

Accurate Measurement of Arsenic in Laver by Gravimetric Standard Addition Method Combined with High Resolution Inductively Coupled Plasma Mass Spectrometry

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Abstract: A gravimetric standard addition method combined with internal standard calibration has been successfully developed for the accurate analysis of total arsenic in a laver candidate reference material. A model equation for the gravimetric standard addition approach using an internal standard was derived to determine arsenic content in samples. Handlings of samples, As standard and internal standard were carried out gravimetrically to avoid larger uncertainty and variability involved in the volumetric preparation. Germanium was selected as the internal standard because of its close mass to the arsenic to minimize mass-dependent bias in mass spectrometer. The ion signal ratios of $^{75}\text{As}^+$ to $^{72}\text{Ge}^+$ (or $^{73}\text{Ge}^+$) were measured in high resolution mode ($R \geq 10,000$) to separate potential isobaric interferences by high resolution ICP/MS. For method validation, the developed method was applied to the analysis of arsenic content in the NMIJ 7402-a codfish certified reference material (CRM) and the result was $37.07 \text{ mg}\cdot\text{kg}^{-1} \pm 0.45 \text{ mg}\cdot\text{kg}^{-1}$ which is in good agreement with the certified value, $36.7 \text{ mg}\cdot\text{kg}^{-1} \pm 1.8 \text{ mg}\cdot\text{kg}^{-1}$. Finally, the certified value of the total arsenic in the candidate laver CRM was determined to be $47.15 \text{ mg}\cdot\text{kg}^{-1} \pm 1.32 \text{ mg}\cdot\text{kg}^{-1}$ ($k = 2.8$ for 95% confidence level) which is an excellent result for arsenic measurement with only 2.8 % of relative expanded uncertainty.

Keywords : arsenic, gravimetric standard addition, internal standard, laver, certified reference material

Introduction

Many countries set regulations on the concentrations of arsenic in drinking water and foods due to its well-known toxicity.¹⁻⁴ Elevated dietary exposure to high levels of arsenic can be a potential threat to human health. Especially in sea weeds, arsenic has been frequently found in concentrations exceeding the regulation limits. In particular, laver has been traditionally consumed in large quantities in far-east Asian countries and, nowadays, they are gaining widespread popularity worldwide. Therefore, the accurate determination of arsenic in laver can be a matter of concern for the food safety in many counties.²⁻⁵ In order to assure the quality of measurement results, use of relevant certified reference

material (CRM) has been recommended to analytical laboratories for the method validation and quality control in ISO/IEC 17025.⁶ The development of CRM for arsenic analysis in laver is also very important as a means to assist field laboratories to get reliable measurement results.

Accurate determination of elemental contents in a complex matrix is best realized using primary methods with the highest level of reliability including the isotope dilution (ID) inductively-coupled plasma mass spectrometry (ICP/MS). However, the ID ICP/MS analysis of arsenic is impossible because arsenic has only one stable isotope. Application of another potential primary method, the instrumental neutron activation analysis (INAA), is often not practically possible due to limited accessibility to facilities with neutron radiation source.⁷ As an alternative approach, development of an arsenic measurement method based on conventional analytical methods such as ICP/MS can be also considered provided that rigorous measurement and calibration strategies are implemented.

For the accurate determination of arsenic using ICP/MS, it is essential to exclude spectral interferences to $^{75}\text{As}^+$ from isobars such as $^{40}\text{Ar}^{35}\text{Cl}^+$ and $^{59}\text{Co}^{16}\text{O}^+$. For this purpose, either higher mass resolution⁸ or collision/reaction cells are used. Non-spectral matrix effect is another important factor to be controlled to get right results from the ICP/MS measurement. Arsenic can be separated from the sample

