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State of Science Review: Nutritional Superiority of Organic Foods

New Evidence Confirms the Nutritional Superiority of Plant-Based Organic Foods

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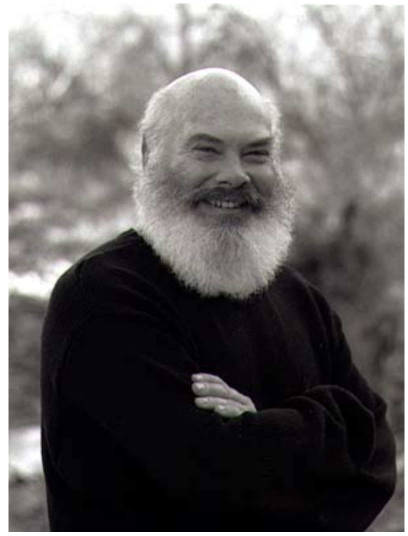
Foreword



By Andrew Weil, MD

Developing a healthy lifestyle requires information and motivation to apply it. Your everyday choices about eating, physical activity and stress management, for example, all influence how you will feel tomorrow and your health risks later in life. It is our choices that individually and collectively determine how gracefully you will age.

Adopting healthy routines, and sticking to them, is key. A practical tip I often give is to spend more time in the company of people who have those routines down. If you want to improve your diet, eat with people who know about and are in the habit of making healthy food choices. Eating well is a foundation of good health. It can help you feel well, give you the energy you need, and cope with routine ailments, from colds to lack of sleep. Long term, it will reduce the risk and delay the onset of the chronic age-related diseases.

For years I have urged people to include several servings of fresh organic fruits and vegetables in their daily diets, and to choose produce that covers all parts of the color spectrum. The medical evidence linking fruits and vegetables to good health is overwhelming. And now, so too is the new evidence that organic fruits and vegetables deliver more nutrients per average serving, including the all-important protective phytonutrients like polyphenols and antioxidant pigments.

Getting in the habit of choosing organic food whenever you can will ensure that you and your family get the nutritional benefits nature provides. It is a cornerstone on which to structure a lifestyle that will promote and maintain health lifelong.

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I. Executive Summary

“We just don’t know...” or

“There is not enough high quality data to reach conclusions” have been the common answers given over the last few years when nutritionists and agricultural scientists have been asked the question on the minds of many consumers -- “Are organic foods more nutritious?”

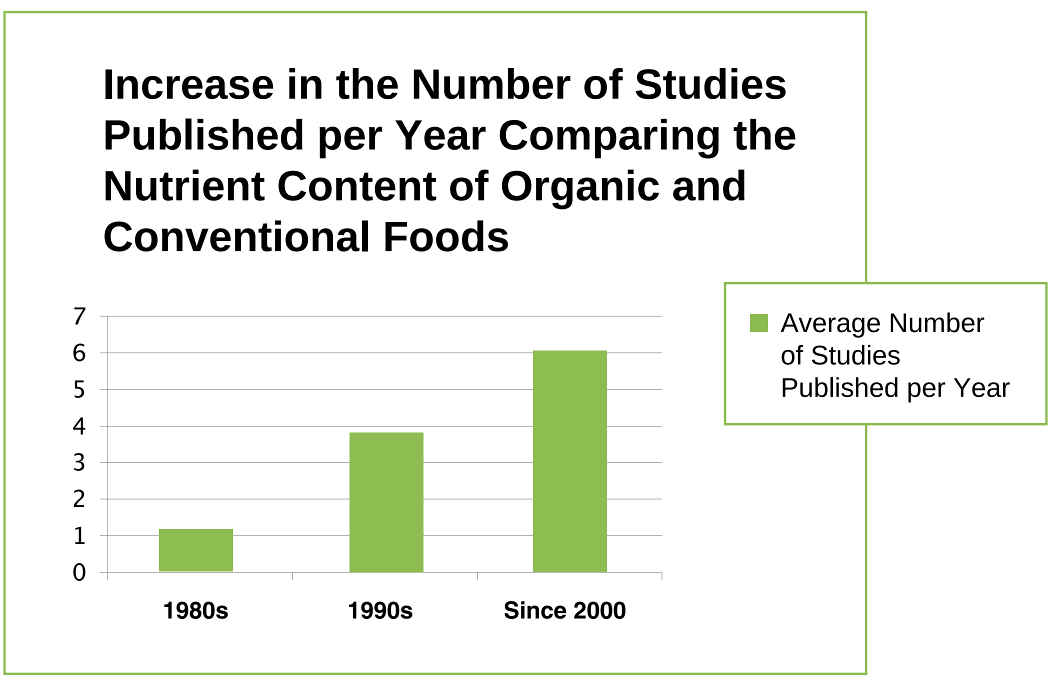
In fact, this sort of ambivalent answer accurately reflects, for the most part, the major conclusions reported in five published scientific literature reviews of studies comparing the nutritional quality of organic and conventional food. These reviews all appeared between 2001 and 2003. The most recent of the five reviews came out in 2003 and covered comparative studies through the end of 2001.

In the six years since 2001, more than forty new studies have been published, increasing the number of peer-reviewed studies comparing the nutritional quality of organic and conventional foods to over 100. Figure 1 shows the steady increase in the number of studies published per year over the last three decades.

Not only has the number of studies doubled since 2000, the quality of the studies has also improved immensely, as has the sensitivity of the analytical methods used to measure nutrients contained in foods.

Most studies in the 1980s focused simply on mineral and vitamin levels, while almost all studies published since 2000 include measures of minerals, vitamins, and health-promoting polyphenols and total antioxidant capacity.

Figure 1.



A Fresh Look

We identified all peer-reviewed studies published in the scientific literature appearing since 1980 comparing the nutrient levels in organic and conventional foods and screened them in two ways for scientific validity. We assessed how the studies defined and selected organic and conventional crops for nutrient level comparisons. From 97 published studies, we identified 236 scientifically valid "matched pairs" of measurements that include an organic and a conventional sample of a given food.

Our first screen took into account the experimental design of each study, the need for the same cultivars to be planted in both the organic and conventional fields, the degree of differences in soil types and topography, the focus of the study and where it was carried out, the definition of organic farming, and years the organic field in a matched pair had been managed organically.

For each crop addressed in a given study, we determined whether the study was "high quality," "acceptable" or "invalid" based on explicit inclusion and exclusion criteria and a rating system. The criteria were chosen to help restrict our analysis of nutrient levels across multiple studies to just those experiments producing the highest quality data. We believe our screening method achieved this objective, but acknowledge that there are many alternative ways to accomplish the same goal.

There were 135 study-crop combinations covered in the 97 studies. Based on our screen, 70% of the study-crop combinations were deemed "acceptable" or "high quality" (94 out of 135), and hence "valid", while 41 were deemed "invalid" for the purposes of this study.

We also screened the 94 valid study-crop combinations for the accuracy and reliability of the analytical methods used to measure nutrient levels. This screen factored in the base resolution, standard deviations, and reliability of the chromatographs and other measurement techniques. Fifty-five study-crop-analytical method combinations were deemed "invalid" for a specific nutrient measurement. (Other nutrient measurements from the same study-crop combination could be deemed valid).

Seventeen criteria and decision rules were also established and adhered to in selecting the most appropriate matched pairs from a given study to include in our cross-study comparisons of nutrient levels. We needed these criteria because some studies reported results on a dozen or more different combinations of production system alternatives, variable rates of fertilizer, different harvest dates, and alternative food formulations (i.e. fresh, dry, frozen, pureed).

We used these 17 decision rules to select the matched pairs from a given study-crop combination that most closely reflected food in its fresh form, grown using routine or typical organic and conventional practices.

As a result of these screens and selection criteria, we had an adequate number of valid matched pairs (at least eight) to compare the levels of 11 nutrients in organic and conventional foods. The nutrients included:

- Four measures of antioxidants (total phenolics, total antioxidant capacity, quercetin, kaempferol),
- Three precursors of key vitamins (Vitamins A, C, and E),
- Two minerals (potassium and phosphorous),
- Nitrates (higher levels are a nutritional disadvantage), and
- Total protein.

Key Findings

There were 236 valid matched pairs across the 11 nutrients. The organic foods within these matched pairs were nutritionally superior in 145 matched pairs, or in 61% of the cases, while the conventional foods were more nutrient dense in 87 matched pairs, or 37%. There were no differences in 2% of the matched pairs.

The organic samples contained higher concentrations of the very important polyphenols and antioxidants in about three-quarters of the 59 matched pairs representing those four phytonutrients. Increasing intakes of these nutrients is a vital goal to improve public health since daily intakes of antioxidants and polyphenols are less than one-half of recommended levels.

Matched pairs involving comparisons of potassium, phosphorous, and total protein levels accounted for over three-quarters of the 87 cases in which the conventional samples were nutritionally superior. While a positive finding, these three nutrients are clearly of lesser importance than the other eight nutrients because, in general, these nutrients are adequately supplied in the average American diet.

The magnitude of the differences in nutrient levels strongly favored the organic samples. One-quarter of the matched pairs in which the organic food contained higher levels of nutrients exceeded the level in the conventional sample by 31% or more. Only 6% of the matched pairs in which the conventional sample was more nutrient dense exceeded the levels in the organic samples by 31% or more.

For five nutrients, Figure 2 shows the percent of total matched pairs for which the orangic sample nutrient level exceeded the conventional sample level by eleven percent or more. Almost one-half of the 57 organic samples in these matched pairs exceeded the conventional sample nutrient level by 21% or more.

Another perspective reinforces the basic point. About 22% of the 145 matched pairs in which the organic samples were more nutrient dense fell within a difference of only 0% to 10%, which can be regarded as minor. Almost two-thirds of the conventional matched pairs found to be more nutrient dense fell within the 0% to 10% difference range.

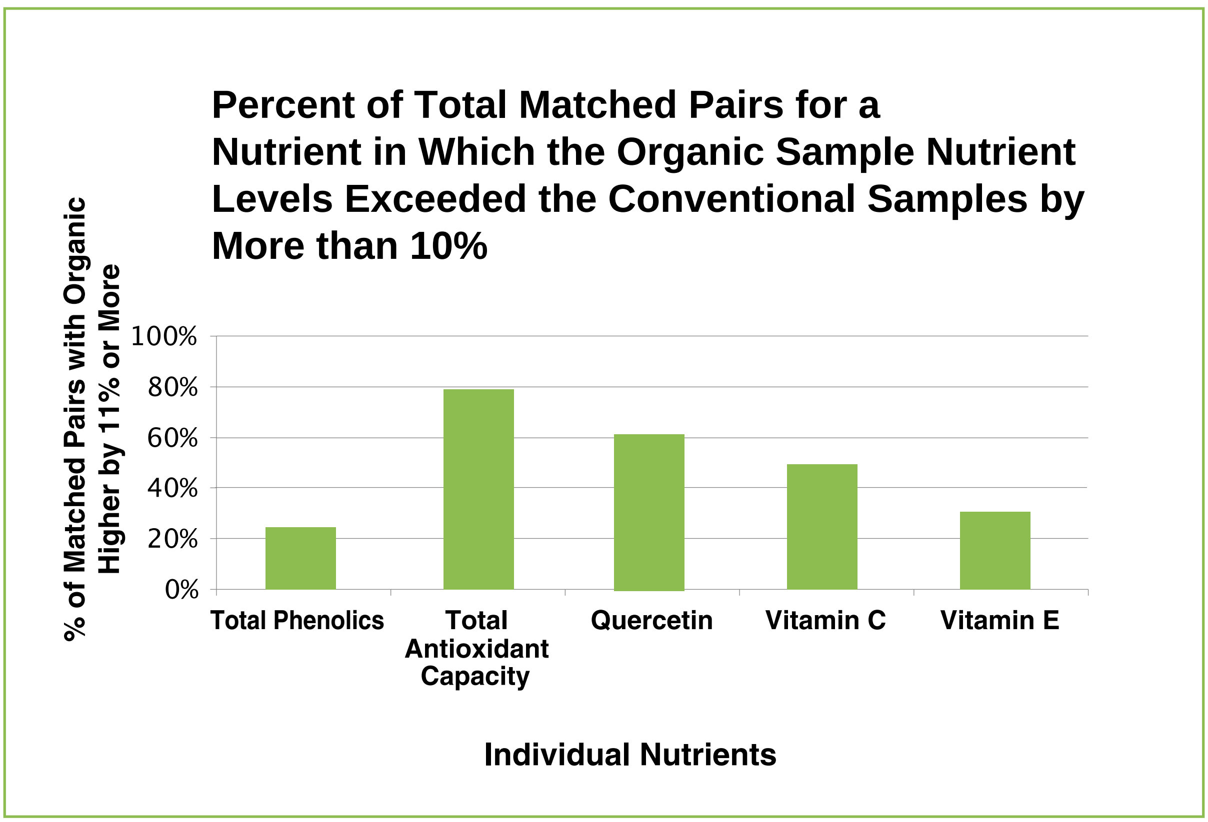
Across all 236 matched pairs and 11 nutrients, the nutritional premium of the organic food averaged 25%. The differences documented in this study are sufficiently consistent and sizable to justify a new answer to the original question–

Yes, organic plant-based foods are, on average, more nutritious.

