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Analysis of Dietary Supplements for Arsenic, Cadmium, Mercury, and Lead Using Inductively Coupled Plasma Mass Spectrometry

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The arsenic, cadmium, mercury, and lead contents of 95 dietary supplement products were determined using microwave digestion and high-resolution inductively coupled plasma mass spectrometry. Precision and accuracy were demonstrated by element recovery from 17 dietary supplements and replicates of 8 reference materials. The concentration ranges were as follows: arsenic, <5−3770 μg/kg; cadmium, <10−368 μg/kg; mercury, <80−16800 μg/kg; and lead, <20−48600 μg/kg. An assessment of estimated exposures/intakes of the four elements is presented.

KEYWORDS: Dietary supplements; arsenic; cadmium; mercury; lead; microwave digestion; high-resolution ICP-MS

INTRODUCTION

In 1994 the U.S. Congress amended the Federal Food, Drug, and Cosmetic Act (the FFD&C Act) (*1*) by passage of the Dietary Supplement Health and Education Act of 1994 (DSHEA) (*2*). This law defined the term "dietary supplement" to mean a product (other than tobacco) that, among other things, is intended for ingestion that contains one or more of the following dietary ingredients: vitamins; minerals; herbs or other botanicals; amino acids; dietary substances for use by man to supplement the diet by increasing the total daily intake; or concentrates, metabolites, constituents, extracts, or combinations of these ingredients; and is labeled as a "dietary supplement" (*3*). Under the FFD&C Act, the dietary supplement manufacturer or distributor is responsible for ensuring that a dietary supplement is safe under the conditions of use recommended or suggested in the labeling or, when no conditions of use are recommended, under ordinary conditions of use, before it is marketed. Currently, the U.S. Food and Drug Administration (FDA) has not published regulations for dietary supplements that establish minimum standards of practices for manufacturing dietary supplements (i.e., current good manufacturing practices).

Use of dietary supplements has greatly increased since the passage of the DSHEA. Consumer sales were approximately $12.7 billion in 1997. The two greatest market shares in 1996 were vitamins with 48% and herbals and botanicals with 28% (*4*). Surveys show an increase in use of herbal medicines between 1990 and 1997 (*5*).

The FDA's Dietary Supplement Strategy includes development of methods and safety research for dietary supplement ingredients and contaminants (*6*). Arsenic, cadmium, mercury, and lead are of primary concern due to their toxicity and potential to be present as contaminants or because they may be occasionally used as ingredients in dietary supplements. Previous studies on the presence of these elements in dietary supplements indicate that relatively high concentrations of these elements may occur (*7*−*14*). One purpose of the present work was to investigate the prevalence and concentrations of these elements in a variety of dietary supplements with an emphasis on botanical-based products.

High-resolution inductively coupled plasma mass spectrometry (HR ICP-MS) was used to analyze dietary supplements for arsenic, cadmium, mercury, and lead. ICP-MS has clear advantages in its multielement characteristics, speed of analysis, and detection limits. Quadrupole ICP-MS has been used to analyze various dietary supplements for the elements of interest (*15*−*19*). The higher mass resolution of an HR ICP-MS provides separation of analyte signals from known spectral interferences. Dietary supplements were digested using a microwave procedure based on a method developed for multielement analysis of foods by inductively coupled plasma atomic emission spectrometry (*20*).

MATERIALS AND METHODS

Instruments. Analytical portions were digested with a microwave system (model MARS5, CEM Corp., Matthews, NC) equipped with temperature and pressure control to 200 °C and 800 psi, respectively. The microwave digestion system was capable of delivering 1200 W of maximum power with controlled temperature ramping. Microwave digestion vessels (model XPS-1500, CEM Corp.) were TFM Teflon-lined and capable of operating at up to 200 °C and 800 psi.

Arsenic, cadmium, mercury, and lead concentrations were measured with a Micromass PlasmaTrace-2 HR ICP-MS (Micromass, Beverly,

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MA). The PlasmaTrace-2 is a magnetic sector mass spectrometer capable of achieving resolutions in excess of 10000, where resolution is defined as the mass/mass difference between peaks for the 10% valley definition (*21*). Plasma operating parameters were 1350 W forward power, <10 W reflected power, and argon flow rates of 1, 1.5, and 13 L/min for the nebulizer, intermediate, and outer gases, respectively. Analytical solutions were aspirated by a fixed cross-flow pneumatic nebulizer (Precision Glassblowing, Englewood, CO) into a water-cooled Scott double-pass spray chamber maintained at 1 °C with a recirculating chiller. A peristaltic pump was used to deliver analytical solution from the autosampler to the nebulizer at 0.7 mL/min. The peristaltic pump was also used to remove the spray chamber waste.

