SELENIUM IN THE AMERICAN FOOD SUPPLY

G.F. COMBS, JR.

CORNELL UNIVERSITY

The Se contents of human foods vary widely due to such factors as the species, the particular variety or cultivar, the methods of preparation and/or processing, the climatic conditions during the growing season, and the amount of biologically available Se in the particular environment (e.g., the soluble Se content of the soil for plant species, the biologically available Se content of the diet for animal species). Of these factors, the most important by far in determining the Se contents of foods and feeds is the last. Due to the intimate relationship between plants and animals in food chains, the Se contents of foods from both plant and animal origins tend to be greatly influenced by the local soil Se environment. Thus, all types of foods tend to show strong geographic patterns of variation in Se content, reflecting in general the local soil Se conditions. Within the United States the Se contents of locally produced foods in the relatively high-Se area of the Dakotas are substantially greater than those of comparable foods produced in the relatively low-Se areas of Ohio and Indiana. Two countries, Finland and New Zealand, with local experiences with Se-deficiency syndromes in livestock, have foods with even lower Se contents. On a global basis, foods with the lowest Se contents have been found in the low-Se regions of China, in particular, the provinces of Heilongjiang, northern Shaanxi and Sichuan. Ironically, high seleniferous foods have also been found in China, in two areas of endemic selenosis of animals and people in Enshi County, Hubei Province and in Ziyang County, Shaanxi Province.

1. Analysis of Se in Foods

The analysis of Se can be accomplished by a variety of techniques some of which are applicable to foods (see Table 1). Of these procedures, the fluorometric method using diaminonapthalene (DAN) has been the most poplar. This method involves oxidation of sample selenium to Se^{+4}, and reaction of the DAN to form benzopiazselenol which fluoresces intensely at 520nm when excited at 390 nm and which, thus, can be quantified using a fluorometer. The chief advantages of the DAN procedure are its good sensitivity (ca. 0.002 ppm in foods) and its relatively low cost. However, the method is laborious and has two potential pitfalls which must be avoided.

The first involves the loss of Se during the acid digestion of samples containing large amounts of organic matter. Adequate acid digestion of Se in biological materials requires the

complete conversion of the native forms of the mineral to Se^{+4} and/or Se^{+6} and the subsequent reduction of any Se^{+6} formed in the process to Se^{+4} without loss of total Se. Inorganic Se can be volatilized under the conditions of acidic digestion in the presence of such large amounts of organic materials that charring occurs, especially when sulfuric acid is used as an oxidant. The release of volatiled Se, probably in the form of H_2Se, can result in significant errors in the analysis of fatty materials, such as egg yolks or fatty meats. Because Se is volatilized from acid solutions by reducing agents, this loss can be avoided by maintaining strongly oxidizing conditions during digestion and by using low heat such that the oxidation of Se^{+4} to Se^{+6} proceeds relatively slowly. This can be achieved by raising gradually the temperature of the perchloric acid solution to 210°C. When the nitric-perchloric acid digestion is controlled and carefully attended, it produces satisfactory conversion to Se^{+4} even of such forms as trimethylselenonium ion (a major urinary metabolite) which are resistant to oxidation by nitric acid alone. Comparisons of the nitric-perchloric digestion method with direct combustion in an oxygen environment have shown that both yield comparable results.

The second potential problem involves interference due to fluorescent degradation products of DAN itself. This can be avoided by purifying the DAN reagent by recrystallization from water in the presence of sodium sulfite and activated charcoal, or by stabilizing it with HCL and extraction with hexane. Several investigators have incorporated these procedures into methods using DAN which are convenient for use in the routine analysis of Se in biological materials.

Conventional atomic absorption spectroscopy (AAS) has not been suitable for the determination of Se in foods due to the generally high limit of detection (ca 0.1 pp.) by that procedure. Variant AAS methods, however, have been developed with sensitivities adequate for biological use. One such method involves hydride generation of sample Se followed by quantitative detection by AAS. This method requires only small sample sizes (e.g., 0.1g), has adequate sensitivity (ca. 0.01 ppm), and the hydride generation step has been automated. However, it suffers from possible interferences due to other elements that can form hydrides (e.g., Cu, As, Sb). Of these, the most serious interference is due to Cu; steps must be taken to remove Cu by the use of HCL, tellurite or thiourea.

