

Nutritional Quality of Organic Versus Conventional Fruits, Vegetables, and Grains

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ABSTRACT

Objectives: To survey existing literature comparing nutrient content of organic and conventional crops using statistical methods to identify significant differences and trends in the data.

Design: Published comparative measurements of organic and conventional nutrient content were entered into a database for calculation. For each organic-to-conventional comparison, a percent difference was calculated:

$$(\text{organic} - \text{conventional})/\text{conventional} \times 100.$$

For nutrients where there was adequate data, the Wilcoxon signed-rank test was used to identify significant differences in nutrient content as represented by the percent difference. Mean percent difference values were also calculated for each significant nutrient by study and by vegetable for the most frequently studied vegetables. The nutrient content of the daily vegetable intake was calculated for both an organic and conventional diet.

Results: Organic crops contained significantly more vitamin C, iron, magnesium, and phosphorus and significantly less nitrates than conventional crops. There were nonsignificant trends showing less protein but of a better quality and a higher content of nutritionally significant minerals with lower amounts of some heavy metals in organic crops compared to conventional ones.

Conclusions: There appear to be genuine differences in the nutrient content of organic and conventional crops.

INTRODUCTION

Organic foods are required in a number of alternative treatments, including several alternative cancer therapies. It is widely assumed that any benefit derived from organic foods is due to an absence of pesticide residues. However, prior to the widespread use of pesticides, those in the health care community who advocated organic foods claimed that these foods contained a better arrangement of nutri-

ents as a result of the superior soil management and fertilization practices used by organic farmers. As a corollary, they cautioned that food grown with chemical fertilizers caused deteriorating health in animals and humans (Cheshire Panel Committee, 1939).

Despite these warnings about the health effects of chemical fertilizers and pesticides, farmers abandoned the labor-intensive practices used in organic agriculture in favor of these easier to use chemicals. Prior to World

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War II, agricultural chemicals were virtually unused. But by 1995, more than 45 million tons of chemical fertilizers and 770 million pounds of synthetic pesticides were used in U.S. agriculture alone (Terry, 1999; Aspelin, 1999). Ninety-five percent (95%) of crops in the United States are now produced with chemical fertilizers and pesticides (U.S. Department of Agriculture, National Agricultural Statistical Service, Agricultural Statistics Board, 2000), and producing crops using these chemicals has come to be known as conventional agriculture.

There is evidence, however, that this major change in agricultural methods may not have been entirely benign from a nutritional point of view. Coincident with the changes in agricultural practices, there have been recently identified changes in the nutrient composition of fresh fruits and vegetables. Four different analyses of U.S. and British nutrient content data have shown a decline in the vitamin and mineral content of fresh fruits and vegetables over the last 60 years (Klein and Perry, 1982; Bergner, 1997; Mayer, 1997; Jack, 1998). Average declines in nutrient content are shown in Table 1.

How does agriculture affect nutrient composition? Are agricultural chemicals responsible for the decrease in nutrient content? A number of studies over the last 75 years have addressed the question of whether agricultural chemicals and other agricultural methods including organic farming affect nutrient content. The question is still unresolved in part due to the large amount of variability in agricultural data resulting from uncontrollable factors such

as rainfall and sunlight, which also influence nutrient content. In addition, few existing studies are exactly alike or even very similar as there are differences in crops grown, fertilization methods used, storage methods if any, etc. These factors can make it hard to interpret data from such studies in any conclusive manner.

Nevertheless, given the relevance of this issue to both alternative medicine and to the food supply in general, it is still useful to take a broad view of the existing data. In that light, the purpose of this study is to examine all of the available comparisons of crops grown organically with those produced conventionally, using computerized and statistical methods to identify differences and trends.

METHODS

This analysis used all available studies that compared crops produced with organic fertilizer or by organic farming systems to crops produced with conventional fertilizers or farming systems. This analysis focused on fertilizers either alone or within farming systems because fertility management is historically the most fundamental difference between organic and conventional agriculture. Studies of produce from research plots and greenhouses, farm-gate produce, stored produce, and produce purchased at markets were all included. Because there are insufficient data from any one of these types of studies to draw meaningful conclusions, all of the data from the various types were used.

In all, 41 studies were included. Table 2 shows the 41 studies and the nutrients that were measured in each study. These 41 studies reported the results of 22 replicated field trials, 4 simple field trials, 4 greenhouse pot experiments, 4 market basket surveys, and 8 surveys of commercial farms or home growers. For 3 studies, detailed methodology was unavailable. In the majority of studies, data were collected over a time period of several years. All unique comparative data were extracted from these 41 studies for this analysis.

A single comparison consisted of a single nutrient in a single organic fruit, vegetable or cereal grain grown in one growing season

TABLE 1. PERCENTAGE DECLINE IN MINERAL CONTENT OF U.S. AND BRITISH CROPS IN THE LAST SIXTY YEARS*

<i>Mineral</i>	<i>U.S. 1963–1992 (13 fruits & vegetables)</i>	<i>Britain 1936–1987 (20 fruits & 20 vegetables)</i>
Calcium	–29	–19
Magnesium	–21	–35
Sodium	N/A	–43
Potassium	–6	–14
Phosphorus	–11	–6
Iron	–32	–22
Copper	N/A	–81

N/A, not analyzed.