Reagents. Reagent water of ASTM Type I grade (*22*) was used for the preparation of reagents, standards, and analytical solutions. Calibration standard solutions and internal standards were prepared from commercial single-element analyte standard solutions (High-Purity Standards, Charleston, SC). Trace metals grade (TMG) nitric acid (A509SK-212, Fisher Scientific) was used for cleaning laboratory ware, and Ultrex-II nitric acid (Mallinckrodt Baker, Phillipsburg, NJ) was used for the preparation of calibration standard solutions and analytical solutions. To stabilize mercury, gold at a concentration of 5 mg/L was added to all standard, rinse, and analytical solutions (*23*).

Samples and Reference Materials. Dietary supplement products were purchased in 1999 primarily from retail stores in the Washington, DC, area. Of the 95 products purchased 84 contained herbs or botanicals as major components. The labeling of 19 products was directed toward women.

The method was validated using the following reference materials from the National Institute of Standards and Technology (NIST; Gaithersburg, MD): orchard leaves (SRM 1571), typical diet (SRM 1548a), whole egg powder (RM 8415), bovine liver (SRM 1577a), trace elements in spinach (SRM 1570), bone meal (SRM 1486). Cocoa powder, an FDA in-house reference material, was also used.

Contamination Control. Tacky floor mats (06-520-3, Fisher Scientific) were placed outside and inside each laboratory entrance. Microwave digestion vessels were cleaned with Micro-90 liquid laboratory grade detergent (Cole-Parmer, Vernon Hills, IL) and warm tap water when first used or after an incomplete digestion. Subsequently, digestion vessels were cleaned with 10 mL of TMG nitric acid using the following microwave cleaning program: 1200 W maximum power, 0 psi control pressure, 10 min ramp time, 3 min hold time, and 200 °C control temperature. Vessels were rinsed with reagent water and dried under class 100 HEPA-filtered laminar flow air. High-density wide-mouth polyethylene 250 mL bottles (02-893-5D, Fisher Scientific) used for storing analytical solutions were soaked in 10% TMG nitric acid overnight and rinsed three times with reagent water. Cleaned bottles were dried, capped, and stored under class 100 HEPA-filtered laminar flow air. Polypropylene autosampler tubes (14-956-7E, Fisher Scientific) were placed in racks (14-791-9B, Fisher Scientific), filled with 10% TMG nitric acid, stored in BioTransport carriers (15-251-2, Fisher Scientific) (rubber gasket was removed) overnight, and rinsed three times with reagent water. Tubes were dried under a class 100 HEPA-filtered laminar flow air and stored in BioTransport carriers until needed. The HR ICP-MS laboratory was equipped with class 100 HEPA-filtered room air supply and a 4-ft × 4-ft class 100 HEPA-filtered laminar flow canopy with a plastic curtain suspended from the ceiling over the autosampler.

Quality Control. Two analytical portions of each product were analyzed. Each analytical batch contained at least two method blanks, one fortified analytical portion and one reference material (orchard leaves). Batches consisted of 24 analytical portions including quality control samples. Fortifications of arsenic, cadmium, mercury, and lead were added (120−2400 μg/kg) prior to digestion to 17 dietary supplement analytical portions representative of the variety of products. Check standard solutions were analyzed after every 10 analytical solutions to ensure instrument performance.

Digestion of Products. Maximum analytical portion size was determined using caloric energy content of a product as an indicator of pressure produced during digestion (*20*). For the 800 psi maximum pressure vessels used, a maximum energy release for digestion was empirically determined as 6 kcal. This energy limit prevents digestion from reaching maximum operating pressure before the digestion program is complete. The maximum analytical portion was calculated by dividing this maximum energy release by the product's energy. A product's energy was calculated from the estimated mass of the product's gelatin capsule, herb, and oil component and, respectively, the caloric values for protein, carbohydrate, and fat (5.25, 4, and 9 kcal/g, respectively). On the basis of these calculations, at least 1 g of solid product would be an appropriate analytical portion for all products and was chosen as the maximum mass. Analytical portions of solids were composed of one or more whole product units to approach 1 g. Products with a unit mass >1 g were cut with a stainless steel razor. The maximum analytical portion for the three liquid products was 1 g of dry weight based on moisture content declared on the product label. Analytical portions ranged from 0.53 to 1.2 for solids and from 1.1 to 6.1 g for liquids with an overall median of 0.83 g.

