Preliminary Report:

A NATIONWIDE STUDY OF THE SELENIUM CONTENT OF U.S. FOODS

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The 1979 edition of The Recommended Dietary Allowances (RDA's) gave an Estimated Safe and Adequate Daily Dietary Intake for selenium (Se) of 50 to 200 mcg per day for adults (National Research Council, 1980). The 10th edition of the RDA's published in 1989 was the first time that an allowance was set for selenium intake. It is 70 mcg per day for adult males and 55 mcg per day for adult females (National Research Council, 1989).

Selenium was first recognized as a toxic element. Probably the first description of chronic selenium toxicity was written by Marco Polo after visiting areas in Western China: "It is a fact that when travelers take that road they cannot venture among the mountains with any beast of burden excepting those accustomed to the country, on account of a poisonous plant growing there, which if eaten by them has the effect of causing the hoofs of the animals to drop off" (U.S. Department of Agriculture, 1961). Franke (1934) indicated that it was high levels of selenium in plant foodstuffs of South Dakota that were responsible for alkali disease in cattle and other livestock. This disease was characterized by loss of hair and hoof deformation--symptoms similar to those described by Marco Polo.

Not until 1957 was selenium shown to be essential for mammals and birds (Schwarz and Foltz, 1957; Schwarz et al., 1957). It was found that traces would prevent dietary liver necrosis in rats and exudative diathesis in chicks.

Selenium was not shown to be essential for man until much later. In China in 1979, systematic dietary supplementation with sodium selenite eliminated a generally fatal congestive cardiomyopathy known as Keshan disease (Keshan Disease Research Group, 1979). Although the etiology of the disease is multifactorial, it appears to be due mainly to selenium deficiency resulting from low levels of the element in soil and foods.

The biochemical functions of selenium in man are related to its presence at the active site of the enzyme glutathione peroxidase, an enzyme that catalyzes the breakdown of hydroperoxides (Hoekstra, 1975). In addition, the anticarcinogenic properties of selenium have been demonstrated in numerous animal experiments, reviewed by Shamberger (1986).

On the other hand, as shown in animal studies, selenium can be toxic. Its toxicity depends on the dose and other factors such as its oxidation state. The level of dietary selenium that would cause chronic poisoning in humans is not known with certainty, but Yang et al. (1983) reported that approximately 5 mg per day from foods resulted in fingernail changes and hair loss in a seleniferous zone of China.

The selenium content of plants is strongly influenced by the quantity of biologically available selenium in the soil in which they grow and hence their geographical origin. Figure 1 is a map of the United States, adapted from one prepared by Kubota and Allaway (1972), showing areas of the country producing low selenium levels in forage crops (<0.05 ppm Se), the shaded areas in the northeast, extreme southeast and areas of the northwest; areas producing variable and adequate levels in forage and grain crops (<0.1 ppm Se), the white areas; and areas where accumulator plants contain high levels of selenium (>50 ppm Se), the dark areas scattered throughout the mountain and plains states. Circles indicate cities where samples were picked up for this study.

Several studies have shown that foods--both plant and animal products--will vary in selenium content depending on where they are produced. The selenium content of the cheeses produced locally in South Dakota (a state containing several high-selenium areas) is many times higher than that of the same types of cheeses purchased in supermarkets in South Dakota (Figure 2) (Olson and Palmer, 1984). An even more dramatic comparison between selenium levels shows in homegrown foods and in foods purchased in local supermarkets in a seleniferous area of South Dakota (Figure 3) (Holden et al., 1988). The supermarket foods had selenium levels similar to literature values for the United States, but values for homegrown foods were many times higher. Even though the people in this study had unusually high selenium intake, they did not exhibit symptoms of selenium toxicity. In Ohio, located in a low-selenium area, the selenium content of beef, chicken, sunflower seeds, and wheat bread is lower in the products produced locally than in the same products purchased in supermarkets (Figure 4) (Snook et al., 1987).

