Application Note

Trace metals in food

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Routine Analysis of Fortified Foods using Single Quadrupole ICP-MS

Simple and robust quantitative analysis of 28 elements in food digests using helium mode

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Introduction

Global sales of fortified foods run to billions of dollars a year. The market for infant formula is continuing to grow, especially in Asia Pacific (*1*). Products that form part of the lucrative diet industry, such as meal replacement drinks remain popular (*2*). To protect consumers, both in terms of essential nutrient-levels and against harmful content, fortified food products are subject to regulation. Example regulations for infant formula include China's GB 10765, the USA's 21 CFR 107, and the EU's Commission Directive 2016/127/EC) (*3–5*). Typically, the regulations state minimum and maximum levels of minerals, including Na, K, Cu, Mg, Fe, Zn, Mn, Ca, P, I, Cl, and Se. The Chinese national food safety standard for infant formula also states a maximum level of 0.15 mg/kg for Pb (*3*). Depending on the food-type, producers must also adhere to regulations, which include maximum concentrations for potentially harmful trace elements, including As, Cd, Hg, Pb, Ni, Sn, and Cr (*6–8*).

Since contaminant elements are only likely to be present in food samples at low concentrations, an analytical technique that can achieve low limits of detection is needed for the application. ICP-MS is a fast, multi-element analysis technique with the necessary sensitivity, and dynamic range to measure nutrient and contaminant elements in fortified food products. With recent improvements in its usability and robustness, ICP-MS is increasingly used for the high throughput, routine analysis of foods.

To ensure accurate results, Agilent ICP-MS systems use a single helium collision cell mode to control common polyatomic interferences. The instruments' 10 or 11 orders linear dynamic range also simplifies method setup, as major and trace analytes can be measured in a single run, meaning fewer reruns due to over-range results. Also, Agilent High Matrix Introduction (HMI) enables the ICP-MS to handle samples with total dissolved solids (TDS) levels up to 3% (and up to 25% with Ultra (U)HMI).

Methods for the determination of multiple-elements in fortified foods can be adapted from standard methods (*9–11*).

This study describes the use of an Agilent ICP-MS system and SPS 4 autosampler for the analysis of major and trace elements in microwave digested fortified food samples. The quality of the data was assessed through the measurement of an infant/adult nutritional formula standard reference material (SRM).

Experimental

Samples and reagents

All samples were bought off-the-shelf from supermarkets in the USA and China. They included two meal-replacement drinks and three infant formula products from western USA, and four infant formula products from northern China. A milk-based SRM NIST 1849a Infant/Adult Nutritional Formula I was used to validate the analytical method.

Nitric acid (≥ 65%, Sigma-Aldrich) was used for microwave digestion and standard/sample preparation. All dilutions were done using 18.2 MΩ·cm (Millipore, Bedford, MA, USA) de-ionized water (DIW).

Standards

Calibration standards for 28 elements were prepared from multi-element standards using 5% (v/v) nitric acid solution or DIW for dilution. Agilent standards were used, including multi-element calibration standard-2A (P/N: 8500-6940), multi-element calibration standard-3 (P/N: 8500-6948), environmental calibration standard (P/N: 5183-4688), multi-element calibration standard-4B (P/N: 8500-6942), and single element calibration standard-phosphorus (P/N: 5190-8428). Iodine (I) standard solution (GSB 04-2834-2011, 1000 ppm in H_2O) from General Research Institute for Nonferrous Metals, China, was diluted with DIW (*12*). Each set of calibration standards was prepared separately.

The internal standard (ISTD) solution containing Sc, Ge, Rh, In, Tb, and Bi was prepared from Agilent's Internal Standard Mix (P/N: 5188-6525) using 5% (v/v) nitric acid solution.

Sample preparation

About 0.2 g of each sample and NIST 1849a SRM were digested in 5 mL of HNO_3 using the microwave digestion (CEM, Mars 6) program outlined in Table 1. The fully digested samples were then diluted to 50 mL with DIW. All samples and NIST SRM were prepared in triplicate.

Table 1. Microwave digestion program.