Analytical portions were weighed into microwave digestion vessels, and 9 mL of Ultrex-II nitric acid was added. Vessels were sealed and placed in the microwave oven, and digestion was performed under the conditions listed in **Table 1**. Digestions were judged to be complete when the temperature reached 200 °C and clear to light yellow analytical solutions were produced. Analytical portions that were incompletely digested were discarded, and a lower weight portion was digested. The microwave digestion program typically took 30−35 min to complete with another 20−30 min to allow vessels to cool for safe handling. Analytical solutions were quantitatively transferred to cleaned 250 mL HDPE bottles, fortified with internal standard elements, and diluted to 100 mL with reagent water.

Determination of Arsenic, Cadmium, Mercury, and Lead. The HR ICP-MS acquisition parameters are listed in **Table 2**. The spectrometer was tuned to give maximum signal at 10000 resolution. Sensitivity was optimized on a daily basis using a 1 μg/L indium solution. Various instrumental parameters were optimized in order to achieve a minimum sensitivity of 40000 cps at low resolution (450) and 1600 cps at high resolution (10000). Integrated peak counts were

Table 1. Microwave Digestion Program[a]

	stage 1	stage 2
maximum power (W)	300	1200
control pressure (psi)	800	800
ramp time (min)	5	20
hold time (min)	0	3
control temperature (°C)	130	200

[a] For each stage, power is applied for the ramp time minutes or until control pressure or control temperature is met. If control pressure or control temperature is met before the end of ramp time, then the program proceeds to hold time prior to proceeding to the next stage. If ramp time is met, then program proceeds to the next stage.

Table 2. Mass Spectrometer Acquisition Parameters

element	mass (amu)	IS[a]	dwell time (ms)	points/ width	peak widths[b]	scans	resolution[c]
As	74.92	Rh	100	40	3.5	3	8500
Rh	102.9		10	20	3.5	3	8500
Cd	110.9	In	20	20	2	3	450
In	114.9		10	20	2	3	450
Lu	174.94		10	20	2	3	450
Hg	201.97	Lu	20	20	2	3	450
Pb	205.97	Bi	10	20	2	3	450
Pb	206.98	Bi	10	20	2	3	450
Pb	207.98	Bi	10	20	2	3	450
Bi	208.98		10	20	2	3	450

[a] Internal standard. [b] Peak width is a flexible method of defining acquisition window width, which finds the optimum window size for each resolution and is calculated by the instrument software. [c] Resolution is defined as mass/mass difference between peaks for the 10% valley definition. The 10% valley definition of resolution means that two peaks of equal heights are said to be resolved if the valley between them is 10% of the peak height.

Table 3. Reference Material Results

reference material	*n*	mean ± SD (mg/kg)	ref value (mg/kg)	*z* score	recovery (%)
		Arsenic			
bone meal (SRM 1486)	3	<0.003	(0.006)		
bovine liver (SRM 1577a)	6	0.041 ± 0.014	0.047 ± 0.006	–1.5	88
cocoa powder (FDA)	3	0.029 ± 0.003	0.034 ± 0.004	–1.1	83
orchard leaves (SRM 1571)	12	10.7 ± 0.7	10 ± 2	0.6	107
spinach (SRM 1570)	3	0.157 ± 0.013	0.15 ± 0.05	0.3	105
typical diet (SRM 1548a)	3	0.146 ± 0.006	0.20 ± 0.01	–6.1	73
whole egg powder (RM 8415)	3	0.0076 ± 0.0005	(0.01)		
		Cadmium			
bone meal (SRM 1486)	3	<0.006	(0.003)		
bovine liver (SRM 1577a)	6	0.439 ± 0.016	0.44 ± 0.06	0.0	100
cocoa powder (FDA)	3	0.387 ± 0.007	0.388 ± 0.059	–0.02	101
orchard leaves (SRM 1571)	8	0.128 ± 0.006	0.11 ± 0.01	2.2	116
spinach (SRM 1570)	3	1.53 ± 0.045	1.39 ± 0.19[a]	1.1	102
typical diet (SRM 1548a)	3	0.040 ± 0.011	0.035 ± 0.0015	2.3	114
whole egg powder (RM 8415)	3	<0.006	(0.005)		
		Mercury			
bone meal (SRM 1486)	3	<0.05			
bovine liver (SRM 1577a)	6	<0.05	0.004 ± 0.002		
cocoa powder (FDA)	3	<0.06			
orchard leaves (SRM 1571)	8	0.169 ± 0.006	0.155 ± 0.015	1.2	109
spinach (SRM 1570)	3	<0.05	0.030 ± 0.005		
typical diet (SRM 1548a)	3	<0.05	(0.005)		
whole egg powder (RM 8415)	3	<0.05	0.004 ± 0.003		
		Lead			
bone meal (SRM 1486)	3	1.62 ± 0.12	1.34 ± 0.01	3.5	121
bovine liver (SRM 1577a)	6	0.127 ± 0.005	0.135 ± 0.015	–0.9	94
cocoa powder (FDA)	3	0.116 ± 0.004	0.110 ± 0.022	0.2	102
orchard leaves (SRM 1571)	12	44.8 ± 1.4	45 ± 3	–0.1	100
spinach (SRM 1570)	3	1.19 ± 0.059	1.2 ± 0.2	–0.1	99
typical diet (SRM 1548a)	3	0.053 ± 0.009	0.044 ± 0.010	1.7	121
whole egg powder (RM 8415)	3	0.056 ± 0.001	0.061 ± 0.012	–0.8	91

