

## Mercury Extraction from Multivitamin Mixtures Followed by Determination Using FI-CV-ICP-MS

Ana B. Viana,<sup>a</sup> Cristiane Pappis,<sup>a</sup> Viviane L. Garcia,<sup>a</sup> Dylan M. Hoffmann,<sup>a</sup> Arthur F. Burg<sup>a</sup> and Valderi L. Dressler<sup>✉\*,a</sup>

<sup>a</sup>Departamento de Química, Universidade Federal de Santa Maria, Campus de Camobi, 97105-900 Santa Maria-RS, Brazil

This study deals with a method for Hg determination in multivitamin supplements. Mercury was extracted with L-cysteine prior to its determination using flow injection-cold vapor generation-inductively coupled plasma-mass spectrometry. A miniaturized flow injection system was employed for Hg vapor generation and its introduction in the plasma whereas 1% (v v<sup>-1</sup>) HCl and 0.005% (m v<sup>-1</sup>) NaBH<sub>4</sub> were used for that purpose. Mercury extraction was carried out using 6 mL of 1% m v<sup>-1</sup> L-cysteine and 50 mg of sample. Accuracy was proved by comparing the Hg concentration found using L-cysteine with the Hg concentration found in the sample decomposed using microwave-assisted digestion, and analysis of certified soil. The limits of detection and quantification of the proposed method were 2 and 6 ng g<sup>-1</sup> of Hg, respectively. The relative standard deviation was < 10% (n = 5). Five samples of multivitamin supplements were analyzed and, in any sample, the tolerable amount of Hg (4.0 µg kg<sup>-1</sup> body weight) recommended by the World Health Organization was exceeded. The proposed method for Hg determination meets the current legislation and is feasible for Hg monitoring in multivitamin supplements.

**Keywords:** mercury, L-cysteine, multivitamin mixture, FI-CV-ICP-MS

### Introduction

The ingestion of nutrient elements, amino acids, proteins, and vitamins is essential for the human body's functioning. Their ingestion varies according to age, sex, physical health, among others.<sup>1</sup> Many people need a supplementation of vitamins, minerals, and other substances due to an unbalanced diet, absorption disorders, age or excessive ingestion of processed foods.<sup>2</sup> For example, vitamin B9 (folate) found naturally in many foods (leafy greens, citrus fruits, nuts, beans, peas, seafood, eggs, dairy, meat, poultry and grains) is necessary in red blood cells and deoxyribonucleic acid (DNA) production, and is especially important for pregnant women because it helps in the growth and development of the fetus. The lack of vitamin D can lead to osteoporosis, whereas the lack of vitamins B1, B2, B3, B6 and B12 can lead to heart diseases and others like depression, eye disorders, deficiency of iron absorption, dermatitis and neurological disorders.<sup>3</sup>

Due to the increasing feeding based on industrialized products and nutritional deficiency, consumption of multivitamin supplements has increased. The marketed mixtures usually comprise vitamins and essential elements like Se, Fe, Mo, Co, Zn, Cu, among others. Studies<sup>4</sup> on the North American population revealed that about 58% of adults aged over 20 years had ingested some multivitamin supplement in the last 30 days. Regarding the Brazil scenario, a study carried out by the Brazilian Association of the Food Industry for Special Purposes (ABIAD)<sup>5</sup> reported that there has been a considerable increase of vitamin supplement consumption, mainly due the coronavirus disease (Covid-19) pandemic. In 2020, at least one person in approximately 59% of Brazilian houses had consumed vitamin supplements, and 79% of those people who had started such consumption stated that they would continue with it.

Therefore, it can be stated that there is a significant consumption of multivitamin supplements and quality control of them is necessary. Contamination of multivitamin supplements by metals can occur due to manufacturing processes and practices, such as extraction, formulation, feedstock, transport, and storage conditions. The addition

\*e-mail: vdressler@gmail.com

Editor handled this article: Maria das Graças A. Korn (Associate)



of herbs, whose elemental composition is influenced by the soil nature and plant feature, may also contribute to the multivitamin supplement's contamination.<sup>6,7</sup>

Elements such as Cd, Pb, Hg and As are considered harmful to humans, even at low concentration levels.<sup>8</sup> Mercury has received special attention because it bioaccumulates in the body and is considered the third most toxic element.<sup>9,10</sup> According to the United States Pharmacopeia (USP),<sup>11</sup> the sum of Hg and other toxic elements in supplements like multivitamin formulations should not exceed  $1.5 \mu\text{g g}^{-1}$ , while the European Commission (EC) of the European Union (EU) establishes that Hg in dietary supplements should not exceed  $0.10 \mu\text{g g}^{-1}$ . In this context, the World Health Organization (WHO) stipulated that the weekly intake of Hg must be lower than  $4 \mu\text{g kg}^{-1}$  body weight.<sup>11-13</sup> Therefore, monitoring the Hg concentration in multivitamin supplements for humans is essential.