Power (W)	Temperature (°C)	Ramping Time (min)	Holding Time (min)	Cooling Time (min)
100	50	15	15	-
1800	210	15	20	30

Instrumentation

Analyses were carried out using a standard Agilent 7800 ICP-MS, which includes the fourth-generation ORS^4 cell system for effective control of polyatomic interferences using helium collision mode (He mode). The ORS^4 controls polyatomic interferences using He to reduce the transmission of all common matrix-based polyatomic interferences. Smaller, faster analyte ions are separated from larger, slower interference-ions using kinetic energy discrimination (KED). All elements, except Se, were measured in He mode with a flow rate of 5 mL/min. Se was measured in High Energy He (HEHe) mode, using a cell gas flow rate of 10 mL/min. The 7800 ICP-MS was configured with the standard sample introduction system consisting of a MicroMist glass concentric nebulizer, quartz spray chamber, quartz torch with 2.5 mm i.d. injector, and nickel interface cones. The 7800 has been superseded by the Agilent 7850 ICP-MS, but the configuration and analytical settings reported here apply to both models.

The sample preparation approach used in this study led to final solutions that contained less than 0.5% TDS, so these samples could be measured directly on the 7800 ICP-MS. For samples with higher levels of dissolved solids, the HMI system allows samples containing up to 3% TDS to be measured routinely.

The ICP-MS was optimized using autotuning functions within the ICP-MS MassHunter software. An Agilent SPS 4 autosampler was used as the sample introduction system. Instrument operating conditions used are shown in Table 2.

Table 2. ICP-MS operating conditions.

Parameter	Setting
RF power (W)	1550
Sampling depth (mm)	8
Nebulizer gas (L/min)	1.16
Lens tune	Autotune
Helium gas flow rate (mL/min)	5 (10 for Se)
KED (V)	5.0

Results and discussion

Calibration, detection limits (DLs), and method DLs

Figure 1 shows linear calibration curves for representative elements (^{39}K, ^{63}Cu, ^{78}Se, and ^{202}Hg) from across the mass range. Analytical DLs and background equivalent concentrations (BECs) are given in Table 3. External method DLs (MDLs) and limits of quantitation (MLOQs) from the repeat analysis of digestion blanks (n=12) are also shown. All LOQs are lower than listed in GB 5009.268 (*10*).

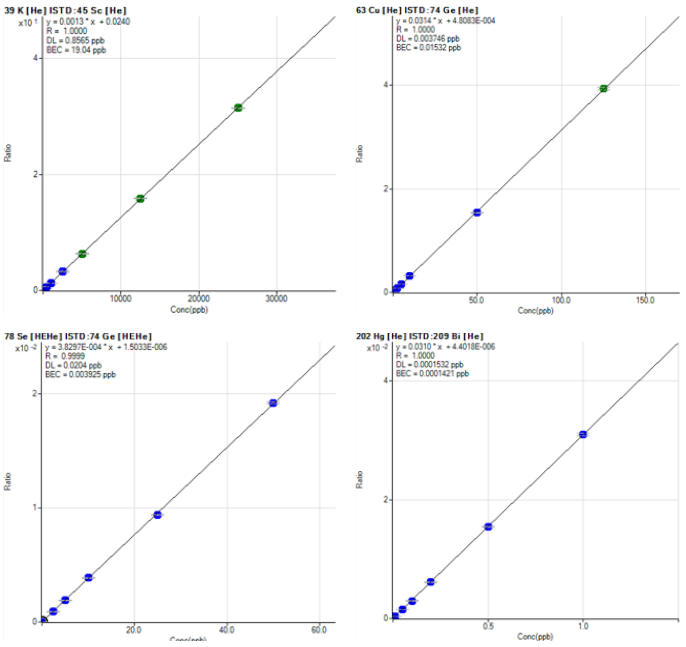

Figure 1. Calibration curves for ^{39}K, ^{63}Cu, ^{78}Se, and ^{202}Hg.

Table 3. DLs, BECs, MDLs, and method LOQs.

