Original Research

# Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999

---

**Donald R. Davis, PhD, FACN, Melvin D. Epp, PhD and Hugh D. Riordan, MD**

*Bio-Communications Research Institute, Wichita, Kansas (D.R.D., M.D.E., H.D.R.), Biochemical Institute, The University of Texas, Austin, Texas (D.R.D.)*

**Key words: Nutritive value, history, food analysis, agriculture**

**Objectives:** To evaluate possible changes in USDA nutrient content data for 43 garden crops between 1950 and 1999 and consider their potential causes.

**Methods:** We compare USDA nutrient content data published in 1950 and 1999 for 13 nutrients and water in 43 garden crops, mostly vegetables. After adjusting for differences in moisture content, we calculate ratios of nutrient contents, R (1999/1950), for each food and nutrient. To evaluate the foods as a group, we calculate median and geometric mean R-values for the 13 nutrients and water. To evaluate R-values for individual foods and nutrients, with hypothetical confidence intervals, we use USDA's standard errors (SEs) of the 1999 values, from which we generate 2 estimates for the SEs of the 1950 values.

**Results:** As a group, the 43 foods show apparent, statistically reliable declines ($R < 1$) for 6 nutrients (protein, Ca, P, Fe, riboflavin and ascorbic acid), but no statistically reliable changes for 7 other nutrients. Declines in the medians range from 6% for protein to 38% for riboflavin. When evaluated for individual foods and nutrients, R-values are usually not distinguishable from 1 with current data. Depending on whether we use low or high estimates of the 1950 SEs, respectively 33% or 20% of the apparent R-values differ reliably from 1. Significantly, about 28% of these R-values exceed 1.

**Conclusions:** We suggest that any real declines are generally most easily explained by changes in cultivated varieties between 1950 and 1999, in which there may be trade-offs between yield and nutrient content.

## INTRODUCTION

During the past 50 years in developed countries, there have been many changes in the way vegetables and other crops are grown and distributed. Changes include cultivated varieties (cultivars) used, cultural practices (fertilizers, pesticides, and irrigation), the location of major production, and distribution methods. Many persons have wondered what effect these changes may have on the nutritional value of foods.

There have been few attempts to answer this question, because of its complexity and lack of adequate data. Mayer found apparent "marked reductions" of some minerals in a comparison of United Kingdom food composition data from the 1930s and 1980s for 7 minerals in 20 fruits and 20 vegetables. She tempered her findings with cautions about the reliability and interpretation of these apparent changes [1]. A less-tempered lay comparison of United States Department of Agriculture (USDA) food composition data between 1975 and 1997 suggested an "alarming decline in food quality" in 12 common vegetables [2]. A former editor at *Organic Gardening* magazine concluded from these two reports that food quality "appears to be declining," and asked the USDA to investigate [3]. In a letter of reply, USDA director Phyllis E. Johnson acknowledged an apparent average decline of some nutrients in 10 vegetables, based on USDA data published in 1950 and 1984, but noted 13 points needing consideration before

---

Address reprint requests to: Donald R. Davis, PhD, Biochemical Institute, The University of Texas, 1 University Station A5100, Austin, TX 78712-0163. E-mail: d.r.davis@mail.utexas.edu

Abbreviations: CI = confidence interval, CV = coefficient of variation = SD/mean, N = number of foods reported, R = ratio of moisture-adjusted mean nutrient contents per weight, 1999/1950′, RSE = relative standard error = SE/mean, SD = standard deviation, SE = standard error, USDA = United States Department of Agriculture.

Journal of the American College of Nutrition, Vol. 23, No. 6, 669–682 (2004)
Published by the American College of Nutrition

conclusions can be drawn about their validity, magnitude and causes [4,5]. She also noted apparent substantial increases in some foods and nutrients.

Here we further examine these issues with USDA data published in 1950 and 1999 for 43 garden crops, mostly vegetables. We adjusted for differences in moisture content, a refinement not used previously. Like earlier authors, we examined changes both for the selected foods as a group, and for individual foods. We show that changes for individual foods should not be evaluated, as they have been previously, without regard to often-large uncertainties in the nutrient content data.

## MATERIALS AND METHODS

### Data and Calculations

Using nearly the same criteria as Mayer [1], we selected 43 raw vegetables and other crops commonly grown in home gardens. The foods had to be included in both the 1950 [6] and 1999 [7] editions of the USDA's tables. No foods were chosen or omitted based on their nutrient content data or the results of our statistical analyses. The 1950 and 1999 food names are shown in Table 1, with the current USDA NDB (Nutritional Database) Number. As much as possible we selected foods described identically in 1950 and 1999, but uncertainties remain about the full comparability of chard, lettuce, the two squashes and tomatoes (see Table 1 footnotes). The foods comprise 39 vegetables, 3 melons and strawberries.

Table 2 shows the USDA's reported average or representative amounts per 100 g for water and all 13 nutrients that are common to the 1950 and 1999 data. These amounts are termed "averages" in 1950 [6] and "means" in 1999 [7]. However, even in 1999, when USDA published the standard errors of the mean (SE) and numbers of samples (N) shown in Table 2, N was sometimes too small to well define the mean.* For most nutrients, the USDA and Table 2 report one more significant figure in 1999 than in 1950 (water, protein, fat, carbohydrate, ash, Fe, thiamin, riboflavin, niacin and ascorbic acid).

We excluded fiber because of a change of analysis from "crude" to "dietary" fiber. We calculated the dry matter content by difference with the water content.

We adjusted the 1950 nutrient contents in Table 2 to the same moisture level as the 1999 data by multiplying them by the ratio, dry matter (1999)/dry matter (1950), yielding what we term 1950′ data (not shown; equivalent in our analyses to expressing both sets of data as amounts per dry weight). To compare the 1999 and 1950′ means, we calculated their ratios, R = 1999/1950′ (except ratios for water and dry matter use unadjusted 1950 data).

For vitamin A, we excluded ratios R for 15 foods that involve 1950 or 1999 means less than 100 IU/100 g, because they are relatively unreliable and have low nutritional significance.

### Statistical Analysis

**Means and Medians of Ratios R = 1999/1950′.** Geometric means of R for 43 foods were calculated for each nutrient from the antilog of mean logarithms of R. These means, the corresponding medians and statistical tests derive from NCSS 2001 statistical software (Kaysville, UT).

**Reliability of Individual R.** To evaluate the statistical reliability of individual ratios R, one needs the SEs of their numerators and denominators. For the numerators, we used published SEs (Table 2), excluding as unreliable those with N = 2. (After 1999, USDA apparently adopted the same policy, as it no longer reports SEs with N = 2.) Because USDA did not report SEs in 1950 (for the denominators of R), we used hypothetical, estimated values based on the 1999 SEs, for purposes of exploration and illustration.

To assess the sensitivity of the results to the assumed 1950 SEs, we used 2 values for each ratio R. One probably is usually unrealistically low; the other is twice as large. For the low estimate, we assumed that the relative standard error, RSE, was the same for the 1950′ mean as for the 1999 mean (RSE = SE/mean). This low estimate would apply if the sample sizes N and the analytical precision were similar in 1950 and 1999. Our high estimate is twice the low estimate. It would apply, for example, if laboratory variation contributed importantly to the 1950 SDs, but was reduced by half in 1999. It would also apply if Ns were 4-fold larger in 1999 than 1950. Smaller reductions in laboratory uncertainty combined with smaller increases in N could produce the same result. We believe that the high estimates are usually more realistic than the low estimates.

Lastly, we assumed that USDA's means for 1999 and 1950 are (1) independent estimates and (2) normally distributed, as is expected for large N. For small N, normality is still expected if the components of the mean are normally distributed (see Results). With these assumptions, we calculated CIs for the individual ratios R by integrating the probability density function of R. (Some statisticians prefer the term, "prediction interval," for this result, instead of CI). The probability density function is given by equation 1 in [8], with $\rho = 0$, or by equation 3 in [9]. Unfortunately, the density function requires numerical integration. For this purpose, we created a Microsoft Excel spreadsheet (available on request) to evaluate the integrand at 601 equally spaced intervals and to integrate it by Simpson's rule. We selected lower and upper limits of integration such that the total cumulative probability was ordinarily

---

* Beginning with Release 14 (2001), USDA provides additional, useful information about nutrient amounts in some foods: Number of studies, minimum value, maximum value, degrees of freedom, lower and upper error bounds, statistical comments, information on how values are generated and source of analytical data (Nutrient Data File).

**Table 1.** The Foods Compared, All Raw (USDA Names and Current Nutrient Database Number)

| Food No. | 1950 Name | 1999 Name | NDB # |
|---|---|---|---|
| 1 | Asparagus | Asparagus | 11011 |
| 2 | Beans, snap, green | Beans, snap, green | 11052 |
| 3 | Beets, common red, peeled | Beets [refuse: parings] | 11080 |
| 4 | Beet greens, common | Beet greens | 11086 |
| 5 | Broccoli, flower stalks | Broccoli | 11090 |
| 6 | Brussels sprouts | Brussels sprouts | 11098 |
| 7 | Cabbage | Cabbage | 11109 |
| 8 | Cabbage, celery or chinese* | Cabbage, chinese (pe-tsai) | 11119 |
| 9 | Cantaloupe [deeply colored] | Melons, cantaloupe | 09181 |
| 10 | Carrots | Carrots | 11124 |
| 11 | Cauliflower | Cauliflower | 11135 |
| 12 | Celery, bleached | Celery | 11143 |
| 13 | Chard, leaves only† | Chard, swiss [refuse = tough stems] | 11147 |
| 14 | Collards | Collards | 11161 |
| 15 | Corn, sweet, yellow | Corn, sweet, yellow | 11167 |
| 16 | Cucumbers [unpared data] | Cucumber, with peel | 11205 |
| 17 | Dandelion greens | Dandelion greens | 11207 |
| 18 | Eggplant | Eggplant | 11209 |
| 19 | Honeydew melon | Melons, honeydew | 09184 |
| 20 | Kale | Kale | 11233 |
| 21 | Kohlrabi | Kohlrabi | 11241 |
| 22 | Lettuce, headed | Lettuce, iceberg (includes crisphead types) | 11252 |
| 23 | Mustard greens | Mustard greens | 11270 |
| 24 | Okra | Okra | 11278 |
| 25 | Onions, mature | Onions | 11282 |
| 26 | Onions, young, green | Onions, spring or scallions (including tops and bulb) | 11291 |
| 27 | Parsnips | Parsnips | 11298 |
| 28 | Peas, green, immature | Peas, green | 11304 |
| 29 | Peppers, green | Peppers, sweet, green | 11333 |
| 30 | Potatoes# | Potatoes, flesh and skin | 11352 |
| 31 | Pumpkin | Pumpkin | 11422 |
| 32 | Radishes | Radishes | 11429 |
| 33 | Rhubarb, stems | Rhubarb | 09307 |
| 34 | Rutabagas | Rutabagas | 11435 |
| 35 | Spinach | Spinach | 11457 |
| 36 | Squash, summer | Squash, summer, all varieties | 11641 |
| 37 | Squash, winter | Squash, winter, all varieties | 11643 |
| 38 | Strawberries | Strawberries | 09316 |
| 39 | Sweetpotato | Sweetpotato | 11507 |
| 40 | Tomatoes§ | Tomatoes, red, ripe, year round average | 11529 |
| 41 | Turnips | Turnips | 11564 |
| 42 | Turnip greens | Turnip greens | 11568 |
| 43 | Watermelons | Watermelon | 09326 |

* In 1963 USDA listed "Cabbage, Chinese (also called celery cabbage or petsai)." It had a separate entry for "Cabbage, spoon (also called white mustard cabbage or pakchoy)." (United States Department of Agriculture: Composition of foods. USDA Agriculture Handbook 8. Washington, D.C.: USDA, 1963).