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matrix to remove the matrix effect but incomplete recovery of arsenic and lack of robust recovery correction method poses a significant challenge to develop it as a reliable analysis method. Standard addition method (SAM) is one of the robust calibration method for ICP/MS analysis to overcome the measurement bias stemming from matrix effects without matrix separation.^{9,10} Provided that the procedure blank is tightly controlled and evaluated, it is expected to produce reliable result even in the presence of severe matrix effects. One of the pitfalls of the SAM, however, is relatively large uncertainty as a natural consequence of the extrapolation calibration. In order to achieve the highest level of accuracy to the extent of assigning the certified value for CRM development, gravimetric sample handling in the standard addition procedure is necessary as well as the use of appropriate internal standards.¹¹ In this study, an ICP/MS-based arsenic measurement procedure was established with rigorous gravimetric standard addition method (SAM) combined with internal standard calibration as the most robust calibration strategy next to the ID ICP/MS. The method was applied to measure arsenic content in NMIJ 7402-a codfish CRM for method validation and certification of arsenic content laver candidate CRM.

Experimental

Materials and reagents

The dry laver powder sample was provided by the National Institute of Metrology (NIM), China, which is a candidate reference material of the Asian Collaboration on Reference Materials (ACRM) program. The codfish CRM (NMIJ CRM 7402-a) used for method validation and quality control was obtained from the National Metrology Institute of Japan (NMIJ). The arsenic standard solution for standard additions and the germanium standard solution for internal standard were produced by Korea Research Institute of Standards and Science (KRISS) with traceability to the SI unit. The working standard solutions of the arsenic and the germanium were freshly prepared just before sample preparation by diluting the stock solutions of 1000 mg·kg⁻¹ with 5% (w/w) nitric acid. Nitric acids with various concentrations used throughout this study were prepared just before sample preparation by diluting the high purity concentrated nitric acid (≥65%) with deionized water (18 MW·cm resistivity) from Milli-Q RG purification system (Millipore, USA). The high purity concentrated nitric acid was obtained by sub-boiling distillation of commercially available concentrated nitric acid from DONGWOO FINE-CHEM (Iksan, Korea).

Sample preparation with standard addition procedure

About 0.2 g of laver powder from each bottle was sampled and weighed directly into a PTFE-TFM microwave vessel. Total six subsamples from different bottles of laver powder were prepared. Then, about 1 g of the germanium working standard solution with an appropriate mass fraction was added

in each PTFE-TFM vessel and weighed exactly. For standard addition calibration, different amounts of the arsenic working standard solution were added in five levels from 1 g to 5 g, respectively, into the five PTFE-TFM vessels containing both sample and internal standard. The remaining one vessel was prepared without adding the arsenic working standard solution. Then, the samples in the six vessels were digested with 8 mL of concentrated nitric acid and 2 mL of 30% hydrogen peroxide solution using microwave digestion system (ETHOS PLUS, Milestone, USA). Microwave-assisted acid digestion was carried out with the temperature control program to increase temperature from room temperature to 200°C for 10 min and maintain it for 10 min. The digested samples were transferred into LDPE bottles and diluted appropriately for ICP/MS measurements. The analysis of the NMIJ 7402-a codfish CRM was also carried out for the validation of the developed method. Six aliquots (0.2 g each) of codfish powder from a single bottle were sampled individually in six PTFE-TFM microwave vessels. Then, the same procedure was used for preparation of standard addition samples.

For dry mass correction of laver powder, three subsamples were taken in parallel with the sampling for arsenic analysis. The subsample was about 0.2 g each and accurately weighed in a weighing bottle. After the samples in weighing bottles were dried at 102°C for 12 hours using a drying oven, the dried weights of the subsamples were measured. Finally, the losses of weights were used for the dry mass correction. In the dry mass correction for NMIJ 7402-a codfish sample, the procedure was the same except for taking 0.3 g of subsamples and drying at 102°C for 6 hours following the instruction of the certificate.

High resolution (HR) ICP/MS measurements of arsenic and germanium

Signal intensities as counts per second (cps) of arsenic ions (⁷⁵As⁺) and germanium ions (⁷²Ge⁺ and ⁷³Ge⁺) were measured using an HR ICP/MS (Element2, Thermo Fisher Scientific Inc., Germany) at high resolution mode. Sample solution was nebulized through quartz micro-concentric nebulizer at a flow rate of 400 mL·min⁻¹ into the Scott-type quartz spray chamber using a peristaltic pump. Fine aerosols generated in the spray chamber were introduced into the ICP plasma by quartz torch and injector. The operating conditions of HR ICP/MS are summarized in Table 1.