Over the next few years another 20-30 studies will likely be completed and published. The Organic Center will add the results of these studies to our database, subject them to the same sort of scientific-merit screens, and then update and refine the analysis reported herein.

Soon, there will be enough high quality studies to reach the threshold of eight valid matched pairs for several more nutrients. Greater numbers of matched pairs for primary nutrients like antioxidants and Vitamin C will allow estimation of

Figure 2.



differences in key nutrients by crop and food – the average difference, for example, in the total antioxidant capacity of organic and conventional apples, or Vitamin C in oranges.

Over time the Center's database will grow to the point where we can explore linkages between specific organic and conventional production practices and the nutrient density of foods. This will open an exciting chapter in the continuous improvement of organic farming systems.

For every farm and agricultural region there are unique combinations of genetics, soils, climate, and practices waiting to be discovered that have the potential to produce exceptionally nutrient dense and flavorful foods. These are the kinds of fruits and vegetables needed to lure children — and adults — away from high-fat, sugar-laden foods, and in the course of doing so set the stage for sustained improvement in public health.

II. The Importance of Nutrient Content

The nutritional value of food to humans rests upon several properties and constituents contained in food, the overall diet consumed, and the health of the individuals consuming food.

A food's nutritional quality depends on how food was stored and the form of the food when consumed – fresh and whole, frozen and thawed, pureed, steamed, dried, or manufactured from multiple ingredients. Nutritional quality is also impacted, in some cases dramatically, by what has been added to a food product (e.g., extra sugar, salt, fats, vitamins and minerals, food additives, coloring agents).

The health and nutritional benefits to an individual consuming food depends on their total diet and their health status, and in particular, the health of the gastro-intestinal (GI) tract. The ability of a person's GI tract to selectively take advantage of the nutrients in food is as complex, and important, as the levels and composition of nutrients in the food when consumed.

The United States and other nations are struggling with the impacts on individual well being and health care costs of obesity and diabetes, and the serious, long-term health problems that often come in their wake. Both epidemics have been triggered, in large part, by adoption of more sedentary daily routines, coupled with qualitative changes in the American food supply and diet.

Slowing, and eventually reversing these trends is the number one public health challenge that America is facing today. Our success in meeting this challenge, or lack thereof, will have enormous long-run economic and social consequences.

A. The Dark Side of the American Diet

On the one hand, our breadth of food choices, the quality and diversity of cuisine, and our increasing appreciation for fresh, local fruits, vegetables and beverages are literally erupting across the landscape. But still, a significant and growing share of total meals is bought at fast food restaurants and in some families, more meals are consumed partially or fully in the car than at home.

The average American consumes less than half the recommended servings of fruits and vegetables, and so our intakes of essential vitamins and minerals can be grossly deficient despite years of public and private sector efforts to encourage fruit and vegetable consumption.

Intakes of added sugar, salt and saturated fat clearly exceed recommended guidelines, and we consume and/or waste about 500 more calories per day than we did in 1970.

For millions of Americans, imbalanced and excessive consumption of food has displaced tobacco and smoking as the nation's number one, preventable cause of disease and premature death and disability.

Getting to the Root of the Problem

When the role of the American diet is studied in the progression of diet-related diseases, the focus is almost always on excess caloric intake and increased consumption of saturated fats. Changes in the nutritional quality of food are rarely addressed, despite evidence that fewer than 12% of Americans meet the criteria for a healthy diet, as defined by the U.S. Department of Agriculture (USDA) in its "Healthy Eating Index" (access information on the index at http://www.cnpp.usda.gov/HealthyEatingIndex.htm).

A person can score a maximum 100 points in the Healthy Eating Index, which assigns scores of 0 to 10 across 10 food groups. The higher the score, the closer an individual is adhering to the recommended dietary guidelines.

Individuals scoring 80 points or above are regarded as generally meeting recommended dietary intakes. In 1990 the average American scored just 64 on the index, while 14% had scores below 50. Updated scores were released in 2005, and the news was not good – the average Healthy Index value had fallen to 58.

The combination of too much food that is high in calories, but low in essential nutrients, with not enough food that is high in nutrients but low in calories has in large part fueled the current increases in morbidity and mortality of obesity, diabetes, and related diseases.

Improvements in food nutrient density will not alone reverse these damaging trends. Dietary choices must also change, as must unhealthy sedentary lifestyles. Still, increasing the nutrient

density of commonly consumed foods, especially whole grains and fruits and vegetables, is a necessary and positive step in the right direction.

A food system-wide campaign to increase nutrient density per serving and calorie consumed is long overdue, given that the nutrient density of most common fruits and vegetables and major grains have been steadily declining now for about five decades.

The nutrient density of many common foods has declined gradually over time in both the U.S. (Davis, et al., 2004) and the U.K. (Mayer, 1997; White and Broadley, 2005). The team led by Dr. Don Davis, University of Texas-Austin, examined changes between 1950 and 1999 in USDA food composition data for 43 garden crops. They found significant declines in median concentrations of six nutrients: protein (Pro), calcium (Ca), phosphorus (P), iron (Fe), riboflavin (Rib) and vitamin C (Vit C), as shown in Figure 2.1.

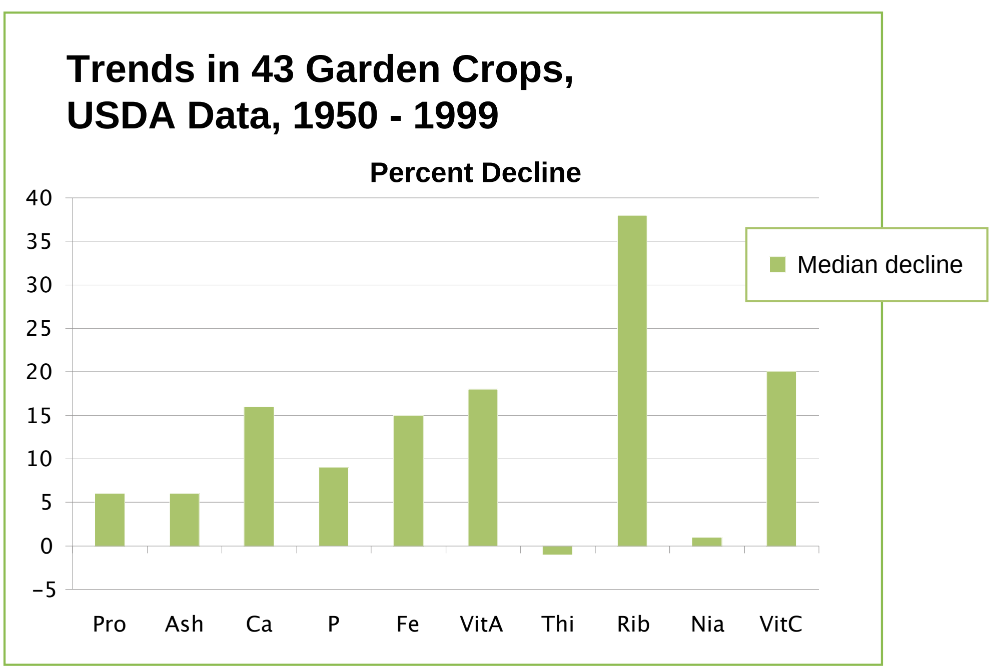
Declining average nutrient levels in the U.S. food supply have been brought about by what agronomists have labeled the "dilution effect," first coined in an important review article published in 1981 (Jarrell and Beverly, 1981). The remarkable increases in per acre crop yields brought about over a half-century through advances in plant breeding, the intensity of fertilizer and pesticide use, and irrigation are well known. However, few are aware that this achievement has come at a cost in terms of food nutritional quality.

A recent Critical Issue Report published by the Center in September 2007 describes in detail the evidence supporting the conclusion that there has been significant nutrient dilution across much of the U.S. food supply (including animal products). The report, "Still No Free Lunch: Nutrient Levels in U.S. Food Supply Eroded in Pursuit of Higher Yields," was written by Brian Halweil and is available from the Center's website (http://www.organic-center.org/science.nutriphp?action=view&report_id=115).

Nutrient Decline in Corn and Soybeans

The steady decline of protein levels in U.S.-grown corn and soybeans has emerged as a major concern in the grain trade since, after all, livestock farmers buying corn and soybeans are basically paying for protein to fuel animal growth. These

Figure 2.1



crops form the backbone of the animal-product portion of the food system, and so declines in average protein levels on the order of 20% in each crop are a cause of concern.

The declining protein content and quality of U.S. soybeans has, all likelihood, been triggered in large part by the adoption of genetically modified, herbicide-tolerant varieties, especially Roundup Ready (RR) soybeans.

The nutritional inferiority of RR soybeans has been documented by a team of scientists at Midwestern land grant universities (Karr-Lilienthal et al., 2004). They compared the protein content and quality of soybeans grown in the 2000-2001 seasons in Argentina, Brazil, the U.S., China, and India. Consistently, Argentinean soybean products contained the lowest level of crude protein, and at that time were about 95% Roundup Ready.

Soybeans from Argentina contained 32.6% crude protein on a dry matter basis, compared to 39.3% in Brazil, 37.1% in U.S. beans, and 44.9% in Chinese soybeans, none of which were genetically altered. When this study was conducted, about one-half of U.S. soybeans were RR, explaining why the U.S. soybean protein levels were intermediate between the almost-all RR beans from Argentina, and conventional (i.e., no RR) soybeans from China.

Today, virtually all non-organic soybeans planted in the U.S. are RR, and the depression in protein content, compared to conventional varieties, is likely comparable to the 25%-plus reduction reported in the Karr-Lilienthal study between soybeans grown in Argentina and China.

In the case of corn, average protein levels have fallen about 20%, from around 9% to 10% in the 1940s, to 7% to 8% today, and sometimes fall below 6%.

The University of Illinois Longterm Corn Experiment has been testing popular corn varieties for more than 100 years. Researchers report that:

> "Among recent commercial corn hybrids, increased yields have further reduced total protein levels." (Uribelarrea et al., 2004)

A separate study found that protein in corn plants decreased about 0.3 percent every decade of the 20th century, while starch increased by 0.3 percent each decade (Pollack and Scott, 2005).

B. The Plant Physiology Behind Nutrient Density

An apple tree or a cucumber plant starts off with genetic instructions that, within limits influenced by the growing environment of the plant, fix the number of cells in each individual apple or cucumber that ultimately will be harvested. The range of sizes of apples or cucumbers picked in a given season is determined by –

- Time of initiation and rate of development of individual fruit,
- Growing conditions during the season, especially temperature and the supply of water and nutrients to the plant,
- Whether and to what extent the plants experienced damaging pests, environmental stresses (e.g. frost), or problems in the soil (e.g. compaction, elevated salt levels), and
- Steps taken by the farmer to alter the number of fruits on a given plant.

Because each individual apple or cucumber starts out with a fixed number of cells, large fruit will contain, on average, larger cells, as well as more air space between the cells than will smaller fruit. These intercellular spaces between cells in a fruit contain few nutrients. For the most part, nutrients are present inside the cells, where growth and metabolic activity mostly occur.

Plants that receive ample to excessive water and nutrients, especially nitrogen, receive what amounts to a big physiological jolt, leading to what one scientist called "photosynthesis on steroids."[1] This surplus of nutrients increases the production of chloroplasts within plant cells, which increase the photosynthetic production of sugars, the precursors of carotenoids, as well as fats and protein in some cases.

This is why beta-carotene and Vitamin A are often higher in conventional fruits and vegetables – the carotenoids are among a few biosynthetic pathways of choice when a plant finds itself in the enviable position of having to make use of extra energy and nutrients. These same conditions, however, are what markedly increases the nitrate levels in fruits and vegetates, which is not desirable for overall plant or human health.

As long as a plant is receiving ample to high levels of nitrogen, other nutrients, water, and sunlight, it will continue vegetative growth, seeking to become larger (to out-compete neighboring plants for light, water, and nutrients). In addition, plants with ample to excess nutrients generally channel the products of photosynthesis to simple carbohydrates, starch, and carotenoids, and away from some important products for humans, such as, ascorbic acid.

The downward impact on ascorbic acid (Vitamin C) stems from the fact that plants do not trigger activity within the ascorbic acid biosynthetic pathway until the plant reproductive cycle has been triggered. [2] This happens at the point the plant determines that the time for vegetative growth is over, initiating a phase of maturation during which the plant diverts most of its remaining energy and nutrients to the physiological and morphological changes that must happen in order to set seed, and survive as a species.

Upon triggering the reproductive phase, roots are signaled to stop active uptake of most major and micro-nutrients. Any nutrient deficiencies or imbalances in the plant at this stage tend to be carried forward into the fruit (unless a farmer foliar-feeds the plant, which is often done to overcome deficient supplies of potassium, calcium, zinc, and boron).

In most high-yield, conventional farming systems where nitrogen is supplied in excess, plants grow vigorously with an abundance of vegetative growth (often requiring aggressive pruning and canopy management), produce extra chloroplasts, and hence elevated levels of carotenoids, but delay the reproductive process and production of Vitamin C. Such plants also experience a buildup of nitrates (a negative for food safety and nutritional quality).