† In 1950 USDA listed two chards, "leaves and stalks" and "leaves only." Beginning in 1963, USDA lists only one chard, with refuse = "tough stem ends" (USDA's Table 2). Its nutrient contents are most similar to the 1950 "leaves only." In 1999 USDA described the refuse as "tough stems" (Food Description File).

# In 1950 USDA listed only one raw potato. It was probably unpeeled, because boiled potatoes were shown both "unpeeled" and "peeled before cooking." In any case, peeling probably matters little for our nutrients: Comparison of the two boiled potatoes shows only small losses of thiamin, riboflavin, niacin and ascorbic acid in the peeled potatoes, probably attributable mainly to the boiling in peeled condition.

§ In 1999 USDA compared red, ripe tomatoes, June thru October average and November thru May average. They differ only in ascorbic acid content, 26 mg/100 g and 10 mg/100 g respectively, based on one sample each. Our year-round-average data are the same, except ascorbic acid = 19.1 mg/100 g, based on 165 samples.

1.00000. For the 95% CI we recorded the R-values corresponding to cumulative probabilities of 0.025 and 0.975. We also recorded the median R (cumulative probability 0.5) and calculated the mean R (integral of the probability density function × R). The mean is termed a "pseudo mean" in [9], because it is not well defined when the denominator of R (the 1950′ mean) has significant probability density near zero. This situation occurs when the 1950′ RSE exceeds about 0.3 to 0.4, in which case the upper limit of the CI and the mean R are approximate or indeterminate, as indicated in the Results section.

# RESULTS

## Adjustment for Moisture Differences

When nutrient contents are expressed in units of amounts per fresh weight (as in Table 2), one should first computationally adjust the nutrient contents of one or both compared foods to the values they would have if they had the same moisture [4].[†] Moisture adjustments are especially important for high-water foods like fresh fruits and vegetables. For example (one more extreme than most), the 1999 mustard greens had 90.8% water and thus 9.2% dry matter. The 1950 greens had 92.2% water and only 7.8% dry matter. The seemingly small 1.4% difference in water corresponds to a much larger 18% difference in dry matter. Thus, for mustard greens we multiplied the 1950 nutrient amounts in Table 2 by $9.2/7.8 = 1.18$ to get 1950′ values corresponding to the same 9.2% dry matter as in 1999. This adjustment for mustard greens nullifies the seeming increases between 1950 and 1999 for energy, protein and carbohydrate (Table 2), and enhances all other 1950 values relative to 1999. Failure to adjust for moisture differences adds unnecessary "noise" to group comparisons like ours and Mayer's. It also potentially biases group comparisons and certainly biases comparisons of individual foods.

## Variability Among Samples of the Same Food

Users of food composition tables sometimes fail to realize that individual samples of food may differ greatly from tabulated means. We quantify this point here, because it limits our ability to make historical comparisons. Variability is conveniently expressed as a coefficient of variation, CV = SD/mean. From the USDA's 1999 data (Table 2), we calculated $\mathrm{CV} = \mathrm{SE} \times \sqrt{\mathrm{N}}/\mathrm{mean}$, excluding SEs based on $\mathrm{N} = 2$. Among our foods with SEs, the median CV for water in 1999 is only 1.7%, but median CVs are quite large for all other nutrients: 17% to 30% for protein, ash, P and niacin; 30% to 40% for Ca, vitamin A, thiamin, riboflavin and ascorbic acid; and 53% and 59% for Fe and fat. When CVs are small ($<\sim 20\%$), their simple interpretation is that about 1/3 of samples of the same food lie outside of ±1 CV of the mean. When CVs exceed ~30%, the distribution of individual values is skewed, and the range of values may be much larger than the simple interpretation suggests. Unless Ns are large, the above CVs create large uncertainties in tabulated means, reflected in USDA's SEs, and they limit our ability to detect historical changes, especially in individual foods.

Variation among food samples is not a new phenomenon induced by modern farming practices or by differences between cultivars. Bear *et al.* in 1948 minimized variations caused by cultivars and maturity and still found very large variations in minerals in 204 samples of 5 vegetables grown in 10 states [10].

## Group Changes Between 1950 and 1999

To compare the 1999 and moisture-adjusted 1950′ mean nutrient contents, we calculated their ratio, R (1999/1950′), for all available foods, usually numbering 42 or 43. Fig. 1 summarizes results for each nutrient in a box plot. Median R-values are near 1.0 for energy, fat, carbohydrate and thiamin. The vertical range of the box (interquartile range) shows the variability of R among the central half of the foods analyzed. Variability is small for energy and carbohydrate, but large for fat, Ca, Fe and the vitamins. Especially for fat, the variability likely partly reflects errors in measuring the small amounts present (Table 2). Values outside the boxes also reflect variability of R, but these values are often individually unreliable, as we will show.

Table 3, left side, shows the median R for each nutrient, with its 95% CI and $p$ (median = 1). The right side of Table 3 shows the geometric mean R for each nutrient, with its 95% CI and $p$ (geometric mean = 1), as in the analysis by Mayer [1]. The latter CIs and $p$-values for geometric means assume a Gaussian distribution for the components of the means, an assumption that failed in our data at the 5% level for 10 of the 15 substances listed. Thus, for purposes of assessing foods as a group, we favor the distribution-free medians (non-parametric analysis), shown here and in Fig. 2.

Compared to the ordinary means used in one analysis [2], medians and geometric means reduce distortion caused by skewing and outliers. Geometric means are somewhat higher than medians when the distributions of R are skewed toward high values (e.g., thiamin and riboflavin, Fig. 1).

The medians and geometric means of R are both reliably <1, in a statistical sense, for 5 nutrients—Ca, P, Fe, riboflavin and ascorbic acid ($p < 0.05$, 2-tailed). The median R for protein is also reliably <1. As measured by the medians, the overall declines between 1950 to 1999 range from 6% for protein (5% by geometric mean) to 38% for riboflavin (28%). Median water content may be about 0.6% higher in 1999, corresponding to about 3%–4% less dry matter, but these differences from 1 are mostly statistically unreliable (Table 3). The 7 other nutrients show no statistically significant changes between 1950 and 1999. These group results are more reliable than results for individual foods (below).

## Changes in Individual Foods between 1950 and 1999

Random errors have little effect on the foregoing group medians and geometric means of R, or on the interquartile ranges in Fig. 1. But R-values for individual foods and nutrients

---

[†] Adding water to a food does not change its nutritional value, but does decrease all nutrient amounts per weight. This sometimes-difficult concept can be illustrated with the example of orange juice concentrate and the diluted juice made from it. Expressed as amounts per moist weight, all nutrients in the concentrate are over 3 times greater than in the juice. Nevertheless, the concentrate is not more nutritious. The nutrient contents are identical when expressed as amounts per dry weight (common in agricultural research literature), amounts per calorie, or amounts per serving (suitably defined). Comparisons like ours based on amounts per fresh weight require computationally adjusting the compared foods to have the same moisture and dry matter.

**Table 2.** USDA's Reported Average or Representative Nutrient Contents per 100 g Edible Portion in 1999 and 1950, with 1999 SE and Number of Samples, N (values in Parentheses Are Not Used*)

