Application Note

Foods

Agilent
Trusted Answers

Automated Analysis of Foods by ICP-QQQ with Discrete Sampling and Autodilution

Fast, accurate AOAC compliant food analysis using the Agilent 9500 ICP-QQQ with AVS MS and ADS 2

Author

Santhosh Siva

Agilent Technologies, Inc.

Introduction

Manufacturers and regulatory bodies, including state and federal governments, have an obligation to ensure that food is safe for human consumption. To protect public health, manufacturers and producers follow rigorous testing procedures, such as AOAC Official Method 2015.01 for the analysis of heavy metals in foods using ICP-MS.[1] In recent years, global initiatives have sought to strengthen existing regulations and further reduce contaminant limits, as shown by the US Food and Drug Administration's Closer to Zero program. Meeting these increasingly stringent targets depends on analytical instruments capable of delivering higher performance, improved sensitivity, and greater accuracy. At the same time, food testing laboratories are actively pursuing greater productivity and workflow efficiency to keep pace with evolving analytical demands.

To support these goals, the Agilent 9500 Triple Quadrupole ICP-MS (ICP-QQQ) and Advanced Dilution System (ADS 2) combine seamlessly to streamline methods, improve productivity, and deliver high-quality results. Using the 9500 instrument's unique Dual-Cell System (DCS) with Advanced Helium Mode (AHM) and Air cell mode enables effective removal of polyatomic and doubly charged interferences and enhances low-mass sensitivity.[2,3] In addition, the ADS 2 simplifies sample preparation by creating calibration standards from a stock solution, pre-diluting samples before analysis, and reactively diluting any samples that exceed the calibration range. Together, these technologies support faster, more reliable delivery of accurate results.

In this study, various standard reference materials (SRMs) were selected to represent different sample types that may be analyzed in food testing laboratories and to validate the method. As these laboratories often require high productivity, the 9500 ICP-QQQ configuration and analytical method were optimized to maximize sample throughput. The performance of the method was evaluated according to criteria set out in the AOAC 2015.01 method.

Experimental

Samples

Several food-matrix SRMs from the National Institute of Standards and Technology (NIST, Gaithersburg, USA) were used as samples. The SRMs included NIST 1566b Oyster Tissue, NIST 1573a Tomato Leaves, and NIST 2976 Trace Elements and Methylmercury in Mussel Tissue.

Sample preparation

Sample preparation was performed according to the procedure stipulated in the AOAC 2015.01 method. The three sample types were digested using a MARS 6 closed-vessel microwave digestion system from CEM Corporation, USA. Approximately 0.25 g of each food sample was accurately weighed into a 75 mL PFA-lined MARS Xpress vessel. Then, 4 mL of HNO_3, 1 mL of H_2O_2, and 0.1 mL of a 50 mg/L solution of gold (Au) and lutetium (Lu) were added to each vessel. The Au is intended to stabilize recoveries for mercury (Hg) while Lu is a spike. Lu is measured to test the recovery of volatile elements following the sample preparation procedure.

Each digestion batch included three reagent blanks. The samples were digested by microwave-assisted digestion using the following program: ramp to 200 °C over 25 minutes, then hold at 200 °C for 15 minutes. After digestion and sufficient cooling, the digests were made up to 20 mL (gravimetrically) and then diluted fourfold before analysis, resulting in a final dilution factor of approximately 320.

Standards and internal standards

While the AOAC 2015.01 method only requires the quantification of arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb) in food samples and Lu as a spike, many additional elements were included in the analysis, as shown in Table 1.

A multi-element stock was prepared by diluting the Agilent Environmental Calibration standard. Single element stocks of Hg, Lu, and Au (Kanto Chemical, Japan) were used to create a second calibration stock of Hg and Lu. They were also used to prepare the 50-mg/L pre-digestion spike solution of Au and Lu. These stock solutions were automatically diluted at 400x, 250x, 25x, 2.5x, and 1x (undiluted) using the ADS 2 to create the required calibration curves (Table 1). For the Continuing Calibration Verification (CCV) solutions, the multi-element stock and a second calibration stock containing Hg were automatically diluted 2.5x and 2x, respectively. A Quality Check (QC) block containing the two CCVs was run every eight samples.