[a] Value from Roelandts and Gladney (*25*).

taken from the spectrometer data system and processed with a Microsoft Excel spreadsheet program. The three isotopes of lead were summed. Concentrations were calculated using internal standard correction, blank subtraction, and a linear fit standardization. The internal standards used are listed in **Table 2**. Internal standard concentrations were determined in analytical solutions prior to internal standard fortification. When the unfortified internal standard concentration was ≥1% of the fortification level, the unfortified concentration was included in the internal standard correction calculation. Some analytical solutions required an additional 100-fold dilution due to their high concentration of analyte compared to the standard solutions.

RESULTS AND DISCUSSION

Method Performance. The results of replicate analyses of reference materials (0.5−1 g analytical portions) were used to assess accuracy and precision. Data from quantifiable results were examined by using a *z* score (*24*) and recovery for accuracy and precision based on relative standard deviation (RSD). *z* scores were defined as in Dolan et al. (*20*). Absolute values of *z* scores of ≤2, between 2 and 3, and ≥3 were used as indications of agreement, questionable agreement, or disagreement, respectively, between measured values and certified or consensus values. Results for the reference materials are listed in **Table 3**. Available *z* scores indicate agreement with the following exceptions: (i) cadmium in orchard leaves and whole egg powder indicates questionable agreement and (ii) arsenic in typical diet and lead in bone meal indicate disagreement. Mean percent recoveries for the individual reference material portions were 94, 108, 109, and 102 for arsenic, cadmium, mercury, and lead, respectively. Precision was lower than 10% except for cadmium and lead in typical diet (29 and 16%, respectively) and arsenic in bovine liver (34%). Mean percent recoveries of the fortifications were 106, 101, 111, and 106 for arsenic, cadmium, mercury, and lead, respectively.

Limits of detection (LOD) were estimated using 3 times the standard deviation of the element concentration in 31 method blanks analyzed throughout the study. LODs were 8.2, 18, 140, and 25 ng/L for arsenic, cadmium, mercury, and lead, respectively. Limits of quantification (LOQ) were estimated using 10 times the standard deviation of element concentration in the 31 method blanks. LOQs based on an analytical portion mass of 0.6 g and an analytical solution volume of 100 mL were 5, 10, 80, and 20 μg/kg for arsenic, cadmium, mercury, and lead, respectively.

Analytical Results. Concentrations of arsenic, cadmium, mercury, and lead in the dietary supplement products are shown in **Table 4** and represent the mean of two replicate analyses. The highest concentrations found were arsenic at 3770 μg/kg in sample 55, cadmium at 368 μg/kg in sample 86, mercury at 16800 μg/kg in sample 53, and lead at 48600 μg/kg in sample 36. The median concentrations are 179, 61, <80, and 403 μg/kg for arsenic, cadmium, mercury, and lead, respectively. The wide ranges of concentrations found are consistent with those reported previously (*7*, *10*, *11*, *14*, *18*). A number of factors preclude a thorough examination of the results to determine the product's component that may be the source of an element or variability between brands. These factors include the authenticity of the components, the amount of component in a product, the effect of the geographical source of the component, the number of various components in a product, and the relatively few samples compared to those available in the market. Some dietary