	Analytical (in solution)		Method (in food)	
	DL (µg/L)	BEC (µg/L)	MDL (mg/kg)	MLOQ (mg/kg)
11 B	0.293	0.333	0.023	0.077
23 Na	0.146	0.955	0.243	0.801
24 Mg	0.134	0.081	0.112	0.369
27 Al	0.301	0.404	0.418	1.381
31 P	1.62	19.2	1.350	4.455
39 K	0.857	19.0	0.479	1.582
44 Ca	2.66	1.47	0.572	1.888
51 V	0.0013	0.0005	0.001	0.002
52 Cr	0.0202	0.0271	0.012	0.041
55 Mn	0.0082	0.0051	0.009	0.028
56 Fe	0.0340	0.3624	0.590	1.946
59 Co	0.0014	0.0004	0.0006	0.0020
60 Ni	0.0173	0.0873	0.005	0.016
63 Cu	0.0039	0.0158	0.006	0.019
66 Zn	0.0486	0.1105	0.140	0.462
75 As	0.0132	0.0050	0.001	0.004
78 Se	0.0155	0.0030	0.002	0.008
88 Sr	0.0284	0.1000	0.003	0.010
97 Mo	0.0050	0.0030	0.003	0.009
111 Cd	0.0010	0.0005	0.0001	0.0004
118 Sn	0.0027	0.0049	0.003	0.008
121 Sb	0.0024	0.0005	0.001	0.003
127 I	0.0269	0.0393	0.047	0.155
135 Ba	0.0144	0.0055	0.004	0.013
201 Hg	0.0017	0.0011	0.0001	0.0003
205 Tl	0.0002	0.0012	0.0001	0.0003
208 Pb	0.0011	0.0069	0.002	0.005
238 U	0.00006	0.00002	0.00004	0.00014

ISTD recovery test

Throughout the six hour ISTD-recovery test, 140 solutions were analyzed. As shown in Figure 2, all the ISTD recovery measurements for all six internal standards were within the ± 20% limits (indicated by the red dotted line). The results demonstrate the excellent stability and matrix tolerance of the ICP-MS. There was no significant signal drift during the sequence and no divergence in the signals for low- and high-mass ISTD elements. The recovery test shows that the plasma was able to decompose the variable sample matrices effectively. Also no significant matrix deposition occurred on the interface during the sequence.

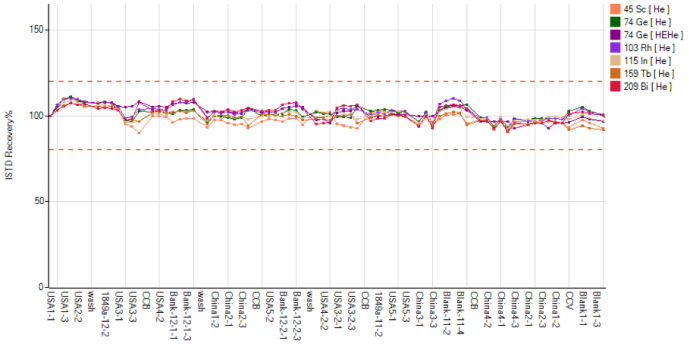

Figure 2. ISTD stability throughout the analysis of a total of 140 solutions measured over a 6-hour run. ISTD recoveries for all samples have been normalized to the calibration blank.

SRM recoveries

To determine the accuracy of the method, 13 elements were measured in NIST 1849a Infant/Adult Nutritional Formula I (milk-based) SRM digest using the 7800 ICP-MS operating in He mode. Table 4 shows the mean measured concentrations for all elements were in excellent agreement with the certified values, with all mean recoveries well within ±10% of the expected value.

Table 4. Mean recovery data for 13 elements present in the NIST nutritional formula SRM.

	Certified mass fraction values	Measured values		
		Mean value	RSD (n=6)	Recovery
	(mg/kg)		(%)	
Calcium (Ca)	5253 ± 51	5278	0.6	101
Copper (Cu)	19.78 ± 0.26	19.58	0.2	99
Chromium (Cr)	1.072 ± 0.032	1.124	1.2	105
Iodine (I)	1.29 ± 0.11	1.34	0.3	104
Iron (Fe)	175.6 ± 2.9	175.3	0.7	100
Magnesium (Mg)	1648 ± 36	1653	0.1	100
Manganese (Mn)	49.59 ± 0.97	49.15	0.5	99
Molybdenum (Mo)	1.707 ± 0.040	1.706	0.8	100
Phosphorus (P)	3990 ± 140	3890	0.5	98
Potassium (K)	9220 ± 110	9279	0.3	101
Selenium (Se)*	0.812 ± 0.029	0.842	2.1	104
Sodium (Na)	4265 ± 83	4268	0.1	100
Zinc (Zn)	151.0 ± 5.6	153.7	0.5	102

*Se was determined in high energy He (HEHe) mode.