Better sensitivity has been obtained using electrothermal AAS. This method avoids the problems associated with wet digestion by employing high temperature oxidation in a graphite furnace. Use of a high temperature (e.g., atomization at 2400°C) reduces interferences due to nonspecific absorption of organic compounds and non-Se salts, but introduces the problem of volatility of Se under such conditions. This problem can be avoided by the use of salts for thermal stabilization. In practice, electrothermal

AAS has sensitivity for Se at ca. 0.003 ppm; with the use of a Zeeman-effect background correction system, sensitivities approaching 0.001 ppm have been reported.

Plasma atomic emission spectrometry (PAES) has not been used widely for the analysis of Se in biological materials. Although very good sensitivity (ca. 0.001 ppm) has been reported using inductively coupled PAES, matrix effects present such a great amount of interference that most laboratories are not able to obtain reasonable sensitivity by this method. Direct current PAES has not had adequate sensitivity for biological use.

Instrumental neutron activation analysis of Se offers the advantages of applicability to small sample sizes and relative ease of sample preparation. Although the greatest sensitivity (ca. 0.02 ppm) by this method is obtained by measuring ^{75}Se, its use necessitates lengthy irradiation (100 hrs), and long periods of post-irradiation holding (60 days) and counting (2 hrs). Greater economy with increased sample throughput has been achieved, at the expense of sensitivity, by the use of the short-lived (17.38 sec half-life) ^{77}Se, This isotope can be irradiated (5 sec), decayed (15 sec) and counted (25 sec) very quickly in an automated system. Due to the ease of this procedure as well as to its non-destructive nature, some investigators with access to research reactors have found instrumental neutron activation analysis useful for the measurement of Se. Nevertheless, the utility of the "fast" method is limited at the present time by its relatively low sensitivity, rendering it unsuitable for accurate quantitation of low concentrations of Se in many foods.

The measurement of Se by proton-induced x-ray emission (PIXE), offers the potential advantage of simultaneous elemental analysis of biological materials. This method involves proton bombardment of target atoms (the sample) to cause loss of inner shell electrons and their consequent replacement by electrons from the outer shell. The x-rays emitted during that transition are characteristic of the energy differences between electron shells and are, therefore, identifiable and quantifiable. At the present time, the sensitivity of this procedure for the determination of Se (ca. 0.01 ppm) makes it useful for many biological purposes, especially when simultaneous elemental analysis may be needed; however, it is not sensitive enough for the accurate determination of very low levels.

X-ray Florescence spectrometry offers another non-destructive technique for multi-element analysis; however, its sensitivity for Se does not compare favorably with other methods available for biological use.

A procedure for determining Se by double isotope dilution has been developed.[1] This method involves the use of two stable isotopes of Se as tracer (^{76}Se). Samples spiked with a known quantity of the internal standard are digested in nitric-

phosphoric acid, undigested lipids are removed with chloroform, and hydrochloric acid is used to reduce any Se^{+6} to Se^{+4}. Selenite is reacted with 4-nitro-o-phenylenediamine to form 5-nitropiazselenol, and the nitropiazselenonium ion cluster is determined by combined gas-liquid chromatography/mass spectrometry. The native Se in the sample is calculated from the measured isotope ratios, using the ^{80}Se naturally present in the sample. Reamer and Veillon[1] have carefully developed this technique and have reported a sensitivity of less than 0.001 ppm. Their method employs a rapid digestion which avoids several of the problems associated with the use of perchloric acid, and is capable of fully oxidizing the often problematic trimethylselenonium. It thus appears to be suitable for biologic measurements and has been put to such use already.