Table 1. Optimized operating conditions of HR ICP/MS for measurements of arsenic and germanium

Measured ions	⁷² Ge ⁺ , ⁷³ Ge ⁺ , ⁷⁵ As ⁺
Sampler/skimmer cones	Ni
Plasma gas flow rate	16 L·min ⁻¹
Auxiliary gas flow rate	0.8 L·min ⁻¹
Nebulizer gas flow rate	0.934 L·min ⁻¹
Plasma RF power	1250 W
Resolution	High resolution (R~10,000)

Results and Discussion

Gravimetric SAM with internal standard: Measurement Equation

The model equation for the gravimetric SAM for the analysis of the element, E, with the internal standard, IS, was derived for the analysis of total arsenic by ICP/MS. In this method, all the handlings of sample X, internal standard solution Y, and standard solution Z are carried out gravimetrically as shown by Figure 1. For an i^{th} solution, mass $m_{Z,i}$ of standard Z with mass fraction $w_Z(E)$ is added into the mixture consisted of mass $m_{X,i}$ of sample X with mass fraction $w_X(E)$ and mass $m_{Y,i}$ of internal standard Y with mass fraction $w_Y(AS)$. Then, ICP/MS measures the ion intensities of E and IS, $R_i(E)$ and $R_i(AS)$ which are proportional to the number of atoms of E and IS, $N_i(E)$ and $N_i(AS)$, respectively.

$$R_i(E) = k_i(E) \cdot N_i(E), R_i(AS) = k_i(AS) \cdot N_i(AS) \quad (1)$$

where $k_i(E)$ and $k_i(AS)$ represent ICP/MS sensitivities of E and IS in the i^{th} sample. The ratio of responses can be written as follows:

$$R_i = \frac{R_i(E)}{R_i(AS)} = \frac{k_i(E)}{k_i(AS)} \cdot \frac{N_i(E)}{N_i(AS)} = \frac{k_i(E)}{k_i(AS)} \cdot \frac{\left\{ \frac{m_{X,i} \cdot w_X(E) + m_{Z,i} \cdot w_Z(E)}{M(E)} \right\}}{\left\{ \frac{m_{Y,i} \cdot w_Y(AS)}{M(AS)} \right\}}, \quad (2)$$

where $M(E)$ and $M(AS)$ are atomic weights of E and IS, respectively. For simpler formula, new sensitivity factor, k_i , is redefined as follows,

$$k_i = \frac{k_i(E)}{k_i(AS)} \cdot \frac{M(AS)}{M(E)}. \quad (3)$$

Then,

$$R = k_i \cdot \frac{m_{X,i} \cdot w_X(E) + m_{Z,i} \cdot w_Z(E)}{m_{Y,i} \cdot w_Y(AS)}. \quad (4)$$

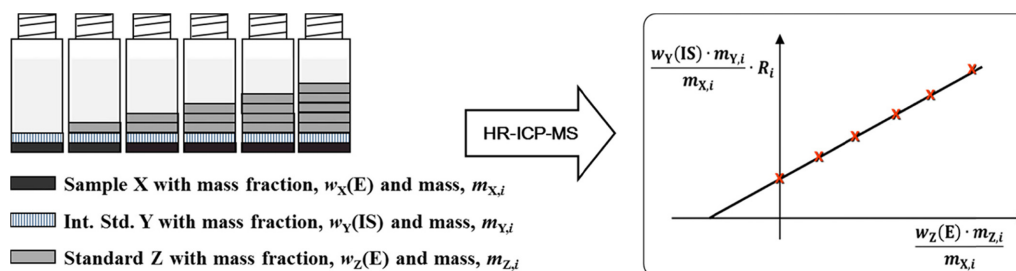


Figure 1. Schematic diagram of the gravimetric standard addition method combined with internal standard and HR ICP/MS. R_i represents the ratio of ion intensities of arsenic over germanium in each standard addition sample. All abbreviations are shown in theoretical section.

