different researchers. This is one of the most commonly used
1033 practices within the scientific community to evaluate accuracy without a certified iAs
1034 value. Furthermore, the sum of As species is usually compared with the certified total
1035 As content (a so-called mass-balance study) or with tAs determined in the sample
1036 extract (column recovery). Mass balances or column recoveries of 80%–110% of total
1037 As are considered acceptable. Values close to 100% indicate full quantification of the
1038 As species present in the sample and guarantee the correctness of the chromatographic
1039 separation.

1040 Therefore, the following paragraphs focuses only on reported iAs values in food
1041 matrix CRMs; so studies reporting tAs or arsenic species in a CRM but not iAs results
1042 are not included in this section. The reported values are summarized in Table III, which
1043 includes type of food, supplier, certified values, total arsenic reported, iAs method,
1044 measurement technique and iAs value.

1045 The authors wish to summarize the ability of the analytical community to
1046 perform iAs analysis in different food matrices CRMs. For this, we focus on reported
1047 iAs results in the most commonly CRMs analyzed: SRM 1568a rice, TORT-2 lobster
1048 and DOLT-4 fish. The reported results in these CRMs are shown in Figure 5 and Figure
1049 6 for SRM 1568a and TORT-2, respectively; and in Table III for DOLT-4. Furthermore,
1050 specific highlights of iAs analysis in these CRMs are summarized in the following
1051 paragraphs.

1052 In the case of SRM 1568a (Figure 5) and TORT-2 (Figure 6), reported results
1053 are tabulated according to the iAs value, from low to high, illustrating the capacity of
1054 the analytical community to measure the iAs content in these CRMs. There are different
1055 ways to express and publish iAs results for these CRMs in the original publications:
1056 total iAs; only arsenite or only arsenate; or both species separately. We express and
1057 summarize all the results as iAs, i.e., the sum of arsenite plus arsenate, in order to
1058 facilitate comparison of the data. Therefore, in the Figures, the continuous lines
1059 represent the average concentration of iAs and the dashed lines delimit the target
1060 interval $X \pm SD$ in mg As kg^{-1} . The individual error bars represent the errors reported in
1061 the original publications. Where arsenite and arsenate were reported separately, the iAs
1062 value (the sum of arsenite and arsenate) and the error bar are calculated (the square root
1063 of the sum of their squared uncertainties or standard deviations). We note that
1064 researchers usually report results as mean value \pm error, which is predominantly SD for
1065 a number of replicates and in a few cases it is referred to the associated U value.

1066

1067 ***Highlights of inorganic arsenic analysis in SRM 1568a rice***

1068 For several years, NIST SRM 1568a rice has been analyzed as part of the
1069 method validation for the determination of As(III), As(V), MA, and DMA in rice.
1070 Although it is only certified for tAs content ($0.290 \pm 0.030 \text{ mg As kg}^{-1}$) and not for

1071 arsenic species, it is routinely used to assess the accuracy of As species by comparing
1072 measured results with the literature. Almost no studies report results for more than 4
1073 species and there seems to be agreement that the material only contains iAs and the two
1074 methylated species, as these are what are detectable by the majority of the methods
1075 employed in the literature reviewed.

1076 Several authors analyze the rice material and dataset includes 46iAs results, as
1077 shown in Figure 5. Plotting the results chronologically does not lead to any further
1078 conclusion: there is no obvious change in the reported values as a function of time,
1079 although the time covered is short (2010-2015). The dataset includes one result outside
1080 the ± 3 standard deviations range, $0.204 \text{ mg As kg}^{-1}$, so this is considered an outlier. If
1081 this value is excluded, the mean value for iAs is $0.098 \pm 0.009 \text{ mg As kg}^{-1}$ ($X \pm SD$,
1082 $n=46$ results, corresponding to 34% of the certified As), where the \pm term is the standard
1083 deviation (SD) of all the reported values. Although several methods and techniques are
1084 used by different researchers, it is worth noting that little dispersion of the iAs results
1085 was found. The iAs results range from 0.074 to $0.113 \text{ mg As kg}^{-1}$. Satisfactory
1086 agreement between the reported values and the calculated mean value is observed. If the
1087 reported values are expressed in terms of error, considering the mean value as a
1088 reference value, they would range from 76% to 116%.

1089 Different measurement techniques are used to determine iAs content, with
1090 HPLC-ICPMS being the most common (with different HPLC columns, different
1091 eluents, etc.): 36 results were found from several authors<sup>37,39,40,162,180-
1092 183,187,190,193,195,197,198,200,239,241,251,266-274</sup> whereas only one researcher used the HPLC-HG-
1093 AFS coupled system²⁷⁵. Several authors use non-coupled HG as a previous step to
1094 measuring iAs with different techniques. Five publications from the same group use FI-
1095 HG-AAS to determine iAs content¹⁴⁷⁻¹⁵¹; while two authors apply an HG-AFS system,
1096 one of them with a prior SPE step¹⁵⁵ and the other without SPE¹⁵⁶. Furthermore, a
1097 validated method using an SPE-HG-AAS system is applied¹³⁸; and also a speciation
1098 method using selective HG conditions and measuring by ICPMS is reported¹⁵⁷. In
1099 addition, a method for determination of inorganic arsenic by CPE-UV-Vis is used²²⁰.
1100 Meanwhile, Lopez-Garcia et al.¹⁰⁷ reports a value for $\text{As(III)} + \text{As(V)} + \text{MA} = 0.099 \text{ mg}$
1101 As kg^{-1} by ETAAS using suspensions prepared in 0.01 mol L^{-1} TMAH, which is in close
1102 to the mean calculated value.

1103 Different extraction solvents are used, supported by sonication, shaking, MAE or
1104 heating in a waterbath, etc. Some of these cause redox changes in the inorganic species
1105 producing a high dispersion in the values reported for arsenite or arsenate, and high
1106 uncertainty over the reported concentrations. In spite of high interconversion between
1107 arsenite and arsenate, the total iAs content remains constant and unaltered with no loss
1108 of analytes observed. This can be seen in Figure 5, in which the results are tabulated as
1109 iAs, and the majority of the data are inside the target interval $X \pm SD$. The most
1110 commonly used extraction solvent is dilute HNO_3 ^{37,181,183,190,195,197,200,239,266–268,271–273}.
1111 Other studies combine the use of HNO_3 with the addition of H_2O_2 to oxidize As(III) to
1112 As(V) and quantify the total iAs as As(V)^{39,40,138,155–157,162,187,251}. Also, a specific
1113 extraction method such as selective extraction of iAs with HCl and subsequent
1114 extraction with CHCl_3 of the iAs present in the acid medium is applied by several
1115 authors^{147–151}. Meanwhile, other extraction methods are also used to extract iAs from
1116 the rice material, including: enzymatic extraction^{193,198,241}; H_2O ^{162,180}; $\text{MeOH}/\text{H}_2\text{O}$
1117 ^{182,269}; TFA^{200,274,275}; and suspensions of TFA in H_2O_2 ²⁰⁰, NH_3 ²⁰⁰ or TMAH¹⁰⁷.

1118 Despite the use of different extraction methods and measurement techniques, the
1119 values reported show no clusters related to the analytical approach. The concentration of
1120 iAs determined in this CRM does not seem to depend on the analytical methodology.
1121 The NIST website indicates SRM 1568a is not available at present (last access: May
1122 2015): this material is currently “out of stock” and was superseded by SRM 1568b,
1123 which was certificated in October 2013. As specified in the certificate of analysis, the
1124 existing material from production of SRM 1568a was used to produce the new SRM
1125 1568b. The certified mass fraction value for iAs in the new SRM is 0.092 ± 0.010 mg
1126 As kg^{-1} , which is in perfect agreement with the data previously reported for the analysis
1127 of the former NIST 1568a (iAs = 0.097 ± 0.009 mg As kg^{-1}). The expanded uncertainty
1128 for SRM 1568b (0.010 mg As kg^{-1}) does include the mean of the values reported for
1129 SRM 1568a, and thus it is likely that the means are not significantly different.
1130 Therefore, we seem to be able to claim that the international analytical chemistry
1131 community is capable of measuring iAs content in rice.

1132

1133 ***Highlights of inorganic arsenic analysis in TORT-2 Lobster Hepatopancreas***

1134 Among the marine food CRMs, TORT-2 Lobster Hepatopancreas is one that is
1135 commonly analyzed in the literature. The material was produced by NRC-CNRC and
1136 the certificate is dated December 1994. It is certified for tAs content (21.6 ± 1.8 mg As
1137 kg^{-1} , mean value \pm uncertainty) but not for arsenic species. Several As species have
1138 been reported in this material, with AB being the major species and DMA, MA and
1139 TMAO minor components^{243,256}.

1140 Thirty-four published iAs contents^{137,163,202,217,243,256,259,276,277} are tabulated and
1141 shown in Figure 6. The dataset includes an outlier: 4.46 mg As kg^{-1} , which is excluded
1142 from our further calculations. Reported values range from 0.230 to 1.233 mg As kg^{-1} for
1143 iAs; and the calculated mean value is 0.606 ± 0.215 mg As kg^{-1} ($X \pm SD$, $n=33$ reported
1144 data), where the \pm term is the standard deviation of all the reported values. High
1145 variability of results is found, the RSD of the reported values is 36%. As expected, iAs
1146 corresponds to a low proportion (2.8%) of the certified tAs content. Classifying the
1147 results chronologically does not lead to any further conclusion about the high dispersion
1148 of the published results. If we assume that the calculated mean value is the “true value”,
1149 values range from 38% to 204% which is not desirable from the analytical point of view.