A recent IUPAC interlaboratory (12 sites) comparison of the more widely used methods for the determination of Se in clinical materials[2] found statistically significant differences among the mean concentrations reported for Se in lyophilized human serum analyzed by either a) acid-digestion/DAN-fluorometry, b) electrothermal AAS, c) acid-digestion/hydride generation AAS, or d) acid-digestion/isotope dilution mass spectrometry, with slightly higher values reported by the first procedure. The four methods compared very favorably for the analysis of pooled lyophilized urine samples. However, only the fluorometric method showed homogeneity of variance among laboratories.

2. Se Contents of Foods

The published information concerning the Se contents of foods from several countries has recently been compiled[3]. Table 2 presents typical Se contents of American foods based upon those collected analytical results. The Se contents of prepared liquid in infant formulas[4,5] and solid infant foods[6] have also been reported. The Se contents of the latter use correlate with those of the corresponding foods. Prepared liquid formulas based upon meat or casein contain approximately an order of magnitude more Se (i.e., 0.073 ppm, fresh weight basis) than those based on milk or soy protein (i.e., 0.011 ppm, fresh weight basis).

The Se contents of several medical food supplements and tube feeding formulas were determined by Zabel et al[4] who found differences in the Se contents of casein hydrolysate-based solutions used for total parenteral nutrition (TPN) and TPN solutions based on mixtures of recrystallized amino acids. Whereas the latter type provided less than 5 ug Se per 1000 kcal of diet, the former type provided at least three times that amount and as much as 95 ug Se per 1000 kcal by virtue of the Se inherent in casein.

3. Sources of Variation in the Selenium Contents of Foods

Much of the variation in the Se content of foods is due to large

scale geographical differences in environmental Se. Such variation is readily seen in comparisons of the Se contents of like foods from different countries. For example, whole wheat grain may contain more than 2 ppm Se (air-dry basis) if produced in the Dakotas,[7] but as little as 0.11 ppm Se if produced in New Zealand,[8] and only 0.005 ppm Se if produced in Shaanxi Province, China.[9] The geographic variation in the Se contents of several different foods produced with similar technologies in the US is shown in Table 3.

The Se contents of foods of plant origin can vary according to climatic conditions during the growing season which may affect crop yield, maturity at harvest, etc. For this reason, annual variations are to be expected in the Se contents of such foods as the cereal grains, with those of grains produced in high-yield seasons to be somewhat lower than those of grains produced in low-yield ones. This effect was apparent in the report of Varo et al.,[10] who found that the Se contents of wheat, rye, barley and oats produced in Finland were low in 1975, which had an exceptionally favorable growing season and good harvesting conditions. This combination of conditions resulted in the production of mature grain with relatively high starch content, but with Se (and other mineral) contents that were only about two-thirds of those of the previous year in which only average yields were realized. In contrast, grains produced in Finland in 1973 were generally higher in Se content due to conditions which resulted in relatively low yields during that year.

The Se contents of foods of animal origin depend, in large part, on the Se intakes of livestock. Food animals raised in regions with feeds of low-Se contents will, thus, deposit relatively low concentrations of the mineral in their edible tissues and products (e.g., milk, eggs); while animals raised with relatively high Se nutriture will produce foods with much greater Se concentrations. Due to the needs of livestock for Se to prevent debilitating deficiency syndromes, Se (usually as sodium selenite) is used as a nutritional supplement in animal agriculture in many parts of the world. This practice, which has become widespread in North America and Europe only within the last 10-15 years, has had the effect of reducing what would otherwise be strong geographic variation in the Se contents of animal food products over many different parts of the world.

In general, increases in dietary Se produce increases in the Se contents of animal meats, milk and eggs (Table 4). However, this relationship, while direct, is not linear. Within the ranges of normal levels of Se intakes, muscle meats from most species tend to plateau in Se concentration at 0.3-0.4 ppm (fresh weight basis). Organ meats usually accumulate greater concentrations of Se; the livers of several species have been found to accumulate about four times as much Se as skeletal muscle, and the kidneys of steers, lambs and swine have been found to accumulate 10-16 times the amounts in muscle. Poultry do not accumulate such great renal concentrations of Se; kidneys

from young broiler chickens and turkey poults average only 4.9 and 1.4 times, respectively, those of muscle. Because of the property of most species to accumulate relatively great concentrations of Se in liver and kidney, food made from these organ meats tend to be rich sources of Se in human diets.