| Food No. | Water (g) | | | | Energy (kcal) | | Protein (g) | | | | Fat (g) | | | | Carbohy. (g) | | Ash (g) | | | | Calcium (mg) | | | | Phosphorus (mg) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | '99 | SE | N | '50 | '99 | '50 | '99 | SE | N | '50 | '99 | SE | N | '50 | '99 | '50 | '99 | SE | N | '50 | '99 | SE | N | '50 | '99 | SE | N | '50 |
| 1 | 92.40 | 0.081 | 23 | 93.0 | 23 | 21 | 2.28 | 0.130 | 6 | 2.2 | 0.20 | 0.038 | 6 | 0.2 | 4.54 | 3.9 | 0.57 | 0.025 | 4 | 0.7 | 21 | 1.148 | 18 | 21 | 56 | 1.944 | 18 | 62 |
| 2 | 90.27 | 0.280 | 161 | 88.9 | 31 | 35 | 1.82 | 0.050 | 100 | 2.4 | 0.12 | 0.033 | 10 | 0.2 | 7.14 | 7.7 | 0.66 | 0.019 | 140 | 0.8 | 37 | 1.405 | 149 | 65 | 38 | 0.807 | 136 | 44 |
| 3 | 87.58 | 0.723 | 21 | 87.6 | 43 | 42 | 1.61 | 0.140 | 9 | 1.6 | 0.17 | 0.051 | 9 | 0.1 | 9.56 | 9.6 | 1.08 | 0.108 | 8 | 1.1 | 16 | 1.810 | 5 | 27 | 40 | 4.927 | 5 | 43 |
| 4 | 92.15 | 0.466 | 6 | 90.4 | 19 | 27 | 1.82 | | 1 | 2.0 | 0.06 | | 1 | 0.3 | 3.97 | 5.6 | 2.01 | | 1 | 1.7 | 119 | | 1 | 118 | 40 | | 0 | 45 |
| 5 | 90.69 | 0.333 | 33 | 89.9 | 28 | 29 | 2.98 | 0.109 | 22 | 3.3 | 0.35 | 0.034 | 22 | 0.2 | 5.24 | 5.5 | 0.92 | 0.027 | 23 | 1.1 | 48 | 2.510 | 28 | 130 | 66 | 1.593 | 27 | 76 |
| 6 | 86.00 | 0.435 | 8 | 84.9 | 43 | 47 | 3.38 | (0.122) | 2 | 4.4 | 0.30 | (0.100) | 2 | 0.5 | 8.96 | 8.9 | 1.37 | | 1 | 1.3 | 42 | (2.500) | 2 | 34 | 69 | | 1 | 78 |
| 7 | 92.15 | 0.258 | 62 | 92.4 | 25 | 24 | 1.44 | 0.253 | 7 | 1.4 | 0.27 | 0.104 | 6 | 0.2 | 5.43 | 5.3 | 0.71 | 0.021 | 28 | 0.8 | 47 | 2.322 | 37 | 46 | 23 | 1.589 | 35 | 31 |
| 8 | 94.39 | 0.438 | 20 | 95.4 | 16 | 14 | 1.20 | | 1 | 1.2 | 0.20 | | 1 | 0.3 | 3.23 | 2.4 | 0.98 | (0.037) | 2 | 0.7 | 77 | 9.098 | 3 | 43 | 29 | 4.601 | 3 | 41 |
| 9 | 89.78 | 0.413 | 85 | 94.0 | 35 | 20 | 0.88 | 0.039 | 81 | 0.6 | 0.28 | 0.020 | 15 | 0.2 | 8.36 | 4.6 | 0.71 | 0.015 | 80 | 0.6 | 11 | 1.328 | 8 | 17 | 17 | 4.848 | 72 | 16 |
| 10 | 87.79 | 0.070 | 237 | 88.2 | 43 | 42 | 1.03 | 0.010 | 182 | 1.2 | 0.19 | 0.020 | 28 | 0.3 | 10.14 | 9.3 | 0.87 | 0.026 | 46 | 1.0 | 27 | 0.667 | 235 | 39 | 44 | 0.803 | 236 | 37 |
| 11 | 91.91 | 0.280 | 31 | 91.7 | 25 | 25 | 1.98 | 0.061 | 16 | 2.4 | 0.21 | 0.025 | 16 | 0.2 | 5.20 | 4.9 | 0.71 | 0.024 | 15 | 0.8 | 22 | 1.202 | 19 | 22 | 44 | 1.384 | 18 | 72 |
| 12 | 94.64 | 0.123 | 47 | 93.7 | 16 | 18 | 0.75 | 0.035 | 26 | 1.3 | 0.14 | 0.017 | 24 | 0.2 | 3.65 | 3.7 | 0.82 | 0.023 | 24 | 1.1 | 40 | 1.809 | 46 | 50 | 25 | 1.066 | 46 | 40 |
| 13 | 92.66 | (0.660) | 2 | 91.0 | 19 | 27 | 1.80 | | 1 | 2.6 | 0.20 | | 1 | 0.4 | 3.74 | 4.8 | 1.60 | | 0 | 1.2 | 51 | | 1 | 105 | 46 | | 1 | 36 |
| 14 | 90.55 | 1.066 | 10 | 86.6 | 30 | 40 | 2.45 | 0.370 | 3 | 3.9 | 0.42 | 0.126 | 3 | 0.6 | 5.69 | 7.2 | 0.89 | 0.154 | 3 | 1.7 | 145 | (0.144) | 2 | 249 | 10 | 0.254 | 10 | 58 |
| 15 | 75.96 | 0.880 | 101 | 73.9 | 86 | 92 | 3.22 | 0.223 | 6 | 3.7 | 1.18 | 0.132 | 6 | 1.2 | 19.02 | 20.5 | 0.62 | 0.044 | 45 | 0.7 | 2 | 1.022 | 51 | 9 | 89 | 3.749 | 77 | 120 |
| 16 | 96.01 | 0.119 | 72 | 96.1 | 13 | 12 | 0.69 | 0.035 | 18 | 0.7 | 0.13 | 0.018 | 18 | 0.1 | 2.76 | 2.7 | 0.41 | 0.015 | 49 | 0.4 | 14 | 0.858 | 43 | 10 | 20 | 1.097 | 38 | 21 |
| 17 | 85.60 | | 0 | 85.8 | 45 | 44 | 2.70 | | 0 | 2.7 | 0.70 | | 0 | 0.7 | 9.20 | 8.8 | 1.80 | | 0 | 2.0 | 187 | | 0 | 187 | 66 | | 0 | 70 |
| 18 | 92.03 | 0.205 | 30 | 92.7 | 26 | 24 | 1.02 | 0.037 | 5 | 1.1 | 0.18 | 0.049 | 5 | 0.2 | 6.07 | 5.5 | 0.71 | 0.125 | 6 | 0.5 | 7 | 1.193 | 7 | 15 | 22 | 1.891 | 6 | 37 |
| 19 | 89.66 | 0.391 | 18 | 90.5 | 35 | 32 | 0.46 | 0.063 | 18 | 0.5 | 0.10 | | 1 | 0.0 | 9.18 | 8.5 | 0.60 | 0.029 | 17 | 0.5 | 6 | | 1 | 17 | 10 | 1.222 | 17 | 16 |
| 20 | 84.46 | 0.531 | 5 | 86.6 | 50 | 40 | 3.30 | | 1 | 3.9 | 0.70 | | 1 | 0.6 | 10.01 | 7.2 | 1.53 | | 0 | 1.7 | 135 | | 1 | 225 | 56 | | 1 | 62 |
| 21 | 91.00 | | 1 | 90.1 | 27 | 30 | 1.70 | | 1 | 2.1 | 0.10 | | 1 | 0.1 | 6.20 | 6.7 | 1.00 | | 0 | 1.0 | 24 | | 1 | 46 | 46 | | 1 | 50 |
| 22 | 95.89 | 0.091 | 110 | 94.8 | 12 | 15 | 1.01 | 0.035 | 21 | 1.2 | 0.19 | 0.035 | 21 | 0.2 | 2.09 | 2.9 | 0.48 | 0.020 | 49 | 0.9 | 19 | 0.636 | 91 | 22 | 20 | 0.509 | 91 | 25 |
| 23 | 90.80 | 1.004 | 9 | 92.2 | 26 | 22 | 2.70 | | 1 | 2.3 | 0.20 | | 1 | 0.3 | 4.90 | 4.0 | 1.40 | | 0 | 1.2 | 103 | (36.600) | 2 | 220 | 43 | (2.350) | 2 | 38 |
| 24 | 89.58 | 0.525 | 8 | 89.8 | 33 | 32 | 2.00 | | 1 | 1.8 | 0.10 | | 1 | 0.2 | 7.63 | 7.4 | 0.70 | | 0 | 0.8 | 81 | | 1 | 82 | 63 | | 1 | 62 |
| 25 | 89.68 | 0.238 | 63 | 87.5 | 38 | 45 | 1.16 | 0.031 | 32 | 1.4 | 0.16 | 0.022 | 28 | 0.2 | 8.63 | 10.3 | 0.37 | 0.024 | 31 | 0.6 | 20 | 0.985 | 74 | 32 | 33 | 0.849 | 69 | 44 |
| 26 | 89.83 | 0.878 | 21 | 87.6 | 32 | 45 | 1.83 | 0.183 | 3 | 1.0 | 0.19 | 0.067 | 3 | 0.2 | 7.34 | 10.6 | 0.81 | 0.084 | 4 | 0.6 | 72 | 15.746 | 3 | 135 | 37 | 0.835 | 3 | 24 |
| 27 | 79.53 | 1.544 | 6 | 78.6 | 75 | 78 | 1.20 | | 1 | 1.5 | 0.30 | | 1 | 0.5 | 17.90 | 18.2 | 0.98 | | 1 | 1.2 | 36 | (4.500) | 2 | 57 | 71 | (1.500) | 2 | 80 |
| 28 | 78.86 | 0.508 | 10 | 74.3 | 81 | 98 | 5.42 | 0.131 | 7 | 6.7 | 0.40 | 0.033 | 7 | 0.4 | 14.46 | 17.7 | 0.87 | 0.042 | 7 | 0.9 | 25 | 2.026 | 8 | 22 | 108 | 4.166 | 8 | 122 |
| 29 | 92.19 | 0.481 | 30 | 92.4 | 27 | 25 | 0.89 | 0.020 | 16 | 1.2 | 0.19 | 0.038 | 14 | 0.2 | 6.43 | 5.7 | 0.30 | (0.000) | 2 | 0.5 | 9 | 0.483 | 32 | 11 | 19 | 0.639 | 32 | 25 |
| 30 | 78.96 | 0.096 | 265 | 77.8 | 79 | 83 | 2.07 | 0.014 | 165 | 2.0 | 0.10 | | 0 | 0.1 | 17.98 | 19.1 | 0.89 | 0.008 | 205 | 1.0 | 7 | 0.412 | 84 | 11 | 46 | 1.538 | 84 | 56 |
| 31 | 91.60 | | 0 | 90.5 | 26 | 31 | 1.00 | | 0 | 1.2 | 0.10 | | 0 | 0.2 | 6.50 | 7.3 | 0.80 | | 0 | 0.8 | 21 | | 0 | 21 | 44 | | 0 | 44 |
| 32 | 94.84 | 0.182 | 33 | 93.6 | 20 | 20 | 0.60 | 0.074 | 11 | 1.2 | 0.54 | 0.426 | 7 | 0.1 | 3.59 | 4.2 | 0.54 | 0.020 | 11 | 1.0 | 21 | 1.654 | 17 | 37 | 18 | 1.984 | 17 | 31 |
| 33 | 93.61 | 0.278 | 38 | 94.9 | 21 | 16 | 0.90 | 0.034 | 34 | 0.5 | 0.20 | | 1 | 0.1 | 4.54 | 3.8 | 0.76 | 0.054 | 33 | 0.7 | 86 | 6.096 | 9 | 51 | 14 | 1.337 | 33 | 25 |
| 34 | 89.66 | 0.534 | 5 | 89.1 | 36 | 38 | 1.20 | | 1 | 1.1 | 0.20 | | 0 | 0.1 | 8.13 | 8.9 | 0.81 | | 1 | 0.8 | 47 | (15.500) | 2 | 55 | 58 | (17.000) | 2 | 41 |
| 35 | 91.58 | 0.268 | 18 | 92.7 | 22 | 20 | 2.86 | 0.112 | 9 | 2.3 | 0.35 | 0.043 | 9 | 0.3 | 3.50 | 3.2 | 1.72 | 0.035 | 8 | 1.5 | 99 | 4.996 | 9 | 81 | 49 | 3.479 | 7 | 55 |
| 36 | 93.68 | | 25 | 95.0 | 20 | 16 | 1.18 | | 10 | 0.6 | 0.21 | | 10 | 0.1 | 4.35 | 3.9 | 0.58 | 0.027 | 6 | 0.4 | 20 | | 10 | 15 | 35 | | 10 | 15 |
| 37 | 88.72 | | 17 | 88.6 | 37 | 38 | 1.45 | | 4 | 1.5 | 0.23 | | 4 | 0.3 | 8.80 | 8.8 | 0.80 | | 0 | 0.8 | 31 | | 4 | 19 | 32 | | 4 | 28 |
| 38 | 91.57 | 0.136 | 100 | 89.9 | 30 | 37 | 0.61 | 0.026 | 91 | 0.8 | 0.37 | 0.135 | 6 | 0.5 | 7.02 | 8.3 | 0.43 | 0.009 | 81 | 0.5 | 14 | 0.504 | 10 | 28 | 19 | 0.464 | 81 | 27 |
| 39 | 72.84 | 0.865 | 25 | 68.5 | 105 | 123 | 1.65 | 0.143 | 11 | 1.8 | 0.30 | 0.029 | 11 | 0.7 | 24.28 | 27.9 | 0.95 | 0.030 | 11 | 1.1 | 22 | 1.607 | 31 | 30 | 28 | 1.833 | 9 | 49 |
| 40 | 93.76 | 0.062 | 210 | 94.1 | 21 | 20 | 0.85 | 0.015 | 89 | 1.0 | 0.33 | 0.062 | 17 | 0.3 | 4.64 | 4.0 | 0.42 | 0.025 | 17 | 0.6 | 5 | 0.328 | 135 | 11 | 24 | 0.341 | 131 | 27 |
| 41 | 91.87 | 0.242 | 5 | 90.9 | 27 | 32 | 0.90 | | 1 | 1.1 | 0.10 | | 1 | 0.2 | 6.23 | 7.1 | 0.70 | | 0 | 0.7 | 30 | | 1 | 40 | 27 | | 1 | 34 |
| 42 | 91.07 | 0.476 | 8 | 89.5 | 27 | 30 | 1.50 | | 1 | 2.9 | 0.30 | | 1 | 0.4 | 5.73 | 5.4 | 1.40 | | 0 | 1.8 | 190 | | 1 | 259 | 42 | | 1 | 50 |
| 43 | 91.51 | 0.208 | 49 | 92.1 | 32 | 28 | 0.62 | 0.018 | 45 | 0.5 | 0.43 | 0.048 | 12 | 0.2 | 7.18 | 6.9 | 0.26 | 0.010 | 44 | 0.3 | 8 | 2.303 | 8 | 7 | 9 | 0.506 | 40 | 12 |

(*Table continues*)

* SE with N = 2 (31 cases) and vitamin A values <100 IU (15 foods). Values are missing for carrot ascorbic acid, 1950 (food no. 10) and rhubarb riboflavin, 1950 (food no. 33).

are affected by random errors in both their numerators and denominators, making it often difficult or sometimes impossible to meaningfully assess changes in single foods.

**Uncertainties in the Numerators of R.** The 1999 USDA data [7] include SEs of the means for slightly over half of our foods and nutrients (58%, excluding SEs in Table 2 based on N = 2). These SEs reflect random errors in the numerators of R (sampling and laboratory errors). Expressed as RSEs, median values are 0.37% for water; 3.8%–4.0% for protein, ash, and P; 5.4%–6.7% for Ca, riboflavin and niacin; 8.6%–10.6% for Fe, vitamin A, thiamin and ascorbic acid; and 16% for fat. (SEs are not reported for energy and carbohydrate, as they are calculated values.) The range of individual RSEs is large; 9 of 12 interquartile ranges exceed the median RSE.