Mercury determination in a solid sample usually requires its decomposition by mineral acids such as nitric ( $\text{HNO}_3$ ) and hydrochloric (HCl) acids, under heating. However, Hg is very volatile and can be easily lost in this step. As such, Hg extraction at low temperature using a chelating agent like L-cysteine has been proposed.<sup>14,15</sup> L-Cysteine is an amino acid, which contains amine and carboxylic acid groups and a  $\beta$ -thiol side chain giving the molecule a great affinity for soft metals like Hg.<sup>6</sup> Thus, L-cysteine has been employed for organic Hg species extraction from soil, hair, seafood, blood, among others.<sup>15-18</sup>

Cold vapor (CV) generation coupled with atomic absorption spectrometry (CV-AAS), atomic fluorescence spectrometry (CV-AFS), inductively coupled plasma optical emission spectrometry (CV-ICP OES) and inductively coupled plasma mass spectrometry (CV-ICP-MS) have been usually employed for Hg determination. Mercury can also be directly determined in solids using other techniques.<sup>15,19-24</sup> However, besides achieving a better limit of detection (LOD), direct solid samples analysis requires a more dedicated equipment.

Cold vapor generation improves the LOD by one order of magnitude or more when compared with pneumatic nebulization for sample introduction in the atomizer. Besides, some interferences in the Hg determination are reduced using CV because Hg is separated from the sample matrix. Mercury vapor generation can be conducted in batch or through flow systems, either by continuous or flow injection (FI) systems. Flow injection systems are more advantageous because reagent consumption and waste generation are reduced, allowing analysis with diminutive sample amount.

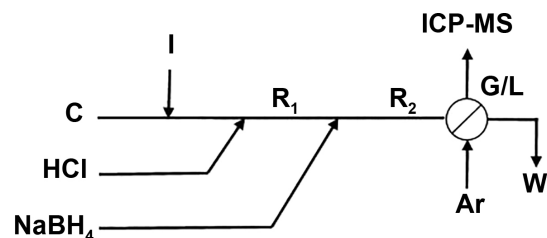
In view of the increased multivitamin supplements consumption and their possible contamination with

Hg, this study focuses on the element determination in such samples. L-Cysteine is proposed for Hg extraction followed by the analyte determination using flow injection-cold vapor generation-inductively coupled plasma mass spectrometry (FI-CV-ICP-MS).

## Experimental

### Instrumental

Mercury was determined using a FI-CV-ICP-MS system. The ICP-MS instrument was from PerkinElmer SCIEX (model ELAN DRC II, Norwalk, Connecticut, USA) and was equipped with a quartz torch and platinum cones. Argon with 99.998% purity (White Martins, São Paulo, Brazil) was used for plasma generation. Figure 1 shows a scheme of the system. The flow injection system is equipped with a peristaltic pump (Gilson, model Minipuls 3, Villiers Le Bel, France), Tygon tubes (black/black and red/red, with 0.76 and 1.14 mm internal diameter, respectively), injection valve (I),<sup>25</sup> U type gas/liquid (G/L) separator and polytetrafluorethylene tubing (0.5 mm internal diameter). Samples or calibration solutions (200  $\mu\text{L}$ ) were injected in the carrier (C) solution (water,  $2.0 \text{ mL min}^{-1}$ ) and subsequently mixed with hydrochloric acid ( $1.0 \text{ mL min}^{-1}$ ) and sodium tetrahydroborate solution ( $1.0 \text{ mL min}^{-1}$ ) in  $R_1$ . After the reduction of  $\text{Hg}^{2+}$  to  $\text{Hg}^0$  in  $R_2$  (30 cm) the vapor is separated in the G/L separator and carried to the plasma by argon flow. The argon flow rate was controlled by the ICP-MS instrument software. Operational conditions of the FI-CV-ICP-MS system were adapted from a work developed by Pilz *et al.*<sup>26</sup> and are shown in Table 1.



**Figure 1.** FI-CV-ICP-MS system used for Hg determination. C: carrier solution (water); I: injection valve for standards or sample solution (200  $\mu\text{L}$ );  $R_1$  and  $R_2$ : reactors (100 and 300 mm, respectively); G/L: gas/liquid separator; W: waste.

Samples were decomposed with concentrated nitric acid and heating in a microwave oven (Berghof-Microwave Digester-Speedwave 4, Eningen, Germany). The microwave oven is equipped with 12 TFM<sup>TM</sup>PTFE flask with 100 mL capacity.