Finally, after rearrangement of equation (4), new linear equation can be obtained:

$$y = ax + b, \quad \text{where } y = \frac{w_Y(AS) \cdot m_{Y,i}}{m_{X,i}} \cdot R_i \text{ and } x = \frac{w_Z(E) \cdot m_{Z,i}}{m_{X,i}} \quad (5)$$

$$\text{with } a = k_i \text{ and } b = k_i \cdot w_X(E).$$

$$\text{Hence, } w_X(E) = \frac{b}{a}. \quad (6)$$

If the slope and y-intercept can be obtained from the linear plot for different standard addition solutions, the unknown mass fraction of sample, $w_X(E)$ can be calculated from b divided by a according to the equations (5) and (6).

Application of the gravimetric SAM: Determination of arsenic in codfish and laver samples

HR ICP/MS was optimized and applied to measure ion signals of arsenic and germanium. Figure 2(a) and 2(b) show typical mass spectra of $^{75}\text{As}^+$ ions obtained from the sample and the arsenic standard solution, respectively. The resolutions were calculated more than 10,000 and no spectral interferences such as $^{59}\text{Co}^{16}\text{O}^+$ and $^{40}\text{Ar}^{35}\text{Cl}^+$ were observed even though $^{59}\text{Co}^{16}\text{O}^+$ ions can be shown on the right tail of $^{75}\text{As}^+$ peak at this resolution. As the internal standard, ion intensities of two Ge isotopes, ^{72}Ge and ^{73}Ge , were monitored with the analyte isotope, ^{75}As , by the fast electric-field scan. Very close mass-to-charge ratios of three isotopes allow fast electric field scanning at a fixed magnetic field with minimum mass dependent biases in the sector-field (SF) ICP/MS. Negligible natural level of Ge in the laver and codfish samples also made it an excellent choice as internal standard compared with Se, which is typically present in food samples. Among the five naturally occurring isotopes of Ge, $^{72}\text{Ge}^+$ and $^{73}\text{Ge}^+$ were chosen because of the absence and/or avoidable nature of isobaric interferences compared with the other isotopes of Ge. For example, $^{70}\text{Ge}^+$ and $^{74}\text{Ge}^+$ interfere with $^{70}\text{Zn}^+$ and $^{74}\text{Se}^+$, respectively. Although the polyatomic interferences such as $^{56}\text{Fe}^{16}\text{O}^+/\beta^{32}\text{S}^{40}\text{Ar}^+$ and $^{57}\text{Fe}^{16}\text{O}^+/\beta^{33}\text{S}^{40}\text{Ar}^+$ also affect $^{72}\text{Ge}^+$ and $^{73}\text{Ge}^+$, respectively, their influences are easily removed by using high mass

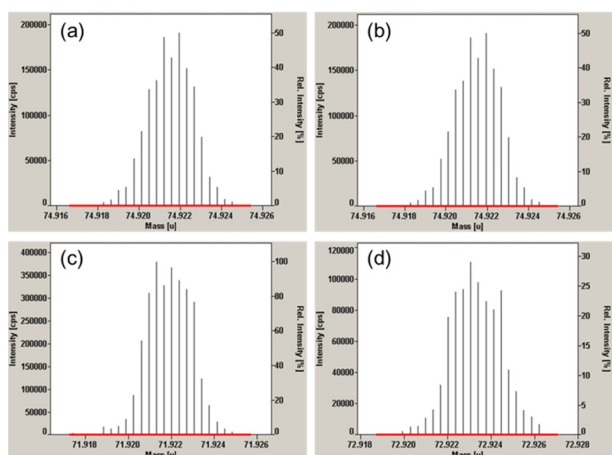


Figure 2. Typical HR ICP/MS mass spectra of (a) $^{75}\text{As}^+$ ions from a digested sample, (b) $^{75}\text{As}^+$ ions from ca. $20 \mu\text{g}\cdot\text{kg}^{-1}$ arsenic standard solution, (c) $^{72}\text{Ge}^+$ ions and (d) $^{73}\text{Ge}^+$ ions from a digested sample spiked with internal standard.