Spike recovery test of regulated elements

The seven most commonly regulated elements in foods include As, Cd, Hg, Pb, Ni, Sn, and Cr. To check the accuracy of the method for actual sample analysis, a spike recovery test for the seven elements was carried out. Three infant formula products, including one from China and two from the USA, were spiked at two concentrations, as detailed in Table 5. The recoveries for all elements at all concentrations ranged between 95 and 109%, showing that the ICP-MS can analyze all these regulated elements with good accuracy.

Table 5. Spike recoveries for regulated metal elements in three infant formula product samples.

			Infant formula product samples					
			CHN-4		USA-3		USA-4	
	Spike amount (µg/L)		Spike recovery (%)					
	A	B	A	B	A	B	A	B
Cr	100	250	104	101	105	101	102	102
Ni	100	250	108	100	109	101	106	101
As	100	250	103	101	104	102	103	102
Cd	100	250	103	100	103	101	104	101
Sn	0.5	1	95	100	99	102	103	96
Hg	0.1	1	103	97	102	98	100	95
Pb	100	250	99	101	98	101	96	98

Quantitative analysis of purchased products

The ICP-MS was used to analyze two meal-replacement drinks and three infant formulas from the USA (Table 6), and four infant formula products from China (Table 7). The quantitative results for potentially toxic elements, such as As, Cd, Hg, Pb, Ni, Sn, and Cr, were well below regulatory or guideline levels (*6–8*). Mineral and nutrition elements required in infant formula, such as Na, K, Ca, Mg, Fe, Zn, Mn, P, and Se, were within the ranges listed in the guidelines.

Table 6. Quantitative data for two meal replacement samples and three infant formula samples. NA: not applicable.

	Infant formula product samples						Meal replacement product samples			
	USA-1		USA-2		USA-3		USA-4		USA-5	
	Mean (mg/kg)	RSD (%, n=3)	Mean (mg/kg)	RSD (%, n=3)	Mean (mg/kg)	RSD (%, n=3)	Mean (mg/kg)	RSD (%, n=3)	Mean (mg/kg)	RSD (%, n=3)
B	0.450	4.3	0.881	0.3	1.02	0.8	0.149	3.4	0.174	4.1
Na	1366	0.8	1572	0.6	1336	0.8	736.6	1.4	671.4	0.6
Mg	385.7	0.4	503.4	0.9	557.8	0.6	427.0	0.1	407.5	0.5
Al	0.527	5.3	4.55	1.3	2.02	1.4	2.77	1.4	0.834	1.0
P	2115	0.2	6085	0.2	2510	0.3	1247	0.3	1062	0.5
K	5633	0.4	7510	0.2	6102	0.4	2101	0.5	1423	0.5
Ca	3990	0.4	9550	1.2	4358	0.2	1881	0.2	1312	0.2
V	0.002	5.3	0.063	2.4	0.013	1.2	0.007	6.0	0.004	1.9
Cr	<MDL	NA	0.121	0.4	<MDL	NA	0.135	0.2	0.150	0.9
Mn	1.23	0.3	0.858	0.1	1.35	0.8	2.33	0.7	3.21	0.3
Fe	90.93	0.7	97.23	0.4	107.3	0.2	21.90	0.4	21.19	0.3
Co	0.004	4.7	0.007	4.1	0.013	1.6	0.003	1.2	0.002	1.2
Ni	<MDL	NA	0.045	0.5	0.075	1.1	0.024	1.3	0.012	1.2
Cu	4.91	0.2	3.46	0.5	4.21	0.4	2.40	0.5	2.38	0.5
Zn	48.51	0.6	39.03	0.8	60.05	0.8	43.02	0.4	19.78	0.2
As	0.007	11.3	0.005	12.4	0.004	1.9	0.003	1.3	0.002	3.8
Se	0.249	2.9	0.176	1.4	0.287	1.0	0.305	2.4	0.107	2.7
Sr	4.62	0.4	4.79	1.6	2.36	0.4	0.855	0.1	1.30	0.3
Mo	0.193	0.8	0.053	0.6	0.361	0.8	0.126	0.1	0.091	0.9
Cd	0.003	3.6	0.008	5.3	0.002	3.9	0.001	2.3	0.002	0.6
Sn	0.106	0.4	0.272	0.8	0.004	5.2	0.001	6.8	<MDL	NA
Sb	0.002	13.7	0.002	8.9	0.001	7.2	0.001	6.0	0.001	2.1
I	1.37	1.1	0.868	0.8	1.25	0.8	0.149	0.8	0.166	0.8
Ba	0.098	1.8	0.346	1.0	0.249	1.0	0.130	0.5	0.701	0.8
Hg	0.0002	45.2	0.0001	25.0	0.0003	14.6	<MDL	NA	<MDL	NA
Tl	0.002	9.5	0.003	1.0	0.002	4.6	0.0003	4.2	0.0002	2.4
Pb	0.004	3.3	0.006	0.1	0.014	1.0	0.002	0.3	0.002	3.6
U	0.001	1.9	0.022	0.7	0.004	0.6	0.003	0.4	0.001	0.7

Table 7. Quantitative data for four Chinese infant formula samples. NA: not applicable.