An Agilent internal standard (ISTD) mix comprising Sc, Ge, Rh, and Bi was diluted to 100 µg/L using 5% HNO_3 and 20% acetic acid (Kanto Chemical, Japan). The ISTD solution was introduced online using the integrated Agilent AVS MS discrete sampling accessory. If any measured analyte concentrations exceeded the calibration range (Table 1), the samples would be automatically diluted with the ADS 2 and remeasured.

Table 1. Calibration ranges of the elements determined in the NIST food SRMs.

Elements	Calibration Range (µg/L)
Fe	10 to 2500
V, Cr, Mn, Co, Ni, Zn, As, Se, Mo, Ag, Cd, Sb, Pb, Tl, Th, U	0.1 to 25
Hg	0.01 to 1
Lu	1 to 100

Instrumentation

Analysis was performed using an Agilent 9500 ICP-QQQ equipped with the unique Dual-Cell System (DCS) collision/reaction cell (CRC). For enhanced sample throughput and minimal operator involvement, the 9500 was equipped with an integrated Agilent AVS MS discrete sampling accessory, SPS 4 autosampler, and ADS 2 autodilutor fitted with 2.5 mL loops (Figure 1).

Figure 1. Agilent 9500 ICP-QQQ with integrated AVS MS, ADS 2 autodilutor, and SPS 4 autosampler.

The sample introduction consisted of the standard MicroMist glass concentric nebulizer, temperature-controlled quartz spray chamber, and quartz torch with 2.5 mm inner diameter (id) injector. A nickel-plated copper sampling cone and a nickel skimmer cone were used for the interface. The 9500 ICP-QQQ was operated using default settings for the AHM and Air cell gas modes and tuned using the Agilent OpenLab ICP-MS software's autotune routine. Instrument operating parameters are listed in Table 2.

Table 2. Agilent 9500 ICP-QQQ operating conditions. The "Food/Clinical" application method included in the Agilent OpenLab ICP-MS software was used. No further adjustment of mode selection or parameters was needed.

Variable	Setting
Plasma Preset	General Purpose
RF Power (W)	1550
Sample Depth (mm)	12.0
Nebulizer Gas Flow (L/min)	1.15
He Flow Rate in AHM (mL/min)	14
Air Flow Rate in Air Cell Mode (mL/min)	0.45
Lens and Cell Tune	Autotune

ADS 2

The ADS 2 effectively reduces the number of manual tasks operators must perform when preparing a quantitative method for ICP-MS or ICP-QQQ, allowing more time to focus on other tasks. Refer to the technical overview for an in-depth look at the features and capabilities of the autodilutor.[4]

In this study, the ADS 2 was used to automatically prepare calibration standards and perform prescriptive dilution of samples and QCs before analysis. The ADS 2 is fully integrated and controlled by OpenLab ICP-MS. A preset method (Food/Clinical) was used for this study; several of these standard methods are selectable in OpenLab ICP-MS. Once selected, the preset method populates most instrument and analyte settings, requiring minimal user input.

Advanced Helium Mode

Advanced Helium Mode (AHM) revolutionizes helium-based interference removal by intelligently optimizing cell conditions for low- and high-mass elements in real time. With up to 20× sensitivity improvements for low-mass elements, AHM simplifies workflows, reduces analysis time, and enhances data quality. Using a dual interference removal approach (KED + CID)[2], the 9500 ICP-QQQ delivers enhanced polyatomic interference removal and improved abundance sensitivity across a wide mass range.

Air cell mode

Agilent triple quadrupole ICP-MS systems have an additional quadrupole mass filter (Q1) before the CRC that controls which ions enter the cell and react with the cell gas. In this tandem MS (MS/MS) mode, reaction cell chemistry can be applied more effectively to remove interferences. However, when transitioning from a single-quadrupole system, new laboratory infrastructure is often required to facilitate reaction cell gases, such as oxygen (O_2). The 9500 ICP-QQQ is equipped with Air cell mode as a standard feature, which uses ambient air as a reactive cell gas in the DCS. This unique capability enables effective interference reduction without the need for a high-purity O_2 supply, simplifying operation while providing efficient and stable interference removal.