SEs tend to be large when N is small. About 40% of our foods and nutrients have N ≤ 2, for which SEs are undefined

**Table 2.** Continued

| Food No. | Iron (mg) | | | | Vitamin A (IU) | | | | Thiamin (mg) | | | | Riboflavin (mg) | | | | Niacin (mg) | | | | Ascorbic Acid (mg)† | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ’99 | SE | N | ’50 | ’99 | SE | N | ’50 | ’99 | SE | N | ’50 | ’99 | SE | N | ’50 | ’99 | SE | N | ’50 | ’99 | SE | N | ’50 |
| 1 | 0.87 | 0.074 | 18 | 0.9 | 583 | 123.09 | 6 | 1000 | 0.140 | 0.018 | 6 | 0.16 | 0.128 | 0.013 | 6 | 0.19 | 1.170 | 0.209 | 6 | 1.4 | 13.2 | 2.592 | 16 | 33 |
| 2 | 1.04 | 0.079 | 151 | 1.1 | 668 | 18.79 | 97 | 630 | 0.084 | 0.002 | 98 | 0.08 | 0.105 | 0.003 | 98 | 0.11 | 0.750 | | 8 | 0.5 | 16.3 | 1.289 | 5 | 19 |
| 3 | 0.80 | 0.195 | 8 | 1.0 | (38) | 15.78 | 4 | (20) | 0.031 | 0.009 | 5 | 0.02 | 0.040 | 0.007 | 5 | 0.05 | 0.330 | 0.026 | 5 | 0.4 | 4.9 | 1.544 | 5 | 10 |
| 4 | 3.30 | | 0 | 3.2 | 6100 | | 0 | 6700 | 0.100 | | 0 | 0.08 | 0.220 | | 0 | 0.18 | 0.400 | | 0 | 0.4 | 30.0 | | 0 | 34 |
| 5 | 0.88 | 0.082 | 34 | 1.3 | 1542 | 44.94 | 5 | 3500 | 0.065 | 0.008 | 15 | 0.10 | 0.119 | 0.004 | 15 | 0.21 | 0.640 | 0.021 | 15 | 1.1 | 93.2 | 2.068 | 15 | 118 |
| 6 | 1.40 | (0.500) | 2 | 1.3 | 883 | (67.00) | 2 | 400 | 0.139 | (0.009) | 2 | 0.08 | 0.090 | (0.050) | 2 | 0.16 | 0.750 | (0.145) | 2 | 0.7 | 85.0 | | 1 | 94 |
| 7 | 0.59 | 0.149 | 30 | 0.5 | 133 | 20.10 | 9 | (80) | 0.050 | (0.000) | 2 | 0.06 | 0.040 | (0.010) | 2 | 0.05 | 0.300 | (0.000) | 2 | 0.3 | 32.2 | 4.147 | 19 | 50 |
| 8 | 0.31 | 0.096 | 3 | 0.9 | 1200 | | 1 | 260 | 0.040 | | 1 | 0.03 | 0.050 | | 1 | 0.04 | 0.400 | | 1 | 0.4 | 27.0 | | 1 | 31 |
| 9 | 0.21 | 0.021 | 77 | 0.4 | 3224 | 211.84 | 10 | 3420 | 0.036 | 0.009 | 6 | 0.05 | 0.021 | 0.004 | 6 | 0.04 | 0.570 | 0.118 | 4 | 0.5 | 42.2 | 2.458 | 19 | 33 |
| 10 | 0.50 | 0.019 | 241 | 0.8 | 28129 | 152.92 | 162 | 12000 | 0.097 | 0.002 | 179 | 0.06 | 0.059 | 0.001 | 177 | 0.06 | 0.930 | 0.082 | 23 | 0.5 | 9.3 | 0.168 | 162 | |
| 11 | 0.44 | 0.028 | 19 | 1.1 | (19) | 2.11 | 15 | (90) | 0.057 | 0.003 | 15 | 0.11 | 0.063 | 0.004 | 15 | 0.1 | 0.530 | 0.024 | 15 | 0.6 | 46.4 | 4.398 | 24 | 69 |
| 12 | 0.40 | 0.089 | 53 | 0.5 | 134 | 14.94 | 19 | (0) | 0.046 | 0.011 | 21 | 0.05 | 0.045 | 0.003 | 18 | 0.04 | 0.320 | 0.014 | 19 | 0.4 | 7.0 | 0.346 | 29 | 7 |
| 13 | 1.80 | | 1 | 2.5 | 3300 | | 1 | 8720 | 0.040 | | 1 | 0.06 | 0.090 | | 1 | 0.18 | 0.400 | | 1 | 0.4 | 30.0 | | 1 | 38 |
| 14 | 0.19 | 0.004 | 10 | 1.6 | 3824 | 982.12 | 3 | 6870 | 0.054 | 0.020 | 3 | 0.11 | 0.130 | 0.062 | 3 | 0.27 | 0.740 | 0.151 | 3 | 2.0 | 35.3 | 5.022 | 3 | 100 |
| 15 | 0.52 | 0.022 | 91 | 0.5 | 281 | 80.37 | 7 | 390 | 0.200 | | 1 | 0.15 | 0.060 | | 1 | 0.12 | 1.700 | | 1 | 1.7 | 6.8 | 0.568 | 7 | 12 |
| 16 | 0.26 | 0.014 | 42 | 1.2 | 215 | 18.61 | 13 | 260 | 0.024 | 0.002 | 13 | 0.03 | 0.022 | 0.001 | 13 | 0.04 | 0.220 | 0.009 | 13 | 0.2 | 5.3 | 0.491 | 21 | 8 |
| 17 | 3.10 | | 0 | 3.1 | 14000 | | 0 | 13650 | 0.190 | | 0 | 0.19 | 0.260 | | 0 | 0.14 | 0.810 | | 0 | 0.8 | 35.0 | | 0 | 36 |
| 18 | 0.27 | 0.022 | 7 | 0.4 | (84) | 8.68 | 3 | (30) | 0.052 | 0.010 | 5 | 0.04 | 0.034 | 0.005 | 5 | 0.05 | 0.600 | 0.017 | 5 | 0.6 | 1.7 | 0.231 | 25 | 5 |
| 19 | 0.07 | 0.009 | 17 | 0.4 | (40) | | 0 | (40) | 0.077 | (0.018) | 2 | 0.05 | 0.018 | (0.002) | 2 | 0.03 | 0.600 | | 1 | 0.2 | 24.8 | 4.114 | 19 | 23 |
| 20 | 1.70 | | 1 | 2.2 | 8900 | | 0 | 7540 | 0.110 | | 1 | 0.10 | 0.130 | | 1 | 0.26 | 1.000 | | 1 | 2.0 | 120.0 | | 1 | 115 |
| 21 | 0.40 | | 1 | 0.6 | (36) | | 1 | (trace) | 0.050 | | 1 | 0.06 | 0.020 | | 1 | 0.05 | 0.400 | | 1 | 0.2 | 62.0 | | 1 | 61 |
| 22 | 0.50 | 0.144 | 97 | 0.5 | 330 | 146.93 | 7 | 540 | 0.046 | 0.005 | 18 | 0.04 | 0.030 | 0.004 | 18 | 0.08 | 0.190 | 0.044 | 7 | 0.2 | 3.9 | 0.379 | 17 | 8 |
| 23 | 1.46 | (0.540) | 2 | 2.9 | 5300 | | 1 | 6460 | 0.080 | | 1 | 0.09 | 0.110 | | 1 | 0.2 | 0.800 | | 1 | 0.8 | 70.0 | | 1 | 102 |
| 24 | 0.80 | | 1 | 0.7 | 660 | | 1 | 740 | 0.200 | | 1 | 0.08 | 0.060 | | 1 | 0.07 | 1.000 | | 1 | 1.1 | 21.1 | 2.322 | 11 | 30 |
| 25 | 0.22 | 0.011 | 75 | 0.5 | (0) | | 10 | (50) | 0.042 | 0.001 | 27 | 0.03 | 0.020 | 0.003 | 5 | 0.04 | 0.150 | 0.008 | 21 | 0.2 | 6.4 | 0.264 | 37 | 9 |
| 26 | 1.48 | 0.874 | 4 | 0.9 | 385 | (15.00) | 2 | (50) | 0.055 | (0.005) | 2 | 0.03 | 0.080 | (0) | 2 | 0.04 | 0.520 | (0.005) | 2 | 0.2 | 18.8 | (0.099) | 2 | 24 |
| 27 | 0.59 | (0.115) | 2 | 0.7 | (0) | | 1 | (0) | 0.090 | | 1 | 0.08 | 0.050 | | 1 | 0.12 | 0.700 | | 1 | 0.2 | 17.0 | | 1 | 18 |
| 28 | 1.47 | 0.050 | 8 | 1.9 | 640 | | 1 | 680 | 0.266 | 0.029 | 7 | 0.34 | 0.132 | 0.009 | 7 | 0.16 | 2.090 | 0.137 | 7 | 2.7 | 40.0 | | 1 | 26 |
| 29 | 0.46 | 0.125 | 34 | 0.4 | 632 | 338.48 | 16 | 630 | 0.066 | 0.004 | 16 | 0.04 | 0.030 | 0.004 | 16 | 0.07 | 0.510 | 0.031 | 16 | 0.4 | 89.3 | 10.933 | 16 | 120 |
| 30 | 0.76 | 0.040 | 84 | 0.7 | (0) | | 0 | (20) | 0.088 | 0.001 | 179 | 0.11 | 0.035 | 0.001 | 179 | 0.04 | 1.480 | 0.028 | 179 | 1.2 | 19.7 | 0.769 | 141 | 17 |
| 31 | 0.80 | | 0 | 0.8 | 1600 | | 0 | 3400 | 0.050 | | 0 | 0.05 | 0.110 | | 0 | 0.08 | 0.600 | | 0 | 0.6 | 9.0 | | 0 | 8 |
| 32 | 0.29 | 0.037 | 17 | 1.0 | (8) | 3.75 | 8 | (30) | 0.005 | 0.001 | 5 | 0.03 | 0.045 | 0.003 | 5 | 0.02 | 0.300 | 0.018 | 5 | 0.3 | 22.8 | 0.240 | 11 | 24 |
| 33 | 0.22 | 0.019 | 33 | 0.5 | 100 | | 1 | (30) | 0.020 | | 1 | 0.01 | 0.030 | | 1 | | 0.300 | | 1 | 0.1 | 8.0 | | 1 | 9 |
| 34 | 0.52 | (0.120) | 2 | 0.4 | 580 | | 1 | 330 | 0.090 | | 1 | 0.07 | 0.040 | | 1 | 0.08 | 0.700 | | 1 | 0.9 | 25.0 | | 1 | 36 |
| 35 | 2.71 | 0.522 | 10 | 3.0 | 6715 | 206.88 | 9 | 9420 | 0.078 | 0.008 | 9 | 0.11 | 0.189 | 0.008 | 9 | 0.2 | 0.720 | 0.032 | 9 | 0.6 | 28.1 | 4.129 | 7 | 59 |
| 36 | 0.46 | | 10 | 0.4 | 196 | | 10 | 260 | 0.064 | | 10 | 0.05 | 0.037 | | 10 | 0.09 | 0.551 | | 10 | 0.8 | 14.8 | | 10 | 17 |
| 37 | 0.58 | | 4 | 0.6 | 4060 | | 4 | 4950 | 0.097 | | 4 | 0.05 | 0.027 | | 4 | 0.12 | 0.800 | | 4 | 0.5 | 12.3 | | 4 | 8 |
| 38 | 0.38 | 0.042 | 84 | 0.8 | (27) | 3.48 | 3 | (60) | 0.020 | | 1 | 0.03 | 0.066 | | 1 | 0.07 | 0.230 | | 1 | 0.3 | 56.7 | 1.882 | 85 | 60 |
| 39 | 0.59 | 0.028 | 40 | 0.7 | 20063 | 1503.31 | 17 | 7700 | 0.066 | 0.005 | 10 | 0.09 | 0.147 | 0.039 | 14 | 0.05 | 0.670 | 0.035 | 14 | 0.6 | 22.7 | 2.577 | 12 | 22 |
| 40 | 0.45 | 0.016 | 137 | 0.6 | 623 | 27.64 | 11 | 1100 | 0.059 | 0.001 | 156 | 0.06 | 0.048 | 0.002 | 156 | 0.04 | 0.630 | 0.027 | 11 | 0.5 | 19.1 | 0.344 | 165 | 23 |
| 41 | 0.30 | | 1 | 0.5 | (0) | | 1 | (trace) | 0.040 | | 1 | 0.05 | 0.030 | | 1 | 0.07 | 0.400 | | 1 | 0.5 | 21.0 | | 1 | 28 |
| 42 | 1.10 | | 1 | 2.4 | 7600 | | 0 | 9540 | 0.070 | | 1 | 0.09 | 0.100 | | 1 | 0.46 | 0.600 | | 1 | 0.8 | 60.0 | | 1 | 136 |
| 43 | 0.17 | 0.009 | 45 | 0.2 | 366 | | 7 | 590 | 0.080 | | 1 | 0.05 | 0.020 | | 1 | 0.05 | 0.200 | | 1 | 0.2 | 9.6 | 0.879 | 8 | 6 |

† 1999 values include dehydroascorbic acid, but 1950 values usually do not.

or not used here. For N > 2, the median Ns in 1999 for our foods are 9 to 12 for fat, vitamin A, thiamin, riboflavin and niacin; 16 to 23 for protein, ash, Ca and ascorbic acid; and 27 to 34 for water, P and Fe.