*U.S. (Bergner, 1997) and British (Mayer, 1997) data.

compared to the same nutrient in the same conventionally grown crop grown in the same season, e.g., 0.30 mg of zinc in 100 g of organic cabbage compared to 0.25 mg in an equal amount of conventional cabbage, both grown in the summer of 1986. Some studies reported pooled comparisons that averaged the results for more than 1 year or more than one crop. These comparisons were included in the analysis when single comparisons were not available. All comparisons were used as reported.

A total of 1,297 comparisons were considered for analysis. Of this total, 57 comparisons came from 4 studies that did not report the numerical nutrient content measurements but instead made statements such as "the products of the conventional and organic plots did not differ in content" or otherwise presented the information in a nonnumeric way (Nilsson, 1979; Harwood, 1984; Reinken, 1984; Termine et al., 1984). Because the majority of these 57 comparisons indicated no difference in nutrient content, these comparisons were excluded from determinations of statistical significance and other computations. The remaining 1,240 comparisons were entered into a database for calculation, encompassing 35 vitamins and minerals as well as protein quality and quantity.

For each comparison, a percent difference was computed as follows:

$$\frac{\text{Organic Value} - \text{Conventional Value}}{\text{Conventional Value}} \times 100.$$

These percent difference numbers indicate the percent more or less of a nutrient found in the organic crop as compared to the conventional crop. The percent difference was used to produce descriptive statistics and in tests of significance.

The statistical significance of the difference in nutrient content between organic and conventional crops was calculated for nutrients where there were adequate data. Most nutrients were measured in 3 or fewer studies and a small number of comparisons. The remaining 12 nutrients were measured in 8 or more studies with 39 or more comparisons: calcium, magnesium, potassium, sodium, zinc, copper, manganese, iron, phosphorus, vitamin C, β -carotene, and nitrates. The statistical significance of the difference was computed for these 12 nutrients using the Wilcoxon signed-rank test (Kohler, 1988).

The vegetables in which each nutrient was measured are shown in Table 3. Five vegetables were more frequently studied than other

TABLE 3. THE TWELVE MOST STUDIED NUTRIENTS AND THE VEGETABLES IN WHICH THEY WERE MEASURED

<i>Nutrient</i>	<i>Vegetables</i>
Calcium	Beet root, cabbage, carrot, celeriac, kale, leek, lettuce, pepper, potato, spinach, tomato, turnip, apple, pear, currant, corn, wheat
Copper	Cabbage, carrot, celeriac, leek, lentil, lettuce, pepper, potato, spinach, turnip, apple, pear, currant, barley, brown rice, corn, wheat
Iron	Cabbage, carrot, celeriac, leek, lentil, lettuce, pepper, potato, spinach, tomato, turnip, apple, pear, currant, barley, brown rice, corn, wheat
Magnesium	Beet root, cabbage, carrot, celeriac, kale, leek, lettuce, pepper, potato, spinach, tomato, turnip, apple, pear, currant, corn, wheat
Manganese	Cabbage, carrot, celeriac, leek, lettuce, pepper, potato, spinach, turnip, apple, pear, corn, wheat
Phosphorus	Beet root, cabbage, carrot, celeriac, kale, leek, lettuce, pepper, potato, spinach, tomato, turnip, apple, pear, currant, corn, wheat
Potassium	Beet root, cabbage, carrot, celeriac, kale, leek, lettuce, pepper, potato, spinach, tomato, turnip, apple, pear, corn, wheat
Sodium	Beet root, cabbage, carrot, kale, leek, lettuce, potato, spinach, tomato, turnip, apple, pear, corn, wheat
Zinc	Cabbage, carrot, celeriac, lentil, lettuce, pepper, potato, spinach, tomato, apple, pear, barley, brown rice, corn, wheat
β -carotene	Beet leaf, carrot, lettuce, spinach, tomato, corn
Vitamin C	Brussel sprouts, cabbage, carrot, celeriac, corn salad, endive, kale, kohlrabi, leek, lettuce, mangel, pepper, potato, snap beans, spinach, tomato, turnip, currant
Nitrates	Beet root, cabbage, carrot, celeriac, chard, corn salad, endive, kale, leek, lettuce, potato, radish, spinach, turnip

crops: lettuce, spinach, carrot, potato, and cabbage. The mean percent difference was also calculated for significant nutrients for each of these five vegetables.

The nutrient content of the vegetable portion of a daily menu was estimated for both an organic and a conventional diet. It was assumed that both diets met the current recommended dietary intake for vegetables and provided 5 servings of vegetables of the recommended size (U. S. Department of Agriculture, Center for Nutrition Policy and Promotion, 1995): 1 cup of raw leafy vegetables and 1/2 cup of other vegetables. It was also assumed that the five most frequently studied vegetables, as listed above, were consumed. U. S. Department of Agriculture (USDA) nutrient composition data (U. S. Department of Agriculture, Agricultural Research Service, 1999) were used to estimate the nutrient content of vegetables produced with agricultural chemicals because nearly all crops in the United States are produced with these chemicals. The amount of each nutrient in each organic vegetable was estimated, using the percent difference numbers calculated for vegetables in this analysis, as follows:

$$(\text{USDA Nutrient Content Value}) \times \frac{(100 + \text{Percent Difference})}{100}$$

where the USDA value and percent difference are for the same nutrient and vegetable. The total amount of each nutrient in organic and con-

ventional menus was calculated by summing the amounts in the five vegetables.