Samples were weighed using an analytical balance (Shimadzu model NT 810, Manila, Philippines) with a

**Table 1.** Operational conditions of the FI-CV-ICP-MS system

CV	Setting
Carrier solution (water) / (mL min <sup>-1</sup> )	2.0
HCl / (% v v <sup>-1</sup> )	0.001-1.20
NaBH <sub>4</sub> / (% v v <sup>-1</sup> )	0.0001-0.1
ICP-MS	
Radiofrequency power / W	1300
Principal gas flow rate / (L min <sup>-1</sup> )	12
Auxiliary gas flow rate / (L min <sup>-1</sup> )	1.12
Carrier gas flow rate / (L min <sup>-1</sup> )	0.98-1.22
Sampler and skimmer cone	Pt
Isotopes monitored <i>m/z</i>	200 and 202
Dwell time / ms	20
Reading	500
Replicate	1

CV: cold vapor; ICP-MS: inductively coupled plasma mass spectrometry.

resolution of 0.0001 g and a maximum weighing capacity of 220 g.

## Reagents

Water was previously distilled, deionized by an ion exchange column, and then purified by a Milli-Q system (Millipore, USA) with resistivity of 18.2 MΩ cm. Concentrated HNO<sub>3</sub> (P.A., 65% m/m, 1.4 kg L<sup>-1</sup>, Merck, Darmstadt, Germany) and concentrated HCl (P.A., 37% m/m, 1.4 kg L<sup>-1</sup>, Merck, Darmstadt, Germany) were purified using a Milestone sub-boiler system (model duoPUR, Milan, Italy).

A stock solution containing 1000 mg L<sup>-1</sup> of Hg (as Hg<sup>2+</sup>) in 2% (v v<sup>-1</sup>) HNO<sub>3</sub> was diluted in 2% (v v<sup>-1</sup>) HNO<sub>3</sub> to obtain a 1.0 mg L<sup>-1</sup> Hg solution for further preparation of the calibration curve. Calibration solutions were prepared daily. Hydrochloric acid solution was prepared by diluting the concentrated acid in water. A 1% (m m<sup>-1</sup>) solution of sodium tetrahydroborate (NaBH<sub>4</sub>) (P.A., 97% purity, Vetec, Rio de Janeiro, Brazil) was prepared by dissolving the solid reagent in 1% (m v<sup>-1</sup>) sodium hydroxide (NaOH) solution (minimum purity 99%, Dinâmica, São Paulo, Brazil). Dilutions of this stock solution were made with NaOH 0.01% m v<sup>-1</sup>. L-Cysteine solution (purity 98% Vetec, Rio de Janeiro, Brazil) was prepared by dissolving the solid reagent in purified water.

## Sample preparation

Five samples of commercial multivitamins of different brands were purchased in local drug stores. All samples

were ground in an agate mortar until a particle size of less than 100 μm was achieved. Samples that had a gelatin envelope had their capsules discarded before milling. Ground samples were stored in polypropylene flasks until analysis.

## Mercury extraction from the samples

Mercury extraction procedure was adapted from the work carried out by Pilz *et al.*<sup>26</sup> In short, about 50 mg of sample was transferred to a 15 mL polypropylene flask and 6.0 mL of 1% m v<sup>-1</sup> L-cysteine solution were added. The mixture was manually stirred for homogenization and then allowed to stand at room temperature (20 °C) and the final volume was made up to 10 mL with purified water. Analyzes were conducted on the same day of Hg extraction. The Hg extraction period evaluated ranged from 20 min to 4 h.

Accuracy of the proposed method was checked by analyzing a certified reference material (Montana I Soil, 2710a, National Institute of Standard and Technology-NIST, Gaithersburg, USA). The certified reference material (CRM) was submitted to the same procedure used for Hg extraction from the samples, except further 10 and 20-fold dilution because the relative high Hg concentration in the final solution. In addition, results were compared with those obtained after sample decomposition using HNO<sub>3</sub>. In this case, approximately 150 mg of sample were weighed and transferred to the TFM<sup>TM</sup>PTFE microwave oven flasks and then 3.0 mL of concentrated nitric acid, 1.0 mL of concentrated hydrochloric acid and 1.0 mL of purified water were added. Afterwards, the flasks were closed and submitted to a heating program, which consists of 5 min ramp to reach 200 °C, remaining at this temperature for 10 min. Maximum temperature and pressure were fixed at 200 °C and 40 bar. After cooling down, the sample solutions were transferred to 15 mL polypropylene flasks and the final volume was adjusted to 15 mL with purified water.