**Uncertainties in the Denominators of R.** USDA did not report SEs (or Ns) in 1950, so we assumed what we believe are reasonable values for exploratory purposes (see Methods).

**Uncertainties in R.** The known and assumed SEs for the numerators and denominators of R yield 95% CIs for 256 individual foods and nutrients, summarized in Table 4. All have N > 2. For the low estimates of 1950 SEs (same RSE as in 1999) 43% of our R-values are reliably <1 in a statistical sense, 16% are reliably >1 and 42% are indistinguishable from 1. For the high estimates of 1950 SEs (twice the low estimates), fewer R-values are reliably <1 (26%) or >1 (11%), and more are indistinguishable from 1 (64%).

Figs. 3, 4 and 5 show results for 3 of 11 nutrients studied (water and dry matter excluded). We illustrate these 3 nutrients because of their diversity and relative reliability. Protein (Fig. 3) and ash (Fig. 4) may be the most reliable nutrients, because

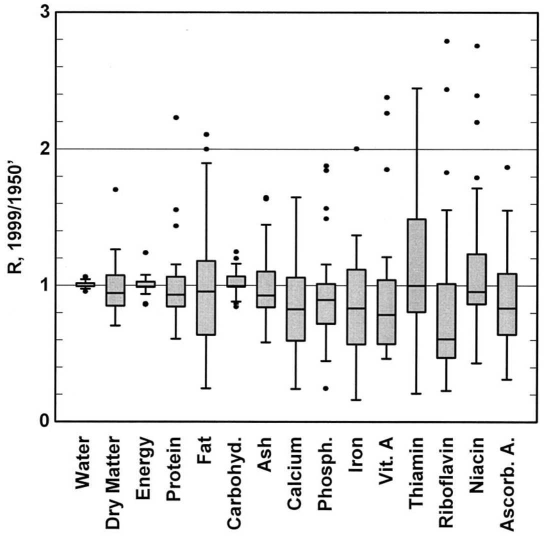

**Fig. 1.** The central range and spread of R-values, moisture-adjusted except for water and dry matter. Each box plot shows the median R (line inside the grey box), the central 50% of R-values (the box, showing the interquartile range, IR), the range of adjacent values that are within 1.5 × IR of the ends of the box, and individual outliers. The number of foods is 42 or 43, except 28 for vitamin A. Ascorbic acid R-values are slight overestimates (see discussion of group changes). Six outliers are not shown: Fat 6.7, vitamin A 3.0 and 3.8, riboflavin 3.4, niacin 3.2 and 3.7.

they are major components and their analytical methods are probably least changed since 1950. Also, their Ns (>2) are commonly large (Table 2). Ash reflects all minerals in foods, dominated by those present in the largest amounts—primarily K for our foods, followed in various orders by much smaller amounts of Cl, P, Ca, Mg and Na. The R-values for ascorbic acid (Fig. 5) are intermediate among the 5 vitamins studied (Fig. 2) and the Ns (>2) tend to be the largest among the 5 vitamins (Table 2). As suggested by Table 4, results for the 8 other nutrients do not differ greatly from these Figs., except the CIs are notably wider for fat and niacin. For vitamin A there are relatively few foods with adequate amounts for consideration.

Although the results in Figs. 3, 4 and 5 are based on hypothetical SEs for 1950, they give perhaps the best available illustration of our current ability to evaluate changes in individual foods. They show how the CIs of R depend sometimes strongly on the 1950 SEs, and they show the potential value of USDA and others now reporting from archived data, if possible, selected SEs and Ns from earlier eras. The Figures also illustrate the sometimes large difference between the median and mean of individual R-values (the predicted median and mean values that would be found from multiple determinations). Although one might expect the mean of R would equal the ratio of means, 1999/1950′, it is the median of R that closely approximates the ratio of means [9]. The means of R are larger than the medians by amounts that depend especially on the 1950 SEs. This non-obvious result stems from the probability density function of R having a long tail toward large R when its denominator (the 1950′ value) has significant probability density near zero. Thus, median R ≈ mean(1999)/mean(1950′) < mean R(low est. of 1950 SE) < mean R(high est. of 1950 SE).

# DISCUSSION

## Group Changes Between 1950 and 1999

We evaluated the moisture-adjusted ratios of USDA nutrient contents, R = 1999/1950′, for 13 nutrients plus water,

**Table 3.** Median and Geometric Mean Ratios R*, with 95% Confidence Intervals and Probabilities That the True Medians and Geometric Means = 1 (two-tailed, bold for $p < 0.05$)

| Nutrient | Foods | Median | 95% CI | | $p$† | G. Mean | 95% CI | | $p$ |
|---|---|---|---|---|---|---|---|---|---|
| Water | 43 | 1.006 | 0.998 | 1.012 | 0.542# | 1.006 | 1.0002 | 1.012 | **0.043** |
| Dry Matter | 43 | 0.957 | 0.893 | 1.023 | 0.542 | 0.974 | 0.926 | 1.024 | 0.287 |
| Energy | 43 | 1.005 | 0.992 | 1.012 | 0.222 | 1.003 | 0.984 | 1.022 | 0.757 |
| Protein | 43 | 0.94 | 0.86 | 0.986 | **0.014** | 0.95 | 0.89 | 1.02 | 0.138 |
| Fat | 43§ | 0.98 | 0.82 | 1.07 | 0.644 | 0.96 | 0.81 | 1.13 | 0.596 |
| Carbohydr. | 43 | 1.01 | 0.99 | 1.03 | 0.126# | 1.02 | 0.996 | 1.04 | 0.100 |
| Ash | 43 | 0.94 | 0.87 | 1.002 | 0.222 | 0.95 | 0.88 | 1.02 | 0.140 |
| Calcium | 43 | 0.84 | 0.66 | 0.97 | **0.014** | 0.77 | 0.68 | 0.89 | **0.0005** |
| Phosphorus | 43 | 0.91 | 0.78 | 0.95 | **0.002** | 0.86 | 0.77 | 0.96 | **0.010** |
| Iron | 43 | 0.85 | 0.67 | 0.94 | **0.005** | 0.73 | 0.62 | 0.86 | **0.0004** |
| Vit. A | 28 | 0.82 | 0.60 | 1.01 | 0.185 | 0.93 | 0.75 | 1.16 | 0.498 |
| Thiamin | 43 | 1.01 | 0.90 | 1.20 | 1.000 | 1.05 | 0.91 | 1.20 | 0.524 |
| Riboflavin | 42 | 0.62 | 0.54 | 0.84 | **0.008** | 0.72 | 0.60 | 0.87 | **0.001** |
| Niacin | 43 | 0.99 | 0.90 | 1.18 | 1.000 | 1.10 | 0.96 | 1.26 | 0.184 |
| Ascorbic a.** | 42 | 0.85 | 0.71 | 0.98 | **0.003** | 0.82 | 0.72 | 0.92 | **0.001** |

* R = ratio of mean nutrient contents per weight, 1999/1950, moisture-adjusted except for water and dry matter.

† Quantile (sign) test.

# $p < 0.05$ by Wilcoxon signed-rank test approximation.

§ 42 for the mean.

** R = values are slight over estimates (see discussion of group changes).

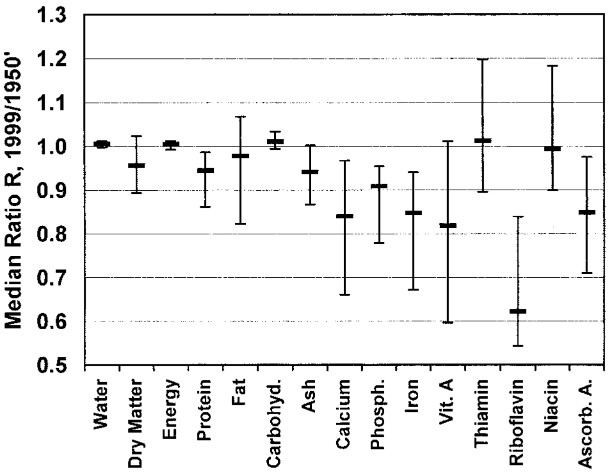

**Fig. 2.** Median ratios R with 95% confidence intervals for 42 to 43 foods (28 for vitamin A). R-values for ascorbic acid are slight overestimates (see discussion of group changes).

usually in 42 to 43 foods. Considered as a group, these foods show apparent, statistically reliable median decreases between 1950 and 1999 for all 3 of the minerals evaluated: Ca (−16%), P (−9%) and Fe (−15%). However, the median ash content (a robust measure of major minerals, mainly K) decreased by only 6%, not reliably different than zero ($p = 0.22$). Two of 5 vitamins show apparently reliable median decreases: riboflavin (−38%) and ascorbic acid (−15% before adjustment; see below). Median protein content apparently dropped slightly (−6%). There were no detectable median changes for vitamin A (28 foods), thiamin, niacin, fat, or carbohydrate (Table 3). Median water content may have increased slightly, about 0.6%.

These group changes are nearly independent of random errors in the source data, but they are potentially confounded by systematic errors and uncertainties of interpretation, as noted by Mayer [1] and Johnson [4]. Johnson, for example, listed uncertainties concerning known or possible changes in:

1. Sampling (geographic and seasonal breadth of sampling, how much outer leaf or stem is considered edible). More garden crops were home-grown or produced locally in the 1940s than now, and in recent decades international sources have become important for some foods.
2. Cultivars used (usually selected for yield, disease resistance, adaptation to local environments, etc., not for nutrient content).
3. Analytical methods (improved analytical specificity and reduced contamination from equipment, reagents and clinging soil tend to yield lower results, especially for minerals; e.g., early values for Fe tend to be high).
4. Environment (changes in climate, distribution methods, location of production and other potential factors).