Accordingly, relatively high levels of beta-carotene, nitrates, and relatively lower levels of Vitamin C are often found in the same sample of food because they all stem from the same physiological roots.

Conversely, in organic systems, levels of Vitamin C are typically elevated compared to plants grown in high-nitrogen systems, and there is little build up of nitrates, while beta-carotene levels are also somewhat depressed. This allows these plants to better deal with stresses from pests and climatic extremes, because of their enhanced ability to scavenge free radicals via Vitamin C and other antioxidant systems.

[1] Phrase from Dr. Gene Lester, Agricultural Research Service, USDA, as well as guidance in describing the physiology of plant growth (personal communication, October 13, 2007). Dr. Kirsten Brandt also contributed significantly to the ideas presented in this section.

[2] Some leafy green vegetables harvested during their vegetative stage can be a rich source of ascorbic acid/Vitamin C.

The findings in section V of this study are fully consistent with the above description on how the physiology of plant growth, development, and reproduction typically impacts the patterns and levels of various nutrients in food crops.

What Do Sugar-Highs and Nitrogen Forms have in Common?

In any well-designed study comparing organic versus conventional production systems, it is important that the total supply of nitrogen be equal. But one of the major differences between organic and conventional farms is the ***forms*** in which nitrogen is present within the soil and cropping system.

On conventional farms the majority of the nitrogen available to plants in the production season is applied as fertilizer in a synthetic form that is rapidly and readily available. On organic farms, on the other hand, nitrogen (N) is supplied in a complex matrix involving N stored in the soil, N affixed by legumes from nitrogen in the air, and N from composted manure, fish emulsion, and other soil amendments. These forms and sources of nitrogen are more slowly delivered and available to the plant.

The difference in forms of nitrogen on conventional and organic farms is important, as is the difference in how a person responds after eating a candy bar instead of an apple. Suppose the candy bar and apple has the same total amount of sugars. The rapidly available sugar in the candy bar triggers a spike in insulin (a problem for diabetics) causing a “sugar-high,” followed by a “crash” in human stamina due to rapidly depleting energy (sugar) levels. With the apple though, the sugars are slowly released due to the prolonged breakdown of the apple tissue’s complex matrix. There is no major spike in insulin, and instead a prolonged, steady period of available energy (sugar), with no sugar crash.

The rapidly available nitrogen in the conventional farming system diverts sugars from photosynthesis to produce more proteins and a spike in vegetative growth. And so the plant produces more leaves, and thus more chloroplasts, and then more carotenoids. Whereas in the organic system, the slower and prolonged supply of nitrogen does not trigger a spike in plant growth, allowing more photosynthetic sugars to be available for other metabolic functions such as producing more Vitamin C and polyphenols.

There is also an environmental dimension to this story. Because N becomes available more gradually in organic systems, the N supply tends to more closely match plant needs. This results in more N winding up in the plant, and less running off the field after a heavy rain, leaching into the groundwater, or being lost to the atmosphere.

Need to Focus on Phytochemicals

Science has made great progress in understanding the importance to human health of a range of secondary plant metabolites, many of which are essential vitamins and health-promoting antioxidants. According to Harborne (1999), secondary plant metabolites can be divided into four classes:

- Phenolic compounds (e.g., flavonoids and phenolic acids),
- Terpenoids (e.g., carotenoids and limonoids),
- Alkaloids (e.g., indoles), and
- Sulfur-containing compounds (e.g., glucosinolates).

These phytochemicals play direct roles in plant responses to biotic (i.e., those caused by insects or plant disease) or abiotic (i.e., caused by weather extremes, or soil nutrient imbalances) sources of stress. They also account for and are the source of the color of foods and contribute to each food's unique flavor.

In a broad and rapidly growing body of research, scientists are exploring the ways that plant secondary metabolites help promote healthy growth and combat disease in animals and people. Hot topics in the biomedical literature include how individuals can enhance cardiovascular health and reduce cholesterol levels, suppress pain and inflammation, prevent diseases such as cancer, and delay the aging process by increasing intakes of plant antioxidants. We reviewed much of this research in our State of Science Review "Elevating Antioxidant Levels in Food through Organic Farming and Food Processing" (accessible at http://www.organic-center.org/scienceantioxphp?action=view&report_id=3).

A small but also growing body of research has shown that methods used in organic farming are among the factors that can markedly, and in some cases dramatically increase the concentration of these plant secondary metabolites in harvested foodstuffs. Differences of 25 percent are common and in some studies up to 300 percent differences attributable to farming systems have been documented (see next section for more discussion).

C. Two Basic Questions

Several studies have shown that organically grown fruit and vegetables have, on average, higher nutrient density than conventionally grown produce, although other studies report little or no differences, and several studies report that for a few specific nutrients, conventionally grown food usually contains higher average levels.

Older research paints a different and in general simpler picture than the more recent, high quality studies. Older studies tend to focus just on relatively easy to measure vitamins and minerals, and pay little attention to polyphenol and antioxidant plant secondary metabolites, which typically require more sophisticated analytical methods to accurately quantify.

Considerable research in the last 15 years has improved both the experimental design of comparison studies and deployed much more sophisticated analytical methods in an attempt to more fully characterize any differences in nutrient content.

Some people and organizations, however, still express the view that there is insufficient quality science to determine whether organic farming typically, or on average, enhances food nutritional quality.

The goal of this SSR is to provide an up to date, rigorous quantitative assessment of all English-language peer-reviewed research in order to answer two questions as fully as possible, given our current scientific understanding —

Does organic farming generally enhance the nutritional quality of fruits, vegetables, and grains?

And if so, for which nutrients and by how much?

Presently, there are about a 100 published studies in peer reviewed journals or conference proceedings that effectively compare the nutrient content of organic and conventionally grown foods. These studies are based upon a wide range of experimental designs, and focus on many different foods, several food forms, and multiple farming system alternatives.

In the next section we summarize the major findings reported in the five peer-reviewed literature reviews published since 2000. Each describes the body of published literature then available to answer these two questions and offers general conclusions on what can be said in light of published science.

For the most part, the five reviews agree that consistent differences do exist for a few (and the same) nutrients, but more research is needed to determine whether organic or conventional farming systems offer generic nutritional advantages across most of the important vitamins, minerals, and antioxidants in food.

Fortunately, much new science has been performed on this topic since the five literature reviews were carried out. Section V presents the results of a quantitative analysis of the 97 studies published through the end of 2007 comparing the nutrient density of organic and conventional food.

A necessary first step, covered in section IV, is identifying from all published studies those experiments and results that are based on scientifically sound experimental designs in the field, coupled with reliable analytical methodology when harvested foods were brought into the laboratory for assessment of nutrient forms and concentration levels.

D. Key Caveats

Some important caveats need to be kept in mind in order to accurately interpret the findings of any given study, or any set of studies.

Multiple Factors can Alter Nutrient Density

Many factors impact the nutrient density of crops, whether they are grown organically or conventionally. Some factors impact both production systems equally, while a few factors tend to have a larger impact on one production system over the other.

Climate has an enormous impact on nutrient levels from one year to the next, or in one region compared to others. Patterns of rainfall and temperatures, in particular, have a large impact on plant growth and development. For any given region, crop, and cultivar, there are weather patterns that will in most years clearly favor organic crop nutrient density, in contrast to conventionally grown crops, and vice versa. In addition, weather patterns and growing conditions may impact different nutrients in different ways.

Three Key Factors to Control in Comparison Studies

Three major factors impacting nutrient density are plant genetics, the method and timing of harvest (especially ripeness), and climate. This is why the most reliable studies incorporate in their experimental designs identical genetics, fields that are either side-by-side or nearby, and crops harvested in the same way and at the same stage of maturity.

How a harvested crop is handled after it leaves the field has an enormous impact on the degree to which the nutrients in the crop at harvest remain in the food when it is eaten. For this reason, studies that measure nutrient density in foods right after harvest in their fresh form avoid several post-harvest factors that can mask or distort actual differences in nutrient levels at the time of harvest.

The Laws of Plant Physiology Render Universal Superiority Unattainable

Organic and conventional farmers are equally bound by the laws of plant physiology. There is no way to maximize all nutrients at once, regardless of genetics, systems, or human skill and effort. Because universal superiority is unattainable, the focus in comparative studies must be on general tendencies and average impacts over multiple years and locations on all nutrients of concern, and in particular, those nutrients for which intakes are often deficient in the human diet.

If a plant is managed organically and develops in a way that leads to higher levels of certain nutrients and core components of food (protein, carbohydrates, vitamins, minerals, and antioxidants) compared to a nearby conventional crop, it stands to reason that the levels of some other nutrients will have to be lower than in the food grown conventionally.

In fact, plant physiologists have uncovered some general rules of thumb regarding how levels of certain clusters of nutrients tend to respond in consistent ways – some increasing, others declining – as a result of certain growing and environmental conditions that impact the development and maturation of the plant.

Farming Systems Differ and are Dynamic

There is a vast and dynamic array of conventional and organic farming systems. It is nearly impossible to define with precision what any organic or conventional system encompasses. In fact, especially for many fresh fruit and vegetable crops, there has been a significant degree of convergence of practices used by organic and conventional farmers in recent years, in some regions.

For example in much of California's central coast region and Italy's Poe Valley, most conventional farmers have adopted some management practices and tactics initially developed for and/or pioneered by organic farmers. For this reason, contemporary comparisons of crop nutritional quality in such regions are likely to find less dramatic differences in nutrient density than if the studies were conducted 10 to 20 years ago.

Sudies Based on Samples Collected at Retail are Costly to Conduct

When researchers compare samples of organic and conventional fruits or vegetables purchased from supermarkets in a given area, or several areas, many factors may account for any differences observed in nutrient levels. A large number of samples would need to be tested in order to determine whether there are any consistent differences in the nutritional quality of organic and conventional foods purchased at the retail level.

To our knowledge, no team of scientists in the U.S., nor anywhere in the world, has been able to carry out a study large enough to support any general conclusions regarding differences in nutrient levels in a cross-section of organic and conventional fruits and vegetables obtained at the retail level. A few high quality studies have focused on a specific food, where enough samples bought from retail outlets were tested to support reliable conclusions regarding differences in nutritional quality for that single food.

III. Overview of the Published Studies and Literature Reviews Comparing the Nutrient Content of Organic and Conventional Food

The body of knowledge available to carry out a meta-analysis (or cross-study comparison) of levels of nutrients in organic and conventional food has dramatically expanded in recent years. The publication of some studies has triggered considerable criticism and controversy over the adequacy of experimental designs and analytical techniques.

Each debate has contributed to the incremental improvement in study design and statistical rigor. This is fortunate, since comparative field studies require a great deal of effort to carry out and are, as a result, resource intensive and time consuming.

The best place to study the performance of organic and conventional farming systems is on side-by-side, well-established organic and conventional farms. But when working with commercial operations, scientists do not have the same degree of control in carrying out a comparative study as they would if the plots were grown on a research station, where the research team is responsible for all decisions and field tasks.

The disadvantages in carrying out comparative research on operating farms, however, pale in comparison to the advantages stemming from the relevance of research results in addressing real-world farm management challenges.

A. Published Studies Comparing the Nutrient Content of Conventional and Organic Food

A variety of past reviews and bibliographic resources were used to compile 97 published studies comparing the nutrient content of organic and conventional foods. A list of these studies appears in Appendix 1, rather than in this study's generic bibliography.

Studies published before 1980 were not included because of questions about –

- The nature of the organic farming systems prior to the articulation of detailed organic production standards,
- Experimental designs, and
- Sample preparation techniques and analytical methods.

Studies published in the 1980s and 1990s account for 52% of the 97 studies, while newer work accounts for 48%, as evident in Tables 2.1 and 2.2

Interest in this topic has clearly grown. In the 1980s, only 1.2 papers appeared on average per year in the peer-reviewed literature. The rate more than tripled during the 1990s to an average 3.8 papers per year. Since the beginning of year 2000 until the end of 2007, the rate almost doubled again, resulting in a total of 47 papers, or an average of six per year.

Just in the last five years, 31% of the 97 papers have appeared. This is why any reviews on this topic that reflect published studies through 2002 are now outdated. Likewise, any individuals or groups that base their conclusions or opinions about the nutritional differences in organic and conventional food on these reviews need to take a fresh look at both the old and new evidence germane to the topic.

B. Review Articles Assessing Studies of Organic Food Quality

Five reviews have been published in peer reviewed journals since 2000 and each are briefly summarized in this section. The reviews reach similar conclusions, although the focus of each is somewhat different.

Brandt and Molgaard, 2001

One of the most provocative reviews published to date appeared in 2001 in the *Journal of the Science of Food and Agriculture* and was entitled

Table 2.1

Number of Peer-Reviewed Studies Comparing the Nutrient Content of Organic and Conventional Food in the 1980s and 1990s

	Total 1980s	Total 1990s	Total 1980s through 1990s	Average per Year in the 1980s	Average per Year in the 1990s
Number of Published Studies	12	38	50	1.2	3.8

Table 2.2

Number of Peer-Reviewed Studies Comparing the Nutrient Content of Organic and Conventional Food Since 1999

	2007	2006	2005	2004	2003	2002	2001	2000
Number of Published Studies	6	4	9	10	6	3	5	4

"Organic agriculture: does it enhance or reduce the nutritional value of plant foods?" Brandt and Molgaard, two Danish scientists, address in some detail the theories explaining why organic food might be more nutritious than conventional food.