1150 Several techniques are employed to determine iAs content, with HPLC-HG-
1151 ICPMS being the most commonly used with different HPLC columns, mobile phases,
1152 extraction solvents, etc. Sixteen values for iAs have been found, resulting in an iAs
1153 value of 0.551 ± 0.142 mg As kg^{-1} (mean \pm SD, $n=16$)^{163,202,242,259}. Fourteen results are
1154 obtained using a coupled HPLC-ICPMS system, resulting in an iAs value of $0.652 \pm$
1155 0.275 mg As kg^{-1} (mean \pm SD, $n=14$)^{137,163,202,243,256,259,276,277}. Differences were
1156 observed when comparing the mean HPLC-HG-ICPMS values with those obtained by
1157 HPLC-ICPMS; however, in both cases the standard deviation is quite high and the
1158 intervals (i.e., mean \pm SD) overlap, which leads us to consider that no differences are
1159 observed between the means for the two techniques. Only one author used another
1160 coupled technique: HPLC-HG-AFS, with an iAs value of 0.369 ± 0.018 mg As kg^{-1}
1161²⁵⁹. A study analyzing iAs content by CE-ICPMS obtained the highest value for iAs:
1162 4.46 ± 0.03 mg As kg^{-1} ²¹⁷. Few data using non-coupled techniques are reported: two
1163 results obtained by SPE-HG-AAS, iAs = 0.90 ± 0.07 mg As kg^{-1} ¹³⁷ and iAs = $0.544 \pm$
1164 0.162 mg As kg^{-1} , as a value obtained from an inter-laboratory comparison (IMEP-32)
1165²⁷⁷. Furthermore, one researcher found an iAs value of 0.669 ± 0.034 mg As kg^{-1} by
1166 high resolution (HR)-ICPMS¹⁶³.

1167 A wide range of solvents supported by sonication, shaking, MAE or heating in a
1168 waterbath are used to extract iAs from the CRM matrix. The most commonly used
1169 extraction solvents are: HCl with or without H₂O₂^{137,163,202,277}; HNO₃ with or without
1170 H₂O₂^{163,202,243}; NaOH in 50% EtOH^{163,202,259,276}; and H₂O^{163,256}. According to the
1171 reported values, mean values for iAs are: 0.674 ± 0.126 (n=8), 0.682 ± 0.097 (n=7) and
1172 0.670 ± 0.264 (n=6) mg As kg⁻¹ (mean ± SD) for HCl, HNO₃ and H₂O extractions,
1173 respectively. No differences in iAs content are observed between the three extraction
1174 solvents. However, mean data for NaOH in 50% EtOH extractions result in a lower
1175 value: 0.390 ± 0.085 mg As kg⁻¹ (mean ± SD, n=7). To a lesser extent, other solvents are
1176 used, such as 50% MeOH or TFA extractions. In some cases, there are large differences
1177 between data obtained using the same extractant, with the measurement technique
1178 possibly being responsible for such dispersion. For example, using 50% MeOH, the
1179 differences between reported values are notable: the iAs value is 0.676 by HPLC-HG-
1180 ICPMS¹⁶³ and 1.233 mg As kg⁻¹ by IC-ICPMS²⁵⁶. Similarly with TFA extractions the
1181 iAs values are 0.315 (with the addition of H₂O₂) and 0.514 mg As kg⁻¹ (without
1182 H₂O₂)¹⁶³; with there being differences in the use of H₂O₂ and also in the measurement
1183 technique: the former using HPLC-HG-ICPMS and the latter HPLC-ICPMS. In another
1184 example, applying selective solubilization of iAs with HCl, subsequent extraction with
1185 CHCl₃ and further back-extraction with HCl, differences were also observed in the iAs
1186 content: 0.669 vs 0.331 mg As kg⁻¹¹⁶³. The higher value is obtained by HR-ICPMS
1187 while the lower value corresponds to using HPLC-HG-ICPMS.

1188 As an overview of iAs content in TORT-2, and in accordance with the values in
1189 Figure 6, we can say that highly variable iAs data have been published, which illustrates
1190 that it is difficult to obtain a consistent value for iAs in this seafood CRM. Comparing
1191 values in the literature according to the extraction method used leads us to state that
1192 NaOH extractions show lower concentrations than other solvents (i.e., HCl, H₂O or
1193 HNO₃). The large differences in the literature between concentrations of iAs in this
1194 seafood material reinforce the need to develop more and more reliable methods for its
1195 determination.

1196

1197 ***Highlights of inorganic arsenic analysis in DOLT-4 dogfish***

1198 The dogfish (*Squalus acanthias*) liver DOLT-4 is one of most analyzed of
1199 seafood CRMs. The material was produced by NRC-CNRC and the certificate is dated
1200 May 2008. It is certified for tAs content (9.66 ± 0.62 mg As kg⁻¹, mean value \pm
1201 uncertainty) but not for iAs. AB is the major As compound followed by DMA, iAs,
1202 MA, TMAO, etc., as minor compounds²⁴³.

1203 Studies analyzing this dogfish liver material produce 17 published values for iAs in the
1204 literature (Table III). Some of the data correspond to values reported from PT, IMEP-
1205 109/30⁴⁷. From the results reported, the values range from 0.010 to 0.387 mg As kg⁻¹ for
1206 iAs; and two of them could be considered as outliers (0.387 and 0.152 mg As kg⁻¹).
1207 Excluding those two values, the calculated mean is 0.024 ± 0.019 mg As kg⁻¹ ($X \pm SD$,
1208 $n=15$, ranging from 0.010 to 0.075), where the \pm term is the standard deviation of all the
1209 reported values. Very high dispersion of results is reported and the RSD of the reported
1210 values is 76%. As usual in fish, the iAs content corresponds to a low proportion (0.3%)
1211 of the tAs content. There are few data in the literature, and a classification
1212 chronologically does not lead any conclusion about the high variability of the published
1213 iAs results. Range of values, considering the mean value as true value, ranged from
1214 41% to 308%; again highlighting the considerable variability of the iAs results in the
1215 literature.

1216 Tabulating the results by measurement techniques shows that the iAs mean
1217 values are: 0.014 ± 0.008 ($n=9$) and 0.031 ± 0.010 ($n=6$) mg As kg⁻¹ (mean \pm SD) for
1218 the coupled techniques HPLC-HG-ICPMS^{163,202} and HPLC-ICPMS^{47,202,243,253},
1219 respectively. Only two results obtained using non-coupled techniques have been
1220 published: iAs= 0.075 ± 0.005 mg As kg⁻¹ by FI-HG-AAS⁴⁷; and iAs= 0.152 ± 0.010
1221 mg As kg⁻¹ by HR-ICPMS⁴⁷.

1222 Sorting the results by extraction method shows that several different solvents
1223 supported by sonication, shaking, MAE or heating in a waterbath, are used to extract
1224 iAs from the fish matrix. For example, the following extractants were used: H₂O ($n=3$)
1225 ^{163,253}; NaOH in 50% EtOH ($n=2$)²⁰²; MeOH ($n=1$)¹⁶³; HCl with H₂O₂ ($n=2$)²⁰²; and
1226 TFA ($n=2$)^{47,163}. Extractions based on HNO₃ provide a mean value of 0.019 ± 0.007 mg
1227 As kg⁻¹ (mean \pm SD, $n=4$). There is high variability between selective extractions of iAs
1228 based on the method of Muñoz et al.¹⁴², depending on the measurement technique

1229 employed; the iAs values are 0.036, 0.075 and 0.152 mg As kg⁻¹ using HPLC-HG-
1230 ICPMS¹⁶³, FI-HG-AAS and HR-ICPMS⁴⁷, respectively.

1231 It should be noted that a low iAs concentration is found in DOLT-4: 0.024 ±
1232 0.018 mg As kg⁻¹ (excluding the two outliers), with high dispersion between the
1233 reported values (Table III). It is not possible to show whether the extraction method or
1234 the measurement technique are significant influential factors; however, most reported
1235 methods show a low concentration of iAs in the material (<0.080 mg As kg⁻¹). Further
1236 developments and improvements of the analytical methods to determine iAs in seafood
1237 are needed in order to provide reliable iAs results.

1238

1239 ***3.1.3 Other strategies to evaluate accuracy***

1240 Although some CRMs with a certified iAs value have been produced in recent
1241 years, this does not seem to cover the wide range of the foodstuffs usually consumed in
1242 common diets. Some alternative approaches to estimate accuracy without the
1243 appropriate and representative CRMs are reported in the literature consulted, as follows:
1244 performing spiking experiments; compare the method with a reference method and
1245 comparing different sample preparations with each other. In the following paragraphs
1246 we summarize some alternatives found in the literature to assess accuracy without a
1247 certified reference value.

1248

1249 ***Spiking experiments***

1250 An alternative, to assess accuracy in the absence of CRMs, is to perform spiking
1251 experiments and then calculate the recovery. Typically, a test material is analyzed by
1252 the method under validation both in its original state and after the addition (spiking) of a
1253 known mass of iAs to the test sample. Spiking (also known as fortification) procedures
1254 must be carefully planned in order to select the most suitable strategy to introduce a
1255 single iAs species or mixture of both (i.e., arsenite and arsenate) into the matrix. Some
1256 other variables that should be checked in order to prepare a spiked sample with a similar
1257 matrix to the original sample are: the maximum volume or weight to be added to the
1258 matrix; the contact time and conditions; and further pre-treatment steps (e.g. drying,

1259 sieving, milling, etc.). Furthermore, the homogeneity of the distribution of the species
1260 within the matrix should be addressed. In the case of the incorporation of a spiking
1261 solution into a liquid homogeneity is relatively easy to achieve; whereas, the process
1262 can be much more difficult when working with a solid matrix. Spiked samples, or
1263 sometimes a blank sample, are subjected to the respective sampling procedures and the
1264 contents measured^{36,39,40,112,137,138,155,157,179,183,187,189,198,200,238,241,243,259}. The recoveries
1265 obtained are usually compared to CODEX criteria: 60%–115% for 10 µg kg⁻¹ and 80%–
1266 110% for 0.1–10 mg kg⁻¹²⁷⁸. Recoveries in these ranges are considered acceptable and
1267 demonstrate the reliability of the sample preparation method. Sometimes spiking
1268 experiments are carried out by adding standards of As species to CRMs before analysis.
1269 Although the iAs content is not certified, the spiking of iAs has been performed on
1270 SRM 1568 rice^{162,198} and also BCR-627 tuna fish¹⁹⁸.