## Results and Discussion

### Method development

All parameters of the FI-CV-ICP-MS system were adjusted in a univariate mode. Initially, conditions of the ICP-MS instrument were adjusted in order to achieve the highest sensitivity for indium (In) and lowest production of oxides (CeO<sup>+</sup>/Ce<sup>+</sup>) and double charge (Ba<sup>2+</sup>/Ba<sup>+</sup>) ions. In a similar way, the carrier gas flow rate (Ar), the HCl and NaBH<sub>4</sub> concentrations, and the sample volume of the flow injection system were optimized in order to achieve the

highest sensitivity for Hg. As expected, these parameters have a high influence of the sensitivity. Based on the results shown in Figures 2a-2d the following conditions were chosen for Hg determination: 1.20 L min<sup>-1</sup> Ar as carrier gas flow rate, HCl 1% (v v<sup>-1</sup>), NaBH<sub>4</sub> 0.005% (m v<sup>-1</sup>) and 200 μL sample volume. In all experiments, sample carrier (water) flow rate was fixed at 2.0 mL min<sup>-1</sup>, while HCl and NaBH<sub>4</sub> solution flow rates were fixed at 1.0 mL min<sup>-1</sup>. For sample volume, 200 μL was the best compromise between volume and signal intensity (cps, peak height), as shown in Figure 2. By using the established conditions good precision (relative standard deviation (RSD), lower than 10%, n = 5) and signal profiles were obtained (Figure 3). All conditions were chosen in order to obtain better sensitivity and accuracy.

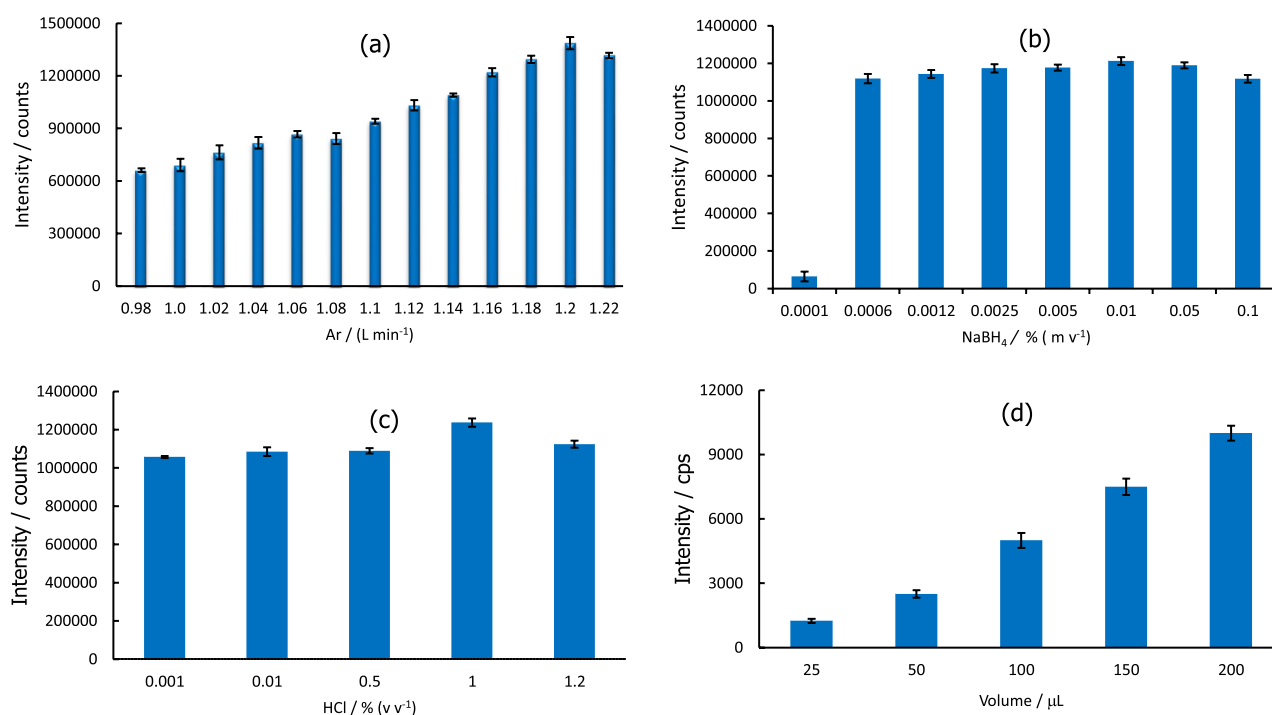
#### Accuracy and sample analysis

After establishing the best conditions of the FI-CV-ICP-MS operation, the LOD and the limit of quantification (LOQ) of the method were 2 and 6 ng g<sup>-1</sup> Hg, respectively, significantly lower than those achieved using microwave assisted digestion, whose values were 16 and 48 ng g<sup>-1</sup> of Hg, respectively. The lower LOD and LOQ of the L-cysteine method is related to the lower blank values in relation to those found for microwave assisted digestion, and better precision of the results. Calibration curves with concentrations ranging from 0.15 to 5.0 μg L<sup>-1</sup>