Data distribution plots were produced for nutrients where the difference in nutrient content was statistically significant. In order to produce a coherent visual display, average percent difference was calculated by study for these nutrients, and these results were plotted for each of these frequently studied nutrients.

Data were analyzed using SAS (SAS Institute Inc., Cary, NC) and plots were produced using NCSS (NCSS Inc., Kaysville, UT).

RESULTS

This analysis was designed to answer several questions for each nutrient considered:

1. Is there a difference in the nutrient content of organic crops and those grown with agricultural chemicals?
2. How much of the time does the difference occur?
3. How big is the difference?

These questions are representative of larger questions such as would a consumer encounter a difference often enough to be affected? And is the difference large enough to be biologically significant?

Of the 12 nutrients that were analyzed statistically, 4 nutrients and 1 toxic substance were significantly different: vitamin C, iron, magnesium, phosphorus, and nitrates. Table 4 shows

TABLE 4. NUTRIENT CONTENT OF ORGANIC VERSUS CONVENTIONAL CROPS: MEAN PERCENT DIFFERENCE, LEVEL OF SIGNIFICANCE, NUMBER OF COMPARISONS, AND NUMBER OF STUDIES FOR STATISTICALLY SIGNIFICANT NUTRIENTS

Nutrient	Mean % difference*	Level of significance p	Range	Number of comparisons [†]			No. of studies
				Organic higher	Organic lower	No difference	
Vitamin C	+27.0%	<0.0001	-100%–+507%	83	38	11	20
Iron	+21.1%	<0.001	-73%–+240%	51	30	2	16
Magnesium	+29.3%	<0.001	-35%–+1206%	59	31	12	17
Phosphorus	+13.6%	<0.01	-44%–+240%	55	37	10	18
Nitrates	-15.1%	<0.0001	-97%–+819%	43	127	6	18

*Plus and minus signs refer to conventional crops as the baseline for comparison. For example, vitamin C is 27.0% more abundant in the organic crop (conventional 100%, organic 127%).

[†]A comparison consists of a single nutrient in a single organic crops grown in one season compared to the same conventionally grown crop from the same season, for example, 0.30 mg of zinc in organic cabbage compared to 0.25 mg of zinc in conventional cabbage, both grown in 1986.

the results for statistically significant nutrients including mean percent difference, level of significance, range of the data, the number of studies for each nutrient, and the number of comparisons where the organic crop had a higher, lower, or equal nutrient content compared to the conventional crop.

For each of the significant nutrients, the organic crops had a higher nutrient content in more than half of the comparisons. For the one toxic compound, nitrates, the organic crop had a lower content the majority of the time. This distribution of results is also evident when the results are compiled by study rather than by individual comparisons. Figure 1 shows the distribution of percent difference results by study for significant nutrients. As shown in Figure 1, most studies report a higher nutrient content or lower nitrate content in the organic crop.

The size of the difference was assessed by calculating a mean percent difference for the nutrient in question. As shown in Table 4, the organic crop has, on average, a higher content of the four significant nutrients and less of the toxic nitrates. For example, the vitamin C content of an organic fruit or vegetable is 27% more, on average, than a comparable conventionally grown fruit or vegetable. In other words, if an average conventional fruit or vegetable contained 100 mg of vitamin C, then a comparable organic one would contain 127 mg. Not too much should be made of the exact numerical differences shown in Table 4 because additional studies could influence the results a

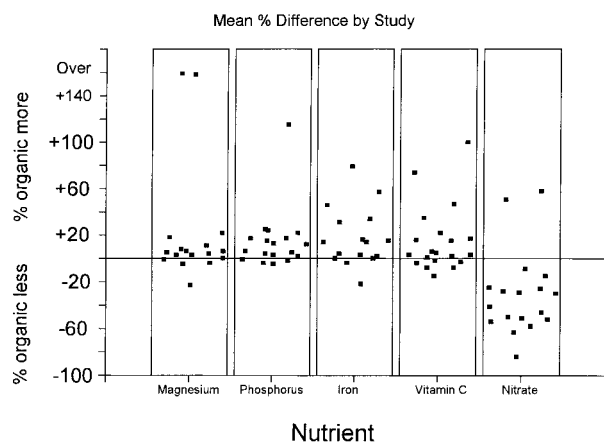


FIG. 1. Distribution of results for selected nutrients.

TABLE 5. DIFFERENCES IN NUTRITIONAL CONTENT BETWEEN ORGANIC AND CONVENTIONAL VEGETABLES: MEAN PERCENT DIFFERENCE FOR FOUR NUTRIENTS IN FIVE FREQUENTLY STUDIED VEGETABLES

Vegetable	Nutrient*			
	Vitamin C	Iron	Magnesium	Phosphorus
Lettuce	+17	+17	+29	+14
Spinach	+52	+25	-13	+14
Carrot	-6	+12	+69	+13
Potato	+22	+21	+5	0
Cabbage	+43	+41	+40	+22

*Plus and minus signs refer to conventional crops as the baseline for comparison. For example, vitamin C is 17.0% more abundant in organic lettuce (conventional 100%, organic 117%).

few percentage points either way. However, these percent difference numbers do indicate the direction and approximate magnitude of observed differences.