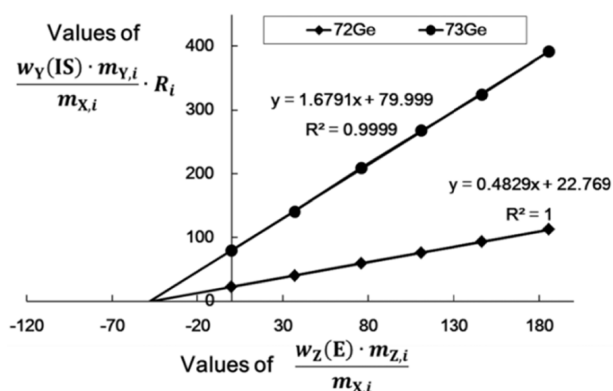


Figure 3. Standard addition calibration curves obtained for the HR ICP/MS-based arsenic measurement in laver samples using the model equation for the gravimetric standard addition method with germanium internal standard. ^{72}Ge and ^{73}Ge denote the experimental values for the ion signal ratios of $^{75}\text{As}^+ / ^{72}\text{Ge}^+$ and $^{75}\text{As}^+ / ^{73}\text{Ge}^+$, respectively.

resolution in the SF ICP/MS.

Standard addition calibration curves for determination of arsenic in laver samples using two different Ge isotopes, ^{72}Ge and ^{73}Ge , as internal standards are shown in Figure 3. From the calibration curve, mass fraction of arsenic was calculated. Both of the two calibration curves show excellent linearity with regression coefficient of 1.0000 and 0.9999, respectively, for ^{72}Ge and ^{73}Ge as internal standards. In the standard addition calibration, the ion signal ratios of $^{75}\text{As}^+ / ^{72}\text{Ge}^+$ were in a narrow range of 0.5 to 1.4 (from 1.7 to 4.7 for $^{75}\text{As}^+ / ^{73}\text{Ge}^+$) to make the linear regression sufficiently accurate approximation. It should be noted that the 6 data used for linear regression include variations due to between-bottle homogeneity. Although there was no noticeable difference between the two results obtained using the two

different Ge isotopes as internal standards within the associated uncertainties, the result obtained using ^{72}Ge as an internal standard was finally used for the analysis because of its smaller uncertainty. Coincidence of the two results also provides a supporting evidence on the robustness of the present method for arsenic determination. In the case of NMIJ 7402-a codfish CRM, which was used for method validation, total arsenic content was measured to be $37.07 \text{ mg}\cdot\text{kg}^{-1} \pm 0.45 \text{ mg}\cdot\text{kg}^{-1}$ which is in good agreement with the certified value, $36.7 \text{ mg}\cdot\text{kg}^{-1} \pm 1.8 \text{ mg}\cdot\text{kg}^{-1}$. The certified value of the total arsenic in the candidate laver CRM was determined to be $47.15 \text{ mg}\cdot\text{kg}^{-1} \pm 1.32 \text{ mg}\cdot\text{kg}^{-1}$ ($k = 2.8$ for 95% confidence level) which is an excellent result obtained by SAM with only 2.8% of relative expanded uncertainty including the homogeneity between bottles. The uncertainties of determined value were calculated following the ISO Guide to the Expression of Uncertainty in Measurement (GUM) guidelines¹².

Conclusion

A gravimetric standard addition method combined with internal standard and HR ICP/MS has been successfully developed for the accurate determination of total arsenic content in laver candidate CRM. A measurement model equation of gravimetric SAM with internal standard was derived. Standard addition calibration curves obtained for gravimetric SAM using Ge internal standard showed excellent linearity, which results in relatively small measurement uncertainties even though they include contributions from between-bottle homogeneity. The developed method was validated using NMIJ codfish CRM and applied for the certification of KRISS laver CRM. The present strategy is expected to provide an alternative means to certify elemental content in complex matrix, when the other primary methods of analysis, such as ID ICP/MS and INAA, are not available.

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