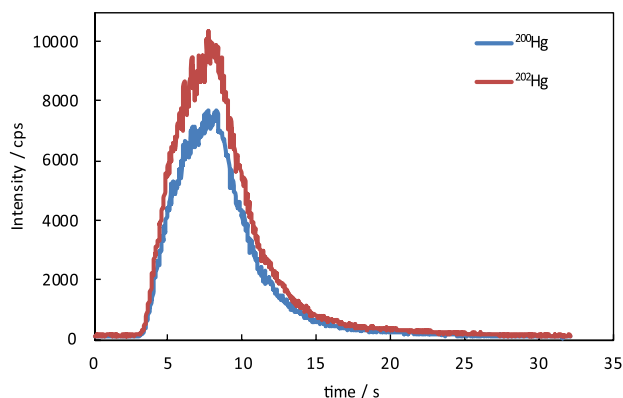
were constructed, whose calibration curve equation was  $y = 24086x + 1650$ , with linear correlation coefficient ( $R^2$ ) of 0.9997.

Studies<sup>16,23,26-28</sup> report the use of L-cysteine for Hg speciation in different matrices, where it is used for the organic Hg species extraction, such as methylmercury, with the aim of avoiding Hg species conversion. The use of L-cysteine for methylmercury extraction from matrices, such as mushrooms, seafood, soil, fish, blood and human hair, is reported, where its efficiency for extracting this species has been proven.<sup>15,16,26-28</sup> However, there are still no reports in the literature of investigations regarding the use of L-cysteine for extracting Hg from multivitamin supplements. It should be noted that sample decomposition is usually carried out by using concentrated acids such as HNO<sub>3</sub> and HCl, and heating by microwave radiation energy (microwave oven) or conduction (in metallic block). Decomposition in microwave ovens is very efficient, but the cost is extremely high, while decomposition in a conventional digester block can lead to mercury losses and takes longer time.<sup>19-23</sup> In this context, as can be observed in Table 2, L-cysteine promoted quantitative extraction of Hg from the analyzed multivitamin supplements. It is important to mention that although the sample was not solubilized with the L-cysteine, it was not necessary to centrifuge or filter the remaining sample mixture because the solid material settled down in less than 3 min after stirring.

As can be observed in Table 2, the results obtained by



**Figure 2.** Effect of (a) carrier gas flow rate, (b) sodium tetrahydroborate concentration, (c) hydrochloric acid concentration, and (d) sample volume on Hg signal intensity. Other instrumental conditions are cited in Table 1 and along the text.



**Figure 3.** Mercury signal profile for the  $^{200}\text{Hg}$  and  $^{202}\text{Hg}$  isotopes obtained by using the established conditions of the FI-CV-ICP-MS operation.

**Table 2.** Concentration of Hg found in multivitamin supplements after Hg extraction with L-cysteine or sample decomposition using microwave assisted-acid digestion. Results are the mean and standard deviation for three sample aliquots ( $n = 3$ )

Sample	Mercury / ( $\text{ng g}^{-1}$ )	
	Extraction with L-cysteine	Microwave assisted-acid digestion
A	$92 \pm 6$	$107 \pm 15$
B	< LOQ	< LOQ
C	$18 \pm 4$	< LOQ
D	$47 \pm 15$	$44 \pm 9$
F	$7 \pm 3$	< LOQ
CRM	$10.3 \pm 0.1$	$9.7 \pm 0.4$

LOQ: limit of quantification; CRM: certified reference material (Montana I soil, 2710a:  $9.88 \pm 0.21 \text{ mg g}^{-1} \text{ Hg}$ ). Results for CRM are in  $\mu\text{g g}^{-1} \text{ Hg}$ .

the proposed method are in good agreement ( $p < 0.05$ ,  $t$ -test) with those obtained by the reference method, where samples were decomposed with nitric and hydrochloric acids and microwave heating. Additionally, the results for the CRM are also in good agreement with the certified value for Hg. Although the soil and multivitamin supplements matrices are different, the results indicate that the Hg extraction with L-cysteine led to accurate results. The precision (standard deviation) of the results shown in Table 2 are high, which can be due to the characteristics of the samples (heterogeneity) and Hg concentration close to the LOQ.