1271

1272 ***Methods comparison***

1273 Another approach to evaluating accuracy is to compare the results achieved with
1274 a fully validated method to test for bias in the proposed method. This is a useful option
1275 when checking an alternative to an established standard method already validated and in
1276 use in the laboratory. Some studies of iAs determination compare methods in rice
1277 samples: SPE HG-AAS with HPLC-ICPMS¹³⁸; HG-ICPMS with HPLC-HG-ICPMS
1278¹⁵⁷; HG-AFS with HPLC-ICPMS¹⁵⁶; a slurry sampling-HG-AAS method¹⁴¹ with the
1279 Chinese standard HG-AFS method⁹⁵. Few studies comparing iAs results in on seafood
1280 samples were found, but one example of such a study compares SPE HG-AAS with
1281 HPLC-ICPMS¹³⁷. Another study used MAE extraction with NaOH (1.5 mg/mL) in 50%
1282 ethanol to extract iAs from seafood samples and CRMs; the results were compared
1283 using different techniques: HPLC-ICPMS vs HPLC-HG-ICPMS vs HPLC-HG-AFS²⁵⁹.

1284 Another strategy to check the reliability of results is to compare different sample
1285 preparation procedures followed by measurements using the same detection technique.
1286 For example, three extraction methods are compared in seafood samples and CRMs,
1287 and the results are discussed according to the use of HPLC-ICPMS with and without
1288 HG²⁰². The same authors extend the study to nine extraction methods for iAs
1289 determination in seafood (i.e., the most commonly used in the literature) followed by
1290 measurements using HPLC-HG-ICPMS and the results are extensively discussed¹⁶³.

1291 Different extraction methods are also applied, followed by measurements using HPLC-
1292 ICPMS, to compare the results in cereal-based food¹⁹⁵ and in rice^{162,250}.

1293

1294 **3.2. Proficiency testing (PT)**

1295 As external QC, PT or inter-laboratory comparisons, is a valuable tool to test the
1296 reliability of a method by comparing results with an assigned reference value. Some
1297 institutions, organizations and laboratories regularly organize PT to evaluate the
1298 performance capabilities of analytical laboratories. In the following section we
1299 summarized PT focused on the determination of iAs in food matrices.

1300

1301 ***3.2.1 EC-JRC-IRMM proficiency testing (PT)***

1302 The Institute for Reference Materials and Measurements (IRMM) of the Joint
1303 Research Centre (JRC), a Directorate General of the European Commission, operates
1304 the International Measurement Evaluation Program (IMEP). It organizes inter-laboratory
1305 comparisons in support of European Union policies. The Directorate General for Health
1306 and Consumers (DG SANCO) of the European Commission (EC) has requested the
1307 European Union Reference Laboratory for Heavy Metals in Feed and Food (EU-RL-
1308 HM) to evaluate the performance of European laboratories with regards to total As and
1309 iAs analysis in food, with a view to future discussions on the need for regulatory
1310 measures. With that brief, several PT protocols have been organized in recent years by
1311 the IMEP on behalf of the EU-RL-HM. In the following paragraph we focus on PT
1312 organized within the IMEP, as summarized in Table IV.

1313 In general, the aim of the selected IMEPs is to: “judge the state of the art of
1314 analytical capability for the determination of total and inorganic arsenic in several
1315 foodstuffs with a view to future discussions on the need for possible regulatory
1316 measures and future discussions on risk management and the possibility of introducing
1317 maximum levels for iAs in the European Union”. In general terms, the IMEP protocol
1318 consists of the distribution of the test material within the participating laboratories
1319 (national reference laboratories (NRLs), official control laboratories (OCLs) or open to
1320 all laboratories) which are requested to determine total As and iAs by their routine

1321 procedures. The participants are asked to report individual results, the mean value and
1322 its associated uncertainty. Sometimes, the test material is certified for tAs (a CRM is
1323 used in some PT) but unfortunately not for iAs, so it is sent to some expert laboratories
1324 in the field to assign a reference iAs value. Expert laboratories are asked to analyze the
1325 material using methods of their choice and no further requirements are imposed
1326 regarding methodology. They are also asked to report their results together with the
1327 measurement uncertainty. The mean of the independent values provided by the expert
1328 laboratories for total As and iAs are used as the “assigned value” (X_{ref} , also called the
1329 “reference value”) and the associated “standard uncertainty” is also calculated. All of
1330 this is in accordance with the International Standards Organization guide 35²⁸⁵. Then,
1331 the organizers calculate the z and ζ parameters for each laboratory in accordance with
1332 ISO 13528²⁸⁶. The ζ -score and z -score are interpreted as follows (according to ISO/IEC
1333 17043²⁸⁷: “satisfactory performance” (≤ 2), “questionable performance” ($> 2 \zeta / z \leq 3$), or
1334 “unsatisfactory performance” (> 3).

1335 Further details, specific information for each IMEP, such as the PT code, type of
1336 food, objective, analyte, assigned values, results of participants (z -score) and comments,
1337 are shown in Table IV.

1338

1339 *IMEP-107: Determination of total and inorganic As in rice*

1340 The first PT to include iAs as an analyte was organized in 2009 and focused on
1341 the determination of total As and iAs in rice (IMEP-107)^{46,184}. Reference values for
1342 total As and iAs were satisfactorily assigned by several expert laboratories. A wide range
1343 of sample pre-treatment methods, and instrumental set-ups were applied by participants
1344 and the expert laboratories. Despite the use of these different methods, the results were
1345 not observed to cluster in relation to the analytical approach. The organizers comment
1346 that no particular problem related to the determination of iAs in rice was detected in the
1347 PT, and the performance of the participating laboratories was satisfactory. Finally, they
1348 conclude that the concentration of iAs determined in rice does not depend on the
1349 analytical method applied and that introduction of a maximum level for iAs in rice
1350 should not be postponed due to analytical concerns⁴⁶. In addition, the IMEP-107 rice
1351 test material has been used as RMs in several studies and was analyzed to assess the
1352 accuracy of iAs results obtained using the specific method^{40,112,138,183}.

1353

1354 *IMEP-109/30: Analysis of total Cd, Pb, As and Hg, as well as MeHg and iAs in seafood*

1355 Encouraged by the satisfactory results for iAs in rice, two inter-laboratory
1356 comparisons, IMEP-109 and IMEP-30, were performed in 2010 of the measurement of
1357 some trace elements, in addition to iAs, in seafood ⁴⁷. Only the EU NRL took part in
1358 IMEP-109 ²⁸⁰, while IMEP-30 was open to all laboratories ²⁷⁹. The commercially
1359 available CRM DOLT-4 from NRC-CNRC was used as the test material for all this PT.
1360 Five expert laboratories, analyzed the test material to establish the reference value for
1361 iAs. The expert laboratories were not able to agree on a value for the iAs within a
1362 reasonable degree of uncertainty. For this reason, it was not possible to establish an
1363 assigned value for iAs and therefore the results from the laboratories for iAs could not
1364 be scored. The organizers concluded that the results were spread over a wide range, but
1365 75% of the laboratories agreed that the iAs content of the test material did not exceed
1366 0.25 mg kg⁻¹. Despite the spread, they stated that there seems to be no clear clustering of
1367 results according to the methods used. According to the results, the determination of iAs
1368 in seafood presented serious analytical problems and iAs is clearly more difficult to
1369 analyze in this seafood matrix than in rice (IMEP-107). Further information and
1370 possible causes for the dispersion of the results, attributed to the extraction and/or
1371 detection steps as the most likely cause, are widely discussed in the IRMM
1372 reports^{279,280} and summarized in Baer et al. ⁴⁷. Additionally, it was concluded that more
1373 research is needed in the future to find appropriate and effective extraction procedures,
1374 as well as chromatographic conditions for reliable separation and quantification of iAs.

1375

1376 *IMEP-112: Determination of total and inorganic in wheat, vegetable food and algae*

1377 IMEP-112 focused on the determination of total and inorganic arsenic in wheat,
1378 vegetable food and algae ^{48,281}. The assigned values (total As and iAs in wheat, and iAs
1379 in vegetable food and algae) were satisfactorily provided by a group of expert
1380 laboratories in the field. The organizers concluded that the concentration of iAs
1381 determined in any of the matrices does not depend on the analytical method applied, as
1382 proven by the results submitted by the seven expert laboratories and by the participants.
1383 A wide range of sample pre-treatment methods and instrumental setups were applied

1384 and despite this, clustering of results related to the analytical approach was not
1385 observed. Furthermore, the participating laboratories performed, in general,
1386 satisfactorily for the determination of iAs in wheat and vegetable food; however, only a
1387 few laboratories obtained a satisfactory score for iAs in algae. Finally, it was also
1388 highlighted that, purely from the analytical point of view, there is no reason not to
1389 consider the option of introducing maximum levels for iAs in wheat, vegetable food and
1390 algae in further discussions of risk management ⁴⁸. Besides, the wheat test material used
1391 in IMEP-112 was also analyzed as external QC ³⁹.