Table 4. Levels of Arsenic, Cadmium, Mercury, and Lead in Dietary Supplements

			concentration (μg/kg)			
no.	major product components[a]	g/day	As	Cd	Hg	Pb
1	*Armillaria mellea* extract, royal jelly	11.6	25	10	80	50
2	*Ashwagandha* extract	2.2	338	81	105	893
3	*Ashwagandha* root extract	1.35	96	74	80	752
4	*Asparagus racemosus* extract	1.87	208	15	185	447
5	*Astragalus* root extract, rosemary leaf extract, orange peel extract, turmeric root extract, red clover flower extract (plus 10 others) (plus vitamins and minerals)	4.17	2060	81	80	142
6	*Avena sativa*, suma, gotu kola, wild yam root, damiana (plus 6 others) (plus vitamins and minerals)	1.61	91	145	80	979
7	bee pollen	4.08	85	42	106	520
8	bee pollen, gotu kola, Siberian ginseng root, royal jelly, ginger root (plus 2 other)	1.13	244	320	139	1330
9	bee pollen, gotu kola, Siberian ginseng, royal jelly	3.47	243	304	121	2190
10	bee pollen, propolic, royal jelly	3.18	147	38	80	795
11	bee pollen, Siberian ginseng, ginger root, peppermint leaves	3.49	95	51	80	1080
12	bee pollen, spirulina, lemon juice powder, wheat grass, dong quai, (plus 14 others)	7.65	1170	209	80	341
13	black cohosh root	1.79	396	207	80	3160
14	black cohosh root and rhizome extract	0.55	5	10	80	20
15	bonnet flower (*Codonopsis pilosula*), *Atractylis ovata*, *Scutellaria baicalensis*, *Glycyrrhiza uralensis*, *Poria cocos* wolf (Polyporaceae)	4.94	464	69	541	751
16	Bupleurum root, Dong Quai root, Atractylodes rhizome, Peony root, Poria fungus (plus 3 others)	3.63	475	32	2230	729
17	*Caulis nillettiae*, *Siegesbckia pubescens*, *Cibotium barometz*, *Moghania philippinensis*, *Rosabella laevigata* (plus 5 others)	5.38	1040	152	864	5070
18	*Codonopsis* root, *Angelicae sinensis* root, *Poria*, *Rhozima atractylodis macrocephalae*, *Polygalae* root (plus 5 others)	5.46	412	58	379	2580
19	*Commiphora mukul*	3.42	396	95	80	272
20	dioscorea B, asparagus, ashoka, arjuna	1.9	1520	51	3110	1200
21	dong quai root	3.91	690	34	80	524
22	dong quai root, Chinese red ginseng root	1.85	190	47	90	1120
23	dong quai root, *Rehmannia* root, *Codonopsis* root, *Poria* fungus, peony root (plus 3 others)	4.64	595	32	866	539
24	*Echinacea* extract	1.42	134	36	80	20
25	*Echinacea* flower and root extract	0.44	92	57	80	54
26	*Echinacea* root extract (plus vitamins and minerals)	2.8	32	86	80	107
27	*Echinacea* whole plant and root extract (plus vitamins and minerals)	1.65	64	10	80	64
28	evening primrose oil, royal jelly, Korean ginseng extract	1.24	10	95	80	20
29	feverfew leaf	1.48	54	216	80	104
30	*Ginkgo biloba* extract	1.32	22	10	80	63
31	*Ginkgo biloba* leaf extract	0.43	98	10	80	35
32	*Ginkgo biloba* leaf extract, choline (plus vitamins and minerals)	1.66	395	64	80	523
33	Korean ginseng extract, Siberian ginseng extract	0.61	202	29	80	238
34	Korean ginseng root extract	1.58	11	78.8	80	20
35	*Panax* ginseng root extract	0.42	87	38	80	37
36	pseudo-ginseng root	10	2860	71	80	48600