Investigations carried out with five dietary supplements from Argentina and United States revealed that total Hg concentration was lower than  $1.3 \mu\text{g g}^{-1}$ .<sup>29</sup> In another study,<sup>30</sup> which evaluated the concentration of Hg in 22 dietary supplements sold in Poland, the Hg concentration in the supplements ranged from  $0.22$  to  $5.85 \mu\text{g kg}^{-1}$ . Regarding the Hg concentrations found in the samples analyzed in this work, in sample D, the Hg concentration was very close to the maximum concentration specified by the EC.<sup>12</sup> The

other samples had Hg concentrations below the maximum limit ( $0.10 \mu\text{g g}^{-1}$ ) allowed by the EC. In general, the Hg concentration found was lower than that reported in other studies.<sup>29,31</sup>

Taking into account the limit stipulated by the WHO ( $4 \mu\text{g kg}^{-1}$  of body weight), a person weighing  $70 \text{ kg}$  can ingest a maximum of  $280 \mu\text{g}$  of Hg *per week*. Considering a  $70 \text{ kg}$  weigh-person and the consumption recommended by the manufacturers of the evaluated multivitamin supplements, the Hg concentration in all samples was below the limit recommended by WHO. The values referring to the concentration of Hg ingested *per week* for each supplement are listed in Table 3. These values were calculated considering the ingestion amount recommended by the manufacturer.

**Table 3.** Mercury intake from vitamins supplements consumption according to the manufacturers' recommendation

Sample	Hg / ( $\mu\text{g per week}$ )
A	$0.77 \pm 0.07$
B	$0.01 \pm 0.00$
C	$0.08 \pm 0.02$
D	$0.20 \pm 0.06$
E	$0.06 \pm 0.05$

A-E: five multivitamin samples.

Although only five samples were analyzed, these results found reinforce the need to monitor contaminants in multivitamins in order to help improve the safety measures for the manufacture and control the consumption of these products.

As mentioned in the Introduction section, several methods are available for Hg determination. Table 4 summarizes some works about Hg determination in multivitamin supplements and similar products. As can be observed, Hg in the solid sample has been directly determined, which normally needs thorough grinding to improve homogeneity or to reduce the sample particles size. Despite that, better LOD and LOQ are achieved by direct analysis of the solid sample. However, acid digestion is still the most used sample preparation procedure. This consists in heating the sample in closed flasks at  $100$ - $200 \text{ }^\circ\text{C}$  in the presence of mineral acids (typically  $\text{HNO}_3$  and  $\text{HCl}$ ). The use of concentrated acid, and several handling steps are the main inconveniences of this procedure. In this context, the proposed extraction with L-cysteine is advantageous, where extraction of Hg is quantitative at room temperature. Furthermore, the extraction time can be reduced to approximately  $20 \text{ min}$ .

**Table 4.** Works dealing with Hg determination in dietary supplements and similar products published

Sample	Sample preparation	Analytical technique	LOD/LOQ	Reference
Dietary supplements added with vitamins and minerals	direct analysis after sample grounding	AAS	0.003 ng g <sup>-1</sup> (LOD)	30
Dietary supplements	direct analysis	CV AAS	0.096/0.29 ng	32
Dietetic supplements	direct analysis after sample grounding	AAS	0.003 ng g <sup>-1</sup> (LOQ)	33
Dietetic supplements	extraction with HNO <sub>3</sub> + H <sub>2</sub> SO <sub>4</sub> + V <sub>2</sub> O <sub>5</sub> (catalyzer)	CV AAS	0.03 mg kg <sup>-1</sup> (LOD)	34
Herbal supplements	direct analysis after sample grounding	AAS	0.003 ng g <sup>-1</sup> (LOD)	35
Dietary supplements	direct analysis after sample grounding	AAS	0.3 ng g <sup>-1</sup> (LOD)	36
Iron based dietary supplements	ultrasound based extraction with 2.5 mL HCl + 5 mL CH <sub>4</sub> N <sub>2</sub> S	CV AAS	30/102 ng L <sup>-1</sup>	37
Omega 3 based dietary supplements	decomposition with 1 mL H <sub>2</sub> O <sub>2</sub> + 2 mL HNO <sub>3</sub> :HClO <sub>4</sub> (1:1) + 5 mL H <sub>2</sub> SO <sub>4</sub>	CV AAS	not informed	38
Dietary supplements	direct analysis after sample grounding	AAS	1.88 / 6.26 µg kg <sup>-1</sup> (LOD)	39

CV AAS: cold vapor atomic absorption spectrometry; AAS: atomic absorption spectrometry; LOD: limit of detection; LOQ: limit of quantification.