1392

1393 *IMEP-116/39: Total Cd, Pb, As, Hg and inorganic As in mushrooms*

1394 Since mushroom consumption has increased considerably in recent years due to
1395 promotion of their nutritional properties, two PT programs were organized using the
1396 same test item (shiitake mushroom) ⁴⁹: IMEP-116 (for NRLs) ²⁸² and IMEP-39 (for
1397 OCLs and other laboratories) ²⁸³. Reference values were satisfactory assigned by five
1398 expert laboratories which analyzed the test item. In general, the performance of the
1399 participating labs was satisfactory for iAs: in IMEP-116 (NRLs), a high percentage of
1400 satisfactory results was obtained (z=81%, n=13) which is considerably higher than in
1401 IMEP-107 (rice). The organizers also pointed out that in IMEP-39, five out of the seven
1402 laboratories which obtained a satisfactory z-score for iAs used AAS-based techniques,
1403 showing that sound determinations of iAs can be made without the need for expensive
1404 sophisticated instrumentation ⁴⁹. Furthermore, the IMEP-116/39 PT item, shiitake
1405 mushroom, has also been used as external QC for iAs analysis ³⁶.

1406

1407 *IMEP-118: Determination of total As, Cd, Pb, Hg, Sn and iAs in canned food*

1408 In 2014, a PT program was produced focused on the determination of total As,
1409 Cd, Pb, Hg, Sn and iAs in canned food (peas in brine) (IMEP-118) ^{51,284}. Participation in
1410 the PT was mandatory for nominated NRLs, and open to other OCLs and interested
1411 laboratories. Unlike other IMEPs, the test material was spiked with arsenic during
1412 preparation. Expert and participant laboratories were asked to analyze total As and iAs
1413 in the canned vegetables, in both the drained product and the solid/liquid composite.
1414 Good agreement between the theoretical and the assigned value for total As in the

1415 solid/liquid composite was obtained; but not in the case of iAs. The brine was spiked
1416 with arsenate and the iAs mass fraction in the solid/liquid composite was found to be
1417 lower than the respective total As mass fraction: 35% lower than the theoretical one.
1418 Some possible causes are discussed and summarized in the IRMM report⁵¹. In spite this,
1419 the results from the two expert laboratories were in agreement and a reference value for
1420 the iAs mass fraction was assigned. From the PT results, it was concluded that the
1421 performance of the participating laboratories at determining iAs was satisfactory for
1422 both sample preparation approaches. However, few laboratories carried out analysis for
1423 iAs determination (only 33% reported values). Furthermore, the outcome of the PT
1424 clearly indicated that guidelines are needed on the sample preparation protocol to be
1425 used when analyzing canned food drained products and solid/liquid composites.

1426

1427 *IMEP-41: Determination of inorganic arsenic in food*

1428 An inter-laboratory comparison was performed on a method evaluation by
1429 means of a collaborative trial for the determination of iAs in seven food products
1430 (IMEP-41)⁵⁰. The method under evaluation was previously developed and in-house
1431 validated and final measurement was performed by FI-HG-AAS¹⁴². The organizers
1432 clearly stated that the standard operating procedure (SOP) was to be strictly followed
1433 and any deviation from the method should be reported. The seven test food items used
1434 in this exercise were RMs covering a broad range of matrices and concentrations (Table
1435 IV). Five experts analyzed the test items using a method of their choice, different from
1436 the one being assayed. From the results, the organizers concluded that the method
1437 evaluated is robust and does not require any adaptation according to the matrix to be
1438 analyzed. Furthermore, the proposed method is considered fit-for-purpose, i.e.,
1439 determination of iAs in different food products⁵⁰.

1440

1441 **4.2.2 Other inter-laboratory comparisons**

1442 Other inter-laboratory comparisons focused on the determination of iAs in food
1443 have been organized in recent years. Institutions, organizations and laboratories
1444 regularly organize PTs to evaluate competency in the analysis of iAs species in food
1445 matrices. The Food Analysis Performance Assessment Scheme (FAPAS) of the Food

1446 and Environment Research Agency (FERA) has organized PT for several years, focused
1447 on several analytes in foodstuffs, with a wide range of tests available throughout the
1448 year. PTs on the determination of total and iAs in several food matrices is regularly
1449 organized²⁸⁸. A rice test material from the FAPAS interlaboratory tests²⁸⁹ was analyzed
1450 in several studies as QC for iAs^{39,40,238}. Brooks Rand Labs organized an inter-
1451 laboratory comparison study for arsenic speciation in white rice flour, brown rice flour,
1452 kelp powder, and apple juice in 2013. A large group of participating laboratories from
1453 around the world, forty-six laboratories from fifteen countries, registered to
1454 participate²⁹⁰.

1455 Specific PTs focused on iAs in rice has recently been organized. The Ministry of
1456 Agriculture, Forestry and Fisheries (MAFF) of Japan organized a collaborative study of
1457 speciation and determination of iAs in rice using HPLC-ICPMS. For it, an SOP of the
1458 method was developed and the proposed method was validated through the
1459 collaborative study of eastern and southeastern Asian countries²⁹¹. Further PT based on
1460 the iAs content of rice was organized by the Inorganic Analysis Working Group
1461 (IAWG) of the Consultative Committee for Amount of Substance (CCQM). The
1462 CCQM-K108 key comparison was organized to test the capacities of the national
1463 metrology institutes or the designated institutes to measure the mass fractions of arsenic
1464 species and tAs in brown rice flour; while the National Metrology Institute of Japan
1465 (NMIJ) acted as the coordinating laboratory. The participants used different
1466 measurement methods to determine the iAs content of a rice sample²⁹².

1467

1468 **4. CONCLUSIONS AND FUTURE TRENDS**

1469 Food control laboratories, consumers, authorities, institutions, health agencies
1470 and legislators have recently become more interested in iAs contents in food. This has
1471 led to several initiatives that move towards the development of robust and reliable
1472 analytical methods for selective determination of iAs in a range of food products.
1473 Although several techniques have been used in iAs determination, spectroscopic
1474 methods are the most commonly applied. Several such methods and techniques have
1475 been developed, but mild chemical extraction of iAs species and further determination
1476 by HPLC-ICPMS is undoubtedly the most popular approach used in iAs analysis in
1477 food. However, some non-chromatographic approaches that determine iAs accurately

1478 even in presence of other organoarsenic compounds have been reported as being less
1479 time-consuming and more cost-effective alternatives than those based on HPLC-
1480 ICPMS.

1481 Although numerous CRMs have been analyzed to evaluate the accuracy of the
1482 methods for total arsenic, few of them are certified for iAs content. The differences
1483 found in the literature between the concentration of iAs in seafood CRMs illustrates that
1484 it is difficult to obtain a consistent value and reinforce the need to develop reliable
1485 methods for its determination, especially when matrices with a complex distribution of
1486 arsenic species are analyzed, as in the case of food of a marine origin. Further
1487 production of seafood CRMs would help in the validation of iAs methods and in
1488 providing reliable iAs data. Furthermore, more PTs for iAs determination in seafood are
1489 needed to assess the reliability of the proposed methods, since to date, they have shown
1490 unsatisfactory performance.

1491 Concerning food safety, the distinction between iAs and total As content or other
1492 species in foodstuffs should be addressed in future maximum levels of arsenic in food.
1493 Moreover, more reliable data on iAs content in foodstuffs, especially less studied food
1494 products, are needed for reliable risk assessment and to estimate the health risk
1495 associated with dietary As exposure.

1496 Finally, more efforts should be made to transfer the knowledge obtained by the
1497 analytical community concerning the development of selective methodologies for the
1498 determination of iAs to the future implementation of that knowledge as routine methods
1499 in food control laboratories. To this end, the validation of methods as well as
1500 participation in PT and the analysis of CRMs should be performed, as mandated by the
1501 ISO/IEC 17025 standard for laboratory accreditation purposes.

1502

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1504

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1509

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Table I. Worldwide regulations on iAs and tAs in food. Table adapted and expanded from Petursdottir et al.⁵³

Country	Food	iAs (mg kg ⁻¹)	tAs (mg kg ⁻¹)	Year	Reference
Australia and New Zealand	Crustacea	2.0		2011	ANZFA 2011 ⁵⁴
	Fish	2.0			
	Molluscs	1.0			
	Seaweed (edible kelp)	1.0			
	Cereals		1		
Canada	Fish protein	3.5		2006	CFIA (2014) ⁵⁵
	Edible bone meal	1.0			
	Fruit juices, fruit nectar or other beverages (not mineral water)	0.1			
	Muscle of swine, chickens and turkeys; eggs	0.5 _a			
	Liver of swine, chickens and turkeys	2.0 _a			
China	Grains (excluding paddy rice)		0.5	2012	MHC (2012) ⁵⁶
	Processed milled grain products (excluding brown and white rice)		0.5		
	Paddy rice, brown rice, white rice	0.2			
	Aquatic animals and products (excluding fish and fish products)	0.5			
	Fish and fish products	0.1			
	Fresh vegetables, edible fungi		0.5		
	Meat and meat products		0.5		
	Raw, pasteurised, sterilised, modified, or fermented milk		0.1		
	Milk powder		0.5		
	Fats and their products		0.1		
	Seasonings (excluding aquatic or algae seasonings and spices)		0.5		
	Aquatic seasonings	0.5			
	Fish seasonings	0.1			
	Sugars and sweeteners		0.5		
	Packed drinking water		0.01 (mg/L)		
	Chocolate and cocoa and chocolate products		0.5		
	Supplementary food for infants and young children (with added algae)	0.2 (0.3)			
	Canned supplementary foods for infants and children	0.1 (0.3)			

France	Algae condiments	3	2010	CEVA (2010) ⁵⁷
European Union	Non-parboiled milled rice (polished or white rice)	0.20	2015	EU (2015) ⁵⁸
	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		
USA	Chicken/turkey (uncooked muscle tissue)	0.5	2001	FDA 2001 ⁵⁹
	Chicken/turkey (uncooked by-products)	2		
	Chicken/turkey (eggs)	0.5		
	Swine (uncooked liver kidneys)	2		
	Swine (uncooked muscle tissue and by-products)	0.5		

2446 ^a ML for arsenilic acid

2447 **Table II.** Available food CRMs with an inorganic arsenic certified value. Results
 2448 obtained from literature (2010-2015) and expressed as mg As kg⁻¹.