Since the majority of people in the United States no longer exclusively consume foods that they have grown themselves, for this study we were interested in looking at the selenium content of food items purchased in supermarkets across the country. The foods selected for analysis were chosen on the basis of their contribution of selenium to the U.S. diet. Over 200 different foods were analyzed over the course of the study. However, the two foods we chose to sample in greatest detail were white bread and cottage cheese. An evaluation of literature values for selenium content of foods by Schubert et al. (1987) contained a ranked list of selenium contributors (Figure 5). White bread was ranked second after cooked beef as a source of selenium in the U.S. diet because of its level of selenium and the amounts consumed by the population. Whole milk and 2% milk ranked 9th and 11th in selenium contribution. Combined they would have ranked 5th. White bread represents a food whose raw ingredient (wheat) would not be locally grown; whereas milk would be produced and marketed within a limited area. Since fluid milk has a low selenium content--less than 3 mcg/100g-- the variation in the analytical method at these low levels could be a problem. Therefore, cottage cheese was chosen as a concentrated milk product that would have a fairly limited production and distribution area.

The United States is divided into four census regions--Northeast, North Central, South, and West. Each region is subdivided into two or three divisions for a total of nine--1) New England, 2) Middle Atlantic, 3) East North Central, 4) West North Central, 5) South Atlantic, 6) East South Central, 7) West South Central, 8) Mountain, 9) Pacific. Using grocery store sales data (Anon., 1989), we identified the city with the highest grocery store sales within each division. These cities were Boston, New York, Atlanta, Memphis, Dallas, Chicago, Minneapolis, Denver, and Los Angeles. Figure 6 shows the location of the cities that were sampled, the nine divisions, and the four regions of the United States.

In order to estimate the mean selenium level of white bread in the United States at the 95 percent confidence level, the number of analytical samples to be prepared was determined, using a statistically based formula, to be at least 24 (Snedecor and Cochran, 1967).

Twenty-seven composite bread samples were prepared during each of three years. In each of the nine cities, two composite analytical samples of store brands of bread and one of a major national brand were prepared. A similar sampling plan was used for cottage cheese, except that in the absence of a single national brand, major regional brands were selected.

In addition to retail bread samples, samples of the national brand of white bread were procured directly from seven manufacturing plants, each located near one of the cities where retail samples were purchased (Figure 7).

At each plant one sample was procured approximately every 2 months for a total of five samples per city to monitor fluctuations in selenium content of bread from plant to plant and month to month. A limited number of flour samples were obtained with the bread samples from plants in New York and Los Angeles.

Retail white bread and cottage cheese samples were shipped to the Nutrient Composition Laboratory in Beltsville, Md., where the samples were logged in, labeled, and composited. After homogenization in an R-15 Robot Coupe[1] food processor, aliquots were frozen at -50 ^{0}C in polyethylene cups and shipped to the analytical contractor for analysis.

Analytical Methods

During the study two different contractors, selected in series, conducted analyses of the samples. For each contract period, the contractor was selected competitively on the basis of its written technical proposal (including the description of a quality control program) and cost proposal. In addition, the prospective laboratories were required to conduct analyses of three reference materials, chosen for their similarity to foods to be included in the nationwide study, and submit their results.

Both contractors used a modified selenium hydride generation method (AOAC, 1984; Perkin-Elmer, 1981; Welz and Schubert-Jacobs, 1986). Both were required to maintain a rigorous quality control program. This included the use of blanks, spike recoveries, at least one certified standard reference material analyzed per batch, 10 percent duplicates, and in-house noncertified reference materials. Quality control results were within acceptable limits specified by the contract.

Results and Discussion

Figure 8 shows a summary of the results for retail samples of white bread from the nine cities. Mean selenium values range from 17 mcg/100g in Los Angeles to 46 mcg/100g in Boston. The mean of these means is 29 mcg/100g. This compares favorably with a mean of 32 mcg/100g from a compilation of published values by Schubert et al. (1987). The mean coefficient of variation within cities was 32 percent.

Figure 9 shows the mean selenium content in bread grouped by region. Both region and city within region show significant variation. As the map for the approximate geographical distribution of selenium in forage crops (Figure 1) shows, Boston is located in a low-selenium area while Los Angeles is in an area where selenium is adequate. However, the hard red spring and hard red winter wheats used for bread are grown primarily in the Great Plains. In 1987, Kansas, North Dakota, Montana, and Oklahoma were the leading states in wheat production (U.S. Department of Agriculture, 1990). Except for Oklahoma, there are areas in each of those states that would produce high-selenium crops.