The mean percent difference by nutrient was also calculated for individual vegetables. Table 5 shows the results for the five most studied vegetables. Because there are fewer studies and a smaller number of comparisons for individual vegetables than there are for the whole data set, these results reflect more of the variability that is characteristic of agricultural data. Overall, the results for individual vegetables are similar to those for the entire data set shown in Table 4.

Next, an attempt was made to quantify how these differences in nutrient content could affect a person's daily nutrient intake. Estimates of the nutrient content of the vegetable portion a daily menu were made for both an organic and a conventional diet. It was assumed that the five most frequently studied vegetables were consumed: lettuce, cabbage, spinach, carrot and potato. Table 6 shows the quantity of iron, magnesium, phosphorus and vitamin C

TABLE 6. NUTRIENT CONTENT OF AN ORGANIC AND CONVENTIONAL DIET: MILLIGRAMS OF VITAMIN C, IRON, MAGNESIUM, AND PHOSPHORUS IN ONE DAY'S VEGETABLE INTAKE

Diet	Vitamin C (mg)	Iron (mg)	Magnesium (mg)	Phosphorus (mg)
Organic	89.2	3.7	80.0	124.0
Conventional	67.9	3.0	68.6	111.8

in the vegetable portion of both organic and conventional menus.

Finally, there are several nonsignificant trends in the data that are worthy of further investigation. First, there appears to be higher amounts of nutritionally significant minerals in organic compared to conventional crops. The organic crop had a higher mean mineral content for all 21 minerals considered in this analysis. Figure 2 shows the mean percent additional mineral content in organic crops by mineral for some of these minerals. In addition, there may be less of the toxic heavy metals in organic crops than in conventional crops. For all four heavy metals considered, the organic crop contained lower amounts of the heavy metals more often than comparable conventional crops. The number of comparisons where the organic crop had less and where the conventional crop had less were 7 and 5 for lead, 6 and 5 for cadmium, 3 and 2 for mercury, and 4 and 1 for aluminum.

A further trend indicates that the quantity of protein may be less but the quality may be better in organic crops than in conventional crops. In all but one of the few measurements that were included in this analysis, the quantity of crude protein was lower in organic compared to conventional crops but the quality was better as measured by essential amino acid content. There is considerable support elsewhere for this difference in protein quantity and qual-

ity, some of which will be reviewed in the next section.

DISCUSSION

These results are in agreement with a review of predominantly German comparative literature conducted by the German government (Woese et al., 1995). The results for nitrates and protein quality and quantity agreed with the German review, which found a lower nitrate content in organic vegetables in nearly all cases, and less protein but higher quality protein in organic cereal grains. In addition, the results for vitamin C are similar to those of the German review. The Germans reported that half of the time the vitamin C content of organic and conventional crops was the same, and the other half of the time the vitamin C content was higher in the organic crop. These findings are consistent with a higher average vitamin C content in the organic crop as found in this analysis.

Further supporting evidence for the results of this analysis comes from the known effects of fertilizers and pesticides on soil ecology and plant metabolism. Before reviewing these effects, it is helpful to know something about the differences in organic and conventional fertilizers and fertility management. In organic

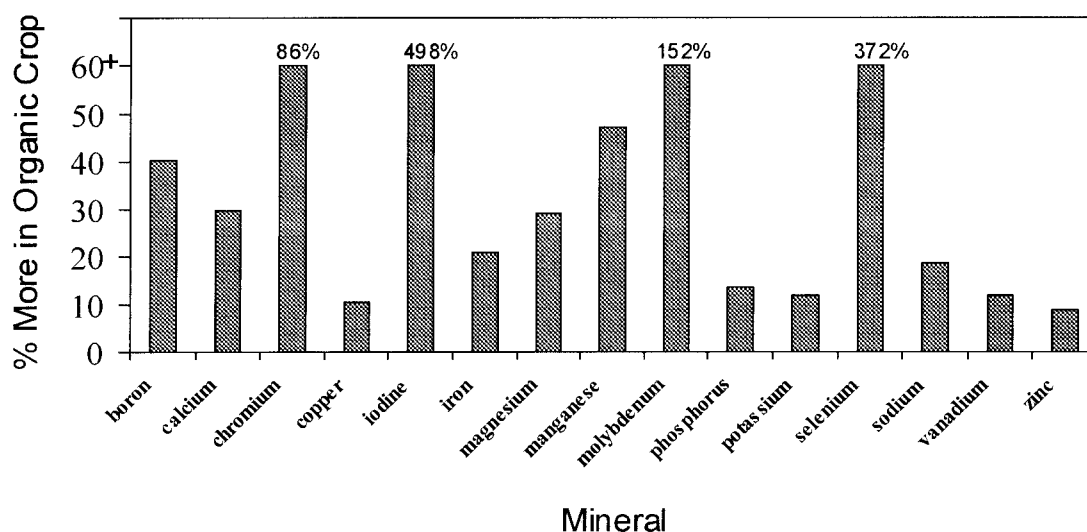


FIG. 2. Mean percent additional mineral content in organic compared to conventional crops.

farming, a number of methods are used to maintain soil fertility. These include: (1) crop rotation, which ensures that one crop does not deplete the soil of the nutrients that it uses most; (2) cover crops to protect against soil erosion; (3) the planting of special crops known as "green manures" that are plowed back into the soil to enrich it; and (4) the addition of aged animal manures and plant wastes, also known as compost, to the soil. The distinguishing feature of these fertility management practices is the addition of organic matter to the soil, in the form of plant and animal wastes, to preserve the soil structure and provide food for soil microorganisms. With these methods, soil nutrients are released slowly over time.