## Conclusions

A method of Hg determination in multivitamin supplements was developed using only L-cysteine for sample preparation. Compared to sample acid digestion procedures that use concentrated acids and expensive equipment, such as microwave systems, the proposed procedure is cheaper and requires only one reagent, which is non-toxic and non-corrosive. The high cost of the detector employed (ICP-MS) and the long extraction time adopted are the most negative aspects. However, more cheaper detectors such as AAS or AFS could be employed and the extraction time reduced to 20 min. The developed method is accurate, assured with the analysis of a certified reference material and sample decomposition through microwave assisted acid digestion. The precision is also good, with a relative standard deviation lower than 10% for five Hg determinations in a sample extract. The LOD and LOQ were 2 and 6 ng g<sup>-1</sup>, respectively, which are lower than the maximum Hg concentration allowed in multivitamin supplements and in compliance with the current legislation.

## Acknowledgments

Valderi Luiz Dressler and Ana Barbosa Viana received scholarship from Conselho Nacional de Desenvolvimento Científico (process No. 310228/2021-2 and process No. 131372-2021-1, respectively) and Cristiane Pappis

from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES process No. 88887868265/2022-00).

## Author Contributions

Ana B. Viana was responsible for experimental execution, data handling, text writing; Cristiane Pappis for text writing; Viviane L. Garcia for sample preparation; Dylan M. Hoffmann and Arthur F. Burg for experimental execution, data handling; Valderi L. Dressler for supervision, text revision.

## References

- Costa-Pinto, R.; Gantner, D.; *Anaesthesia Crit. Care Pain Med.* **2020**, *21*, 157. [Crossref]
- Winson, A.; *The Industrial Diet: The Degradation of Food and the Struggle for Healthy Eating*, 1<sup>st</sup> ed.; University of British Columbia Press: Canada, 2013.
- Tulchinsky, T. H.; *Public Health Rev.* **2010**, *32*, 243. [Crossref]
- Mishra, S.; Stierman, B.; Gahche, J. J.; Potischman, N.; *Dietary Supplement use Among Adults: United States, 2017-2018*; CDC, 2021. [Crossref]
- Associação Brasileira da Indústria de Alimentos para Fins Especiais (ABIAD); Hábitos de Consumo de Suplementos Alimentares, <https://abiad.org.br/pesquisa-de-mercado-suplementos-alimentares/>, accessed in November 2023.
- Costa, J. G.; Vidovic, B.; Saraiva, N.; Costa, M.; Del Favero, G.; Marko, D.; Oliveira, N. G.; Fernandes, A. S.; *Free Radical Res. Commun.* **2019**, *53*, 1113. [Crossref]