Varietal differences can be the sources of significant variation in the Se contents of some plant species. Although there have been few extensive varietal comparisons of Se content, the work of Wauchope[11] has nicely demonstrated the phenomenon in the case of soybeans. He compared the Se contents of 18 varieties of soybeans grown on adjacent plots either in Ames, Iowa, or in Stoneville, Mississippi. (Figure 1). The six varieties grown in Iowa varied in Se content by 600% (i.e., 0.08-0.48 ppm, air-dry weight). The 12 varieties in Mississippi varied in Se content by ca. 550% when grown in clay soil, and by ca. 145% when grown in loamy soil. The significant interactive effect of variety and soil type shows that varietal differences in the Se contents of foods of plant origin can vary between different geographic regions according to the local agronomic conditions.

The processing of cereal grains and oil seeds can produce food products with Se concentrations less than those of the parent materials due to the removal of relatively Se-rich components. For example, in soybean Se, which is associated with the protein fraction, is increased almost two-fold in the processing of isolated soy protein. In general, the germ and outer layers of cereal kernels are richer in Se than the endosperm. Therefore, milling products based on germ, bran and shorts (e.g., wheat screenings, corn mill germ, rice bran) tend to contain higher levels of Se than the parent whole grains; products based primarily on endosperm (e.g., wheat patent flour, corn flour, polished rice) tend to contain lower levels of Se than the parent whole grains. Nevertheless, the reductions in Se concentrations due to milling of cereal grains are generally only of low magnitude inasmuch as the differences in Se content of the various fractions of the kernel tend to be small. For example, Ferretti and Levander[12] found that the Se contents of wheat flour, white corn flour, yellow corn flour and polished rice were approximately 87%, 86%, 79%, and 92%, respectively, of the corresponding whole grain.

The Se contents of wheat flours are affected by the blend of wheat milling fractions used to make them. Lorenz[13] found that the Se contents of wheat flour milled in several locations actually show that the apparent decrease in Se content due to the milling of flour varied enormously (i.e., from -5% to 86%). Although he concluded that the Se content of flour decreased as the extraction percentage of the patent decreased, his data showed that the apparent decreases were <u>not</u> related to either the extraction percentage of the patent or to the Se content of the whole grain. They were greatest for soft red winter and Ontario soft winter wheats (e.g., 31% and 42%, respectively) in comparison to the other wheats studied (e.g., hard red winter:

19%; hard red spring: 16%).

Most techniques used in western-style cooking (e.g., boiling, baking, broiling) do not cause appreciable losses of Se from most foods (Table 5). In fact, some cooking methods, such as those which remove fats from meats, cause apparent increases in Se in the cooked food. However, heat drying of breakfast cereals and boiling of asparagus and mushrooms (both of which are relatively high in Se) have been found to result in significant loss of (presumably volatile forms) of Se.

4. Selenium in Human Diets

Differences in geography, agronomic practices, food availability and preferences, and methods of food preparation result in differences in the dietary contents of Se among human populations. Because many of these differences are difficult to quantify, evaluations of Se intakes of specific human population groups are often not precise. General comparisons can be made, however, of the Se contents of different food supplies by using the average Se concentrations determined within specific major classes of foods in different locales. The typical Se contents of the major classes of foods in the US, presented in Table 2, are, for the most part, based upon actual analyses of foods. Where analytical values were not available and where it was considered reasonable to do so, estimates have been given by the author.

Several authors have estimated the average per capita daily Se intakes of adult Americans (Table 5). These Se estimates indicate that the Se intakes of residents of different regions are highly variable. Nevertheless, residents in the so-called low-Se portions of the United States (e.g., Northeast, Southeastern Seaboard, Pacific Northwest) have estimated Se intakes approximately 2- to 5-fold those of residents of Finland or New Zealand.