They cover the effects of growing conditions on plant physiology and the production of primary plant and food constituents. They point out that "Generally, protein content increases with nitrogen uptake, and sugar content rises when phosphorous levels are low relative to other elements." In the case of Vitamin C, they note that levels tend to rise whenever a plant is subjected to oxidative stress, which can be triggered by sunlight, drought, or low availability of nitrogen.

They argue that while conventionally grown crops typically have somewhat higher levels of protein, this confers little benefit to humans in developed countries where more than enough protein is consumed as part of the average diet. They also question whether there are inadequate intakes of vitamins and minerals as well, but do conclude that intakes are clearly deficient of antioxidant plant secondary metabolites, and that fruits and vegetables are uniquely important in providing these nutrients to people.

In one of the most interesting parts of the review, they point out that plant secondary metabolites can be toxic when consumed at high levels, and indeed become pro-oxidants as opposed to antioxidants. They explain that some plant secondary metabolites are anti-nutrients (compounds that make protein and other nutrients less bioavailable). In this way, they can mimic the consequences of caloric restriction by making nutrients less bioavailable, and in this way actually improve health (Brandt and Molgaard, 2001).[3]

In terms of specific nutrients, they report no consistent differences between organic and conventional foods for most vitamins and minerals, but higher protein and nitrate levels in conventionally grown crops. They also note that organic crops "have more intrinsic resistance than conventional ones, since they can cope so relatively well [with plant pathogens] without the protection of pesticides."

Based on all the evidence they reviewed and their research experience, the authors were able to reach a tentative conclusion on antioxidant levels:

> "…we will dare to estimate levels of plant defence-related secondary metabolites in organic vegetables to be 10-50% higher than in conventional ones."

The most recently published studies cited in the Brandt-Molgaard review appeared in 2000.

Worthington, 2001

A comparison of mineral and vitamin levels in food produced with organic and conventional fertilizers was published in the *Journal of Alternative and Complimentary Medicine* by Virginia Worthington and has been widely cited because of its simple, straightforward approach and findings. Worthington focused on studies of fertilizers and food nutrient levels because "fertility management is historically the most fundamental difference between organic and conventional agriculture."

The Wilcoxon signed-rank test was used to identify statistically significant differences in nutrient levels across 41 published studies encompassing 22 replicated field trials, four simple field trials, four greenhouse pot studies, four market basket surveys, and eight surveys of commercial farms or home growers.

Most of the studies used in this meta-analysis were published in the 1970s and 1980s, and no study that appeared after 1999 was cited.

Twelve nutrients were analyzed, most of them minerals. Four nutrients were significantly higher in organic food than in conventional food, while

[3] The Organic Center will release in the summer, 2008 a State of Science Review focusing on obesity and diabetes. The rapidly growing body of knowledge on the role of antioxidants in triggering a sense of satiety (fullness), and in mimicking the positive effects of caloric restriction will be discussed in detail.

one "toxic" substance (nitrate) was significantly lower (a desirable difference) in organic food. The nutrients studied and percentage differences of organic food relative to conventional foods were:

- Vitamin C, +27%
- Iron, +21%
- Magnesium, +29%
- Phosphorous, +14%
- Nitrates, -15%

Data was presented reporting the range of differences in nutrient levels in a variety of vegetables. Evidence also indicated a trend toward higher protein levels in conventional food, but higher quality protein in organically grown foods. (The balance of amino acids in protein determines its "quality" in terms of meeting human nutritional needs).

Bourn and Prescott, 2002

Two scientists from New Zealand published an in-depth comparative review of the sensory (taste, aroma) and nutritional value of organic versus conventional foods, and also assessed differences in food safety. The Bourn and Prescott paper came out in 2002 and covered the literature through most of 2000.

They highlighted the lack of well-designed comparative studies encompassing sensory and nutritional quality, as well as food safety. They concluded that there is strong evidence in support of a difference in the nutritional quality of conventional and organic foods only in the case of nitrates.

They also stressed the need for more research on the impacts of farming systems on nutrient forms and bioavailability, a theme echoed in more recent reviews and the biomedical literature.

They concluded that existing studies were inadequate to draw any conclusions on the sensory differences between the two farming systems. They also conclude there is no evidence of significant differences in the susceptibility of organic or conventional food to microbiological contamination. Last, they noted that organic foods typically contain fewer and lower levels of pesticide residues, but also note the lack of documentation in support of this conclusion.

Williams, 2002

Christine Williams, a nutritionist at the University of Reading in the U.K. published a study focusing just on nutritional quality in the *Proceedings of the Nutrition Society*. She focused on studies comparing nutrient content, as well as several reports of animal feeding studies with organic or conventional feed. She notes "reasonably consistent findings for higher nitrate and lower vitamin C contents of conventionally-produced vegetables, particularly leafy vegetables." Otherwise, there are too few high-quality studies to draw conclusions or too many conflicting results in the literature.

As in the case of the Bourn and Prescott review, the most recent study cited by Williams came out in 2000.

Magkos et al., 2003

Nutrition and dietetic experts from Greece published the most recent review to appear in a peer-reviewed journal, in this case the *International Journal of Food Sciences and Nutrition*. They noted the lack of well-designed studies and concluded that results need to be interpreted "with caution." Still, they identified some differences, including slightly higher levels of ascorbic acid/ Vitamin C in organically grown leafy greens and potatoes.

They also note a trend toward lower protein concentrations, but higher protein quality in some organic vegetables and cereal crops. They also conclude that there is evidence of a slight improvement in animal health and reproductive performance when fed organic animal feeds.

Three studies published in 2002 were cited by the Magkos et al. review. One reported on a consumer survey, the review by Bourn and Prescott was cited, and an original research report on sheep nutrition and health was discussed. Accordingly, this review also reflects the published literature only through 2001.

Need for a Contemporary Review

There has been no new published review on this topic since 2003, and the most recent review was based on literature through 2001. In the ensuing six-plus years more than forty new studies have been published (including those shown in Table 2.2 on page 17, plus several that have appeared in the first two months of 2008).

Accordingly, the time has come for new reviews to be published review of the literature on comparative nutrient levels in organic and conventional food. The Food Standards Agency in the U.K. has recently commissioned such a review, scheduled to be released by mid-2008. A team of European scientists affiliated with the Quality Low-Input Food (QLIF) project is working on a comprehensive review of plant-based food, which should be published in mid- to late 2008, and another QLIF team has begun work on a review that is focused on animal products.

The team that carried out the current study for The Organic Center is also working on a more sophisticated statistical analysis of this body of literature, and will include several new studies that have appeared in the first months of 2008. This review will hopefully be published in an appropriate peer-reviewed journal in due course.

C. Methodological Issues in Comparing Nutrient Levels in Organic and Conventional Foods

Because so many factors impact the nutritional quality of food, studies seeking to compare the nutritional quality of conventional and organic foods must be designed to eliminate or control, to the fullest extent possible, multiple potentially confounding variables.

Two articles have addressed directly the proper design of studies striving to compare the performance of alternative farming systems. In 1997 van der Werf et al. published a paper entitled "Methodological Issues in Comparative Agro-Economic On-farm Research Assessments of Organic Versus Conventional Farming Techniques" in the U.K. journal *Biological Agriculture and Horticulture*. While the focus of the paper is on carrying out such studies in developing countries, the basic issues addressed, and suggestions made, apply universally.

The need for clear definitions of the production systems being compared is emphasized. The authors recommend use of the International Federation of Organic Agricultural Movements (IFOAM) definition of organic farming. They argue that conventional agriculture should be defined "as the most common set of agricultural practices of the research population" (van der Werf et al., 1997).

Three possible approaches are described to carry out comparative research –

- Single farms are compared with regional averages;
- Matched pairs (or groups) or farms and/or fields are identified, each containing an organic and conventional farm/field; or
- A controlled experiment is carried out on a research station, emulating to the extent possible organic and conventional systems.

The authors favor the second approach for several reasons including its relevance to commercial operations, ability to select matched pairs that control for a variety of confounding variables, and tendency to produce more reliable results. They also recommend that research teams focus on defined sets of practices, as opposed to whole-farm performance, because the later raises so many additional analytical and data collection challenges.

Ideally, farmers should have at least two years of experience in carrying out a given organic technique before they are asked to participate in a comparison study. In addition, it is important to assure that the farms, and farmers, chosen to be included in a matched pair are representative of a broader population of organic and conventional farmers.

Optimal Design Features in a Rigorous Comparative Study

Dr. Gene Lester, a plant physiologist at the Kika de la Garza Subtropical Agricultural Research Center in Weslaco, Texas, authored a 2006 review in *Hort Science* entitled "Organic versus Conventionally Grown Produce: Quality Differences, and Guidelines for Comparison Studies." Lester reviews several published studies, often critically, and describes many methodological flaws in study design and conduct that can lead to questionable results.

He notes the "huge variability" in the data on nutrient content, and points out that this complicates the interpretation of this body of data as a whole. He traces the variability in study results to difficulties in controlling or standardizing the basic factors impacting plant development and yield. Still, he argues, "….there is a wealth of information in the available data and with proper standardization, consistent conclusions may be extracted…" (Lester, 2006).

He argues that it is critical to control for the influence of production practices, handling, and storage variables, all of which can alter nutrient levels. A rigorous study protocol is described in detail, based on work done at the de la Garza

Center on conventional and organic grapefruit. He also offers a general set of principles to follow, to the full extent possible, during the growing season, at harvest, and post-harvest.

According to Lester, the growing season/preharvest conditions that should ideally be met in a high-quality comparison study include –

- Organic site must be certified organic.
- Identical soil textures throughout the root-growth profiles, and comparable soil quality.
- Identical previous crops.
- Similar irrigation methods, source, and amounts.
- Study sites as close as possible in proximity (without violating the separation requirements in organic production standards).
- Identical cultivars and/or ages of plants/trees/vines.
- Repeat study for three or more years, or three crop cycles.
- Record all production inputs.

The harvest requirements include the same method of harvest, same size and maturity of fruit, same time of day (nutrient levels can change dramatically over night, and then again by nightfall), and harvested raw foods should be held, transported, and stored the same way until nutrient testing is carried out.

While Lester agrees that more rigorous data will enlighten the ongoing debate over the nutritional quality of organic and conventional food, he contends that:

> "The real benefit of these comparisons is that they will identify the production input weaknesses and strengths that affect taste and nutrition, so that changes can be made to improve both organic and conventionally grown produce" (Lester, 2006).

The insights described by Lester and van der Werf on the often tricky challenges confronting researchers carrying out comparative studies of the nutritional quality of organic and conventional food were taken into account in designing the screening methods to identify valid studies, as well as the criteria used to select matched pairs of organic and conventional foods for inclusion in cross-study nutrient comparisons. Both are explained in section IV.

IV. Screening Methods and Selection Criteria to Identify Valid Matched Pairs

The goal of this study is to determine whether the published, high-quality comparative studies of the nutrient content of organic and conventional foods favor the organic, conventional, or neither production system.

We also examine the magnitude of differences for various key nutrients across organic and conventional foods, in the hope of determining whether or not organic farming does indeed produce, on average, more nutritious food.

Our Approach

Two steps were required to answer this study's two basic questions:

1. To identify scientifically valid studies in which nutrient contents of matched pairs of organic and conventional foods have been measured when grown under largely identical circumstances – other than the differences between organic and conventional farming methods.

2. To determine whether the differences, on average, favor organic, conventional, or neither production system across the complete set of matched pairs in which organic and conventional food values for a given nutrient have been measured.

Using two simple methods to characterize the magnitude of differences observed in the matched pairs for individual nutrients, we report differences in nutrient levels for those nutrients that have eight or more valid matched pairs. Eleven nutrients meet this test.

This section describes how we accomplished the first step – identifying a set of valid matched pairs of organic and conventional foods.

Past reviews of this body of literature have used various screening criteria to select from all available studies those that are deemed "acceptable," "valid," or "reliable." We concur that such screening is necessary in a meta-analysis of published study findings.

Because many of the studies before 1980 were carried out with questionable experimental designs, analytical methods, and before there was a clear definition of organic farming systems, we did not review nor include any study published before 1980. In addition, we developed and applied to 97 published studies two screens focused on:

- A study's experimental design and agronomic features (covered in section A); and
- The analytical methods used to measure and report nutrient levels (section B).

Several studies include results on more than one crop. We applied each of the two above screens independently to each crop included in a given study.

We developed and applied a set of criteria and decision rules for each attribute or method within a screen, and on the basis of these criteria and rules assigned all study-crop combinations into one of three categories – high quality, acceptable, or invalid. Studies were independently evaluated by a panel of five scientists with expertise in nutrition, horticulture, agronomy, statistical methods, farming systems, organic standards, and phytochemical analysis.

Any study-crop combination that was deemed “invalid” in the agronomic practices and experimental design screen was not analyzed further, and no results were included in the cross-study comparisons of nutrient levels in the organic and conventional samples within a matched pair.