In contrast, chemical fertilizers contain a few mineral substances, principally nitrogen, potassium, and phosphorus. Sometimes trace minerals are also added. These fertilizers dissolve easily in the water that is present in soil. As a result, plants fertilized with chemical fertilizers are presented with large quantities of nutrients all at once, often in excess of their needs. Farmers who use chemical fertilizers control erosion of topsoil through methods such as no-till planting, where weed-killing pesticides are used in place of plowing to prepare a field for planting. With chemical fertilizers, there is no attempt to influence soil structure or to encourage soil microorganisms (Cacek and Lagner, 1986).

These differences in the management of soil fertility affect soil dynamics and plant metabolism, which result in differences in plant composition and nutritional quality. Soil that has been managed organically has more microorganisms (Hader, 1986; Henis, 1986). These microorganisms produce many compounds that help plants, including substances such as citrate and lactate that combine with soil minerals and make them more available to plant roots (Stevenson and Ardakani, 1972). For iron, in particular, this is especially important because many soils contain adequate iron but in an unavailable form (Allaway, 1975). The presence of these microorganisms at least partially explains the trend showing a higher mineral content of organic food crops.

Nitrogen from any kind of fertilizer affects the amounts of vitamin C and nitrates as well

as the quantity and quality of protein produced by plants. When a plant is presented with a lot of nitrogen, it increases protein production and reduces carbohydrate production. Because vitamin C is made from carbohydrates, the synthesis of vitamin C is reduced also. Moreover, the increased protein that is produced in response to high nitrogen levels contains lower amounts of certain essential amino acids such as lysine and consequently has a lower quality in terms of human and animal nutrition. If there is more nitrogen than the plant can handle through increased protein production, the excess is accumulated as nitrates and stored predominately in the green leafy part of the plant (Salunkhe and Desai, 1988; Mozafar, 1993). Because organically managed soils generally present plants with lower amounts of nitrogen than chemically fertilized soils, it would be expected that organic crops would have more vitamin C, less nitrates and less protein but of a higher quality than comparable conventional crops.

Potassium fertilizer can reduce the magnesium content and indirectly the phosphorus content of at least some plants. When potassium is added to soil, the amount of magnesium absorbed by plants decreases. Because phosphorus absorption depends on magnesium, less phosphorus is absorbed as well. Potassium is presented to plants differently by organic and conventional systems. Conventional potassium fertilizers dissolve readily in soil water presenting plants with large quantities of potassium while organically managed soils hold moderate quantities of both potassium and magnesium in the root zone of the plant (Bear et al., 1949; Hannaway et al., 1980). Given the plant responses just described, it would be expected that the organic crops would contain larger amounts of magnesium and phosphorus than comparable conventional crops.

Several kinds of fertilizers contain toxic heavy metals that enter the soil and are absorbed by plants. Phosphate fertilizers often are contaminated by cadmium. Also, trace mineral fertilizers and liming materials derived from industrial waste can contain a number of heavy metals (Batelle Memorial Institute, 1999). These heavy metals build up in the soil when these

fertilizers are used year after year. As the soil becomes more contaminated, the crops grown on these soils also become more contaminated. When chemical nitrogen fertilizers are added to these soils, plants may absorb even more toxic heavy metals (Reuss et al., 1976; Harmon et al., 1998). Organic farmers only rarely use trace mineral fertilizers and virtually never use fertilizers produced from industrial waste, which are the most contaminated (Organic Crop Improvement Association, 1996; Batelle Memorial Institute, 1999). As a consequence, it might be expected that organic crops would contain lower amounts of toxic heavy metals, but more investigation is required to confirm this expectation.

Furthermore, it is reasonable to ask how the observed differences in nutrient content might affect a person's nutrient intake and health. Estimates of the nutrient content of organic and conventional daily vegetable intake were made, and the organic vegetables had higher amounts of all nutrients shown. For vitamin C, in particular, five servings of the organic vegetables met the recommended daily intake of 75 mg for women and 90 mg for men (Krinsky, 2000) whereas the same vegetables produced conventionally failed to do so. Considering that the recommended intake for vitamin C has been raised twice in the last 30 years, it is possible that the difference seen here could have significant effects on the public health.

However, the health effects that might accrue from these differences in nutrient content have not been assessed to any extent. Animal studies suggest that such functions as reproduction and resistance to infection might be adversely affected by conventionally produced foods as compared to organically produced ones (Linder, 1973; Aehnelt and Hahn, 1978; Voghtmann, 1988; Plochberger, 1989; Velimirov et al., 1992). The one existing human study reported that the percentage of normal sperm increased as the percentage of organic food in men's diets increased (Juhler et al., 1999). Although preliminary, these findings are consistent with the results of the animal studies. Moreover, it should be noted that some of the animal studies included no pesticide usage at all so that the poorer outcome of the conventionally fed animals cannot be entirely attributed to pesticide

residues. Soil factors appear to have an effect as well.