CRMs Code	Type of food	Supplier	Certified value	tAs report	iAs method	iAs technique	iAs reported value	References
CRM 7503-a	Rice	NMI J	tAs= 0.098 ± 0.007	0.098 ± 0.005	MAE/(HNO ₃ /H ₂ O ₂)	HPLC-ICPMS	iAs= 0.0849 ± 0.0007	Llorente-Mirandes et al. ⁴⁰
			As(III)= 0.0711 ± 0.0029	± 0.095 ± 0.005	MAE/(HNO ₃ /H ₂ O ₂)	HPLC-ICPMS	iAs= 0.0837 ± 0.0016	Llorente-Mirandes et al. ³⁹
			DMA= 0.0133 ± 0.0009	± 0.095 ± 0.001	HEAT (block)/(HNO ₃)	HPLC-ICPMS	As(III)= 0.067 ± 0.001	Huang et al. ¹⁸³
			As(V)= 0.013 ± 0.0009	±			As(V)= 0.015 ± 0.002	
				0.101 ± 0.005	HEAT (block)/(H ₂ O)	HPLC-ICPMS	As(III)= 0.0740 ± 0.0023	Narukawa et al. ¹⁸⁰
				As(V)= 0.0140 ± 0.0005			±	
	0.096 ± 0.002	MAE/(H ₂ O)	HPLC-ICPMS	As(III)= 0.0130 ± 0.0005	Narukawa et al. ¹⁹¹			
	As(V)= 0.0711 ± 0.0008			±				
	0.096 ± 0.002	HEAT (block)/(HNO ₃)	HPLC-ICPMS	As(III)= 0.0133 ± 0.0005				
	As(V)= 0.0717 ± 0.0007			±				
	0.096 ± 0.002	HEAT (block)/(HNO ₃ /A	HPLC-ICPMS	As(III)= 0.0712				

				As(V)= 0.0135	
0.096 ± 0.002	HEAT (block)/(HClO ₄)	HPLC- ICPMS	As(III)= 0.0714		
			As(V)= 0.0138		
0.099 ± 0.001	HEAT (block)/(HNO ₃)	HPLC- ICPMS	As(III)= 0.0714		Narukawa et al. ²³⁷
			0.0004		
			As(V)= 0.0134	±	
			0.0002		
No reported	Shaking/(HCl) /extraction (CHCl ₃ /back extr. 1 M HCl)/	ICPMS	iAs= 0.008	0.080 ±	Fontcuberta et al. ²³⁸
0.096 ± 0.002	HEAT (block)/(HNO ₃)	HPLC- ICPMS	As(III)= ± 0.002	0.057	Kuramata et al. ²³⁹
			As(V)= ± 0.003	0.017	
No reported	Shaking/(HCl) /extraction (CHCl ₃ /back extr. 1 M HCl)/	ICPMS	iAs= 0.0085	0.0815 ±	Wu et al. ²⁴⁰
No reported	Heat block/HNO ₃	HPLC- ICPMS	As (V)= ± 0.001	0.013	Baba et al. ¹⁹⁰
			As (III)= 0.068 ± 0.003		
No reported	Heat with water/Enzymatic ext.(amylase)	HPLC- ICPMS	As(III)= 0.0602		Nookabkae w et al. ²⁴¹
			0.0025		
			As(V)= 0.0145	±	
			0.0017		
No reported	Shaking/HCl/pep sin (bioaccessible extracts)	HPLC- HEPO- HG- ICPMS	As(III)= 0.0594		Oguri et al. ²⁴²
			0.0028		
			As(V)= 0.0226	±	
			0.0004		
No reported	MAE/ Enzymatic ext.(amylase)	CE- ICPMS	As(III)= 0.0621		Qu et al. ²¹⁸
			0.00173	±	
			As(V)= 0.01927	±	
			0.0011		
No reported	MAE/ Dispersive liquid-liquid micro- extraction integrated with the solidification of a floating organic drop	ETAAS	As(III)= 5.3	68.2 ±	Ahmadi- Jouibari and Fattahi ¹⁰⁹
			As(V)= 1.2	13.5 ±	
			iAs= 85.5 ± 6.1		

(DLLME-SFO)

ERM-BC211	Rice	IRM M	tAs= 0.260 ± 0.013	0.256 ± 0.009	MAE/(HNO ₃ /H ₂ O ₂)	HPLC-ICPMS	iAs= 0.122 ± 0.006	Llorente-Mirandes et al. ³⁶
			DMA= 0.119 ± 0.013	0.263 ± 0.011	MAE/(HNO ₃ /H ₂ O ₂)	HPLC-ICPMS	iAs= 0.119 ± 0.005	Zmozinski et al. ²⁴³
			iAs= 0.124 ± 0.011	No reported	MAE/(HNO ₃ /H ₂ O ₂)	SPE-HG-AFS	iAs= 0.124 ± 0.002	Chen. G et al. ¹⁵⁵
				No reported	MAE/(HNO ₃ /H ₂ O ₂)	HG-AFS	iAs= 0.1214 ± 0.0048	Chen. B et al. ¹⁵⁶
				0.256 ± 0.008	HEAT/(TFA)	HPLC-HG-AFS	iAs= 0.129 ± 0.012	Cano-Lamadrid et al. ¹⁷²
				0.257 ± 0.015	MAE/(HNO ₃)	HG-AAS	iAs= 0.116 ± 0.003	Cerveira et al. ¹³⁹
				No reported	HAE/(HNO ₃)	HPLC-ICPMS	iAs= 0.127 ± 0.001	Narukawa et al 2015 ¹⁸⁶
SRM 1568b	Rice	NIS T	tAs= 0.285 ± 0.014	No reported	MAE/ Enzymatic ext.(amylase)	CE-ICPMS	As (III)= 0.05542 ± 0.0019	Qu et al. ²¹⁸
			DMA= 0.180 ± 0.012				As(V)= 0.04092 ± 0.00678	
			MA= 0.0116 ± 0.0035					
			iAs= 0.092 ± 0.010	No reported	MAE/(HNO ₃ /H ₂ O ₂)	HPLC-ICPMS	iAs= 94.5 ± 2% *	Signes-Pastor et al. ³⁸
				No reported	HAE/(HNO ₃)	HPLC-ICPMS	iAs= 0.092 ± 0.004	Narukawa et al 2015 ¹⁸⁶
CRM 7532-a	Rice	NMI J	tAs=0.320 ± 0.010	No reported	HAE/(HNO ₃)	HPLC-ICPMS	iAs= 0.298 ± 0.003	Narukawa et al 2015 ¹⁸⁶
			iAs=0.298 ± 0.008					
			DMA= 0.0186 ± 0.0008					
CRM 7405-a	<i>Hizi kia fusif orme</i>	NMI J	tAs= 35.8 ± 0.9	No reported	Shaking/HCl/pep sin (bioaccessible extracts)	HPLC-HEPO-HG-ICPMS	As(V)= 10.2 ± 0.1	Oguri et al. ²⁴²
			As(V)= 10.1 ± 0.5					
				34.6 ± 0.7	Sonication/ 50% methanol solvent in 1% HNO ₃ / Anion-exchange cartridge	HPLC-ICPMS	As(V)= 9.8 ± 0.8	Khan et al 2015 ²⁰⁵

2449 Notes. The ± terms are as provided by the original publications. They are predominantly standard
2450 deviations for some number of replicates or in some cases uncertainties. MAE: microwave assisted
2451 extraction. HAE: heat assisted extracted technique.

2452 * Expressed as the original publication as % of recovery compared to the certified value.

2453

2454 **Table III.** Food CRMs with published results of an inorganic arsenic content. Results
 2455 obtained from literature (2010-2015) and expressed as mg As/kg.

CRMs Code	Type of food	Supplier	Certified tAs value	tAs reported	iAs method	iAs technique	iAs reported value	References	
NCS ZC73008	Rice	CN CIS	0.102 ± 0.008	0.105 ± 0.006	MAE/(HNO ₃ /H ₂ O) ₂	HPLC-ICPMS	iAs= 0.080 ± 0.003	Llorente - Mirandes et al. ⁴⁰	
				No reported	MAE/(HNO ₃ /H ₂ O) ₂	HPLC-ICPMS	iAs= 0.084 ± 0.001		
GBW 10010	Rice	CA GS	0.102 ± 0.008	0.1099 ± 0.0072	Incubation 80°C/Ultra-pure water	HPLC-ICPMS	As(III)= 0.0461 ± 0.0024 As(V)= 0.156 ± 0.0016	Liang et al. ²⁵⁰	
					Incubation 80°C/(Acetic acid (1%))	HPLC-ICPMS	As(III)= 0.0477 ± 0.0009 As(V)= 0.0152 ± 0.0004		
					Incubation 80°C/(Nitric acid (1%))	HPLC-ICPMS	As(III)= 0.0616 ± 0.0045 As(V)= 0.0079 ± 0.0051		
					Incubation 80°C/(TFA (0.2 M))	HPLC-ICPMS	As(III)= 0.0645 ± 0.0009 As(V)= 0.0110 ± 0.0003		
					Incubation 80°C/(TFA (2 M))	HPLC-ICPMS	As(III)= 0.0619 ± 0.004 As(V)= 0.0174 ± 0.003		
					Incubation 80°C/(Methanol (50%))	HPLC-ICPMS	As(III)= 0.0536 ± 0.0077 As(V)= 0.0128 ± 0.002		
					Incubation 80°C/Methanol (50%)/TFA (0.2M)	HPLC-ICPMS	As(III)= 0.0626 ± 0.0056 As(V)= 0.0118 ± 0.0029		
SRM	Whea	NIS	0.00	0.0065	MAE/(enzymatic	HPLC-	As(III)= 0.0032 ±	Tsai et	