One example of interference reduction using Air cell mode involves suppressing doubly charged rare earth element (REE^{++}) ion interferences, such as $^{150}Nd^{++}$ and $^{150}Sm^{++}$ on ^{75}As and $^{156}Gd^{++}$ and $^{156}Dy^{++}$ on ^{78}Se. NIST 1573a Tomato Leaves contains Gd and Sm, reflecting the presence of REEs in certain foods. After dilution, the concentrations of analytes and interferents in the SRM sample were approximately 0.35 and 0.17 ppb for As and Se, and 0.59 and 0.5 ppb Sm and Gd, respectively.

Figure 2 compares the recoveries of As and Se in AHM and Air cell mode in the presence of the REE^{2+} interferences. While the AHM signal response for As and Se is enhanced by interferents, Air cell mode avoids them, as shown by recoveries closer to 100%. Further details of Air cell mode are available elsewhere.[3]

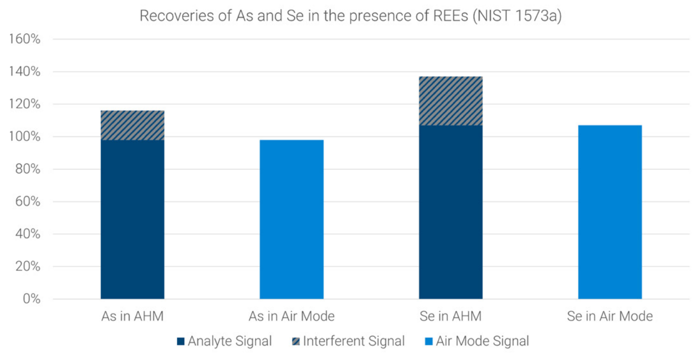

Figure 2. Recovery comparison of As and Se measured in NIST 1573a Tomato Leaves that contains high concentrations of Sm and Gd using the Agilent 9500 ICP-QQQ in AHM (dark blue) and Air Cell mode (blue).

Results and discussion

Detection limits

Table 3 displays the Detection Limit (DL) and Background Equivalent Concentration (BEC) calculated by the OpenLab ICP-MS software and the Limits of Quantification (LOQs) calculated in accordance with the AOAC Method. The LOQ was calculated as six times the standard deviation of 10 method blank measurements.

The performance of the 9500 ICP-QQQ far exceeded the LOQs reported in the AOAC 2015.01 method. Furthermore, using the integration times listed in the table, the sample-to-sample time averaged approximately 2 minutes and 45 seconds. This acquisition time is more than 30 seconds faster than an equivalent multitune method on a single-quadrupole ICP-MS.

Table 3. Agilent 9500 ICP-QQQ Detection Limits and Background Equivalent Concentrations, and Limits of Quantification calculated in accordance with the AOAC 2015.01 method.

Element	Tune Mode	Q1	Q2	Integration Time (s)	ISTD	DL (ppb)	BEC (ppb)	LOQ (ppb)
V	AHM		51	0.3	45 Sc	0.0006	0.0005	0.001
Cr	AHM		52	0.3	72 Ge	0.004	0.029	0.03
Mn	AHM		55	0.3	72 Ge	0.001	0.008	0.02
Fe	AHM		56	0.3	72 Ge	0.02	0.2	0.2
Co	AHM		59	0.3	72 Ge	0.0007	0.001	0.0004
Ni	AHM		60	0.3	72 Ge	0.02	0.06	0.02
Cu	AHM		63	0.3	72 Ge	0.004	0.02	0.01
Zn	AHM		66	0.3	72 Ge	0.003	0.04	0.02
As	AHM		75	1	72 Ge	0.0006	0.001	0.003
As	Air	75	91	1	72 -> 88 Ge	0.0009	0.0008	0.007
Se	AHM		78	1	72 Ge	0.002	0.003	0.004
Se	Air	78	94	3	72 -> 88 Ge	0.003	0.0006	0.005
Se	Air	80	96	3	72 -> 88 Ge	0.001	0.0004	0.003
Mo	AHM		90	0.3	72 Ge	0.001	0.005	0.002
Ag	AHM		107	0.3	103 Rh	0.0009	0.001	0.03
Cd	AHM		111	2	103 Rh	0.0001	0.00008	0.0005
Lu	AHM		175	0.1	209 Bi	0.0005	0.0003	0.001
Hg	AHM		201	1	209 Bi	0.0005	0.0002	0.002
Tl	AHM		205	0.3	209 Bi	0.0003	0.0009	0.0007
Pb	AHM		208	1	209 Bi	0.0003	0.001	0.0009
Th	AHM		232	0.3	209 Bi	0.0002	0.0001	0.001
U	AHM		238	0.3	209 Bi	0.0000	0.00002	0.0005