In the past, most flour milling took place in the Midwest near the wheat- farming areas. However, because of changes in transportation prices, it is more economical to transport wheat than flour. Wheat production and milling locations have become separated geographically, as some millers have moved their mills closer to consuming areas (Martin and Schmidt, 1983). Therefore, even if the location of the flour mill is known, it is difficult to pinpoint where the wheat was grown.

The mean selenium level (25 mcg/100g) for the 35 plant samples of the national brand is similar to the mean value obtained overall (29 mcg/100g) as well as the mean value determined for the national brand retail samples

[1] Identification of commercial products does not constitute an endorsement by the U.S. Department of Agriculture.

(30 mcg/100g) selected in the same seven cities.

The mean selenium content of the 10 bread flour samples obtained from the plants in New York and Los Angeles was 43 mcg/100g with a standard deviation of 8 mcg/100g (dry weight basis). The selenium content of bread obtained at the same time was 39 mcg/100g with a standard deviation of 10 mcg/100g (dry weight basis). A study by Zook et al. (1970) also found the selenium content of bread to be slightly lower than that of the flour from which it was made. Differences in selenium levels between flour and bread can probably be attributed to the addition of other ingredients containing little or no selenium and to the baking process.

Figure 10 summarizes the results of analysis of the cottage cheese samples by city. Mean selenium values ranged from 7 mcg/100g in Atlanta and New York to 15 mcg/100g in Dallas. Denver was also high with a value of 14 mcg/100g. The grand mean for the cities was 9 mcg/100g with a coefficient of variation of 36 percent.

Figure 11 shows the mean selenium contents of cottage cheese grouped by region. Variability among cities within a region is apparent when comparing the means for the cities in the South and West. Denver is located near high- selenium areas, and this probably accounts for the higher selenium content of the cottage cheese. However, Dallas is not near a high-selenium area. We can not account for this high value, but some possible explanations are that cattle feed may be brought in from high-selenium areas, or fluid or nonfat dry milk from other areas could be brought in for cottage cheese production.

Conclusions

The mean selenium level in white bread is 29 mcg/100g. The concentration of selenium in white bread varies from city to city because of the variety of geographical sources of the wheat used. The mean selenium level in cottage cheese is 9 mcg/100g. Although milk produced locally would account for the majority of milk used in cottage cheese production, during some periods milk from other areas could be shipped in or nonfat dry milk could be used. Because of the complex marketing system that exists in the United States, the selenium content of foods purchased in supermarkets does not necessarily correspond to the selenium levels in local soils.

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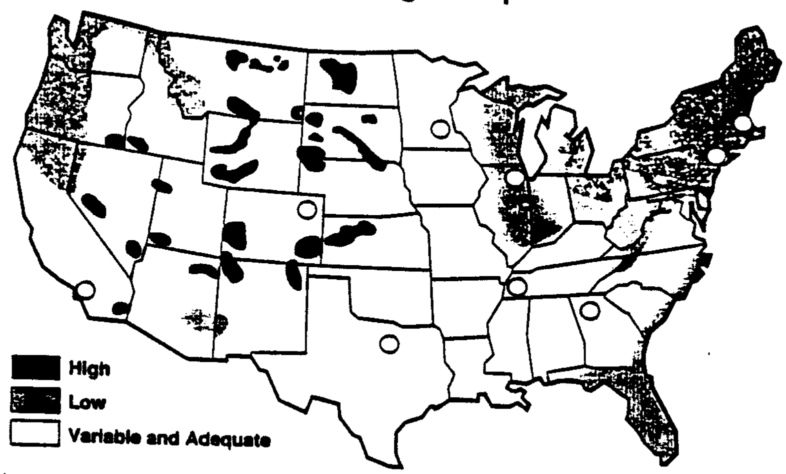
Fig. 1