1567a	Wheat flour	T	6	±	0.0006	extraction)	ICPMS	0.00004		al. ¹⁹³
								As(V)=	0.0027 ±	
								0.00005		
SRM 8436	Durum Wheat Flour	NIS				SON/(MeOH/H ₂ O)	HPLC-ICPMS	As(III)=	0.0012 ±	
								0.0002		
								As(V)=	0.00723 ±	
								0.00008		
						0.013 ±	Ultrasonic probe/(H ₂ O)	HPLC-ICPMS	As(III)=	0.00318 ±
						0.001			0.00009	D'Amato et al. ¹⁹⁵
								As(V)=	0.0027 ±	
								0.00025		
						0.013 ±	MAE/(HNO ₃)	HPLC-ICPMS	As(V)=	0.0109 ±
						0.001			0.0006	
						0.013 ±	MAE/(enzymatic extraction)	HPLC-ICPMS	As(III)=	0.00216 ±
						0.001			0.00044	
								As(V)=	0.00169 ±	
								0.0003		
SRM 1570a	Spinach leaves	NIS	0.06	8 ±	No reported	Shaking/(HCl)/extraction (CHCl ₃ /back 1 M HCl)/	FI-HG-AAS	iAs=	0.038 ± 0.005	
			0.01	2		MAE/(HNO ₃ /H ₂ O ₂)	HPLC-ICPMS	iAs=	0.075 ± 0.004	
						Shaking/(HCl)/extraction (CHCl ₃ /back 1 M HCl)/	ICPMS	iAs=	0.074 ± 0.010	de la Calle et al. ⁴⁸
						MAE/(HNO ₃ /H ₂ O ₂)	HPLC-ICPMS	iAs=	0.060 ± 0.002	
						MAE/(HNO ₃ + H ₂ O ₂)	HPLC-ICPMS	iAs=	0.055 ± 0.003	
						MAE/(HCl/H ₂ O ₂)	HPLC-ICPMS	iAs=	0.034 ± 0.005	
						MAE/(TFA/H ₂ O ₂)	HPLC-ICPMS	iAs=	0.045 ± 0.003	
						0.069 ±	MAE/(HNO ₃ /H ₂ O ₂)	HPLC-ICPMS	iAs=	0.059 ± 0.005
						0.005				Llorente - Mirandes et al. ³⁶
SRM 1573a	Tomato leaves	NIS	0.11	2 ±	No reported	UAE/(H ₂ SO ₄ /EDTA)	HG-AFS	As(V)=	0.0879 ±	Sousa-Ferreira et al. ¹⁵⁴
			0.00	4				0.0021		
								As(III)=	0.0226 ±	
								0.0003		
NCS ZC730 12	Cabbage	CN CIS	0.06	2 ±	0.0603 ±	MAE/(HNO ₃ /H ₂ O ₂)	HPLC-ICPMS	iAs=	0.0519 ±	Norton et al. ²⁵¹
			0.01	4	0.0007			0.0035		
SRM 1577	Bovine	NIS	0.05	5 ±	0.053 ±	SON/HNO ₃ /MeOH	HPLC-ICPMS	As(V)=	0.012 ±	Batista et al. ¹⁰³
			0.00		0.002			0.001		

	Liver		0.005						
SRM 1566a	Oyster tissue	NIS T	14.0 ± 1.2	No reported	Shaking/(HCl)/extraction (CHCl ₃ /back 1 M HCl)/	FI-HG-AAS	iAs= 0.586 ± 0.049	Ruangwises et al. ¹⁴⁶	
				No reported	Shaking/(HCl)/extraction (CHCl ₃ /back 1 M HCl)/	FI-HG-AAS	iAs= 0.601 ± 0.037	Ruangwises et al. ¹⁴⁹	
				No reported	Shaking/(HCl)/extraction (CHCl ₃ /back 1 M HCl)/	FI-HG-AAS	iAs= 0.598 ± 0.035	Ruangwises et al. ¹⁴⁴	
				No reported	Shaking/(HCl)/extraction (CHCl ₃ /back 1 M HCl)/	FI-HG-AAS	iAs= 0.581 ± 0.050	Saipan et al. ¹⁴⁵	
				No reported	Shaking/(HCl)/extraction (CHCl ₃ /back 1 M HCl)/	FI-HG-AAS	iAs= 0.601 ± 0.037	Ruangwises et al. ¹⁵⁰	
				No reported	Shaking/(HCl)/extraction (CHCl ₃ /back 1 M HCl)/	FI-HG-AAS	iAs= 0.601 ± 0.037	Saipan et al. ¹⁵¹	
SRM 1566b	Oyster tissue	NIS T	7.65 ± 0.65	6.94 ± 0.2 and 7.2 ± 0.3	MAE/(MeOH/H ₂ O)	HPLC-ICPMS	As(V)= 1.16 ± 0.01	Santos et al. ²⁵²	
				7.67 ± 0.13	MAE/(HNO ₃ /H ₂ O)	HPLC-ICPMS	iAs= 0.05 ± 0.001	Zmozinski et al. ²⁴³	
				No reported	MAE/(H ₂ O)	IEC-ICPMS	As(III)= 0.357 ± 0.057 As(V)= 0.427 ± 0.038	Leufroy et al. ²⁵³	
				8.06 ± 0.08	MAE/(MeOH/H ₂ O)	IC-ICPMS	As(V)= 0.05 ± 0.01	Nam et al. ²⁵⁴	
CRM 108-04-001	Oyster tissue	KRI SS	13.51 ± 0.30	14.19 ± 0.09	MAE/(MeOH/H ₂ O)	IC-ICPMS	As(V)= 0.03 ± 0.01	Nam et al. ²⁵⁴	
MURS T-ISS-A2	Antarctic Krill	BC AA	5.02 ± 0.44	5.29 ± 0.4	Shaking/(MeOH/H ₂ O)	HPLC-ICPMS	As(V)= 0.03 ± 0.01	Grotti et al. ²⁵⁵	
SRM 2976	Musshell tissue	NIS T	13.30 ± 1.8	13.7 ± 0.25	MAE/(HNO ₃ /H ₂ O)	HPLC-ICPMS	iAs= 0.11 ± 0.013	Zmozinski et al. ²⁴³	
ERM-CE278	Musshell tissue	IRM M	6.07 ± 0.13	6.09 ± 0.21	MAE/(HNO ₃ /H ₂ O)	HPLC-ICPMS	iAs= 0.07 ± 0.003	Zmozinski et al. ²⁴³	
				5 ± 0.6	SON/	HPLC-	As(III)= 0.2 ± 0.02	Batista	

					(HNO ₃ /MeOH)	ICPMS	As(V)= 0.4 ± 0.04		et al. ¹⁰³
BCR 627	Tuna fish tissue	IRM M	4.8 ± 0.3	5.2 ± 0.5	± MAE/(H ₂ O)	IEC/ICP-MS	As(III)= 0.014	0.054 ±	Leufroy et al. ²⁵⁶
			4.8 ± 0.3	± MAE/(MeOH/H ₂ O)	IEC/ICP-MS	As(III)= 0.071	0.172 ±		
			4.68 ± 0.03	± MAE/(MeOH/H ₂ O)	HPLC-ICPMS	As(III)= 0.29 ± 0.04	±	Santos et al. ²⁵²	
						As(V)= 0.035 ± 0.001			
			4.1	SON/(Enzymatic solution)	IC-ICPMS	iAs= 0.036		Dufailly et al. ¹⁹⁸	
			4.84 ± 0.13	± MAE/(HNO ₃ /H ₂ O)	HPLC-ICPMS	iAs= 0.02 ± 0.002		Zmozinski et al. ²⁴³	
			No reported	MAE/(H ₂ O)	IEC-ICPMS	As(III)= 0.003	0.068 ±	Leufroy et al. ²⁵³	
						As(V)= 0.041 ± 0.001			
4.20 ± 0.03	± Shaking (two-step sequential extraction)/acetone and MeOH/water	HPLC-HR-ICPMS	As(III)= LOD	below	Ruiz-Chancho et al. ²⁵⁷				
			As(V)= below LOD						
No reported	Cell clean-up - PAEH	HPLC-ICPMS	As(III)= 0.0006	0.075 ±	Moreda-Piñeiro et al. ²⁵⁸				
4.82 ± 0.41	± Shaking/(HCl)/extraction (CHCl ₃ /back extr. 1 M HCl)/	HR-ICPMS	iAs= 0.82 ± 0.049		Lewis et al. ¹²¹				
DOLT -3	Dogfish Muscle	NR C-CN RC	10.2 ± 0.5	10.0 ± 0.4	± MAE/(H ₂ O)	IEC-ICPMS	As(III)= 0.011	0.074 ±	Leufroy et al. ²⁵⁶
							As(V)= 0.073 ± 0.007		
			9.6 ± 1.1	± MAE/(MeOH/H ₂ O)	IEC-ICPMS	As(III)= 0.004	0.136 ±		
			No reported	MAE/(Enzymatic extraction)	CE-ICPMS	iAs below LOD		Hsieh et al. ²¹⁵	
10 ± 0.4	SON/(HNO ₃ /MeOH)	HPLC-ICPMS	As(III)= 0.3 ± 0.1		Batista et al. ¹⁰³				
			As(V)= 0.4 ± 0.2						
DOLT -4	Dogfish Muscle	NR C-CN RC	9.66 ± 0.62	No reported	MAE/(HCl/H ₂ O ₂)	HPLC-ICPMS	iAs= 0.039 ± 0.001		
					MAE/(HCl/H ₂ O ₂)	HPLC-HG-ICPMS	iAs= 0.011 ± 0.002		Pétursdóttir et al. ²⁰²
					MAE/(HNO ₃)	HPLC-ICPMS	iAs= 0.028 ± 0.003		
					MAE/(HNO ₃)	HPLC-HG-	iAs= 0.011 ± 0.002		