7. Mathews, N. M.; *Sports Health* **2018**, *10*, 19. [Crossref]
8. Tchounwou, P. B.; Yedjou, C. G.; Patlolla, A. K.; Sutton, D. J.; *Molecular, Clinical and Environmental Toxicology*, vol 3; Luch, A., ed.; Springer: Basel, 2012, p. 133. [Crossref]
9. Rice, K. M.; Walker Jr., E. M.; Wu, M.; Gillette, C.; Blough, E. R.; *J. Prev. Med. Public Health* **2014**, *47*, 74. [Crossref]
10. US Department of Health and Human Services, Public Health Service; *Toxicological Profile for Mercury*; US Department of Health and Human Services: Atlanta, 2022, p. 1-847. [Link] accessed in November 2023
11. United States Pharmacopeia (USP); <2232> *Elemental Contaminants in Dietary Supplements*, vol. 36; Washington, DC, USA. 2010, p. 2-10.
12. EU European Union; Commission Regulation (EC) No 629/2008, *Amending Regulation (EC) No. 1881/2006 Setting Maximum Levels for Certain Contaminants*; Official Journal of the European Union, 2008. [Link] accessed in November 2023
13. World Health Organization (WHO); *Mercury*; Food and Agriculture Organization, 2011. [Link] accessed in November 2023
14. Matusiewicz, H.; Sturgeon, R. E.; *Appl. Spectrosc. Rev.* **2012**, *47*, 41. [Crossref]
15. Bollen, A.; Biester, H.; *Water, Air, Soil Pollut.* **2011**, *219*, 175. [https://doi.org/10.1007/s11270-010-0696-2]
16. de Souza, S. S.; Rodrigues, J. L.; Souza, V. C. O.; Barbosa, F.; *J. Anal. At. Spectrom.* **2010**, *25*, 79. [Crossref]
17. Rodrigues, J. L.; de Souza, S. S.; Souza, V. C. O.; Barbosa, F.; *Talanta* **2010**, *80*, 1158. [Crossref]
18. Batista, B. L.; Rodrigues, J. L.; de Souza, S. S.; Souza, V. C. O.; Barbosa, F.; *Food Chem.* **2011**, *126*, 2000. [Crossref]
19. Duarte, F. A.; Bizzi, C. A.; Antes, F. G.; Dressler, V. L.; Flores, E. M. M.; *Spectrochim. Acta, Part B* **2009**, *64*, 513. [Crossref]
20. da Silva, D. L. F.; da Costa, M. A. P.; Silva, L. O. B.; dos Santos, W. N. L.; *Food Chem.* **2019**, *273*, 24. [Crossref]
21. Yuan, X.; Li, K.; Zhang, Y.; Miao, W.; Xiang, Y.; Sha, Y.; Zhang, M.; Huang, K.; *Microchem. J.* **2020**, *155*, 104695. [Crossref]
22. Dressler, V. L.; Santos, C. M. M.; Antes, F. G.; Bentlin, F. R. S.; Pozebon, D.; Flores, E. M. M.; *Food Anal. Methods* **2012**, *5*, 505. [Crossref]
23. Schmidt, L.; Bizzi, C. A.; Duarte, F. A.; Dressler, V. L.; Flores, E. M. M.; *Microchem. J.* **2013**, *108*, 53. [Crossref]
24. Wohlmann, W.; Neves, V. M.; Heidrich, G. M.; Silva, J. S.; Costa, A. B.; Paniz, J. N. G.; Dressler, V. L.; *Spectrochim. Acta, Part B* **2018**, *149*, 222. [Crossref]
25. Krug, F. J.; Bergamin Filho, H.; Zagatto, E. A. G.; *Anal. Chim. Acta* **1986**, *179*, 103. [Crossref]
26. Pilz, C.; Antes, F. G.; Moreira, C. M.; Mello, P. A.; Duarte, F. A.; Pozebon, D.; Flores, E. M. M.; Dressler, V. A.; *Braz. J. Anal. Chem.* **2011**, *1*, 228. [Link] accessed in November 2023
27. Liu, Q.; *Microchem. J.* **2010**, *95*, 255. [Crossref]
28. Sogame, Y.; Tsukagoshi, A.; *J. Chromatogr. B* **2020**, *1136*, 121855. [Crossref]
29. Marrero, J.; Rebagliati, R.J.; Leiva, E.; Londonio, A.; Smichowski, P.; *Microchem. J.* **2013**, *108*, 81. [Crossref]
30. Brodziak-Dopierała, B.; Fischer, A.; Derkacz, A.; Stojko, J.; *Ann. Acad. Med. Siles.* **2019**, *73*, 203. [Crossref]
31. Kowalski, A. Frankowski, M.; *Regul. Toxicol. Pharmacol.* **2015**, *73*, 396. [Crossref]
32. Brzezińska-Rojek, J.; Rutkowska, M.; Ośko, J.; Konieczka, P.; Prokopowicz, M.; Grembecka, M.; *J. Food Compos. Anal.* **2022**, *114*, 104828. [Crossref]
33. Puścion-Jakubik, A.; Mielech, A.; Abramiuk, D.; Iwaniuk, M.; Grabia, M.; Bielecka, J.; Markiewicz-Żukowska, R.; Socha, K.; *Front. Pharmacol.* **2021**, *12*, 738549. [Crossref]
34. Ćwieląg-Drabek, M. Piekut, A.; Szymala, I.; Oleksiuk, K.; Razzaghi, M.; Osmala, W.; Jablonska, K.; Dziubanek, G.; *Food Sci. Nutr.* **2020**, *8*, 3535. [Crossref]
35. Brodziak-Dopierała, B.; Fischer, A.; Szczelina, W.; Stojko, J.; *Biol. Trace Elem. Res.* **2018**, *185*, 236. [Crossref]
36. Levine, K. E.; Levine, M. A.; Weber, F. X.; Uh, Y.; Perlmutter, J.; Grohse, P. M.; *J. Anal. Methods Chem.* **2005**, *2005*, ID 159897. [Crossref]
37. Barbosa, U. A.; Silva, L. O. B.; Santos, I. F.; Ferreira, S. L. C.; dos Santos, A. M. P.; *Curr. Anal. Chem.* **2014**, *11*, 44. [Crossref]
38. Oti-Boakye, A.; Acheampong, A.; Nathan, O. G.; Agbosu, A. A.; Agyei, A. C.; *Afr. J. Pure Appl. Chem.* **2017**, *12*, 50. [Crossref]
39. Van Anh, N. T.; Trang, N. T.; Chien, D. V.; Giang, T. H.; Hien, L. T. M.; Chau, N. M.; *Vietnam J. Food Control* **2022**, *5*, 433. [Crossref]

Submitted: June 7, 2023

Published online: November 22, 2023