In summary, this analysis found more iron, magnesium, phosphorus, and vitamin C and less nitrates in organic crops as compared to conventional crops. In addition, there were several trends showing less protein but of a better quality, more nutritionally significant minerals, and lower amounts of some heavy metals in organic crops compared to conventional ones. More research is needed both to verify these findings and to discover relevant mechanisms in both plants and soil. As with all real-world data, there is considerable variability in agricultural measurements, making it necessary to collect and consider a lot of data in order to identify underlying patterns. Consequently, for most nutrients, there is a need for additional data collection before any further analysis is warranted. Finally, because the data collected to date suggest that there are real differences in nutrient content between organic and conventional crops, more research into the relative health effects is certainly in order.

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REFERENCES

- Aehnelt E, Hahn J. Animal fertility: a possibility for biological quality assay of fodder and feeds. *Biodynamics* 1978;25:36-47.
- Ahrens E, Elsaidy S, Samaras I, Samaras F, Wishingausen EV. Significance of fertilization for the post-harvest condition of vegetables, especially spinach. In: Lockeretz W, ed. *Environmentally Sound Agriculture*. New York: Praeger, 1983:229-246.
- Allaway WH. The Effect of Soils and Fertilization on Human and Animal Nutrition. *Agricultural Information Bulletin* No. 378. Washington, D.C.: USDA, 1975.
- Aspelin AL. Pesticide Industry Sales and Usage 1994 and 1995 Market Estimates. Washington, D.C.: US EPA, 1999: <http://www.epa.gov/oppbead1/95pestsales/>.
- Barker AV. Organic vs. inorganic nutrition and horticultural crop quality. *Hort Sci* 1975;10:50-53.

- Batelle Memorial Institute. Background Report on Fertilizer Use, Contaminants and Regulations. Washington, D.C.: National Program Chemicals Division, U.S. Environmental Protection Agency, 1999:27–51.
- Bear FE, Toth SJ, Prince AL. Variation in mineral composition of vegetables. *Proc Soil Sci Soc Am* 1949;13:380–384.
- Bergner P. The Healing Power of Minerals, Special Nutrients and Trace Elements. Rocklin, CA: Prima Publishing Co., 1997:46–75.
- Bessenich F. Regarding the vitamin content of vegetables. *Biodynamics* 1946;4:7–10.
- Blanc D, Gilly G, Leclerc J, Causeret J. Appreciation de l'effet long terme de la nature organique ou minerale de la fertilisation sur la composition de laitue et de la pomme de terre. *Sciences Aliments* 1984;4:267–272.
- Brandt CS, Beeson KC. Influence of organic fertilization on certain nutritive constituents of crops. *Soil Sci* 1951;71:449–454.
- Cacek T, Lagner LL. The economic implications of organic farming. *Am J Altern Agric* 1986;1:25–29.
- Chang P-T, Salomon M. Metals in grains sold under various labels—Organic, natural and conventional. *J Food Qual* 1978;1:373–77.
- Cheshire Panel Committee. Nutrition, soil fertility and the national health. *Br Med J* 1939;1:157S–159S.
- Clarke RP, Merrow SB. Nutrient composition of tomatoes homegrown under different cultural procedures. *Ecol Food Nutr* 1979;8:37–46.
- Dlouhy J. The quality of plant products under conventional and bio-dynamic management. *Biodynamics* 1977;124:28–32.
- Fischer A, Richter C. Influence of organic and mineral fertilizers on yield and quality of potatoes. In: Vogtmann H, Boehncke E, Fricke I, eds. *The Importance of Biological Agriculture in a World of Diminishing Resources*. Witzhausen: Veriagsgruppe Weiland, 1984:236–248.
- Hader Y. The role of organic matter in the introduction of biofertilizers and biocontrol agents to soil. In: Chen Y, Avnimelech Y, eds. *The Role of Organic Matter in Modern Agriculture*. Boston: Martinus Nijhoff Publishers, 1986:169–180.