SRM recoveries

To verify the method's accuracy, triplicate preparations of the three food SRMs were each measured three times using the 9500 ICP-QQQ. As shown in Table 4, all analytes were recovered within the ±25% tolerance range specified in the AOAC method. Because each SRM contains a different set of analytes, empty cells indicate that no certified value is provided for that analyte in that SRM.

Samples were measured at a minimum dilution factor of 320x after the described digestion procedure. If the concentration of any analytes was outside the calibration range, the samples were automatically diluted using the ADS 2 and remeasured. The results for Cu and Zn in oyster tissue, Mn and Zn in tomato leaves, and Zn in mussel tissue in Table 4 follow a reactive dilution by the ADS 2. From these various measurements, the most appropriate results for each element are displayed.

The AOAC method also requires a Lu spike in each sample digestion to confirm that no volatile elements have been lost during the analytical process. Lu recoveries for all samples exceeded 98%, showing excellent preservation of volatile elements.

Table 4. Mean recovery results for the three NIST food SRMs. The mean concentrations were calculated from triplicate measurements of triplicate digests.

Element and Mode	Oyster Tissue				Tomato Leaves				Mussel Tissue			
	Certified Value (mg/kg)	Measured Value (mg/kg)	ADS 2 Dilution	Recovery (%)	Certified Value (mg/kg)	Measured Value (mg/kg)	ADS 2 Dilution	Recovery (%)	Certified Value (mg/kg)	Measured Value (mg/kg)	ADS 2 Dilution	Recovery (%)
51 V [AHM]	0.577 ± 0.023	0.557 ± 0.032		95								
52 Cr [AHM]					1.988 ± 0.034	1.761 ± 0.049		89				
55 Mn [AHM]	18.5 ± 0.2	18.6 ± 0.4		100	246.3 ± 7.1	273.0 ± 2.1	100	111				
56 Fe [AHM]	205.8 ± 6.8	203.8 ± 1.1		100	367.5 ± 4.3	348.0 ± 4.7		95	171.0 ± 4.9	173.2 ± 4.9		100
59 Co [AHM]	0.371 ± 0.009	0.366 ± 0.009		99	0.5773 ± 0.0071	0.5392 ± 0.0052		93				
60 Ni [AHM]	1.04 ± 0.09	0.925 ± 0.03		89	1.582 ± 0.041	1.414 ± 0.018		89				
63 Cu [AHM]	71.6 ± 1.6	78.76 ± 4.01	400	110	4.70 ± 0.14	4.47 ± 0.06		95	4.02 ± 0.33	3.847 ± 0.09		96
66 Zn [AHM]	1 424 ± 46	1528 ± 90	400	107	30.94 ± 0.55	26.82 ± 1.08	100	94	137 ± 13	158 ± 3.4	50	114
75 -> 91 As [Air]	7.65 ± 0.65	7.42 ± 0.27		97	0.1126 ± 0.0024	0.1098 ± 0.0041		98	13.3 ± 1.8	14.3 ± 0.4		108
78 -> 94 Se [Air]	2.06 ± 0.15	1.96 ± 0.08		95	0.0543 ± 0.0020	0.0583 ± 0.0007		107	1.80 ± 0.15	1.86 ± 0.04		103
111 Cd [AHM]	2.48 ± 0.08	2.49 ± 0.07		100	1.517 ± 0.027	1.460 ± 0.026		96	0.82 ± 0.16	0.894 ± 0.03		109
201 Hg [AHM]	0.0371 ± 0.0013	0.0342 ± 0.0021		92	0.0341 ± 0.0015	0.032 ± 0.0022		94	61.0 ± 3.6	61.6 ± 3.1		101
206 Pb [AHM]	0.308 ± 0.009	0.297 ± 0.009		96					1.19 ± 0.18	1.27 ± 0.07		106