The most important sources of Se in the diets for most people are cereals, meats and fish. This is shown by the relative contributions of each class of food to the total Se intakes of residents of several countries, as estimated by several authors (Table 7). In general, meats and fish appear to contribute around 40-50% of the total intake. The Se contributions of cereals, in contrast, appear to vary with the total Se intake, indicating that the relative consumption of this class of foods may also be an important factor in determining the total Se intakes of population. Similar data from other countries shows that; whereas, cereals provide from about one-quarter to two-thirds of the dietary Se in countries with total Se intakes greater than about 40 ug per person per day, they appear to contribute only one-tenth to one-quarter on the total dietary Se in countries with intakes lower than that level (e.g., Finland, New Zealand, Italy). Dairy products and eggs contribute small amounts (i.e., up to 12 ug per person per day) of Se to the

total intakes in most parts of the US (i.e., moderate Se areas). Vegetables and fruits, uniformly low in Se (when expressed on a fresh weight basis), provide only small amounts (less than 5% of the total intake) of the mineral in most diets.

Differences in patterns of food consumption, whether general ones due to cultural influences or specific ones due to personal preferences and food availability, can significantly affect Se intake. In a study of the Se intakes of Maryland residents, Welsh et al.[14] found that individual variation was great. Although the mean daily intake of Se by the 22 subjects in their study was 81 ug per person, approximately 17% of a sampling of 132 diets selected by those subjects were found to contain less than 50 ug Se per person per day. A total of 54% of the diets provided more than 150 ug Se per person per day.

Although the dietary Se needs of Americans are not firmly established, estimates have been made[3,28] suggesting that dailly intakes of 50-60 ug Se per adult should be adequate. Because studies indicate that most Americans consume substantially more than that amount, concern for the Se status of our population should be greatest for those groups living in geographic areas of relatively low Se, as well as those whose habits are likely to provide small amounts of the element. For the purposes of addressing questions of Se and health in these and other groups, it is unfortunate that presently available food Se analyses are restricted to a relatively few geographic areas of the US. The usefulness of national values of food Se contents is, thus, limited, particularly for many types of food that are not widely distributed on national basis.

REFERENCES

1. Reamer, D.C. and Veillon, C., A double isotope dilution method for using stable selenium isotopes in metabolic tracer studies: Analysis by gas chromatography/mass spectrometry (GC/MS), J. Nutr. 113, 786, 1983.

2. Thomassen, Y., Ihnat, M., Veillon, C. and Wolynet, M.S., IUPAC interlaboratory trail for the determination of selenium in clinical material, in Proceedings of the Third international symposium on Selenium in Biology and Medicine, Combs, G.F., Jr., Spallholz, J.E., Levander, O.A., and Oldfield, J.E., Eds., Avi Publishing Co., Westport, CT, 1985.

3. Combs, Jr., G.F. and S.B. Combs, The Role of Selenium in Nutrition, Academic Press, New York, 1986, 525 pp.

4. Zabel, N.Z., Harland, J., Gormican, A.T. and Ganther, H.E., Selenium contents of commercial formula diets, Amer. J. Clin. Nutr. 31, 850, 1978.

5. Smith, A.M., Picciano, M.F. and Milner, J.A., Selenium intakes and status of human milk and formula fed infants, Amer. J. Clin. Nutr. 35, 521, 1982.

6. Morris, V.C. and Levander, O.A., Seleniuim content of foods, J. Nutr. 100, 1383, 1970.

7. Schroeder, H.A., Frost, D.V. and Valassa, J.J., Essential trace elements in man: selenium, J. Chron. Dis. 23, 227, 1970.

8. Watkinso, J.H., Changes in blood selenium in New Zealand adults with the importation of Australian wheat, Amer. J. Clin. Nutr. 34, 936, 1982.

9. Tan, J., Aheng, D., Hou, S., Ahu, W., Li, R., Zhu, Z. and Wang, W., Selenium ecological and chemico-geography and endemic Keshan disease and Kaschin-Beck's Disease in China, in Proceedings of the Third International Symposium on Selenium in Biology and Medicine, Combs, G.F., Jr., Slappholz, J.E. Levander, O.A., and Oldfield, J.E., Eds., Avi Publ. Co., Westport, CT. 1985.