Any study-crop combination that was judged “high quality” or “acceptable” based on the agronomics and experimental design screen was then reviewed using our analytical methods screen.

In the case of analytical methods, we assessed each method for a given nutrient independently. Therefore, in a given study, the method used to measure organic acids may be deemed “acceptable,” while the total antioxidant capacity method may be judged “invalid.” The criteria and decision-rules governing these judgments are explained below. All results linked to study-crop combinations with analytical methods deemed “invalid” were excluded from further consideration.

The Universe of Studies

As noted in the previous section, a wide range of studies conducted over decades have compared the nutrient profile of organically and conventionally grown foods. The studies have varied in many ways:

- The definition, nature, and longevity of organic and conventional production systems,
- Field protocols and experimental design,
- Soil types and fertility treatments,
- Plant genetics,
- Pest management and other cultural practices,
- Harvest methods and timing,
- Post-harvest handling, and the food form tested (e.g., fresh, dried, canned, frozen),
- The nutrient types and forms measured, how samples were prepared for testing, measurement tools and techniques, and the basis for reporting results (dry-weight basis, fresh-weight basis, etc), and
- The statistical tests used to probe for significant differences in nutrient levels in organic and conventional food samples within matched pairs.

In a few studies a single organic system is compared to a single conventional system, while most involve two or more variations of an organic system, and/or one to several variations of conventional systems. Around a quarter of all studies report results on production systems characterized as sharing some, but not all features of organic and conventional systems (e.g., IPM-based, integrated, or low-input systems).

Some studies present results from a single location and year, but most studies report results for multiple years, multiple locations, different cultivars, different sources of nutrients (e.g., chicken manure, compost), and specific practices (e.g., use of a cover crop, a specific rotation).

For example, a given study might report a dozen or more comparisons of specific vitamin, mineral, or antioxidant levels in matched pairs of organic apples, cucumbers or leafy vegetables, versus conventional apples, cucumbers, or leafy vegetables.

The greater the number of matched pair comparisons from a given study that are included in cross-study analyses, the more weight that is implicitly assigned to that study in terms of the outcome of cross-study analyses (assuming the results from each matched pair are assigned equal weight).

A method is therefore needed, in the context of the current study, to minimize this potential source of reporting bias. For this purpose, we developed a set of criteria and decision rules that governed our selection of which matched pairs of nutrient data from a given study would be incorporated in our cross-study analyses (see section C). Collective adherence to all the decision rules determined the total number of matched pairs included from a given study.

A. Agronomic Practices and Experimental Design Screen

The purpose of the agronomic practices and experimental design screen is to assure that any differences observed in nutrient levels within a matched pair of foods can, with a high level of confidence, be attributed to differences in the production systems, rather than other factors, or simply chance.

Each matched pair of fields includes a field managed "conventionally" and another field managed "organically." Ideally, the two fields selected for a matched pair have been managed at a comparable level of skill, in order to remove, or at least minimize, the possible impacts on crop nutritional quality of the timeliness and precision with which routine farming practices were carried out (e.g., tillage, plant spacing, weed control, and canopy management when applicable). Based on the information presented in most published studies, it is rarely possible to determine the degree to which this condition is met.

In general, conventional fields should be managed using methods and inputs that are typically applied in the area on farms that do not aspire to, or follow a defined set of farming practices or philosophies like organic, biodynamic, ecological, or natural. In general, such farms typically are more specialized and rely on purchased chemical fertilizers and synthetic pesticides that may not be used on organic farms.

Two factors are used in the current study in assessing the validity of the organic fields included in a matched pair – the nature of the organic system, and the time under organic management. Sufficient information must be provided in a published study to determine whether the practices used on a field adhere to, or are largely consistent with the basic national or international standards and production requirements applicable to organic production.

The time period under continuous organic management is a second classification criterion. The biological benefits of organic farming rest upon changes in soil quality, nutrient cycling, biodiversity, and pest management dynamics, and these changes take time to fully develop.

The agronomic practices and experimental design screen described below was developed in light of the specific objectives of this study.

It is important to stress that several studies judged "acceptable" or "high quality" based on this study's two screens might be "invalid" based on a different set of screens and criteria developed in response to another study's objectives.

This study's agronomic practices and experimental design screen includes five criteria:

- Experimental design,
- Soil type and field topography,
- Crop variety and cultivar (plant genetics),
- Type of study,
- Organic standards followed, and
- Years under organic management.

Each study-crop combination is judged as high quality, acceptable, or invalid for these five attributes. A point system was developed as shown in Table 3.1. Study-crop combinations scoring 12 or more points out of a possible 30 were judged "acceptable" or "high quality" based on this screen; the analytical methods screen was then applied to each valid study-crop combination.

Experimental Design

Studies classified as "acceptable" or "high quality" will include a recognized experimental design, coupled with an appropriate statistical methodology for testing differences in nutrient levels. These can include complete random design, randomized complete block design, split plot design, or related terms, to describe the plot layout and design structure of the experiment.

Table 3.1

Agronomic Practices and Experimental Design Scoring System: Criteria and Points Assigned for Invalid, Acceptable and High Quality Studies, and Basis for the Final Classification of Studies (Maximum of 30 Points Possible)

Criterion	Invalid	Acceptable	High Quality
Experimental Design	0	3	6
Soil Type and Topography	0	3	6
Crop Variety/Cultivar	0	3	6
Type of Study	0	2	4
Organic Standards Followed	0	2	4
Years Under Organic Production	0	2	4
Overall Classification of Studies Based on the Sum of Points from the Six Criteria	**<12**	**12 to 19**	**>19**

The results of the agronomic practices and experimental design screen for the 135 study-crop combinations in the 97 published studies included in this analysis are posted as part of this report's "Supplemental Information" on the Organic Center's website (http://www.organic-center.org/sciencenutriphp?action=view&report_id=124). The supplemental information shows the classification and score of each of the six categories, and total scores. The table listing study-crop combinations appears in two ways: studies in alphabetical order, and second, studies ranked by aggregate scores.

Based on the cutoffs in Table 3.1, 94 study-crop combinations are judged as valid because they are "acceptable" or "high quality," or 70% of the total. The remaining 41 were classified as "invalid" (aggregate scores less than 12).

A study may be classified "acceptable" if the plot design and nature of replicates is described, or can be derived from the materials and methods section of the paper.

Some studies compare crop nutrient levels between a single organic field and a single conventional field. Even when multiple samples are taken from each field, this sort of study lacks statistical power because of the absence of independent replication, especially if just one year of data is collected.

Such single matched pair, study-crop combinations will be deemed "acceptable" under two circumstances:

- First, when two or more years of data are collected, and the experimental design is otherwise acceptable.

- Second, in the case of a study based on one year of data, when an appropriate method is used for the random collection of samples within each field, and information in the research report shows clearly that the fields have been managed no less than three years consistent with conventional and organic practices typical to the region.

"High quality" studies are those containing a well-defined plot design, at least three independent replicates, and a clear explanation of the statistical analysis carried out. ("Independent" means samples are taken from randomly assigned plots, a different location, or in another year).

Soil Type and Topography

A given study-crop will be considered as "invalid" if the soil type and/or topography of organic plots are significantly different from the conventional plots, e.g., sandy loam for organic and clay loam in the conventional field.

In studies classified as "acceptable," the soil type and topography of organic plots is similar to, or the same as that of the conventional plots. Minor differences in field topography and soil classification and characterization are acceptable, as long as there is no reason to predict that the differences would markedly alter soil productivity, crop nutrient levels, and soil water-holding capacity.

In the "high quality" study-crop combinations, the soil types and topography in organic and conventional plots are nearly identical, and adequate information is reported to support such a conclusion.

Crop Cultivar

A given study-crop combination will be classified as "invalid" if the variety or crop cultivars under investigation are different between the organic and conventional treatments, or when no information is provided regarding plant genotypes.

In "acceptable" study-crop combinations, adequate information must be offered to determine that the same or similar cultivars were grown and harvested in the organic and conventional plots. In the case of grafted crops (usually fruit crops), the scion must be the same or similar genotype, while the rootstock may vary.

"High quality" studies, or crops within a study, will require identical cultivars for organic and conventional production, including both scion and rootstock, in the case of grafted crops.

Type of Study

There are three major types of studies comparing organic and conventional food nutritional quality: food purchase studies, on-station experiments, and commercial farm trials. In food purchase studies, conventional and organic food products are purchased from retail markets. Typically, no or incomplete information is available on crop variety/cultivar, soil, and cultural practices.

For this reason, food purchase studies are considered "invalid" given the purpose of this study. Such studies also almost always are judged "invalid" in other criteria, and hence do not reach the 12 point threshold for being judged "acceptable" for the purposes of this study.

On-station experiments and commercial farm trials are classified as "acceptable" or "high quality" as long as the production systems and farming methods are carried out in a way that is deemed representative of commercial operations in the region.

"High quality" on-station or commercial farm trials use well-characterized production systems that closely reflect contemporary commercial production systems, tactics, and practices.

Organic Standards Followed

Study-crop combinations, and sometimes entire studies, are classified "invalid" when:

- Inadequate information is provided to determine whether a defined or typical set of national or international organic standards was followed, or
- A production input or practice was used that is incompatible with widely accepted national or international organic standards and requirements.

"Acceptable" study-crop combinations include organic fields that were, according to the authors, managed under a recognized set of organic standards, or equivalent or stricter standards (e.g., biodynamic), assuming there is no information reported that would raise uncertainty over whether widely accepted organic practices were in fact followed.

"High quality" studies include organic fields that were managed in compliance with recognized national or international organic production standards and certified as organic by an independent third party, or described in sufficient detail to support a judgment that the field would likely have been eligible for certification.

Years Under Organic Management

A study-crop combination will be classified as "invalid" if the organic field or fields have been under continuous organic management for less than four years, with one exception noted below.

"Acceptable" studies include organic fields that have been managed organically for at least four years, including any years during the transition from conventional cropping. An organic field that was recently converted from fallow or pasture may be classified as "acceptable" after two continuous years under certified organic management, as long as the field had not been treated with a prohibited input or practice for at least two years prior to the conversion.

"High quality" studies include organic fields that have gone through at least two full rotational cycles under continuous organic management, or in the event of perennial crops, no less than four years of certified organic production following the transition from another production system.

Studies lacking the information needed to evaluate length of time under organic management will be classified as "invalid."

B. Analytical Methods Screen

Most comparative studies assess a range of nutritional parameters including macronutrients (protein, fat, fiber), vitamins, minerals, individual antioxidants and flavonoids, and total phenolics and antioxidant capacity. The validity of these methods have been assessed and classified as "invalid," "acceptable" or "high quality." These judgments have been made for each method used to measure a given nutrient in a study-crop combination.

Unspecified, undocumented, or unclear methods are classified as "invalid."

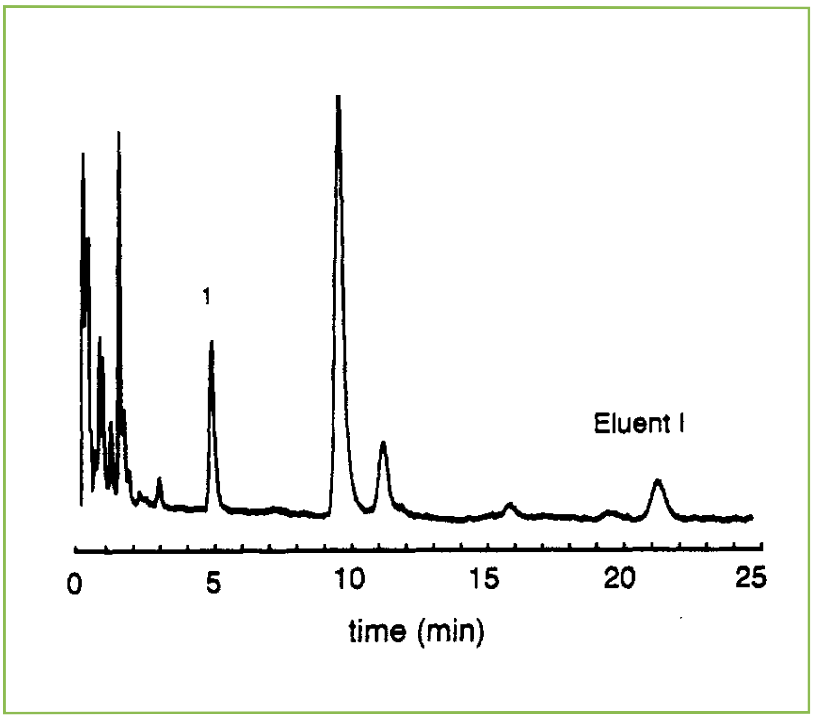
When the authors report that they used a published method, and a valid citation was given for the method, the original citation was obtained and reviewed to determine if the method was adequately described and validated.

A method was classified as "acceptable," unless data is reported in a study that raises questions about the accuracy of the method or the consistency of its application over time.

For example, chromatographs for methods reporting HPLC-based results were reviewed to assess separation and baseline resolution. The peaks representing individual compounds should be well separated, with adequate baseline separation and time separation from other compound peaks. There should be no endogenous peaks causing overestimation in the concentration calculations linked to the peaks of interest.