For ascorbic acid, our median $R = 0.85$ is a slight overestimate, because of a change in analysis of this nutrient between

**Table 4.** Numbers of Foods with Data, with Usable 1999 SE, and with 95% Confidence Intervals (CI) of R That are Less Than 1, Greater Than 1 and Straddle 1, Based on Low and High Estimates of the SE for the 1950 Means (footnotes Mark a Few Foods with 95% CI That Are Too Large to Be Determined Accurately, R = Ratio of Mean Nutrient Contents per Weight, 1999/1950, Moisture-Adjusted except for Water and Dry Matter)

| Nutrient | With Data | With ’99 SE | Low est. ’50 SE | | | High est. ’50 SE | | |
|---|---|---|---|---|---|---|---|---|
| | | | R < 1 | R > 1 | R ~ 1 | R < 1 | R > 1 | R ~ 1 |
| Protein | 43 | 27 | 9 | 4 | 14 | 6 | 4 | 17 |
| Fat | 43 | 24 | 2 | 2 | 20* | 1 | 2 | 21† |
| Ash | 43 | 27 | 13 | 3 | 11 | 10 | 1 | 16 |
| Calcium | 43 | 26 | 11 | 4 | 11# | 8 | 2 | 16§ |
| Phosphorus | 43 | 28 | 19 | 2 | 7 | 12 | 2 | 14 |
| Iron | 43 | 28 | 15 | 1 | 12 | 11 | 0 | 17** |
| Vitamin A | 28 | 13 | 4 | 3 | 6 | 4 | 3 | 6†† |
| Thiamin | 43 | 20 | 7 | 5 | 8 | 3 | 4 | 13## |
| Riboflavin | 42 | 20 | 11 | 5 | 4 | 5 | 3 | 12## |
| Niacin | 43 | 19 | 3 | 6 | 10 | 1 | 3 | 15 |
| Ascorbic acid§§ | 42 | 24 | 15 | 5 | 4 | 5 | 3 | 16 |
| Totals | 456 | 256 | 109 | 40 | 107 | 66 | 27 | 163 |
| Percent of 456 | 100 | 56 | 24 | 9 | 23 | 14 | 6 | 36 |
| Percent of 256 | | 100 | 43 | 16 | 42 | 26 | 11 | 64 |

* 32 (radish).
† 7 (cabbage), 32 (radish).
# 18 (eggplant).
§ 15 (corn), 18 (eggplant).
** 8 (Chinese cabbage), 26 (green onion).
†† 22 (lettuce), 29 (green peppers).
## 14 (collards).
§§ Uncorrected for dehydroascorbic acid (see discussion of group changes).

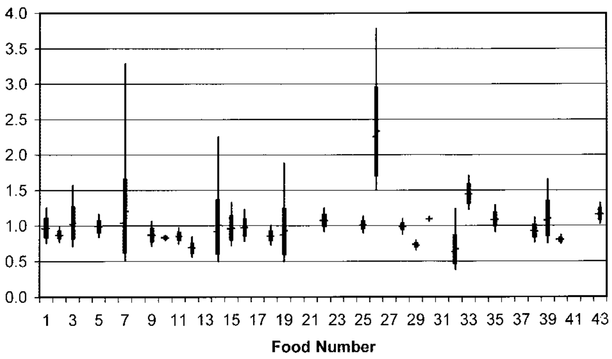

**Fig. 3.** Ratios of mean protein contents R (1999/1950′) for individual foods. Mean R-values and their 95% confidence intervals are shown for two estimates of the uncertainty (SE) of the 1950 means. For the low estimates of the 1950 SEs, the mean R-values are the left tic marks, and the 95% CIs are the wide vertical lines. For the high estimates, the mean R-values are the right tic marks, and the 95% CIs are the narrow vertical lines. Median R-values (not shown) are less than or usually about equal to the left tic marks, and do not depend appreciably on the SEs. Missing foods have inadequate data for this analysis.

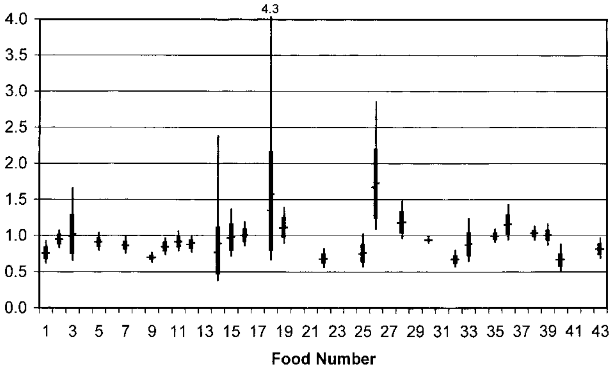

**Fig. 4.** Ratios of mean ash contents R (1999/1950′). See Fig. 3 caption. For food no. 18, the narrow line extends to 4.3.

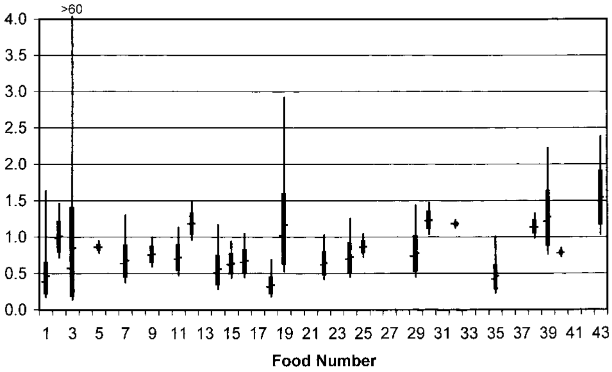

**Fig. 5.** Ratios of mean ascorbic acid contents, R (1999/1950′). See Fig. 3 caption. For food no. 3, the narrow line extends beyond 60. Most values are slight overestimates (see discussion of group changes).

1950 and 1999. USDA's 1999 values for ascorbic acid include the usually minor, oxidized form, dehydroascorbic acid (DHAA), whereas the 1950 values "for the most part" do not [6]. R-values based on 1950 data without DHAA can be corrected by dividing them by 1 + DHAA/AA, where DHAA/AA is the ratio of oxidized to reduced ascorbic acid. Reported ratios DHAA/AA for 13 of our 43 foods yield a median ratio of 0.10 [11]. A full correction thus yields an estimated median R = 0.85/1.10 = 0.77. A "for-the-most-part" correction might yield R ~ 0.80, for a median decrease of ~20% instead of 15%.

Analytical methods may differ in their degree of extraction of nutrients from foods and in their ability to distinguish the intended nutrient from other food substances that may interfere with its measurement. Another kind of systematic error occurs when food samples are contaminated with the nutrient analyzed. Soils contain ~$10^4$-fold more Fe than plants, so tiny amounts of unremoved soil can raise values for Fe. Anderson and colleagues found only about 15 years ago [12,13] that earlier measurements of chromium in foods were often several-fold too high, because of contamination from stainless steel laboratory equipment (personal communication, R.A. Anderson).

According to USDA staff, most data published in 1950 came from the literature and did not represent nationally representative composites (N.J. Miller-Ihli, personal communication). The same must be true for our many 1999 data with small N, but may not be true for some or most foods with large N in 1999. This potential difference between some 1950 and 1999 data may have relatively little effect on group comparisons, but it adds uncertainty to the interpretation of individual R-values for single foods and nutrients.

Mayer [1] studied only minerals and water with mostly British data. She included 3 minerals that we studied, in 20 vegetables, 16 of which we included. Without adjusting for moisture differences, she reported geometric mean decreases for Ca (−19%), Fe (−22%) and P (−6%), though only Ca differed reliably from zero. Her data showed a geometric mean 3% decrease in dry matter between the 1930s and 1980s, similar to our finding (Table 3). This decrease partly explains her decreases in minerals. When we adjusted her vegetable data for moisture differences, the apparent changes for all 7 minerals moved closer to 0%: −16% instead of −19% for Ca (still reliably non-zero), −20% instead of −22% for Fe and −3% instead of −6% for P. Our corresponding values are −23%, −27%, and −14%, all reliably non-zero. Thus, Mayer's results are similar to ours for these 3 minerals. Mayer also found apparent non-zero decreases for Mg, Cu and Na, but USDA did not report those minerals in 1950.

In 20 fruits, Mayer reported geometric mean decreases for Ca, Fe and P of 0%, −32%, and −1%, but correction for the large decrease in dry matter in her data (9%) makes two of these trends actually positive by about 8%.

Both Jack [2] and Mayer [1] discussed R-values (or equivalent percent changes = [R − 1] × 100%) *for individual foods*, but without considering their generally large uncertainty. Jack reported percent changes to 3 significant figures, most or all of which figures are unwarranted. Of his 48 comparisons, 20 use USDA "means" derived from only a single sample.

The apparent overall decreases for some nutrients are interesting and potentially of concern, but like Mayer and Johnson, we urge caution about their interpretation. Mineral decreases are popularly predicted for, or blamed on, mineral deficiencies in soil and fertilizer [5], but without sufficient consideration of contrary evidence and other possibilities. Both N and P (the "N" and "P" in "NPK fertilizers") are added routinely to modern soils. Yet we find apparent group decreases between 1950 and 1999 in the corresponding nutrients, protein and P. We also find a possible small decrease in ash, which represents mainly K, the "K" in NPK fertilizer. Further, our finding that substantial numbers of individual R-values probably exceed 1 seems difficult to reconcile with a broad mineral-depletion hypothesis (next section). Factors other than soil mineral concentrations seem to have primary control of food mineral contents for the foods and minerals studied here. (The minerals I and Se are well known exceptions to this rule.) In the case of Fe, depletion is never an issue; instead, the issue is the ability of the plant to acquire the Fe that it needs. The fraction of soluble Fe in soils may be only about $10^{-13}$ of total soil Fe [14].

Many environmental factors affect nutrients in foods, and these may contribute to our findings. For example, there are many studies of the effects of N fertilizers on vitamins in plant foods. A review of this literature [15] found the best evidence pertained to carotene (increases), thiamin (increases) and ascorbic acid (increases and decreases, but mostly decreases). Thus increasing use of N fertilizers between 1950 and 1999 might help explain our group findings for ascorbic acid, but not for vitamin A or thiamin. Soil type and climate may also affect nutrient contents and thereby affect nutrient composition data through changes in the location of production of foods. For ascorbic acid, changes in a few foods might be caused by changes in storage time or maturity at harvest. There are also potential unknown or unexpected environmental factors. For example, increasing atmospheric $CO_2$ generally decreases the N (protein) content of plants [16]. Doubled $CO_2$ concentrations and sometimes other stresses mostly decreased nutrient elements in wheat [17–19] and rice [20] (N −14%, P −5%, Fe −17%, Zn −28%, Ca +32%). In potatoes grown at 7 sites across Europe, a 1.8-fold increase in $CO_2$ concentration reliably decreased 3 of 8 nutrient elements studied: N −6%, K −4% and Mg −3% (dry-weight basis) [21].

## Changes in Individual Foods between 1950 and 1999

With the necessary use of estimated SEs for 1950, we were able to explore the statistical reliability of changes in slightly over half of the individual foods and nutrients studied. The resulting R-values are often indistinguishable from 1. Based on the low estimates of the 1950 SEs, R is indistinguishable from 1 for 42% of our 256 comparisons. Based on the high estimates, indistinguishability rises to 64% (Table 4). These findings are obviously qualitative, but the trend is certain, as are the implications about the value of retrieving, if possible, SEs and Ns for early nutrient content data for basic food crops.

Among our R-values that differ reliably from 1 in a statistical sense, most show $R < 1$, but respectively 27% and 29% show $R > 1$ for the low and high estimates of the 1950 SEs. Because the proportion with $R > 1$ is insensitive to a 2-fold change in assumed SEs, this new observation seems robust and likely realistic.

Substantial proportions of ratios $R > 1$ cast doubt on the generality of several potential explanations for Mayer's [1] and our findings of apparent group decreases for some nutrients. For example, R-values $> 1$ seem difficult to reconcile with broad or major roles for explanations such as changes in agricultural practices [3], mineral depletion in soils [5], "decline of the natural environment" [2], post-harvest nutrient losses or rising atmospheric $CO_2$ [16].