10. Varo, P., Nuurtamo, M., Saari, E., and Koivistoinen, P., Mineral element composition of Finnish foods. III. Annual variations in the mineral element composition of cereal grains, Acta Agric. Scand., Suppl. 22, 27, 1980.

11. Wauchope, R.D., Selenium and arsenic levels in soybeans from different production regions of the United States, J. Agric. Good Chem. 26, 266, 1978.

12. Ferretti, R.J. and Levander, O.A., Effect of milling and processing on the selenium content of grains and cereal products, J. Agric Food Chem. 22, 1049, 1974.

13. Lorenz, K., Selenium in wheat and commercial wheat flours, Cereal Chem. 55, 287, 1978.

14. Welsh, S.O., Holden, J.M., Wolf, W.R. and Levander, O. A., Selenium in self-selected diets of Maryland residents, J. Amer. DIet. Assn. 79, 277, 1981.

15. Ullrey, D.E., Brady, P.S. Whetter, P.A. Fu, P.K. and Magee, W.T., Selenium supplementation of diets for sheep and beef cattle, J. Anim. Sci. 46, 559, 1977.

16. Ewan, R.C. Effect of vitamin E and selenium on tissue composition of young pigs, J. Anim. Sci. 32, 883, 1971.

17. Mahan,D.C. and Moxon, A.L., Effects of adding inorganic or organic selenium sources to the diets of young swine, J. Anim. Sci. 47, 456, 1978.

18. Scott, J.L. and Thompson, J.N., Selenium content of feedstuffs and effects of dietary selenium levels upon tissue selenium in chicks and poults, Poultry Sci. 50, 1742, 1971.

19. Combs, G.F., Jr. and Scott, M.L., The selenium needs of laying and breeding hens, POultry Sci. 58, 871, 1979.

20. Conrad H.R. and Moxon, A.L., Transfer of dietary selenium to milk, J. Dairy Sci. 62, 404, 1979.

21. Higgs, D.J., Morris, V.C. and Levander, O.A., Effect of cooking on selenium content of foods, J. Agric Food Chem. 20, 678, 1972.

22. U.S. Food and Drug Administration, Bureau of Foods Compliance Program Evaluation Report: Total Diet, Studies fiscal year 1974, U.S. Gov't. Print. Off., Washington, DC, 1975.

23. Ganapathy, S.N. Joyner, B.J., Sawyer, D.R. and Hafner K.M., Selenium content of selected foods, in Trace Element Metabolism in Man and Animals III, Kirchgessner, M., Ed., Technische Univ., Munich, 332, 1978.

24 Watkinson, J.H., The selenium status of New Zealanders, N.Z. Med. J. 80, 202. 1974.

25. Schrauzer, G.N. and White, D.A., Selenium in human nutrition. Dietary intakes and effects of supplementation, Bioinorganic, Chem. 8, 63, 1975.

26. Mahaffey, K.R., Corneliussen, P.E. Jelinek, C.F., and Fiorin, J.A., Heavy metal exposure from foods, Environ., Health Perspect. 12, 63, 1975.

27. Olson, O.E., Palmer, I.S. and Howe, S.M., Selenium in foods consumed by South Dakotans, Proc. S. Dakota Acad. Sci. 5, 113, 1978.

28. National Academy of Sciences, Food and Nutrition Board, Recommended Dietary Allowances, National Academy Press, Washington, DC, 1980.

Table 1. Methods of Analysis of Selenium in Biological Materials.