					MAE/(NaOH/EtOH)	ICPMS HPLC-ICPMS	iAs= 0.027 ± 0.003	
					MAE/(NaOH/EtOH)	HPLC-HG-ICPMS	iAs= 0.010 ± 0.003	
No reported					MAE/(HCl/H ₂ O ₂)	HPLC-ICPMS	iAs=<0.040	
					MAE/(MeOH/H ₂ O)	HPLC-ICPMS	iAs=ND	
					SON/(TFA/H ₂ O ₂)	HPLC-ICPMS	iAs= 0.047 ± 0.006	
					Shaking/(HCl)/ /extraction (CHCl ₃ /back extr. 1 M HCl)/ Shaking/(HCl) /extraction (CHCl ₃ /back extr. 1 M HCl)/	FI-HG-AAS	iAs= 0.075 ± 0.005	Baer et al. ⁴⁷
						HR-ICPMS	iAs= 0.152 ± 0.010	
No reported					MAE/(HCl/H ₂ O ₂)	HPLC-HG-ICPMS	iAs= 0.011 ± 0.002	
					MAE/(H ₂ O/MeOH)	HPLC-HG-ICPMS	iAs= 0.012 ± 0.003	
					SON and MAE/(TFA/H ₂ O ₂)	HPLC-HG-ICPMS	iAs= 0.011 ± 0.004	
					Shaking/(HCl)/ /extraction (CHCl ₃ /back extr. 1 M HCl)/	HPLC-HG-ICPMS	iAs= 0.036 ± 0.007	
					MAE/(HNO ₃)	HPLC-HG-ICPMS	iAs= 0.011 ± 0.002	Pétursdóttir et al. ¹⁶³
					MAE/(HNO ₃ /H ₂ O ₂)	HPLC-HG-ICPMS	iAs= 0.017 ± 0.003	
					MAE/(H ₂ O)	HPLC-HG-ICPMS	iAs= 0.011 ± 0.003	
					SON/(H ₂ O)	HPLC-HG-ICPMS	iAs= 0.010 ± 0.001	
					MAE/(NaOH/EtOH)	HPLC-HG-ICPMS	iAs= 0.010 ± 0.003	
	9.64 ± 0.11				MAE/(HNO ₃ /H ₂ O ₂)	HPLC-ICPMS	iAs= 0.02 ± 0.003	Zmozinski et al. ²⁴³
No reported					MAE/(H ₂ O)	IEC-ICPMS	As(III)= 0.253 ± 0.019 As(V)= 0.134 ± 0.006	Leufroy et al. ²⁵³
DOR M-2	Dogfish Muscle	NR C-NR	18.0 ± 1.1	18.75 ± 0.66	MAE/(MeOH/H ₂ O)	HPLC-ICPMS	As(III)= 0.61 ± 0.04	Santos et al. ²⁵²

				17.9 ± 0.9	MAE/(H ₂ O)	IEC-ICPMS	As(III)= 0.014 As(V)= 0.018	0.031 ± 0.029	Leufroy et al. ²⁵⁶
				19.7 ± 0.4	MAE/(MeOH/H ₂ O)	IEC-ICPMS	As(III)= 0.011 As(V)= 0.002	0.064 ± 0.026	
				17.0 ± 0.7	Shaking (two-step sequential extraction)/acetone and MeOH/water	HPLC-HR-ICP-MS	As(III)= LOD As(V)= below LOD	below LOD	Ruiz-Chancho et al. ²⁵⁷
				17.9 ± 0.98	Step 1: MAE/(HClO ₄ /Fe ₂ (SO ₄) ₃ /HCl) Step 2: (As(III)):SON/HCl/CHCl ₃ /HCl	ETTAS	As(III)= 0.001 As(V)= 0.002	0.053 ± 0.051	Shah et al. ¹¹¹
				16.9 ± 0.3	Cell clean-up PAEH	HPLC-ICPMS	As(III)= 0.0005	0.081 ± 0.081	Moreda-Piñeiro et al. ²⁵⁸
				19.5 ± 1.3	Shaking/(HCl)/extraction (CHCl ₃ /back extr. 1 M HCl)/	HR-ICPMS	iAs= 0.131 ± 0.010		Lewis et al., 2012 ¹²¹
				No reported	Ultrasonic bath/H ₂ O	SIA-HPLC-AFS	As(III)= 0.02	0.037 ± 0.037	Jesus et al. ¹⁶⁹
DOR M-3	Dogfish Muscle	NR C-NRC	6.88 ± 0.30	5.8 ± 0.4	MAE/(H ₂ O)	IEC-ICPMS	As(III)= 0.014 As(V)= 0.023	0.085 ± 0.243	Leufroy et al. ²⁵⁶
				7.1 ± 0.4	MAE/(MeOH/H ₂ O)	IEC-ICPMS	As(III)= 0.018 As(V)= 0.036	0.129 ± 0.276	
				No reported	MAE/(EtOH/NaOH)	HPLC-ICPMS	iAs= 0.073 ± 0.008		Pétursdóttir et al. ²⁵⁹
				No reported	MAE/(H ₂ O)	HPLC-HG-ICPMS	iAs= 0.11 ± 0.01		
					MAE/(H ₂ O/H ₂ O ₂)	HPLC-HG-ICPMS	iAs= 0.12 ± 0.01		Pétursdóttir et al. ¹⁶³
					MAE/(HNO ₃ /H ₂ O ₂)	HPLC-HG-ICPMS	iAs= 0.16 ± 0.01		
				No reported	MAE/(HCl/H ₂ O ₂)	HPLC-ICPMS	iAs= 0.19 ± 0.01		Rasmusen et al. ¹³⁷
					MAE/(HCl/H ₂ O ₂)	SPE-HG-AAS	iAs= 0.18 ± 0.02		
				No reported	MAE/(H ₂ O)	IEC-ICPMS	As(III)= 0.134 ± 0.134		Leufroy

				reported		ICPMS	0.008 As(V)= 0.263 ± 0.009	et al. ²⁵³
			7 ± 0.8	SON/(HNO ₃ /MeOH)		HPLC-ICPMS	As(V)= 0.4 ± 0.06	Batista et al. ¹⁰³
			No reported	Shaking/SON/(H ₂ O)		CE-ICPMS	As(V)= 1.40 ± 0.04	Liu et al. ²¹⁷
CRM n 9	<i>Sargassum mfulvellum</i>	NIE S	115 ± 9	110.3 ± 0.7	Shaking/(Water)	HPLC-ICPMS	As (V) = 69.9 ± 1	Llorente - Mirandes et al. ^{260,261}
				117 ± 2	Shaking/(Water)	HPLC-ICPMS	As(V)= 68.5 ± 6.6	Ruiz-Chancho et al. ²⁶²
				109 ± 2	MAE/(Water)	HPLC-(UV)-HG-AFS	As(V)= 70 ± 1	Garcia-Salgado et al. ¹⁷⁰
BCR-279	<i>Ulva lactuca</i>	IRM M	3.09 ± 0.21	2.9 ± 0.3	Shaking/(Water)	HPLC-ICPMS	As(III)= 0.06 ± 0.03 As(V)= 0.53 ± 0.04	Pell et al. ^{263,264}
				3.4 ± 0.1	SON/(Water)	HPLC-ICPMS	As(V)= 0.7	Caumette et al. ²⁶⁵

2456 Notes. The ± terms are as provided by the original publications. They are predominantly standard
2457 deviations for some number of replicates or in some cases uncertainties. MAE; Microwave Assisted
2458 Extraction; SON: Sonication; PAEH: Pressurized Assisted Enzymatic Hydrolysis Extraction; UAE:
2459 Ultrasound-Assisted Extraction.

2460

2461 **Table IV.** Proficiency tests and method validation focused on the determination of iAs
2462 in foodstuffs organized by EC-JRC-IRMM.