An example of such high-quality chromatographs is presented in Figure 3.1. This flavonoid-HPLC method was employed in the yellow plum study of Lombardi-Boccia et al. (2004). Note the baseline resolution of peak 1 (luteolin) and 2 (apigenin) without interfering peaks. The authors adequately report CV% < 12% and recoveries > 88% (Hertog et al., 1992).

Figure 3.1.



Representative High Quality Chromatograph Produced by Analytical Methods Deemed "High Quality" (extracted from Hertog et al., 1992).

A chromatograph produced by a method deemed "invalid" appears in Figure 3.2. The carotenoids method producing the chromatograph in Figure 3.2 was also employed in the yellow plum study of Lombardi-Boccia et al. (2004). Note that peaks 16 and 16' (trans- and cis-b-carotene respectively) are not separated. Most of the other carotenoids are poorly resolved (no baseline resolution), plus there are other compounds of interest eluting at similar time points.

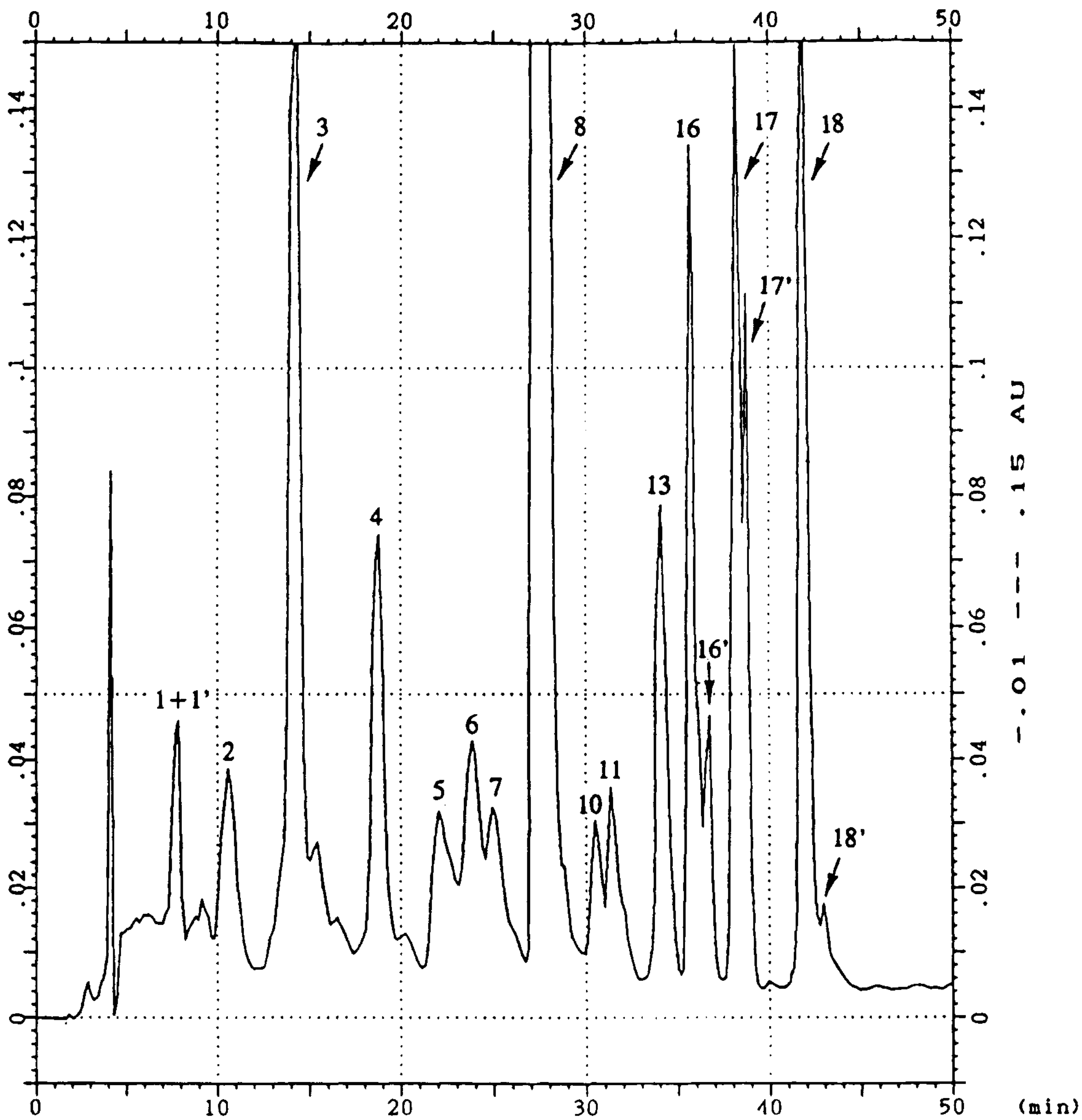
This feature in a chromatograph makes it impossible to accurately and reliably quantify the concentration of the compounds associated with these mixed and overlapping peaks (see peaks 5, 6, and 7). Furthermore, the authors report a CV% of up to 32%, indicating high variability and lack of reproducibility (Tonucci et al., 1995).

Chromatographs that display baseline resolution of peaks of interest, absence of endogenous peaks, and absence of peaks overlaying each other will be regarded as "acceptable."

In order for a method to be judged "high quality," the method must have a CV% or RSD% values lower than 16% and bias percentile values lower than 12%, or similar parameters indicating adequate reproducibility, accuracy, and precision.

Variations of published methods are often used to quantify individual phenolic and antioxidant compounds. Variants of published methods that have been validated will be regarded as "acceptable," as long as there is no evidence in the paper suggesting a lack of precision or resolution in the modified method (i.e., a CV% or RSD% values higher than 16% and bias percentile values higher than 12%).

Figure 3.2



Representative Chromatograph Displaying Problems Sufficient to Classify an Analytical Method "Invalid" (extracted from Tonucci et al., 1995).

For methods to be judged "high quality," they must be baseline resolved, have absence of endogenous peaks, and absence of peaks overlaying each other. The method also must be validated, with CV% or RSD% values lower than 16% and bias percentile values lower than 12%, or similar parameters indicating adequate reproducibility, accuracy, and precision.

Total phenolics quantification will be "acceptable" if the method is published, validated, and widely used, such as the Folin-Ciocalteu method. A total phenolics method will be judged "high quality" if it has relatively low levels of variability (SD lower than 15%, SEM lower than 12%).

For total antioxidant activity, there are multiple methods, each with several variations. These methods will be judged "acceptable" if they report adequate method-related reliability (SD lower than 15%, SEM lower than 12%). "High quality" total antioxidant methods will also be characterized by relatively low variability (SD lower than 15%, SEM lower than 12%), and the inclusion in published papers of adequate information to apply these, or related tests of analytical variability/reliability.

Results of Analytical Method Screen

Table 3.2 lists the 55 study-crop-analytical method combinations deemed "invalid" based on the criteria in the analytical methods screen.

Table 3.2

Analytical Methods Deemed "Invalid" for Specific Crops and Nutrients		
Nutrient	**Crop**	**Study and Year**
Total Antioxidants	Tomato	Pascale (2006)
Individual Phenolics	Apple	Weibel (2000)
	Wheat	Mazzoncini (2007)
	Wine	Tinttunen (2001)
Individual Flavonoids	Apple puree	Rembialkowska (2007)
Carotenoids	Tomato	Pascale (2006)
	Tomato	Schulzova (2007)
	Beef	Walsh (2006)
	Yellow plum	Lombardi-Boccia (2004)
	Lettuce	Rattler (2005)
Lycopene	Tomato	Schulzova (2007)
Phosphorous	Apple	Weibel (2000)
Potassium	Apple	Weibel (2000)
	Carrot	Rembialkowska (2003)
Minerals	Potato, pea, onion, cabbage, carrot	Fjelkner-Modig (2000)
	Tomato	Premuzio (1998)
Vitamins	Potato, cabbage	Ruthovieve (1997)
	Tomato	Schulzova (2007)
Vitamin C	Peach, pear	Carbonaro (2002)
	Potato, cabbage, carrot, onion, pea	Fjekner-Modig (2000)
	Potato	Rembialkowska (1999)
	Potato, cabbage	Rutkoviene (1997)
	Tomato	Schulzova (2007)
	Apple	Tarozzi (2004)
	Orange	Tarozzi (2005)
	Apple	Weibel (2000)
Protein	Potato, red beet, wheat, carrot	Raupp (1997)
	Wheat	Mazzoncini (2007)
	Beef	Walsh (2006)
Nitrate	Pea, carrot, cabbage, onion, potato	Fjekner-Modig (2000)
	Beetroot	Mader (1993)
	Multiple	Malmauret (2002)
	Lettuce	Rattler (2005)
	Potato	Rembialkowska (1999)
	Potato, carrot	Rembialkowska (2003)
	Leafy vegetable	Sanchez (2005)

C. Outlier Values

Some studies report “outlier values” that warrant special assessment. An outlier value for a given nutrient is one that differs from the mean of all other values by a substantial margin, say for example, by two or more standard deviations.

For example, in most studies, Vitamin C levels in the organic and conventional samples tested of a given food vary by no more than 30%, either within all conventional or organic samples, or between organic and conventional samples. One study, however, reports two Vitamin C levels in matched pairs that are dramatically different than all other values.

In the study by Warman et al. (1997; see Appendix 1 for bibliography), the organic value for Vitamin C in a matched pair of cabbage samples is 29-times higher than the conventional value, because the conventional value was about 20-times lower than the typical levels found in cabbage. A second matched pair in the same study, this time involving carrots, contained 29-times more Vitamin C in the conventional sample, compared to the organic carrot sample. In this case it is the conventional carrot Vitamin C level that is far higher than any other reported Vitamin C level in carrots (499, compared to a range of 17 to 34 in four other carrot matched pairs)

In addition to the two matched pairs with outlier Vitamin C values in the Warman et al. study, an outlier value for the antioxidant kaempferol was reported in a matched pair of cabbage plants (Ferreres et al., 2005). In this case, the level in the organic sample was 47-times higher than the conventional sample, probably because of heavy insect damage on the outer leaves of the cabbage.

If this matched pair had been retained in the cross-study comparison of kaempferol levels, a small advantage in favor of the organic samples in 11 matched pairs (about 5% higher) would have ballooned to a 4.9-fold advantage across 12 matched pairs.

The only plausible explanations for such a value are that some highly unusual combination of factors impacted the plant in the field, or mistakes were made in sample preparation and/or in carrying out the analytical chemistry.

An outlier value triggers a more in-depth review of methods and research reports to see if the authors described any factors that might explain the physiological basis for the outlier value. In the absence of a plausible explanation, the study-crop-method combination producing an outlier value is classified as “invalid.”

D. Criteria for Selecting the Matched Pairs from a Study for Inclusion in Cross-Study Analyses

Most studies encompass comparisons of multiple matched pairs in several locations, and/or under alternative fertility or pest management practices, and often over two or more years. Twenty or more comparisons of nutrient levels are included in some studies, while others might report a single comparison.

The goal of the current study is to determine whether the majority of published studies support a conclusion that nutrient levels in organic food are higher, lower, or the same as levels in conventional foods. We developed a set of criteria and decision rules to identify how many, and which matched-pair results to include from a given study in cross-study comparisons, in order to minimize bias in cross-study analyses based simply on the number of results reported in a given study.

Seventeen Rules Guided Selection of Matched Pairs

Seventeen decision rules were developed to determine which matched pairs from a given study would be selected for inclusion in cross-study meta-analyses. Adherence to each of these 17 decision rules collectively determines how many matched pairs, in total, are included from a given study in the cross-study analyses of differences in the levels of a specific nutrient.

1. If different types of crops are investigated, at least one matched-pair set of fields for each crop will be included in cross-study nutrient level comparisons.

2. If distinct cultivars are planted or studied for a given crop, a matched paired of fields/results for each cultivar will be included in cross-study comparisons.

3. If a nutritional attribute is measured over time at different plant growth stages, only one pair of comparative data will be included representing the crop stage closest to typical maturity at harvest. If a crop is commonly consumed at two distinct life stages, a second pair of data may be included.

4. If a study is conducted over multiple years and matched pair results are only reported independently for each year, a matched pair of results for each year will be included, unless the authors highlight some endogenous factor(s) impacting the results in a given year, or years, that raise uncertainty regarding either the accuracy of the results, or the degree to which the results reflect typical production conditions. Such unusual cases will not be included in the cross-study analyses. In studies where results are reported for individual years, as well as averages for all years combined, the matched pair data for the pooled, all-years comparisons will be used.

5. If the study is conducted at different locations, a matched pair for each location will be included in cross-study comparisons, unless the authors highlight some endogenous factor(s) impacting the results from a location that raise uncertainty regarding either the accuracy of the results, or the degree to which the results reflect typical production conditions.

6. If several organic or conventional treatments are investigated, the matched pair chosen will represent the most common organic and conventional treatments.

7. If organic, biodynamic, low-input, integrated, and conventional treatments are all studied, only matched pairs involving organic and conventional systems will be included when assessing differences in nutritional parameters across studies.