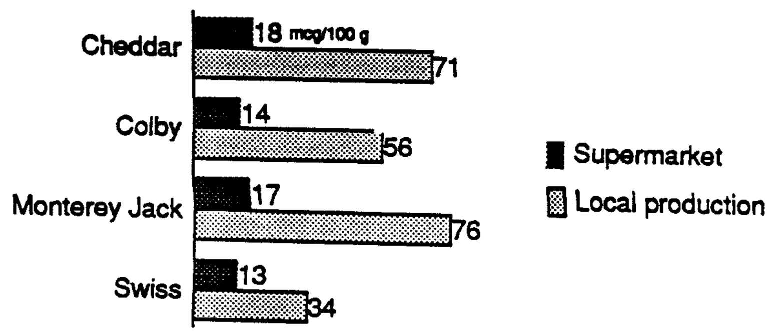
Levels of Selenium in Forage Crops*



*Adapted from Kabuta and Allaway, 1972

Fig. 2

Selenium Content of South Dakota Cheeses



Olson & Palmer, 1984

Fig. 3

Selenium Content of Foods from a Seleniferous Area of South Dakota

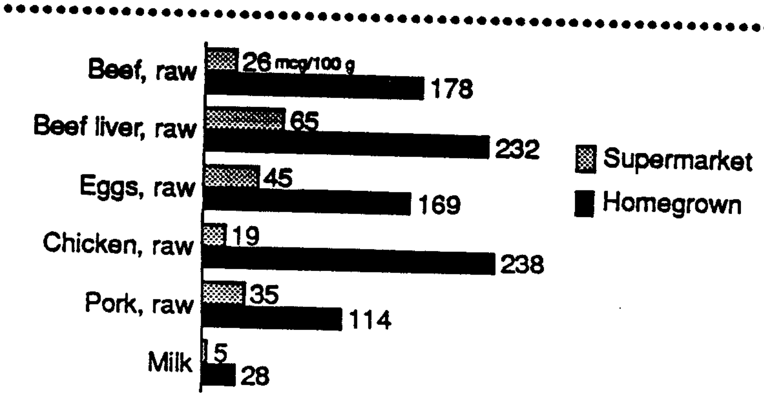
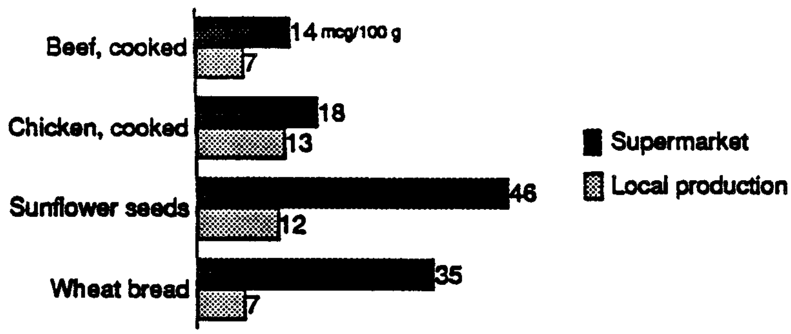


Fig. 4

Selenium Content of Ohio Foods



Snook et al., 1987

Fig. 5

Major Contributors of Selenium in the U.S. Diet

	Mean (mcg/100 g)	Cumulative % of daily intake
1. Beef, cooked	26	17
2. Bread, white	32	31
3. Pork/Ham, cooked	35	40
4. Chicken, cooked	21	46
5. Eggs, cooked	25	51
6. Rolls	34	55
7. Bread, whole wheat	44	58
8. Pasta, cooked	20	61
9. Milk, whole	1.6	64
10. Tuna, canned	72	66
11. Milk, 2% fat	2.6	68