## Genetic Variations and Trade-Offs

We observe apparent overall declines in some nutrients, combined with apparent increases in a significant minority of individual foods and nutrients. A possible explanation for this observation is changes in cultivars during the period represented by data published in 1950 and 1999. Cultivars commonly are selected for yield, growth rate, pest resistance and other attributes, but seldom have they been selected for nutrient content. It is well accepted in agricultural research that selection for one resource-using function may take resources away from other resource-using functions. For example, there are often trade-offs between growth rate and pest resistance [22], between yield and resistance to herbivory [23] and between the number of seeds and their size [24]. As we will illustrate, cultivars selected for yield, rapid growth or other non-nutrient characteristic may suffer resource limitations in their abilities to extract soil minerals or transport them within the plant, or in their abilities to synthesize proteins, vitamins and other nutrients. Such trade-offs are usually unpredictable in size, however, and because of ever-present genetic variability, some fraction of cultivars will show enhanced contents of individual nutrients.

**Genetic Variations in Nutrient Contents.** Large genetic variations in nutrient contents were found in a study of 5 antioxidant nutrients in 50 broccoli varieties grown together under controlled conditions [25]. The authors concluded from an analysis of variance that most of the variation is genetically determined. After conversion of the authors' data to a dry-weight basis, we find total variations of 3.5-fold in $\alpha$-carotene, 4-fold in $\beta$-carotene, 9-fold for $\alpha$-tocopherol, 22-fold for $\gamma$-tocopherol (10-fold without 2 outliers) and 2.8-fold in ascorbate.

In tomatoes [26], ascorbate levels varied over 3-fold among 98 cultivars. P concentration (of interest to plant breeders for its effect on pH and tomato flavor) varied over 2-fold in 25 cultivars. A study of its inheritance “indicated a strong genotype-environmental interaction that could not be related to variation in available soil P.”

Ascorbate levels in potatoes varied 2.6-fold among 75 North American clones, based on averages from field studies in 3 states during 2 growing seasons (fresh-weight basis) [27]. The variation was 2.0-fold among the 20 clones that have been named and released.

Genetic variation of Ca concentration has been shown in green beans [28], tomatoes [29,30] and broccoli [31]. The latter study in broccoli included both Ca and Mg measured during 2 seasons in 27 commercial hybrids and 19 inbred lines available for breeding programs. Mean concentrations of Ca and Mg (dry weight basis) varied about 2-fold and 1.5-fold respectively among both the hybrids and the inbred lines. Most of the variation was environmental for Ca (differing by season and perhaps soil preparation), but the genetic component was relatively strong for Mg. Further examples come from international researchers who measure the genetic variability of Fe and Zn in foods used as staples in developing countries. They hope to breed new varieties high in these nutrients [32]. Among 132 wheat genotypes, both Fe and Zn vary by about 2-fold. In 1000 common beans (*Phaseolus vulgaris* L.), both nutrients range 2.6-fold. Among 939 genotypes of brown rice, Fe and Zn vary by 3-fold and 4-fold, respectively.

A recent study explored both genetic and environmental influences in 14 hard red winter wheats on concentrations of Fe, Zn, Cu and Se [33]. The wheats were grown together during a single season in 2 areas of Kansas. All 4 minerals showed significant environmental effects (higher concentrations of Fe, Zn and Cu at one area, but much lower Se). Analysis of variance showed there were also generally highly reliable genetic differences among the wheats, except for Se at one area.

**Vitamin A in Carrots and Sweet Potatoes.** Among our 149 R-values that most likely differ from 1 (Table 4), only 4 exceed 2.23. Remarkably, 2 of these 4 largest values are for one nutrient (vitamin A) in the only two of our foods that are visibly orange-colored. Carrot vitamin A has R = 2.27 (CI 2.21–2.32, widest estimate) and sweet potato has R = 3.0 (CI 2.2–4.4). This seeming coincidence is easily explained, at least for carrots. Selection for darker orange color in carrots has been ongoing between 1950 and 1999 [34] (and personal communication, P.W. Simon). Carrot color derives principally from $\beta$-carotene, the main precursor of vitamin A. The two largest R-values for vitamin A differ sharply from the 11 others with 1999 SEs, which range from 0.54 to 1.21 (mean = 0.74 ± SE 0.07). These other foods are all green except for sweet corn, tomatoes (colored mainly by lycopene) and cantaloupe (color not visible at purchase).

Our other two largest R-values are both for riboflavin—3.4 in sweet potatoes and 2.8 in radish—for which there is no similar explanation based on color.

**Trade-Offs Involving Nutrients.** We hypothesize that Mayer’s and our findings of overall nutrient declines may result importantly from decades of selecting food crops for high yield, with resulting inadvertent trade-offs of reduced nutrient concentrations. For example, in tomatoes there are sometimes large trade-offs between yield (harvest weight) and dry weight, between yield and ascorbate concentration, between fruit size and ascorbate concentration, and between lycopene (the red color of tomatoes) and $\beta$-carotene (vitamin A precursor) [26]. “In some cases, fruit composition has inadvertently been changed as a result of efforts to breed for other characteristics.”

In the previously mentioned study of broccoli hybrids and inbred strains [31], mean concentrations of Ca and Mg (mg/g dry weight) varied inversely with yield (head weight). Correlation coefficients for the 27 commercial hybrids ranged from $-0.46$ to $-0.69$ (mean $-0.62$). All heads had about the same dimensions when harvested. Thus, the heavier heads were denser. The authors postulate a “dilution effect [that] could occur as those hybrids with denser heads accumulate relatively more dry matter (primarily phloem delivered) without increasing Ca and Mg (primarily xylem-delivered) in the same relative proportion” [31]. Consumers get more nearly the same total amount of Ca and Mg per head, but diluted in a larger amount of water, dry matter, fiber and energy. Recently the most successful commercial broccoli hybrids in the United States tend to have high yield and high head density (especially ‘Marathon,’ released in 1985 and dominant since the early 1990s). “In our trials, ‘Marathon’ had consistently low concentrations of Ca and Mg” averaging respectively about 2.6 mg/g and 2.2 mg/g dry weight. In the same units, USDA’s reported contents for (Ca, Mg) are (13, unreported) in 1950, (9.4, 2.2) in 1963, (5.2, 2.7) in 1982 through 2002 and (4.4, 2.0) in 2003 (release 16). Broccoli is a potentially important non-dairy source of both minerals.

A similar trade-off between yield and mineral concentrations is found in the above-mentioned study of 14 hard red winter wheats [33]. The wheats were originally released between 1873 and 1995 (mostly 1943 and later). Regression analysis found 4 instances (out of 8 possible) in which there was an association between nutrient concentration and release date, with a tendency for lower concentrations in the newer varieties (Fe, Zn and Se). The reported rate of decrease in micronutrient concentration ranged from 0.2% to 0.3% per year.

The authors explored their other data for the biological basis for this observation. In nearly every case, they found that mineral concentrations varied inversely with yield and biomass. Correlation coefficients between mineral concentration and yield were uniformly negative for 4 minerals at 2 locations, ranging from $-0.11$ to $-0.85$ (mean $-0.45$). They were also all negative for 2 other reported minerals, P and S (mean $-0.65$). These authors, too, suggest a diluting effect of yield: “The negative correlation between yield and both Fe and Zn is not surprising; higher yields likely result in partitioning of plant Fe and Zn to a larger ‘sink.’” In other words, yield increases were not accompanied by corresponding increases in minerals.

The authors conclude that their results support the feasibility of major efforts to breed wheats with increased Fe and Zn (see below) but note that "the negative associations between the levels of some of the micronutrients and yield may pose an obstacle."

We asked many leading vegetable breeders about other studies of genetically based trade-offs between yield and nutrient concentration, without success. However, for many decades agronomists have cited "the dilution effect" to describe reduced nutrient concentrations caused by intensive agricultural practices [35,36]. For example, when fertilization is adjusted to maximize yield, the harvest weight and dry matter may increase more rapidly than the accumulation of nutrients. Thus, environmentally caused trade-offs between yield and nutrient concentrations were known long before the recently reported genetic trade-offs. The environmental dilution effect is probably an additional factor contributing to Mayer's [1] and our findings.

In summary, we hypothesize that a combination of two emerging genetic phenomena may help explain our findings of apparent overall declines in some nutrients and apparent increases in significant numbers of individual foods and nutrients:

1. Downward pressure on the acquisition or synthesis of many nutrients, caused by decades of selecting cultivars for other resource-limited traits such as yield, growth rate and pest resistance. Selection for yield especially, may enhance the carbohydrate-water fraction in vegetables, without fully proportionate increases in other nutrients. Selection for yield probably has operated most intensely in the last half-century, but certainly not exclusively.
2. Unpredictable genetic variability among cultivars large enough to explain our observation of sometimes increased levels of nutrients.

To the extent that our genetics-based hypothesis may contribute toward the apparent general declines found by us and Mayer [1], those declines are unlikely to be reversed by environmental approaches such as organic growing methods, as suggested by some [2,3,5]. Instead, we would need to consider older, lower-yielding cultivars, or attempt to develop new varieties selected for both high yield and high nutrient density.

The International Food Policy Research Institute has organized a major effort to increase a few nutrients in major staple foods used in developing countries—rice, wheat, maize, phaseolus beans and cassava [14,37,38]. The Institute hopes to substantially increase levels of Fe, Zn, vitamin A and I (in cassava), while maintaining current high yields. This ambitious goal might prove difficult to achieve, especially if plant breeders also consider potential trade-offs involving many other relevant nutrients (amino acids, other minerals, other vitamins and phytochemicals).

## CONCLUSION

This study adds to our knowledge about possible changes in the nutrient content of one class of foods, garden crops. Its strengths and innovations include our broad sample of crops, adjustment for moisture differences, primary use of distribution-free, non-parametric statistics, evaluation of CIs, attention to the statistical reliability of changes in individual foods and nutrients, and our new and testable hypothesis that may help explain Mayer's and our findings. Our study also has many limitations, both chosen and inadvertent. We focused on one class of foods and an interesting biological phenomenon, without selecting foods based on their national consumption or contribution to nutrient intakes. Thus, our study is not useful for estimating possible effects on dietary intakes. Other classes of foods are important for study. We also did not select foods based on the adequacy of their nutrient content data. Thus, for many foods we are limited by missing or poorly adequate data. Future studies could focus on foods with the most reliable nutrient content data. Our analysis of changes in individual foods and nutrients was further limited by lack of Ns and SEs in USDA's 1950 data. Finally, we compared nutrient contents published on only two dates, 1950 and 1999. Many other publication dates are available, and additional statistical methods can be applied to time series for those foods (probably few) with independent data for each date. Further, time-series analyses are fully subject to many of the same uncertainties as is our approach (changes in analytical methods, location of major production, definition of edible portion, etc.).

Our statistical methods address the effects of *random* errors and uncertainties in laboratory data and sampling. But they cannot detect *systematic* errors caused by changes in laboratory techniques or sampling. If recent lab methods are more specific or less subject to contamination than methods used decades earlier, then the recent lab measurements will be systematically lower than the old measurements, without real changes in the food. Careful attention to these issues will likely be useful in future studies like ours. However, no amount of effort with historical data can reliably eliminate all potential sources of confounding.

Fortunately, the central part of our hypothesis can be tested directly, eliminating most uncertainties. As in the cited studies of broccoli [31] and wheat [33], historical and modern cultivars can be grown together under controlled conditions, preferably in multiple environments. This approach would remove uncertainties about half-century changes in soil composition, fertilization, climate, atmospheric $CO_2$, location of production, portions considered edible, etc. Most importantly, the nutrient contents of both old and new cultivars can be measured simultaneously by the same, modern methods, eliminating all uncertainties about changes in analytical methods. Further, the nutrients that can be considered will not be limited to those that were known and analyzed many decades ago. Finally, yields and other agronomic traits can be compared simultaneously in the same environments, adding greatly to the currently very limited information about trade-offs between yield and the broad range of nutrients and phytochemicals of interest.