8. In studies lacking fields classified as "conventional," other terms will be accepted as the functional equivalent of "conventional", as long as the reported information supports a judgment that the system involves inputs, practices and tactics comparable to those on most conventional farms in the area.

9. In studies lacking fields classified as "organic," other terms will be accepted as the functional equivalent of "organic," as long as evidence is reported that supports a judgment that the system involves inputs, practices and tactics comparable to organic systems that comply with defined, recognized national or international standards.

10. If different food forms are assessed, e.g., fresh, frozen, or dried, matched pairs for fresh food (or the least processed food form) will be selected for use in nutrient level comparisons across studies.

11. When a study reports results for food stored under different conditions for different periods of time, the matched pairs included in cross-study analyses shall be stored in the same way, and for the least amount of time.

12. When different storage technologies or temperatures are used, the matched pair chosen for cross-study analyses shall be the one most likely to retain or preserve the nutrient profiles that were present at the time of harvest. In general, storage under cooler temperatures retards ripening and spoilage, and hence would be expected to better preserve the nutrients in produce at harvest.

13. If results are reported for crops grown in the field and greenhouses, but otherwise under similar conditions, the results for field-grown matched pair crops will be used.

14. If a study reports results for both pasteurized and non-pasteurized juices, the results for non-pasteurized juice will be used. Otherwise, results for pasteurized juices may be included in cross-study analyses.

15. If multiple sources of plant nutrients are used in different plots (e.g., raw cow manure, compost, pelletized chicken manure in organic fields), the matched pairs from such a study should reflect the most common, or typical source of nutrients in the applicable farming systems.

16. When two rates of nitrogen are used in an experiment, the matched pair reflecting the higher rate will be used for cross-study comparisons. If three rates are used, the middle rate shall be selected. If four or more rates are used, the rate nearest to the average of all rates shall be selected.

17. Some studies report multiple racemic or glycoside forms of a given nutrient. When nutrient levels in all forms are combined in an estimate of "total" nutrient content, this value is used in comparing matched pair nutrient levels. When no total or combined nutrient level is reported, the results for the form of the nutrient with the highest level in either the organic or conventional sample within a matched pair will be incorporated in cross-study analyses.

The Goal of these 17 Criteria

The logic shaping these 17 rules is simple. This study is focused on organic and conventional foods in the least processed form for which nutrient data are available. When there were multiple matched pairs to select from representing multiple combinations of agronomic practices in a given study, we selected only those matched pairs that reflect the most common organic and conventional practices.

When multiple forms of nutrients were reported, we sought matched pairs that reflect the major form. When multiple methods were used to report results, we chose the method that reflected the most global summary of a given study's findings. In short, we selected matched pairs that collectively reflect, as closely as possible, routine commercial farming conditions and the consumption of fresh food soon after harvest.

Taken together, these decisions rules eliminate, to the extent possible, factors that could confound, mask, or skew real differences in nutrient levels between organic and conventional foods as reported in this body of literature.

V. Differences in the Nutrient Content of Organic and Conventionally Grown Foods

The differences in nutrient content between the organic and conventional food samples within 236 matched pairs were assessed for 11 nutrients. There were eight or more valid matched pairs for each nutrient, and up to 46 in the case of ascorbic acid/Vitamin C. The nutrients include:

- Four measures of antioxidants and total phenolics,
- Three vitamins,
- Two minerals,
- Total protein, and
- Nitrates (higher levels are indicative of greater risk of food safety problems; lower levels are regarded as a nutritional advantage).

The antioxidant measures included total phenolics, total antioxidant capacity, and the polyphenols quercetin and kaempferol.

The three vitamins covered are Vitamin C/ascorbic acid, beta-carotene (precursor for Vitamin A), and Vitamin E (alpha-tocopherol). The two minerals were potassium and phosphorous.

For each nutrient, we selected all study-crop combinations that met the agronomic practices and experimental design screen, the analytical methods screen, and the matched-pair selection criteria. All matched pairs meeting these criteria were placed in a table listing the study, crop, cultivar, study year, and food form tested, along with the nutrient level in the organic sample within each matched pair, and the level in the conventional sample.

The ratio of the nutrient level in the organic sample, compared to the conventional sample was then calculated. Ratio values greater than one indicate a higher level of nutrients in the organic sample, and vice versa. Finally, the average of these ratio values was calculated and used as a basic summary statistic representing the average difference between the organic and conventional samples for a given nutrient.

The 11 tables covering the nutrients analyzed in the current study have been posted on the Center's website as supplemental information.[4] The tables identify for each matched pair the study, crop, levels, ratios and summary statistics.

A. Nutrient Density Comparisons for Valid Matched Pairs

The results of this study are reported in three ways. One set of tables provides an overview of the number of matched pairs in which the organic value was higher for a given nutrient, and the number of pairs in which the conventional value was higher.

Other tables present the magnitude of the differences in nutrient levels: one for those matched pairs in which the organic food samples had higher levels, and a second table encompassing the conventional food samples with higher levels. Each of these tables reports the number of matched pairs in which the nutrient values are greater by:

- 0% to 10%,
- 11-20%,
- 31-50%, and
- 50% or more.

The average differences in the ratio values across all matched pairs for a given nutrient are a third method used to summarize the nutrient density differences observed in this analysis.

[4] Access the "Supplemental Information" at http://www.organic-center.org/science.nutri.php?action=view&report_id=124

Overview of Differences

We identified 191 matched pairs with valid comparisons of antioxidant, vitamin and mineral levels. Of these, 119 organic samples within the matched pairs had higher nutrient levels, or 62% of the total matched pairs. The conventional samples contained higher levels of nutrients in 68 matched pairs, or 36%, as shown in Table 5.1. Nutrient levels were reported as equal in 2% of the matched pairs.

We also analyzed two other nutrients – nitrates and protein. Across 18 matched pairs, nitrate levels in the conventional samples were higher in 83% of the pairs (undesirable), while protein levels were higher in 85% of the conventional samples in 27 matched pairs (desirable). These differences are shown in Table 5.2.

Table 5.1

Overview of Differences in the Nutrient Content in Organic and Conventional Foods in 191 Matched Pairs

Nutrient	Number of Matched Pairs	Number Organic Higher	Number Conventonal Higher	Percent Organic Higher	Percent Conventonal Higher
Antioxidants					
Total Phenolics	25	18	6	72%	24%
Total Antioxdiant Capacity	8	7	1	88%	13%
Quercetin	15	13	1	87%	7%
Kaempferol	11	6	5	55%	45%
Vitamins					
Vitamin C/Ascorbic Acid	46	29	17	63%	37%
B -Carotene	8	4	4	50%	50%
a- Tocopherol (Vitamin E)	13	8	5	62%	38%
Minerals					
Phosphorus	32	20	10	63%	31%
Potassium	33	14	19	42%	58%
Totals and Averages	191	119	68	62%	36%

Table 5.2

Differences in Nitrate Levels in 18 Matched Pairs and Protein in 27 Matched Pairs

Nutrient	Number of Matched Pairs	Number Organic Higher	Number Conventional Higher	Percent Organic Higher	Number Conventional Higher
Nitrates	18	3	15	16.7%	83.3%
Protein	27	4	23	14.8%	85.2%

Magnitude of Differences

The magnitude of the differences in the nutrient levels in organic foods versus conventional foods is clearly greater in those pairs in which the organic food contained higher levels of nutrients. Table 5.3 displays the magnitude of differences in the 119 matched pairs in which the organic samples contained higher nutrient levels, while Table 5.4 reports the same information for matched pairs in which the conventional samples were found to contain higher levels of nutrients.

For the 119 matched pairs in which the organic food sample had higher nutrient levels, the magnitude of the difference was 21% or greater in 42% of the cases. The nutritional premium in favor of organic food was 31% or more in nearly one-quarter of the cases.

Table 5.3

Magnitude of Differences in 119 Matched Pairs Where the Organically Grown Food Contained Higher Levels of Nutrient

Nutrient	Number of Studies with Organic Greater than Conventional By —				
	0 to 10%	11% to 20%	21% to 30%	31% to 50%	Over 50%
Antioxidants					
Total Phenolics	9	4	1	4	
Total Antioxdiant Capacity		3	2	1	1
Quercetin	2		3	1	7
Kaempferol	1	3	1		1
Vitamins					
Vitamin C/Ascorbic Acid	3	14	7	3	2
B -Carotene	1	1			2
a- Tocopherol (Vitamin E)	3	2	1	1	1
Minerals					
Phosphorus	7	7	3	3	
Potassium	5	5	2	1	1
TOTALS	31	39	20	14	15

In the 68 matched pairs in which the conventional sample was more nutrient dense, the magnitude of the difference was 21% or greater in just 15% of the cases, and was greater than 31% in only 6% of the cases. Accordingly, the magnitude of the advantage in nutrient density within the organic samples was far greater than the magnitude of differences in those conventional samples that contained higher levels of nutrients.

The same point is reinforced by looking at the category with the smallest differences in nutrient levels – between 0% and 10%. Twenty-six percent of the matched pairs in which the organic food had higher levels of nutrients fell in this category, compared to 66% in the case of conventional samples found to be more nutrient dense within matched pairs.

In the case of nitrates, the same point is obvious. The magnitude of differences in the 15 matched pairs favoring organic are (i.e. lower nitrate levels) quite large. Six of the 15 matched pairs differ by over 50% and 12 favors the organic samples by 31% or more, accounting for 80% of all cases, as shown in Table 5.5.

In the three matched pairs in which the nitrate levels were higher in the organic samples (nutritional undesirable), all three were 1.1% or less higher, or in other words, they were nearly the same. These data help to explain why nitrate is the one nutrient cited in all five literature reviews discussed in section III as favoring organic food.

Conventional food clearly contains, on average, higher protein levels, although the magnitude of

Table 5.4

Magnitude of Differences in 68 Matched Pairs Where the Conventionally Grown Food Contained Higher Levels of Nutrients

Nutrient	Number of Studies with Conventional Greater than Organic By —				
	0 to 10%	11% to 20%	21% to 30%	31% to 50%	Over 50%
Antioxidants					
Total Phenolics	4	2			
Total Antioxdiant Capacity	1				
Quercetin	1				
Kaempferol	3		1		1
Vitamins					
Vitamin C/Ascorbic Acid	11	2	4		0
B -Carotene	3	1			
a- Tocopherol (Vitamin E)	3	1		1	
Minerals					
Phosphorus	8	1	1		
Potassium	11	6		2	
TOTALS	45	13	6	3	1

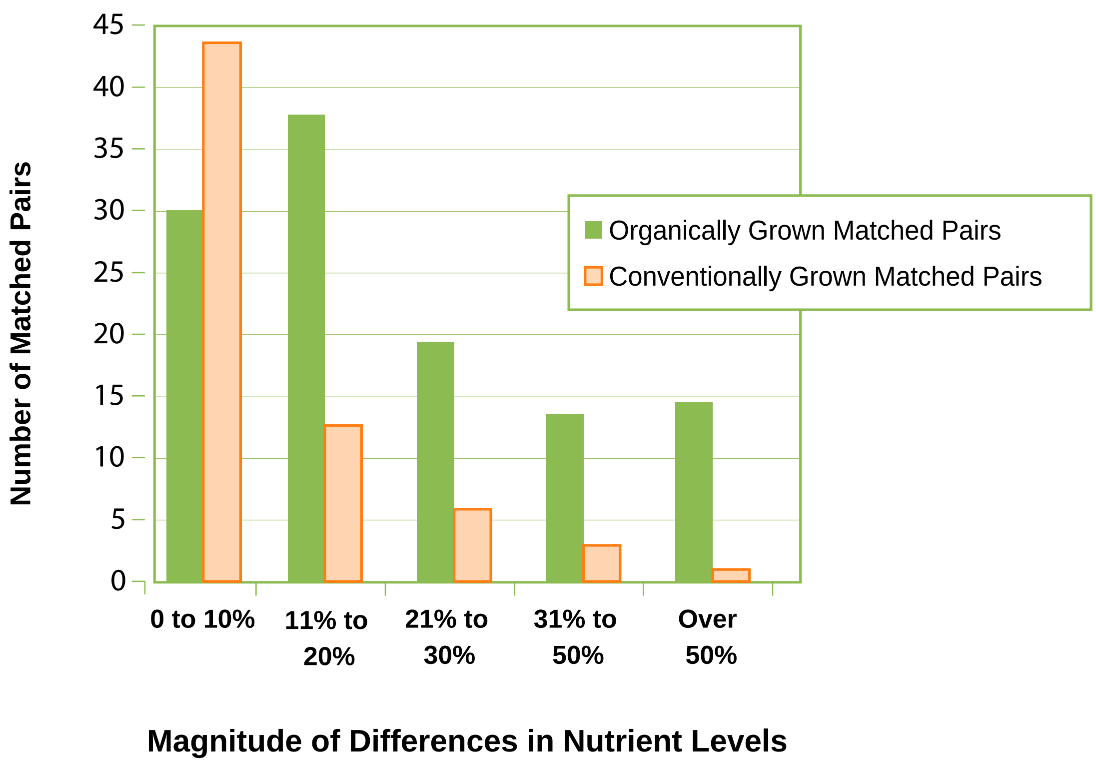
Table 5.5

Magnitude of Differences in Matched Pairs Where Conventional Food Contained Higher Levels of Nitrates and Protein					
Nutrient	Number of Studies with Conventional Greater than Organic By —				
	0 to 10%	11% to 20%	21% to 30%	31% to 50%	Over 50%
Nitrates	1	0	2	6	6
Protein	9	10	3	1	0

the differences is not great. The protein level was between 0% and 20% higher in 83% of the matched pairs in which the conventional samples contained more protein. Only one matched pair fell in the "31% to 50%" category (an eggplant sample with a 38% higher protein level in the conventional sample than in the organic sample).