	Infant formula product samples							
	CHN-1		CHN-2		CHN-3		CHN-4	
	Mean (mg/kg)	RSD (%, n=3)	Mean (mg/kg)	RSD (%, n=3)	Mean (mg/kg)	RSD (%, n=3)	Mean (mg/kg)	RSD (%, n=3)
B	0.694	2.4	0.967	2.0	0.505	3.9	0.551	5.4
Na	2117	0.8	1417	0.1	1560	0.8	1533	0.7
Mg	784.4	0.1	541.8	0.8	504.0	0.7	530.4	0.4
Al	1.96	1.4	1.69	1.2	2.60	0.1	1.22	3.3
P	4188	0.1	3983	0.4	4304	0.8	4497	0.2
K	7028	0.1	6275	0.6	7042	0.2	7668	0.4
Ca	6111	0.1	5667	0.2	6065	0.2	6812	0.4
V	0.004	3.1	0.010	0.3	0.012	0.6	0.004	0.5
Cr	0.164	1.2	0.045	1.1	0.065	0.6	<MDL	NA
Mn	0.861	0.2	1.16	0.7	0.816	0.1	0.455	0.3
Fe	85.49	0.6	79.13	0.6	69.36	0.9	74.74	0.1
Co	0.008	3.3	0.010	3.4	0.008	2.8	0.007	2.4
Ni	0.080	2.0	0.037	6.8	0.049	1.4	0.019	3.4
Cu	3.83	0.1	3.02	0.2	2.84	0.1	3.65	0.3
Zn	42.06	0.2	45.60	0.3	46.07	0.1	39.49	0.6
As	0.004	2.8	0.008	7.9	0.005	3.7	0.004	7.2
Se	0.087	0.6	0.260	2.0	0.080	0.1	0.088	1.9
Sr	2.40	0.3	3.67	0.8	2.82	0.1	2.50	0.1
Mo	0.159	2.2	0.175	1.0	0.127	0.1	0.183	1.5
Cd	0.0004	13.6	0.0002	13.3	0.001	2.7	0.0002	18.5
Sn	0.003	7.0	0.006	4.7	0.003	1.9	0.003	2.5
Sb	0.014	2.4	0.001	2.1	0.001	8.3	0.001	2.1
I	1.06	1.9	1.66	1.0	0.862	2.0	0.848	0.1
Ba	1.49	0.5	0.268	1.3	0.456	1.4	0.370	0.6
Hg	0.0001	23.9	0.001	0.2	0.0001	22.5	<MDL	NA
Tl	0.004	2.2	0.001	1.8	0.001	4.2	0.0003	3.4
Pb	0.013	2.3	0.004	2.4	0.006	1.0	0.003	2.3
U	0.001	1.5	0.003	0.8	0.005	3.0	0.0003	4.8

Conclusion

An Agilent single quadrupole ICP-MS was used to analyze 28 elements in nine fortified food product samples, prepared by microwave digestion. Method development was simplified using the instrument's standardized helium collision mode and autotune features. The instrument's sensitivity and analytical dynamic range of 10 orders of magnitude enabled major, mineral elements such as Na, K, Ca, and Mg to be determined in the same analytical run as trace elements including Cr, As, Cd, Pb, and Hg.

The accuracy of the method was evaluated by analyzing 13 nutrient elements in a nutritional formula SRM and conducting a spike recovery test for seven contaminant elements in three infant formula samples. Excellent recoveries were achieved in all cases. The ICP-MS also demonstrated excellent stability over a six-hour run and exceeded detection limit requirements specified in the GB standard method.

The study showed that Agilent ICP-MS instruments are suitable for the routine, multi-element screening of trace level elements and high concentration mineral elements in foods, ensuring quality control of elemental nutrients as well as contaminants.

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