### Perspective

Further study is needed of possible historical changes in nutrient contents of widely consumed foods. Substantial declines in the major sources of nutrients would be of obvious interest. We lack answers to important questions. Are there real nutrient declines in staple sources of nutrients? Which nutrients are most affected? Have declines been offset by increases in other foods or by new sources of nutrients, including fortification in some countries? Fortunately, these questions can be addressed in multiple ways.

Fortunately, too, if real declines have occurred, there is a simple, known remedy easily available, at least to those in the developed world. That remedy is for consumers to eat somewhat less of the three major staples that we *know* have suffered much larger and broader nutrient losses than those suggested by Mayer's and our findings. Refined sugars, separated fats and oils and white flour and rice have all suffered losses much greater and broader than the potential losses suggested here for garden crops [7]. American diets on average derive well over half of their calories and dry weight from these three staples [39]. Therefore, most diets in developed countries are nutritionally compromised much more by heavy consumption of these staples than they would be by any real losses like those potentially suggested here.

Thus, for those concerned about nutrient losses, the most important measure is to partly replace these known-depleted staples with more nutrient-dense whole foods, especially vegetables, fruits, whole grains, nuts and beans. This remedy is similar to dietary changes already widely recommended in developed countries [40–42]. Plant cells require most human nutrients for their own functioning. They cannot grow, much less be viable commercial food crops, without synthesizing or acquiring their own needed levels of a broad range of nutrients. Thus, no whole plant food can be as broadly depleted of nutrients as are refined sugars and separated fats and oils.

Currently available vegetables and fruits are still our most broadly nutrient-dense foods, and hundreds of studies document their superior health-promoting qualities [43–52]. If modern vegetables, whole grains and other nutrient-dense foods do provide sometimes less nutrition than they have in decades past, and we can learn to improve them in practical ways, so much the better they will be.

## ACKNOWLEDGMENTS

We thank Anne-Marie Mayer, Virginia Worthington and Alex Jack for helpful comments and references. Elizabeth H. Jeffery, Mark W. Farnham, Ross M. Welch, Robin D. Graham and others kindly helped us find references regarding nutrient variability and trade-offs; Tom Shively and Chuck Paltiel aided our search for the statistical properties of ratio populations. We also thank members of the USDA Food Composition Laboratory for valuable critical reviews and information (James M. Harnly, Nancy J. Miller-Ihli and Gary R. Beecher). None of these persons necessarily share our views.

## REFERENCES

1. Mayer AM: Historical changes in the mineral content of fruits and vegetables. Br Food J 99:207–211, 1997.
2. Jack A: Nutrition under siege. One Peaceful World (Kushi Institute newsletter), Becket, MA, Spring 1998, pp 1, 7–8.
3. Long C: Is chemical farming making our food less nutritious? Organic Gardening, Nov./Dec. 1999, p 12.
4. Johnson PE: Letter to Cheryl Long of Organic Gardening, Dec. 14, 1999.
5. Anon: As food quality drops, the USDA just shrugs. Organic gardening, May/June 2000, p 14.
6. United States Department of Agriculture: "Composition of Foods." USDA Agriculture Handbook 8. Washington, DC: USDA, 1950.
7. United States Department of Agriculture, Agricultural Research Service: USDA Nutrient Database for Standard Reference, Release 13, 1999. Nutrient Data Laboratory Home Page: http://www.nal.usda.gov/fnic/foodcomp
8. Hinkley DV: On the ratio of two correlated normal random variables. Biometrika 56:635–639, 1969.
9. Brown KS: Ratio populations, www.mathpages.com/home/kmath042/kmath042.htm Accessed Jan. 3, 2003.
10. Bear FE, Toth SJ, Prince AL: Variation in mineral composition of vegetables. Proc Soil Sci Soc Amer 13:380–384, 1948.
11. Lee SK, Kader AA: Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharv Biol Technol 20:207–220, 2000.
12. Anderson RA, Bryden NA, Polansky MM: Dietary chromium intake. Biol Trace Elem Res 32:117–121, 1992.
13. Kahn A, Bryden NA, Polansky MM, Anderson RA: Insulin potentiating factor and chromium content of selected foods and spices. Biol Trace Elem Res 24:183–188, 1990.
14. Bouis HE, Graham RD, Welch RM: The CGIAR micronutrients project: Justification, history, objectives and summary of findings, paper presented to "Improving Human Nutrition Through Agriculture: The Role of International Agricultural Research," a conference in Los Banos, Philippines, October 5–7, 1999, www.ifpri.org/themes/grp06/papers/bouis.pdf Accessed Aug. 14, 2003.
15. Mozafar A: Nitrogen fertilizers and the amount of vitamins in plants: a review. J Plant Nutr 16:2479–2506, 1993.
16. Loladze I: Rising atmospheric $CO_2$ and human nutrition: toward globally imbalanced plant stoichiometry? Trends Ecol Evol 17: 457–461, 2002.
17. De la Puente LS, Pérez PP, Martínez-Carrasco R, Morcuende RM, Martín del Molino IM: Action of elevated $CO_2$ and high temperatures on the mineral chemical composition of two varieties of wheat. Agrochimica 44:221–230, 2000.
18. Fangmeier A, De Temmerman L, Mortensen L, Kemp K, Burke J, Mitchell R, van Oijen M, Weigle H-J: Effects on nutrients and on grain quality in spring wheat crops grown under elevated $CO_2$ concentrations and stress conditions in the European, multiple-site experiment 'ESPACE-wheat'. Eur J Agron 10:215–229, 1999.
19. Manderscheid R, Bender J, Jaeger H-J, Weigle HJ: Effects of

season long $CO_2$ enrichment on cereals: II. Nutrient concentrations and grain quality. Agric Ecosyst Environ 54:175–185, 1995.

20. Seneweera SP, Conroy JP: Growth, grain yield and quality of rice (*Oryza sativa* L.) in response to elevated $CO_2$ and phosphorus nutrition. Soil Sci Plant Nutr 43:1131–1136, 1997.
21. Fangmeier A, De Temmerman L, Black C, Persson K, Vorne V: Effects of elevated $CO_2$ and/or ozone on nutrient concentrations and nutrient uptake of potatoes. Europ J Agron 17:353–368, 2002.
22. Rosenthal JP, Dirzo R: Effects of life history, domestication and agronomic selection on plant defense against insects: Evidence from maizes and wild relatives. Evolutionary Ecol 11:337–355, 1997.
23. Welter SC, Steggall JW: Contrasting the tolerance of wild and domesticated tomatoes to herbivory: Agroecological implications. Ecological Appl 3:271–278, 1993.
24. Eriksson O, Jakobsson A: Recruitment trade-offs and the evolution of dispersal mechanisms in plants. Evolutionary Ecol 13:411–423, 1999.
25. Kurilich AC, Tsau GJ, Brown A, Howard L, Klein BP, Jeffery EH, Kushad M, Wallig MA, Juvik JA: Carotene, tocopherol and ascorbate contents in subspecies of *brassica oleracea*. J Agric Food Chem 47:1576–1581, 1999.
26. Stevens MA: Inheritance of tomato fruit quality components. Plant Breeding Rev 4:273–311, 1986.
27. Love SL, Salaiz T, Shafii B, Price WJ, Mosley AR, Thornton RE: Stability of expression and concentration of ascorbic acid in North American potato germplasm. HortScience 39:156–160, 2004.
28. Quintana JM, Harrison HC, Nienhuis J, Palta JP, Grusak MA: Variation in calcium concentration among sixty $S_1$ families and four cultivars of snap bean (*Phaseolus vulgaris* L.). J Amer Hort Sci 121:789–793, 1996.
29. Giordano LB, Gabelman WH, Gerloff GC: Inheritance of differences in calcium utilization by tomatoes under low-calcium stress. J Amer Hort Sci 107:664–669, 1982.
30. Li Y, Gabelman WH: Inheritance of calcium use efficiency in tomatoes grown under low calcium stress. J Amer Hort Sci 115: 835–838, 1990.
31. Farnham MW, Grusak MA, Wang M: Calcium and magnesium concentration of inbred and hybrid broccoli heads. J Amer Hort Sci 125:344–349, 2000.
32. Welch RM, Graham RD: Breeding crops for enhanced micronutrient content. Plant Soil 245:205–214, 2002.
33. Garvin DF, Welch RM, Finley JW, Fritz AK, Donmez E, Shroyer JP, Paulsen GM: Seed micronutrient contents of a historical collection of hard red winter wheats. In: Annual meeting abstracts [CD-ROM], Am Soc Agron/Crop Sci Soc Amer/Soil Sci Soc Amer, Madison, WI, 2002, submitted for publication.
34. Rubatzky VE, Quiros CF, Simon PW: "Carrots and Related Vegetable *umbelliferae*." New York: CABI Publishing, p 77, 1999.
35. Jarrell WM, Beverly RB: The dilution effect in plant nutrition studies. In Brady NC (ed): "Advances in Agronomy," vol. 34. New York: Academic Press, pp 197–224, 1981.
36. Marschner H: "Mineral nutrition of higher plants," 2nd ed. London: Academic Press, 1995.
37. Bouis H: Enrichment of food staples through plant breeding: A new strategy for fighting micronutrient malnutrition. Nutr Rev 54:131–137, 1996.
38. Bouis HE: Plant breeding: a new tool for fighting micronutrient malnutrition. J Nutr 132:491S–494S, 2002.
39. Briggs GM: Foods and nutrition. In "Britannica Yearbook of Science and the Future (1972)." Chicago: Encyclopaedia Britannica, Inc., pp 249–253, 1971.
40. "Nutrition and Your Health: Dietary Guidelines for Americans," 5th ed, US Departments of Health and Human Services and Agriculture, 2000 http://www.health.gov/dietaryguidelines/#current Accessed Sept. 18, 2003.
41. "Canada's Food Guide to Healthy Eating," Ottawa, Ontario: Health Canada, 1992, http://www.hc-sc.gc.ca/hpfb-dgpsa/onpp-bppn/food_guide_rainbow_e.html Accessed Oct. 6, 2003.
42. "Guidelines for a healthy diet." Health Development Agency (United Kingdom), http://www.wiredforhealth.gov.uk/doc.php-?docid=7267 Accessed Oct. 6, 2003.
43. Terry P, Terry JB, Wolk A: Fruit and vegetable consumption in the prevention of cancer: an update. J Intern Med 250:280–290, 2001.
44. Eichholzer M, Luthy J, Gutzwiller F, Stahelin HB: The role of folate, antioxidant vitamins and other constituents in fruit and vegetables in the prevention of cardiovascular disease: the epidemiological evidence. Int J Vit Nutr Res 71:5–17, 2001.
45. van't Veer P, Jansen MC, Klerk M, Kok FJ: Fruits and vegetables in the prevention of cancer and cardiovascular disease. Pub Health Nutr 3:103–107, 2000.
46. Mathers JC: Pulses and carcinogenesis: potential for the prevention of colon, breast and other cancers. Brit J Nutr 88 Suppl 3:S273–S279, 2002.
47. Epstein LH, Gordy CC, Raynor HA, Beddome M, Kilanowski CK, Paluch R: Increasing fruit and vegetable intake and decreasing fat and sugar intake in families at risk for childhood obesity. Obes Res 9:171–178, 2001.
48. Tucker K: Dietary patterns and blood pressure in African Americans. Nutr Rev 57:356–358, 1999.
49. Ness AR, Powles JW: The role of diet, fruit and vegetables and antioxidants in the aetiology of stroke. J Cardiovas Risk 6:229–234, 1999.
50. Weisburger JH: Lycopene and tomato products in health promotion. Exp Biol Med 227:924–927, 2002.
51. Griffiths G, Trueman L, Crowther T, Thomas B, Smith B: Onions—a global benefit to health. Phytother Res 16:603–615, 2002.
52. Johnson EJ: The role of carotenoids in human health. Nutr Clin Care 5:56–65, 2002.

*Received November 26, 2003; revision accepted May 7, 2004*