Stability

As part of the AOAC method's required QC procedure, a CCV sample was measured after the calibration and after every 10 samples. As displayed in Figure 3, all nine CCV samples recovered within the required ±15% limit. ISTD recovery was also stable at 87–118% throughout the 5.5-hour analytical run, well within the AOAC requirements of 60–125%. Both sets of results demonstrate the robustness of the 9500 ICP-QQQ for food analysis.

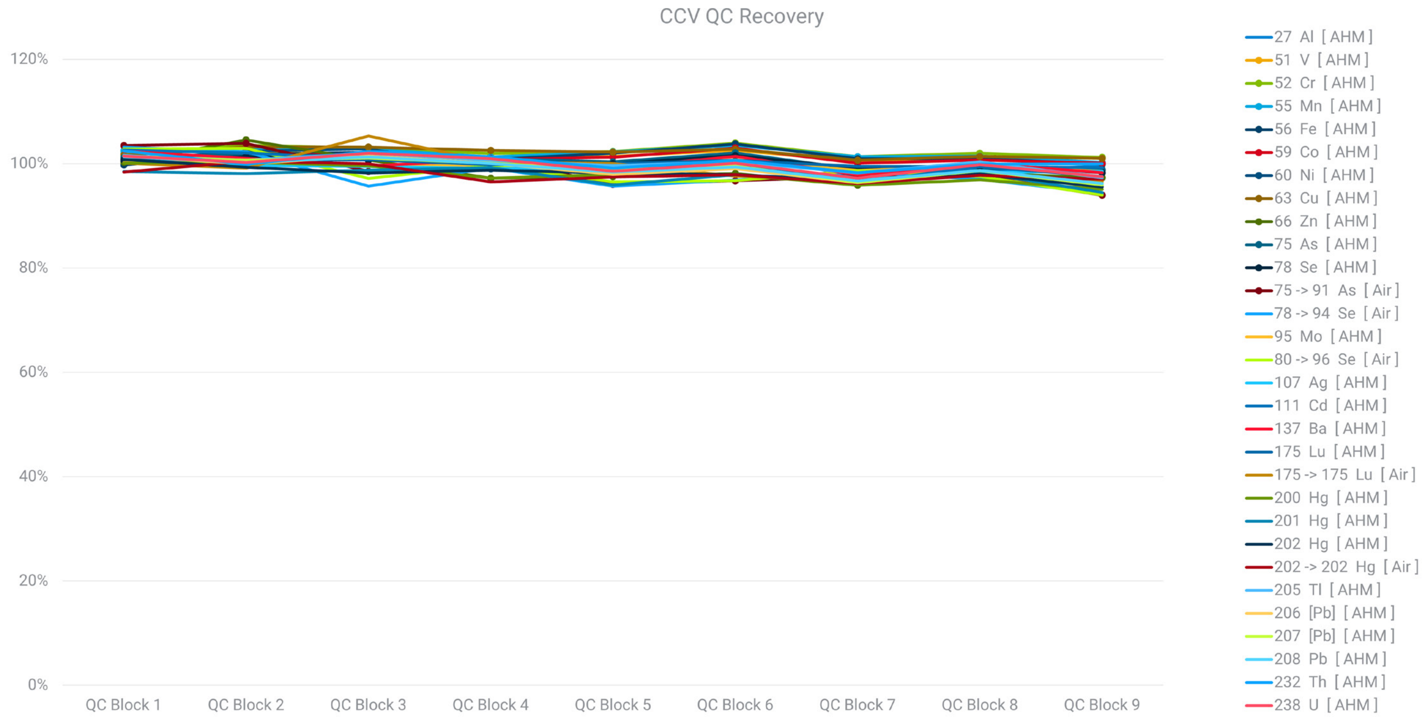

Figure 3. CCV recoveries over a 5.5-hour sequence, including at the start and end of the analytical sequence.