- Hannaway DB, Bush LP, Leggett JE. Plant Nutrition: Magnesium and Hypomagnesemia in Animals. Bulletin 716. Lexington, KY: University of Kentucky, College of Agriculture, 1980.
- Hansen H. Comparison of chemical composition and taste of biodynamically and conventionally grown vegetables. *Qualitas Plantarum* 1981;30:203–211.
- Harmon RE, McLaughlin MJ, Naidu R, Correll R. Long term changes in cadmium bioavailability in soil. *Environ Sci Technol* 1998;32:3699–3703.
- Harwood RR. Organic farming research at the Rodale research center. In: Kral DM, Hawkins SL, eds. *Organic Farming: Current Technology and Its Role in a Sustainable Agriculture*. Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, 1984:1–17.
- Henis Y. Soil microorganisms, soil organic matter and soil fertility. In: Chen Y, Avnimelech Y, eds. *The Role of Organic Matter in Modern Agriculture*. Boston: Martinus Nijhoff Publishers, 1986:29–54.
- Jack A. Nutrition under siege. *One Peaceful World* 1998;34:1–8.
- Juhler RK, Larsen SB, Meyer O, Jensen ND, Spano M, Giwercman A, Bonde JP. Human semen quality in relation to dietary pesticide exposure and organic diet. *Arch Environ Contam Toxicol* 1999;37:415–423.
- Kansal BD, Singh B, Bajaj KL, Kaur G. Effect of different levels of nitrogen and farm yard manure on yield and quality of spinach (*Spinacea oleracea* L.). *Qualitas Plantarum* 1981;31:163–170.
- Klein BP, Perry AK. Ascorbic acid and vitamin A activity in selected vegetables from different geographical areas of the United States. *J Food Sci* 1982;47:941–948.
- Kohler H. *Statistics for Business and Economics*. Glenview, IL: Scott, Foresman and Company, 1988:458–461.
- Krinsky N. *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium and Carotenoids*. Washington, D.C.: Food and Nutrition Board. Institute of Medicine. National Academy of Sciences, 2000.
- Lairon D, Termine E, Gautier S, Trouilloud S, Lafont H, Hauton JCH. Effects of organic and mineral fertilizations on the contents of vegetables in minerals, vitamin C and nitrates. In: Vogtmann H, Boehncke E, Fricke I, eds. *The Importance of Biological Agriculture in a World of Diminishing Resources*. Witzhausen: Veriagsgruppe Weiland, 1984a:249–260.
- Lairon D, Spitz N, Termine E, Ribaud P, Lafont H, Hauton J. Effect of organic and mineral nitrogen fertilization on yield and nutritive value of butterhead lettuce. *Qualitas Plantarum* 1984b;34:97–108.
- Lairons D, Lafont H, Leonardi J, Hauton J, Ribaud P. reported in Lairon D, Termine E, Lafont H. Valeur nutritionnelle comparee des legumes obtenus par les methodes d l'agriculture biologique ou de l'agriculture conventionnelle. *Cah Nutr Diet* 1984c;XIX: 331–339.
- LeClerc J, Miller ML, Joliet E, Rocquelin G. Vitamin and mineral contents of carrot and celeriac grown under mineral or organic fertilization. *Biol Agric Hort* 1991;7:339–348.
- Linder MC. A review of the evidence for food quality differences in relation to fertilization of the soil with organic or mineral fertilizers. *Biodynamics* 1973;107:1–11.
- Mader P, Pfiffner L, Niggli U, Balzer U, Balzer F, Plochberger K, Velimirov A, Besson JM. Effect of three farming systems (bio-dynamic, bio-organic, conventional) on yield and quality of beetroot (*Beta vulgaris* L. var. *esculenta* L.) in a seven year crop rotation. *Acta Horticulturæ* 1993;339:10–31.
- Mayer A-M. Historical changes in the mineral content of fruits and vegetables: A cause for concern? *Br Food J* 1997;99:207–11.
- Miller DS, Dema IS. Nutritive value of wheat from the Rothamsted Broadbalk field. *Proc Nutr Soc* 1958;17:xliv–xlv.
- Mozafar A. Nitrogen fertilizers and the amount of vitamins in plants: A review. *J Plant Nutr* 1993;16:2479–2506.