37	red *Panax* ginseng	0.5	6	91	80	34
38	Siberian ginseng extract	1.45	508	14	80	51
39	Siberian ginseng extract, *Astragalus* extract, *Ligustrum lucidi* extract, *Schizandra* extract, *Ganoderma* nushroom (plus 6 others)	3.57	266	128	87	4610
40	Siberian ginseng extract, *Panax* ginseng extract (plus vitamins and minerals)	2.1	72	33	80	67
41	Siberian ginseng root extract	1.65	44	41	80	20
42	Siberian ginseng root extract, royal jelly concentrate, kola nut, cayenne (plus vitamins and minerals)	0.6	109	34	80	307
43	Siberian ginseng root extract, Siberian ginseng root	1.22	461	38	80	357
44	Siberian ginseng root, Siberian ginseng root extract, Chinese ginseng root extract, American ginseng root extract, Korean ginseng root extract (plus 10 others)	3.28	827	61	80	2330
45	ginseng, royal jelly	11.6	13	10	80	28
46	great northern white bean, chitosan (plus vitamins)	2.68	10	18	80	74
47	kava kava extract	1.14	225	77.5	80	179
48	marigold flower extract, tomato extract, dong quai, uva ursi, vitex (chaste) berry extract (plus 3 others) (plus vitamins and minerals)	3.8	914	294	80	744
49	*Mucuna prurens* extract, *Centella asiatica*, valerian, ashwagandha extract	2.04	74	28	80	582
50	*Paeonia* root extract, nettle leaf extract, red raspberry leaf extract, chamomile flower extract, organic orange extract (plus 9 others) (plus vitamins and minerals)	4.56	569	119	80	951
51	Pau d'Arco bark, burdock root, goldenseal root, black cohosh root, dandelion root and leaf (plus 7 others)	3.11	533	192	80	1550
52	*Picrorrhiza* kurroa plant extract, milk thistle fruit extract	2.41	163	17	446	472
53	*Pinelliae* rhizome, *Pericarpium citri chachiensis*, *Poria*, *Glycyrrhizae* root, *Zingiberis recens* rhizome	8.07	2780	37	16800	912
54	*Pinelliae* rhizome, *Pericarpium citri chachiensis*, *Poria*, *Glycyrrhizae* root, *Zingiberis recens* rhizome	9.18	110	21	165	546
55	red clover blossoms, echinacea, licorice root, buckhorn bark, burdock root (plus 7 others)	4.83	3770	105	80	920
56	soybean extract, lecithin, black cohosh root extract (plus vitamins and minerals)	2.79	516	127	88	98
57	soy extract, black cohosh extract (plus vitamins and minerals)	1.89	145	68	80	285
58	St. John's wort extract	0.24	149	72	80	101
59	St. John's wort extract	3.15	5	10	80	20
60	St. John's wort extract	1.2	53	155	80	146
61	St. John's wort extract	1.18	58	154	80	472
62	St. John's wort extract	1.94	67	33	80	20
63	St. John's wort extract	2.55	92	12	80	20
64	St. John's wort extract, Siberian ginseng extract (plus vitamins and minerals)	1.68	228	273	80	185
65	St. John's wort extract, St. John's wort	1.64	54	286	80	403
66	St. John's wort flower and leaf	1.22	20	262	80	150
67	St. John's wort flower and leaf extract	1.22	49	27	80	31
68	St. John's wort leaf and flower extract, lecithin, kava kava rhizome and root extract (plus vitamins and minerals)	1.85	179	231	80	191
69	stinging nettle leaf extract, ginger root extract, (plus vitamins and minerals)	2.04	68	142	80	114