Conclusion

The Agilent 9500 ICP-QQQ with Dual-Cell System (DCS) successfully quantified a broad range of metals in diverse food matrices in accordance with an AOAC standard method. Most elements were measured in AHM, while As and Se were accurately determined at trace levels in Air cell mode using ambient air to eliminate severe doubly charged REE interferences. AHM mode effectively suppressed polyatomic interferences such as NaAr on Cu, even in samples such as NIST 1573a Tomato Leaves, where Na is present at more than 20 times the concentration of Cu.

Together, the two DCS gas modes provided comprehensive interference control for routine food analysis, as demonstrated by recoveries of certified elements within ±25% for the food SRMs.

Compared to single-quadrupole ICP-MS, DCS operation in both modes reduced analysis time by about 30 seconds per sample. Automation using the Agilent AVS MS discrete sampling accessory, SPS 4 autosampler, and ADS 2 autodilutor further improved productivity and delivered reliable results, including:

- Detection limits for As, Cd, Pb, and Hg well below the LOQs reported in AOAC 2015.01
- Effective removal of REE^{2+} interferences on As and Se
- Over 98% Lu recoveries across all SRMs, demonstrating excellent preservation of volatile elements throughout the analysis
- Stable operation over five hours, maintaining CCV and ISTD recoveries within AOAC limits

The 9500 ICP-QQQ enables high-throughput, AOAC-compliant food analysis by controlling interferences with AHM and Air cell mode, ideal for labs that need speed, reliability, and accuracy.

References

1. Association of Official Analytical Chemists (AOAC), Determination of Heavy Metals in Food by Inductively Coupled Plasma–Mass Spectrometry: First Action 2015.01. *J. AOAC Int,* 98(4), **2015,** 1113–1120
2. Dual-Cell System (DCS) and Advanced Helium Mode (AHM), Agilent publication, 5994-8985EN
3. Air Cell Mode of the Agilent 9500 ICP-QQQ with Dual-Cell System, Agilent publication, 5994-8987EN
4. Capabilities and Operation of the Advanced Dilution System 2, Agilent publication, 5994-7211EN

Products used in this application

Agilent products

Product Type	Description	Part Number
Sample Introduction System	Quartz sample introduction system for 9500 ICP-MS	M5150-67107
	MicroMist nebulizer for 9500 ICP-MS	M5150-67024
Interface	ICP-MS sampler cone for 9500 ICP-MS, nickel plated	M5150-67001
	Nickel skimmer cone for 9500 ICP-MS with u-lens	M5150-67005
	Extraction-Omega lens assembly, u-lens, stainless steel base	M5150-67022
Tubing Kits	Easy-fit peristaltic-pump tubing, PVC, white/white, 1.02 mm id, for sample	5005-0020
	Easy-fit peristaltic-pump tubing, PVC, blue/orange, 0.25 mm id, for internal standard	5005-0021
	Easy-fit peristaltic-pump tubing, beige thermoplastic, yellow/blue, 1.52 mm id, for drain	5005-0022
	Sample loop for ADS 2/AVS MS, 2.50 mL, 1.00 mm id	5005-0427
	AVS MS preconfigured tubing kit for 9500 ICP-MS	M5171-67001
Bottle Kits	Diluent/carrier 6 L bottle kit, includes a 6 L can, GL45 StaySafe cap, fittings, and venting valve	5005-0435
	Diluent 2 L PFA bottle kit for ICP-MS, includes 2 L PFA bottle, GL45 StaySafe cap, fittings, and venting valve	5005-0436
	Waste container kit, includes a 10 L waste can, S60 StaySafe cap, fittings, and acid vapor filter	5005-0437
Chemical Standards	Internal standard mix	5183-4681
	Environmental calibration standard	5183-4688

www.agilent.com/chem/9500icpqqq

DE-013656

Published in the USA, June 01, 2026
5994-9095EN

Agilent
Trusted Answers