Method	Reported Detection Limit (ppm)	Sample Preparation	Known Interferences
Polorigraphic determination of piazselenol after reaction with diaminobenzidine	0.01	perchloric-nitric acid digestion	-
Cathodiac stripping voltametric following ion-exchange separation of Se	0.001	nitric-sulfuric acid digestion	preconcentration of Se on anion-exchange resin
Inductively coupled plasma atomic spectrometry with hydride generation	0.0005	HCl digestion	hydride generation matix effects
Direct current plasma atomic emission spectrometry	0.02	acid digestion	matrix effects
Atom-trapping atomic absorption spectrometry	0.025	O_2 combustion	mineral cations
Electrothermal atomic absorption spectrometry	0.003	thermal stabilization with Ni	matrix effects
Atomic absorption spectrometry with hydride generation	0.01	acid digestion; hydride generation	matrix effects (particiulary Cu,As, and Sb)
Proton-induced x-ray emission analysis	0.01	lyophilization: pelletization	pelletization
X-ray fluorescence spectrometry	0.04	lyophilization, pelletization	-
Isotope dilution with detection by combined gas-liquid chromatography/ mass spectrometry	0.0005	nitric-phosphoric acid digestion; chelation with 4-nitro-o-phenylene-diamine	-

Neutron activation analysis using ^{75}Se	0.02	-	-
"Fast" neutron activation analysis using ^{77m}Se	0.05	-	-
Fluormetric determination of piazselenol after reaction of Se^{+4} with 3,3-diaminobenzidine	0.01	nitric-perchloric acid digestion, or O_2 combustion	loss of volatilized Se if digests clar
Fluormetric determination of piazselenol after reaction of Se^{+4} with 2,3-diaminoapthalene	0.002	nitric-perchloric acid digestion, or o_2 combustion	loss of volatilized Se if digests char

Table 2. Typical Se contents of foods in the United States.[a]

	Se contents, ppm (fresh weight)		
	low-Se area	moderate-Se area	high-Se area
Cereal	.300	.330	.560
Vegatables	.010	.040	.070
Fruits	.004	.006	.006
Nuts and seeds	.190	.190	.200
Red muscle meats	.195	.210	.370
Organ meats	1.070	1.020	1.335
Processed meats	.350	.350	.375
Poultry	.100	.120	.410
Fish	.665	.665	.665
Shellfish	.710	.710	.710
Milk	.010	.030	.055
Cheeses	.085	.100	.300
Butter. cream	.006	.006	.016
Eggs	.060	.100	.450
Sweetners, condiments	.010	.010	.010

[a]Combs and Combs[3]

Table 3. Geographic variation in Se contents (ppm) of selected foods produced in the United States.

State of Origin	Hard winter wheat[a]	Hard spring wheat[a]	Soft winter wheat[a]	Soybeans[b]
Arizona	.05			
Arkansas				.16
Florida				< .07
Idaho	.10	.12	.06	
Illinois			.05	
Indiana			.13	< .07
Iowa				.28
Kansas	.20-.30			
Maryland				< .07
Minnesota	.83	.53-.70		
Mississippi			.05	.90
Missouri			.12	
Montana	.79-.85			
North Carolina				< .07
North Dakota		.43-.54		
Ohio			.04-.09	
South Dakota		.68		
Tennessee			.03-.08	
Texas	.25			
Washington		.64	.07	

[a] 14% moisture basis, from Lorenz[13]

[b] air-dry basis, from Wauchope[11]

Table 4. Influence of the Se concentrations of livestock feeds on the Se contents of meat, milk and eggs.

Animals	Type of diet	Dietary Se[a] ppm (fresh weight basis)	Se content of food product ppm (fresh weight basis)			Reference
Steers			Muscle	Liver	Kidney	
	practical, low-Se	.085	.070	.258	1.483	15
		.206	.086	.384	1.372	
		.294	.100	.435	1.366	
	practical, high-Se	.199	.135	.498	1.458	15
		.255	.136	.499	1.578	
		.328	.158	.524	1.544	
Lambs			Muscle	Liver	Kidney	
	practical, low-Se	.085	.088	.242	1.207	15
		.206	.092	.380	1.261	
		.294	.110	.533	1.233	
	practical, high-Se	.199	.167	.618	1.301	15
		.255	.159	.656	1.351	
		.328	.167	.756	1.211	