- Muramoto J, reported in Brown M. Study compares nitrate levels in organic and conventional crops. *The Cultivar*. Santa Cruz, CA: Center for Agroecology & Sustainable Food Systems, University of California, 1999:http://zzyx.ucsc.edu/casfs/Newsletter2/nitrogen_study.html.
- Nilsson T. Yield, storage ability, quality and chemical Composition of carrot, cabbage and leek at conventional and organic fertilizing. *Acta Horticulturae* 1979;93:209–233.
- Organic Crop Improvement Association. International Certification Standards. 1996:<http://www.gks.com/library/standards/ocia/ociain.html>.
- Peavy WS, Grieg JK. Organic and mineral fertilizers compared by yield, quality, and composition of spinach. *J Am Soc Hort Sci* 1972;97:718–723.
- Pettersson BD. A comparison between the conventional and biodynamic farming systems as indicated by yields and quality. In: Lockeretz W, ed. *Environmentally Sound Agriculture*. New York: Praeger, 1983:87–94.
- Pfeiffer E. The experimental garden of 1950. *Biodynamics* 1951;9:11–12.
- Plochberger K. Feeding experiments. A criterion for quality estimation of biologically and conventionally produced foods. *Agric Ecosys Environ* 1989;27:419–428.
- Rauter W, Wolkerstorfer W. Reported in: Lairons D, Termine E, LaFont H. Valeur nutritionnelle comparee des legumes obtenu par les methods de l'agriculture biologique ou de l'agriculture conventionnelle. *Cah Nutr Diet* 1984c;XIX:331–340.
- Reinken G. Six years of biodynamic growing of vegetables and apples in comparison with conventional farm management. In: Vogtmann H, Boehncke E, Fricke I, eds. *The Importance of Biological Agriculture in a World of Diminishing Resources*. Witzhausen: Veriagsgruppe Weiland, 1984:161–174.
- Reuss J, Dooley HL, Griffis W. Plant uptake of cadmium from phosphate fertilizer. 600/3-76-053. Corvallis, OR: Ecological Research Service, 1976:1–37.
- Salunkhe DK, Desai BB. Effects of agricultural practices, handling, processing, and storage on vegetables. In: Karmas E, Harris RS, eds. *Nutritional Evaluation of Food Processing*. New York: AVI Publishing Co, 1988: 23–71.
- Schudel P, Eichenberger M, Augustberger F, Klay R, Vogtmann H. The influence of compost or NPK fertilization on yield, vitamin C and nitrate content of spinach and spinach beet. *Schweizerische Landwirtschaftliche Forschung* 1979;18:337–349.
- Schuphan W. Nutritional value of crops as influenced by organic and inorganic fertilizer treatments. *Qualitas Plantarum* 1974;23:333–358.
- Shier NW, Kelman J, Dunson JW. A comparison of Crude protein, moisture, ash and crop yield between organic and conventionally grown wheat. *Nutr Rep Int* 1984;30:337–349.
- Smith B. Organic foods vs. supermarket foods: element levels. *J Appl Nutr* 1993;45:35–39.
- Stevenson FJ, Ardakani MS. Organic matter reactions involving micronutrients in soils. In: Mortvedt JJ, Giordano PM, Lindsay WI, eds. *Micronutrients in Agriculture*. Madison, WI: Soil Science Society of America, 1972:79–114.
- Stopes C, Woodward L, Forde G, Vogtmann H. The nitrate content of vegetable and salad crops offered to the consumer as from “organic” or “conventional” production systems. *Biol Agric Hort* 1988;5:215–221.
- Stopes C, Woodward L, Forde G, Vogtmann H. Effects of composted FYM and a compound fertilizer on yield and nitrate accumulation in 3 summer lettuce cultivars grown in an organic system. *Agric Ecosys Environ* 1989;27:555–559.
- Svec LV, Thoroughgood CA, Mok HCS. Chemical evaluation of vegetables grown with conventional or organic soil amendments. *Commun Soil Sci Plant Anal* 1976; 7:213–228.
- Termine E, Lairon D, Taupier-Letage B, Gauthier S, Hauton JC. Influence des techniques de fertilisation organique et minerale sur la valeur nutritionnelle de legumes. *Science Aliments* 1984;4:273–277.
- Termine E, Lairon D, Taupier-Letage B, Gautier S, Lafont R, Lafont H. Yield and content in nitrates, minerals and ascorbic acid of leeks and turnips grown under mineral or organic nitrogen fertilizations. *Plant Foods Hum Nutr* 1987;37:321–32.
- Terry DL. U.S. consumption of fertilizer and plant nutrients (1960–1995). Lexington KY: Regulatory Services, University of Kentucky, 1999: <http://www.uky.edu/Agriculture/RegulatoryServices/natonage/cf95/page3.htm>.
- U.S. Department of Agriculture, Agricultural Research Service. USDA Nutrient Database for Standard Reference. Release 13. Nutrient Data Laboratory Home Page, 1999:<http://www.nal.usda.gov/fnic/foodcomp/>.
- U.S. Department of Agriculture, Center for Nutrition Policy and Promotion. The Food Guide Pyramid. Home and Garden Bulletin Number 252. Washington, DC: USDA, 1995.
- U.S. Department of Agriculture, National Agricultural Statistical Service, Agricultural Statistics Board. *Agricultural Chemical Usage (PCU-BB)*. 2000: <http://www.usda.mannlib.cornell.edu/reports/nassr/other/pcu-bb/>.
- Velimirov A, Plochberger K, Huspeka UW, Schott W. The influence of biologically and conventionally cultivated food on the fertility of rats. *Biol Agric Hort* 1992;8: 325–337.
- Vogtmann H. Organic farming practices and research in Europe. In: Kral DM, Hawkins SL, eds. *Organic Farming: Current Technology and Its Role in a Sustainable Agriculture*. Madison, WI: American Society of Agronomy, Crops Science Society of America, Soil Science Society of America, 1984:19–36.
- Vogtmann H. From healthy soil to healthy food: an analysis of the quality of food produced under contrasting agricultural systems. *Nutr Health* 1988;6:21–35.
- Vogtmann H, Temperli AT, Kunsch U, Eichenberger M, Ott P. Accumulation of nitrates in leafy vegetables grown under contrasting agricultural systems. *Biol Agric Hort* 1984;2:51–68.

- Warman PR, Havard KA. Yield, vitamin and mineral content of four vegetables grown with either composted manure or conventional fertilizer. *J Vegetable Crop Production* 1996;2:13–25.
- Warman PR, Havard KA. Yield vitamin and mineral contents of organically and conventionally grown carrots and cabbage. *Agric Ecosys Environ* 1997;61:155–162.
- Woese K, Lange D, Boess C, Bogl KW. A comparison of organically and conventionally grown foods—Results of a review of the relevant literature. *J Sci Food Agric* 1995;74:281–293.
- Wolfson JL, Shearer G. Amino acid composition of grain protein of maize grown with and without pesticides and standard commercial fertilizers. *Agron J* 1981;73: 611–613.
- Worthington V. Iron Content and Bioavailability of Organically Versus Conventionally Grown Crops [doctoral dissertation]. Baltimore, MD: Johns Hopkins University; 1996.

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