Shubert et al., 1987

Fig. 6

Nationwide Sampling Plan for Bread Products

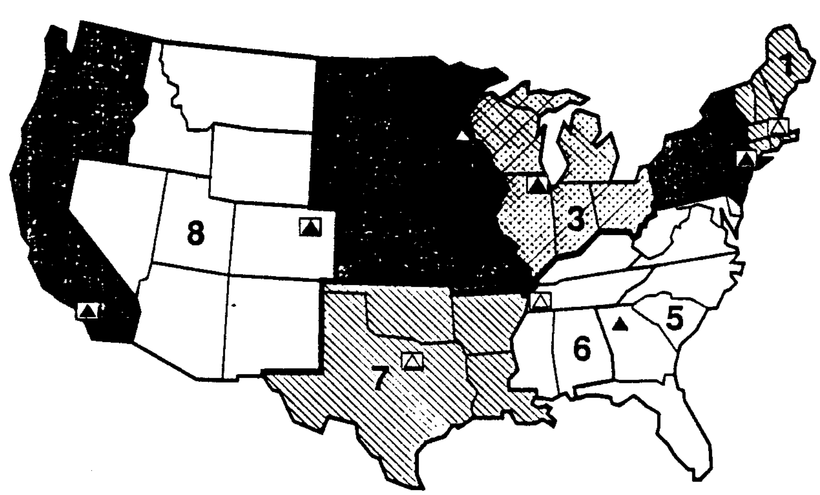


Fig. 7

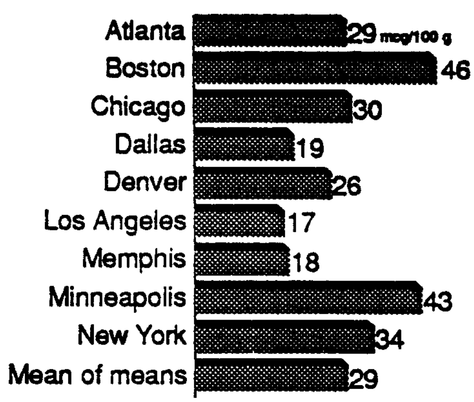
Plant Samples of the National Brand of White Bread

City	Month (1988)
• Boston	• *January*
• Chicago	• *March*
• Dallas	• *May*
• Denver	• *July*
• Los Angeles*	• *November*
• Memphis	
• New York*	

* Bread flour also obtained

Fig. 8

Levels of Selenium in Retail Samples of White Bread



	Range (mcg/100 g)	CV (%)
Atlanta	(21-39)	25
Boston	(21-74)	37
Chicago	(20-49)	37
Dallas	(9-31)	43
Denver	(16-33)	25
Los Angeles	(6-29)	49
Memphis	(11-23)	24
Minneapolis	(28-65)	22
New York	(14-50)	31
Mean of means		32

Fig. 9

Means for Selenium in Bread—Grouped by Region

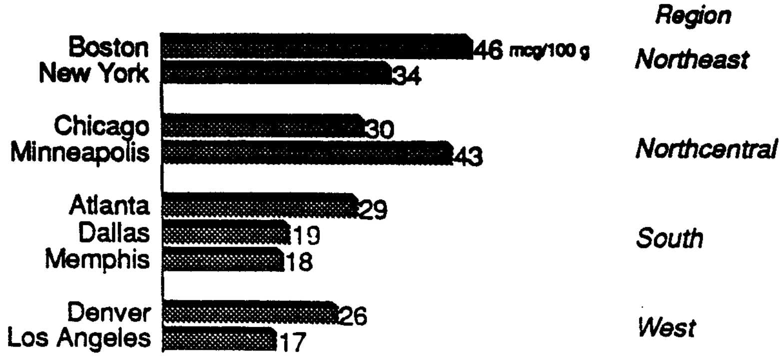


Fig. 10

Levels of Selenium in Cottage Cheese

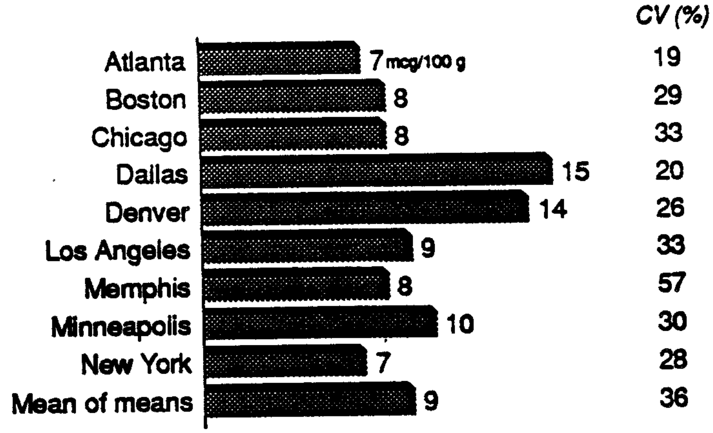


Fig. 11

Means for Selenium in Cottage Cheese-- Grouped by Region