			Muscle	Liver	Kidney	
Pigs						
	Se-deficient	< .02	.070	.084	1.25	16
		.05	.308	1.381	7.50	
	practical, low-Se	+.10 (as Na_2SeO_3)	.062	.233	1.129	17
		+.40 (as Na_2SeO_3)	.094	.464	1.218	
		+.10 (as fish meal)	.058	.167	.904	
		+.40 (as fish meal)	.122	.436	1.339	
		+.10(as browen's grains)	.093	.276	1.038	
		+.40(as browen's grains)	.116	.554	1.458	
Chickens			Muscle	Liver	Kidney	
	practical, low-Se (.07 ppm)	.07	.061	.25	.39	18
		.17	.071	.48	.34	
		.27	.103	.53	.80	
		.47	.114	.59	.56	
		.67	.126	.80	.62	
		.87	.157	.77	.71	
	practical, high Se (.67 ppm)	.67	.293	.80	1.08	18
		.87	.423	1.05	.98	

Turkeys			Muscle	Liver	Kidney	
	practical, low-Se (.07 ppm)	.07	.056	.15	.07	18
		.17	.07	.33	.14	
		.27	.08	.54	.13	
		.47	.11	.56	.12	
		.67	.10	.78	.16	
		.87	.10	.94	.17	
	practical, high-Se (.69 ppm)	.68	.32	1.03	.36	18
		.88	.35	1.06	.31	
Hens			Whole egg	Hen muscle		
	practical, low-Se (.04 ppm)	.04	.136	-		19
		.09	.252	-		
		.14	.260	-		
		.24	.295	-		
	practical, high-Se (.45)	.45	.325	-		19
		.50	.355	-		
		.55	.376	-		
		.65	.391	-		

Cows			Milk	
	practical, low-Se	+0	.010	20
		.094	.017	
		.225	.017	
	practical, high-Se	.334	.040	13
		.385	.047	
		.450	.064	

Table 5. Effects of cooking procedures on the Se contents of foods.[a]

Cooking procedure	Food	Se content, ppm dry matter		Apparent Se loss,%
		fresh	processed	
heat drying (100°,overnight)	wheat breakfast cereal	.039	.030	23
	oat breakfast cereal	.051	.047	8
Boiling,5 min.	oatmeal	.078	.084	-8
	wheat cereal	.047	.051	-8
Boiling,20 min	oatmeal	.078	.067	14
	wheat cereal	.047	.053	9
	polished rice	.023	.023	0
	egg noodles	.065	.061	6
	mushrooms	1.40	.78	44
	asparagus	.96	.68	29
Boiling, 45 min.	egg noodles	.065	.066	-2
Baking (175°C), 45 min.	chicken breast	.48	.49	-2
Baking (175°C), 60 min.	flounder fillet	1.38	1.51	-9
Broiling,20 min.	lamb chops	.34	.34	0
	t-bone steak	.70	.60	14
Broiling,45 min.	pork chops	.22	.20	9

[a]from Higgs eg al.[2]

Table 6. Estimated average per capita daily intakes of Se by adult Americans.

Area	Estimated intake, ug	Reference
low-Se	60-150	7
	147[a], 154[a], 198[a]	22
	82[b], 86[c], 93	23
moderate-Se	132	24
	90-168	25
	150	26
	81[d]	14
high-Se	191[a], 216[a]	22
	216	27

[a]estimates based on surveys conducted in different states

[b]ovo-lacto vegetarian diet

[c]strict vegetarian diet

[d]estimate by duplicate plate analysis

Table 7. Contributions of major classes of foods to the Se intakes of adult Americans.

Class of foods (reference)	Se intake; ug/person/day		
	moderate Se area		hi Se area
Cereals	45[a] (34%)[d]	93[b] (62%)	57[c] (26%)
Vegetables, fruits	5 (4%)	1 (0.6%)	10 (5%)
Meats, fish	69 (52%)	56 (37%)	101 (47%)
Dairy products, eggs	13 (10%)	0 (0%)	48 (22%)
Total	132	150	216

[a] USDA[22]

[b] Schrauzer and White[25]

[c] Olson et al[27]

[d] numbers in parentheses show the percentage of the total intakes contributed by each class of food.

Fig. 1 Se contents of soybeans grown on two soil types in Mississippi (Wauchope, 1978)