Proficiency test	Type of food	Objective	Analyte	Assigned values (mg As kg ⁻¹) ^a	Results of participants ^b	Com
IMEP-107 (2010)	Rice (produced IRMM)	Judge the state of by the art of analytical capability for the determination of total and iAs	tAs and iAs	tAs= 0.172 ± 0.018 and iAs= 0.107 ± 0.014	tAs, z= 77% (n=71) and iAs, z= 75% (n=21)	· Sa · iAs. · Th · that · A · unce
IMEP-30/109 (2010)	Dogfish (NRC DOLT-4)	liver · To evaluate the analytical capabilities of nominated NRL and other laboratories	Cd, Pb, As, Hg, iAs and MeHg	tAs= 9.66 ± 0.62 and iAs= not assigned	· IMEP-30: tAs, z= 89% (n=42) and no scored for iAs · IMEP-109: tAs, z= 85% (n=28) and no scored for iAs	· Fe · resu · Un

IMEP-112 (2011)	Wheat (produced by IRMM)	To judge the state of the art of the determination of total and iAs in food	tAs and iAs	tAs= 0.177 ± 0.012 and iAs= 0.169 ± 0.025	tAs, z= 84% (n=51) and iAs, z= 58% (n=23)	· Sa
	Vegetable food (NIST SRM 1570a spinach leaves)			tAs= 0.068 ± 0.012 and iAs= 0.054 ± 0.012	tAs, z= 74% (n=35) and iAs, z= 77% (n=23)	· Sa
	Algae (produced by IRMM)			tAs= 58.3 ± 7.0 and iAs= 0.188 ± 0.025	tAs, z= 82% (n=41) and iAs, z= 16% (n=6)	· Lo · Tv · bias · Un · dige
IMEP-39/116 (2013)	Mushroom (produced by IRMM)	To test the analytical capabilities of laboratories to determine heavy metals and iAs in mushrooms.	Cd, Pb, As, Hg and iAs	tAs= 0.646 ± 0.048 and iAs= 0.321 ± 0.026	· IMEP-116: tAs, z= 91% (n=29) and iAs, z= 81% (n=13) · IMEP-39: tAs, z= 65% (n=35) and iAs, z= 64% (n=7)	· In · In · for i · F · repc · ICP · A · wer
IMEP-118 (2014)	Canned food (peas in brine) (produced by IRMM)	· To assess the analytical capabilities of participating laboratories · To evaluate the various sample preparation approaches when analyzing canned vegetables using the drained product or the the solid/liquid composite	As, Cd, Pb, Hg, Sn and iAs	Drained product: tAs= 0.117 ± 0.018 and iAs= 0.098 ± 0.020 Solid/liquid composite: tAs= 0.121 ± 0.014 and iAs= 0.082 ± 0.008	tAs, z= 92% (n=47) and iAs, z=84% (n=16). tAs, z= 82% (n=42) and iAs, z=74% (n=17).	· iA · agre · · over · tA · drai · solid · A · A · unce · Si · repc · meth
IMEP-41 (2014)	Rice (IMEP-107)	· To determine the performance characteristics of an analytical method for the quantification of inorganic arsenic	· Inorganic arsenic	iAs= 0.108 ± 0.011	· RSD _r = 7.8% · RSD _R = 15.6 · Overall mean= 0.096 ± 0.030 · Rec= 88.9 ± 29.4	
	Wheat (IMEP-112)			iAs= 0.165 ± 0.021	· RSD _r = 10.1% · RSD _R = 10.9% · Overall mean= 0.146 ± 0.032 · Rec= 88.7 ± 22.5	
	Mussels (ERM-CE278k)			iAs= 0.0863 ± 0.008	· RSD _r = 8.6% · RSD _R = 18.2% · Overall mean= 0.133 ± 0.048 · Rec= 153.7 ± 57.6	

Cabbage (IAEA-359)	iAs= 0.091 ± 0.016	· RSD _r = 9.6% · RSD _R = 22.1% · Overall mean= 0.074 ± 0.033 · Rec= 81.6 ± 38.7	· The in th agre expe by i orga spec
Mushroom (IMEP-116)	iAs= 0.321 ± 0.026	· RSD _r = 4.1% · RSD _R = 6.1% · Overall mean= 0.275 ± 0.034 · Rec= 85.8 ± 12.6	
Seaweed (NMIJ-7405a)	iAs= 10.10 ± 0.50	· RSD _r = 4.7% · RSD _R = 15.2% · Overall mean= 7.548 ± 2.301 · Rec= 74.7 ± 23.1	
Fish (DORM-4)	iAs= 0.271 ± 0.061	· RSD _r = 10.3% · RSD _R = 22.8% · Overall mean= 0.295 ± 0.134 · Rec= 108.8 ± 55.4	Poin cont sepa
Rice (ERM-BC211)	iAs= 0.124 ± 0.011	Pre-test item of participants laboratories	Lab the IME

2463 ^a Assigned value for expert laboratories as $X_{ref} \pm U_{ref}(k = 2)$;

2464 ^b In IMEP-107, IMEP-30/109, IMEP-112, IMEP-39/116 and IMEP-118: results of
2465 participants are referred to % of z-score to $z \leq 2$ (n=number of laboratories).

2466 RSD_r= repeatability relative standard deviation; RSD_R= reproducibility relative standard
2467 deviation; Rec=Recovery= X participants · 100/X assigned value.

2468

2469 **Inorganic arsenic determination in food: A review on analytical proposals and**
2470 **quality assessment over the last six years**

2471

2472 **Figure captions**

2473

2474 **Figure 1.** Blue plot is the number of papers published each year dealing with the As
2475 species either iAs as a function of time (1985-2014). Red plot refers to number of
2476 papers dealing with speciation of As species and iAs in the field of food and
2477 alimentation. Green plot shows the number of publications dealing only with iAs and
2478 relationship with food and alimentation.

2479 **Figure 2.** Distribution of publications (2010-2015) on the basis of research area of
2480 inorganic arsenic (a) and on the basis of types of analyzed foods of inorganic arsenic
2481 (b).

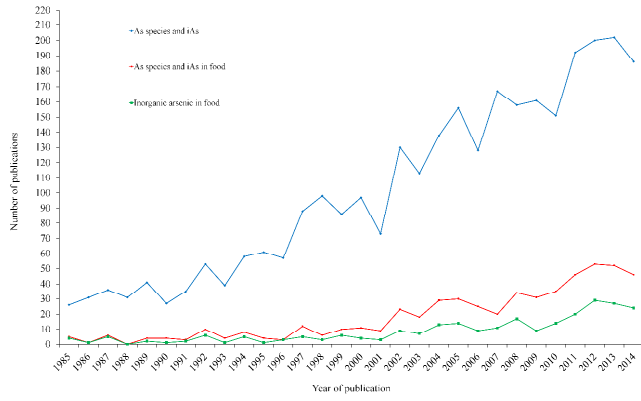
2482 **Figure 3.** Scheme of the different steps required to perform total and inorganic arsenic
2483 determination in foodstuffs.

2484 **Figure 4.** Anion exchange HPLC-ICPMS chromatograms of rice (a), infant multicereals
2485 (b), Hijiki seaweed (*Sargassum fusiforme*) (c), mushroom supplement (*Grifola*
2486 *frondosa*, commercially known as Maitake) (d), tuna fish (e), and mussel (f).

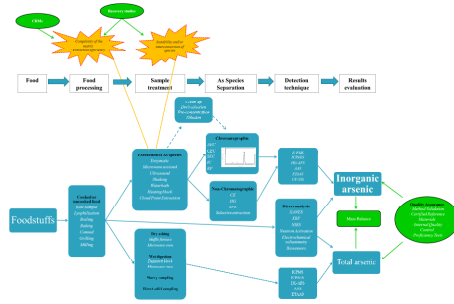
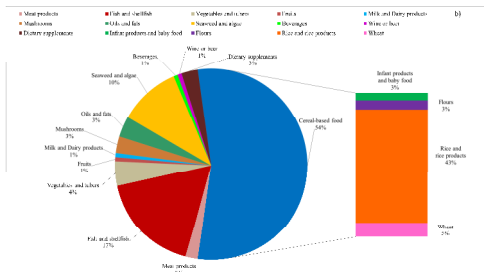
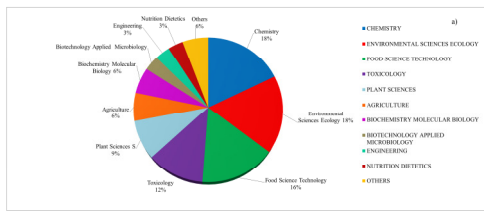
2487 **Figure 5.** Inorganic arsenic concentration in NIST SRM 1568a reported in the literature
2488 (blue rhombus, 2010-2015). The continuous black line represents the average
2489 concentration and the red dashed lines delimit the target interval ($X \pm SD = 0.098 \pm$
2490 $0.009 \text{ mg As kg}^{-1}$ of inorganic arsenic). X axis shows the measurement technique and
2491 reference.

2492 **Figure 6.** Inorganic arsenic concentration in NRC-CNRC TORT-2 reported in the
2493 literature (green rhombus, 2010-2015). The continuous black line represents the average
2494 concentration and the red dashed lines delimit the target interval ($X \pm SD = 0.606 \pm$
2495 $0.215 \text{ mg As kg}^{-1}$ of inorganic arsenic). X axis shows the measurement technique and
2496 reference.

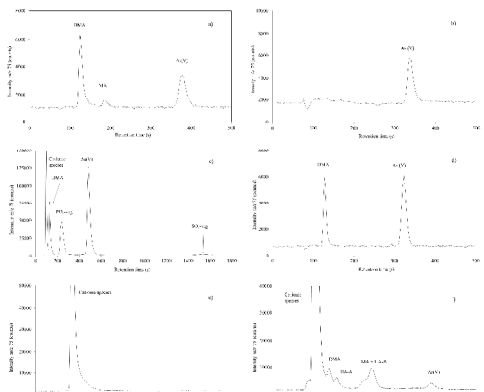
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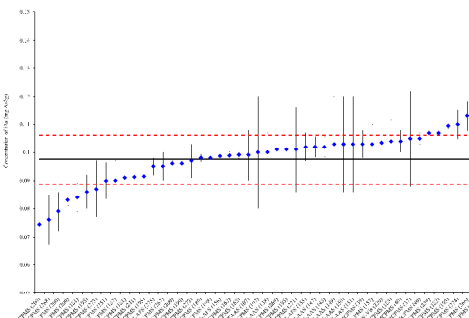
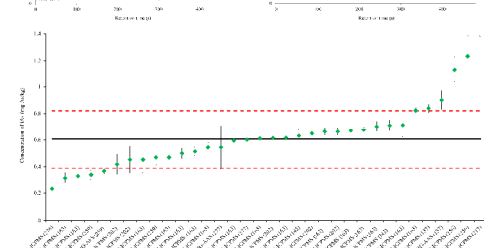
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