Table 4. (Continued)

no.	major product components[a]	g/day	concentration (μg/kg) As	Cd	Hg	Pb
70	*Thymus* extract, *Echinacea* root, blue flag extract, goldenseal root extract (plus vitamins and minerals)	3.19	375	98	80	791
71	vitex (chaste) berries, cramp bark, dong quai, poria, squaw vine, (plus 3 others)	7.34	186	76	80	938
72	vitex extract	0.37	10	10	80	20
73	vitex fruit, wild yam root, chamomile flower, ginger rhizome, hawthorn leaf and flower (plus 16 others) (plus vitamins and minerals)	7	1130	182	80	308
74	blue/green algae, soy lecithin, apple pectin, apple fiber, *Hydrilla veticillata* (plus 27 others) (plus vitamins)	10.53	133	38	80	238
75	chlorella (plus vitamins and minerals)	2.95	288	17	80	412
76	Klamath blue green algae	0.62	3110	93	138	709
77	spirulina (plus vitamins and minerals)	3.56	101	175	80	81
78	spirulina, chlorella, klamath blue/green algae, kelp, *Dunleilla salina*	7.49	858	339	93	1270
79	spirulina, wheat grass juice, sprouted barley juice, flaxseed oil, chlorella, (plus 10 others) (plus vitamins and minerals)	6.31	791	126	80	400
80	Mexican yam root	0.46	339	51	80	1540
81	Mexican yam root extract, wild yam root	0.84	116	37	80	621
82	wild yam root	1.54	103	162	80	677
83	bovine cartilage	10.15	104	23	80	143
84	chondroitin sulfate (bovine, porcine and/or shark cartilage, rice powder)	1.83	27	25	80	113
85	glucosamine HCl, sodium chondroitin sulfate/mixed clycosaminoglycans (plus vitamins and minerals)	4.45	9	10	80	33
86	shark cartilage	7.93	1070	368	205	1410
87	chitosan	5.72	97	72	80	136
88	deer antler extract	3	48	10	80	297
89	honey, fructus chaenomelis lagenariae, *Angelicae sinensis* root, *Ligustici wallichii* rhizome, *Atractylodis macrocephalae* rhizome (plus 17 others)	3.76	2230	95.1	417	5150
90	male silkworm moth, ginseng root, *Morindae* root, *Cuscutae* seed, *Caulis cistanchis* (plus 1 other)	1.81	1330	67	293	2630
91	*Cordyceps sinensis* mushroom isolate	3.78	1950	31	3310	512
92	Shilajit extract	0.69	1366	50	1169	672
93	Shilajit extract	1.86	1420	49	3230	765
94	list of components not provided (menopause symptoms capsule)	2.44	522	56	103	792
95	(ist of components not provided (Sudarshan tablets)	0.66	1430	93	3320	3410

[a] Products containing the same components were from different manufacturers with the following exceptions: St. John's wort extract samples 60 and 61 and Shilajit extract samples 92 and 93.

supplements contain levels of toxic elements that raise potential concerns. The results suggest that manufacturers may need to institute controls to minimize toxic element content and that good manufacturing practice regulations may need to specifically address the issue of toxic element contaminants in dietary supplements.

Assessment of Maximum Exposures. Estimated exposures/intakes of arsenic, cadmium, mercury, and lead were assessed with respect to safe/tolerable exposure levels described by various national and public health organizations. Maximum daily intakes for each element from each product were calculated by multiplying maximum recommended daily intake on the product label by the mean product unit mass (based on 20 units) and by the mean element concentration determined in this study. Cadmium exposures are well below the tolerable intake of 7 μg/kg of body weight (bw)/week (using 70 kg of bw) as established by the International Program on Chemical Safety of the World Health Organization (IPCS/WHO) (*26*). With the exception of one product (sample 53, 13.6 μg/kg of bw/week), mercury exposures are also well below the tolerable intake of 5 μg/kg of bw/week as established by the IPCS/WHO (*27*). Assessment of mercury is predicated on the assumption that the mercury measured as total mercury is present as methylmercury. If part of the mercury exists as an inorganic form, then any potential concern would be reduced. The degree of this reduced concern is dependent in turn on the proportion of mercury present in inorganic form. With respect to arsenic, the consumption of none of the products would result in maximum exposures that exceed a tolerable level of exposure of 15 μg/kg of bw/week that is deemed to be unsafe (*28*). Assessment of arsenic is predicated on the assumption that the arsenic measured as total arsenic is present as inorganic arsenic. If part of the arsenic exists as an organic form, as is found in foods such as seafood, then any potential concern would be reduced. The degree of this reduced concern is dependent in turn on the proportion of arsenic present in an organic form. Levels of lead found in 11 of the products (sample 9, 7.6 μg/day; sample 17, 27 μg/day; sample 18, 14 μg/day; sample 36, 486 μg/day; sample 39, 16 μg/day; sample 44, 7.6 μg/day; sample 53, 7.4 μg/day; sample 71, 6.9 μg/day; sample 78, 9.5 μg/day; sample 86, 11 μg/day; sample 89, 19 μg/day) result in exposures that exceed the tolerable intakes of some sensitive segments of the population such as children and women of child-bearing age, particularly pregnant women. The current provisional total tolerable intake levels for children and women of child-bearing age, particularly if pregnant, are 6 and 25 μg of lead per day, respectively (*29*). Consumption of these products by children would result in exposures that would exceed the tolerable level of exposure. The consumption of one product in particular (sample 36) would result in significant daily lead exposures.

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