Figure 5.1 combines our findings on the magnitude of differences in the density of nine antioxidant, vitamin, and mineral nutrients. The figure displays the number of matched pairs in which nutrients were higher in the organic or conventional samples, arrayed by progressively larger percent differences.

Figure 5.1 **Magnitude of Differences in the Nutrient Content of Organic and Conventionally Grown Foods in 189 Matched Pairs**



Estimating Nutritional Premiums

For each of the nine antioxidant, vitamin, and mineral nutrients, we calculated the average ratio of organic sample nutrient levels to conventional sample nutrient levels within each matched pair. The results are summarized in Table 5.6. In the case of nitrates where higher levels are undesirable, we calculated the organic advantage by inverting the ratios across the 15 matched pairs.

Organic samples within matched pairs were more nutrient dense in the case of eight of the 11 nutrients. Protein levels were marginally greater in the conventional samples, while nitrate levels strongly favored the organic samples.

For the two nutrients where the conventional samples contained higher levels (protein, beta-carotene), the differences were in no case greater than 10%.

The differences were 24% or greater in favor or the organic samples within matched pairs for four nutrients (total antioxidant capacity, quercetin, Vitamin C/ascorbic acid, and nitrates).

Table 5.6

Differences in the Nutrient Content in Organic and Conventional Foods Across 11 Nutrients and 236 Matched Pairs

Nutrient	Number of Matched Pairs	Average Ratio of Organic to Conventional Values
Antioxidants		
Total Phenolics	25	1.10
Total Antioxdiant Capacity	8	1.24
Quercetin	15	2.40
Kaempferol	11	1.05
Vitamins		
Vitamin C/Ascorbic Acid	46	1.10
B -Carotene	8	0.92
a- Tocopherol (Vitamin E)	13	1.15
Minerals		
Phosphorus	32	1.07
Potassium	33	1.00
Other Nutrients		
Nitrate	18	1.80
Protein	27	0.90
Total Pairs and Average Ratio	236	1.25

Note: The nitrate ratio reflects the magnitude of the advantge of organic foods, which contain substantially lower levels of nitrate.

B. Conclusions

Based on the findings reported above, we can now answer the two basic questions that have been this study's focus –

Yes, organic plant-based foods are, on average, more nutritious in terms of their nutrient density for compounds validated by this study's rigorous methodology.

The significant margins in favor of organic food in several of the most important nutrients, and modest margins in favor of conventional samples for less important nutrients, strengthens the evidence supporting this conclusion.

The average serving of organic plant-based food contains about 25% more of the nutrients encompassed in this study than a comparable-sized serving of the same food produced by conventional farming methods.

This is roughly the same margin in favor of organic food reported in the Organic Center's 2005 State of Science Review on antioxidants.

The number of valid studies and matched pairs is still too limited to quantify with a high level of confidence the differences for four or five of the individual 11 nutrients, although the evidence in published studies seems to be reasonably consistent in the case of Vitamin C, antioxidant capacity, nitrates, some individual polyphenols, and protein.

Because of the significant increase in the number of high quality studies over the last few years (see Tables 2.1 and 2.2), there are now enough high-quality studies on an ample diversity of foods to support the above general conclusions regarding nutrient content, at least for several important nutrients and on average across multiple fields and production regions.

We believe that the conclusions supported by this study are generally applicable to most fresh and lightly processed organic and conventional plant-based food products currently on the market. Our inferences and conclusions must be limited to plant-based foods because the vast majority of existing studies focuses on foods of plant origin.

There is strong evidence, however, that poultry and livestock that consume animal feeds and pastures grown using organic methods actually produce meat, milk, and eggs that has –

- Modestly higher levels of protein,
- More of some vitamins and minerals, and
- Elevated levels of heart-healthy omega-3 and conjugated linoleic acid (CLA) fats.

The Union of Concerned Scientists recently published an in-depth review of several pertinent studies on the impact of organic farming on the fatty acids in animal products (Clancy, 2007).

The FQH Network, a consortium of European Union research teams focusing on organic food, have also just published a provocative assessment of how organic feed for poultry improves chicken health, and in many instances, the nutritional quality of poultry products (Huber, 2007).

The impact of organic farming methods and organic feed on the nutritional quality of animal products is just beginning to receive the scientific attention it deserves. But for now, we limit our conclusions regarding the nutritional superiority of organic foods to those of plant-based origin.

Appendix 1. Bibliography of Studies Used in Selecting Matched Pairs

Abu, S. and A. Saleha. 1992. Studies on the effects of organic vs. inorganic form of nitrogen on the quality of okra. J. Maharashtra Agr. Univ. 17: 133-134.

Akcay,Y.D., H.K. Yldrm, U. Guvenc, and E.Y. Sozmen. 2004. The effects of consumption of organic and nonorganic red wine on low-density lipoprotein oxidation and antioxidant capacity in humans. Nutr. Res. 24:541-554.

Amodio, M.L., Colelli, G., Hasey, J., and A.A. Kader. 2007. A comparative study of composition and postharvest performance of organically and conventionally grown kiwifruits. J. of the Science of Food and Agriculture (in press)

Asami, D.K., Y. J. Hong, D.M. Barrett, and A.E.Mitchell. 2003. Comparison of the total phenolic and ascorbic acid content of freeze-dried and air-dried marionberry, strawberry, and corn grown using conventional, organic, and sustainable agricultural practices. J. Agr. Food Chem. 51:1237-1241.

Baxter, G.J., A.B. Graham, J.R. Lawrence, D. Wiles, and J.R. Paterson. 2001. Salicylic acid in soups prepared from organically and non-organically grown vegetables. European J. Nutr. 40:289-292.

Bergamo, P., E. Fedele, L.Iannibelli, and G. Marzillo. 2003. Fat-soluble vitamin contents and fatty acid composition in organic and conventional Italian dairy products. Food Chem. 82:625-631.

Carbonaro, M., M. Mattera, S. Nicoli, P. Bergamo, and M. Cappelloni. 2002. Modulation of antioxidant compounds in organic vs conventional fruit (peach Prunus persica L., and pear, Pyrus communis L.). J. Agr. Food Chem. 50:5458-5462.

Caris-Veyrat C., M.J. Amiot, V. Tyssandier, D. Grasselly, M. Buret, M. Mikolajczak, J.C. Guilland, C. Bouteloup-Demange, and P. Borel. 2004. Influence of organic versus conventional agricultural practice on the antioxidant microconstituent content of tomatoes and derived purees; Consequences on antioxidant plasma status in humans. J. gr. Food Chem. 52:6503-6509.

Cayuela, J.A., J.M. Vidueira, M.A. Albi, and F. Gutierrez. 1997. Influence of the ecological cultivation of strawberries (Fragaria_ Ananassa cv. Chandler) on the quality of the fruit and on their capacity for conservation. J. Agr. Food Chem. 45:1736-1740.

Curuk, S., T. Sermenli, K. Mavi, and F. Evrendilek. 2004. Yield and fruit quality of watermelon (Citrullus lanatus (Thumb.) matsum. & nakai.) and melon (Cucumis melo L.) under protected organic and conventional farming systems in a Mediterranean region of Turkey. Bio Agr. Hort. 22:173-183.

Dani, C., Oliboni, L.S., Vanderlinde, R., Bonatto, D., Salvador, M., and J.A.P. Henriques. 2007. Food and Chemical Toxicology 45: 2574-2580.

DeEll, J.R. and R.K. Prange. 1993. Postharvest physiological disorders, diseases and mineral concentrations of organically and conventionally grown McIntosh and Cortland apples. Can. J. Plant Sci. 73:223-230.

Dimberg, L.H., C. Gissén, and J. Nilsson. 2005. Phenolic compounds in oat grains (Avena sativa L.) grown in conventional and organic systems. Ambio 34:331-337.

Eggert, F.P. 1983. Effect of soil management practices on yield and foliar nutrient concentration of dry beans, carrots, and tomatoes. p. 247-259. In: W. Lockeretz (ed.) Environmentally sound agriculture: selected papers, 4th Conference, International Federation of Organic Agriculture Movements. Aug. 20. Cambridge, MA.

Eggert, F.P. and C.L. Kahrmann. 1984. Response of three vegetable crops to organic and inorganic nutrient sources. ASA Amer. Soc. of Agr - Special Pub. no. 46:97-109.

El Sheikh, E.A.E. and A.A. El Zidany. 1997. Effect of Rhizobium inoculation, organic and chemical fertilizers on proximate composition, in vitro protein digestibility, tannin and sulphur content of faba beans. Food Chem. 59:41-45.

Eppendorfer, W.H. and B.O. Eggum BO. 1996. Fertilizer effects on yield, mineral and amino acid composition, dietary fiber content and nutritive value of leeks. Plant Foods Hum. Nutr. 49:163-174.

Evers, A.M. 1989. Effects of different fertilization practices on the carotene content of carrot. J. Agr. Sci. Finland. 61:7-14.

Ferreres, F., P. Valentão, R. Llorach, C. Pinheiro, L. Cardoso, J.A. Pereira, C. Sousa, R.M. Seabra, and P.B. Andrade. 2005. Phenolic compounds in external leaves of tronchuda cabbage (Brassica oleracea L. var. costata DC). J. Agr. Food Chem. 53:2901-2907.

Fjelkner-Modig, S., H. Bengtsson, R. Stegmark, and S. Nystrom. 2000. The influence of organic and integrated production on nutritional, sensory and agricultural aspects of vegetable raw materials for food production. Acta Agric. Scan. Section B, Soil Plant Sci. 50:102-113.

Granstedt, A. and L. Kjellenberg. 1997. Long-term field experiment in Sweden: Effects of organic and inorganic fertilizers on soil fertility and crop quality. p. 79-90. In: W. Lockeretz (ed.). Agricultural Production and Nutrition, Proceedings of an International Conference. Tufts University School of Nutrition Science and Policy, March 19-21, Boston, MA.

Grinder-Pedersen, L., S.E. Rasmussen, S. Bügel, L.V. JØrgensen, L.O. Dragsted, V. Gundersen, and B. Sandstrom. 2003. Effect of diets based on foods from conventional versus organic production on intake and excretion of flavonoids and markers of antioxidative defense in humans. J. Agr. Food Chem. 51:5671-5676.

Gutierrez, F., T. Arnaud, and M.A. Albi. 1999. Influence of ecological cultivation on virgin olive oil quality. J. Amer. Oil Chem. Soc. 76:617-621.

Hajslova, J., V. Schulzova, P. Slanina, K. Janne, K.E. Hellenas, and C. Andersson. 2005. Quality of organically and conventionally grown potatoes: four-year study of micronutrients, metals, secondary metabolites, enzymic browning and organoleptic properties. Food Add. Contam. 22:514-534.

Hakala, M., R. Tahvonen, R. Huopalahti, H. Kallio, and A. Lapvetelainen. 2002. Quality factors of Finnish strawberries. Acta Hort. 567:727-730.

Häkkinen, S.H. and A.R. Törrönen. 2000. Content of flavonols and selected phenolic acids in strawberries and Vaccinium species: influence of cultivar, cultivation site and technique. Food Res. Intl. 33:517-524.

Hansen, H. 1981. Comparison of chemical composition and taste of biodynamically and conventionally grown vegetables. Qual. Planta _ Plant Foods Human Nutr. 30:203-211.

Harder, L., L.P. Christensen, B.T. Christensen, and K. Brandt. 1998. Contents of flavonoids and other phenolics in wheat plants grown with different levels of organic fertilizer. Polyphenols Communications 98:495-496.

Hogstad, S., E. Risvik, and K. Steinsholt. 1997. Sensory quality and chemical composition in carrots: A multivariate study. Acta Agr. Scan. Section B, Soil Plant Sci. 47:253-264.

Hukkanen, A.T., T.P. Mikkonen, K.R. Maatta, A.R. Torronen, S.O. Karenlampi, H.I. Kokko, and R.O. Karjalainen. 2002. Variation in flavonol content among blackcurrant cultivars. Acta Hort. 585:121-124.

Ishida, B.K. and M.H. Chapman. 2004. A comparison of carotenoid content and total antioxidant activity in catsup from several commercial sources in the United States. J. Agr. Food Chem. 52:8017-8020.

Jorhem, L. and P. Slanina. 2000. Does organic farming reduce the content of Cd and certain other trace metals in plant foods? A pilot study. J. Sci. Food Agr. 80:43-48.

Lairon, D., N. Spitz, E. Termine, P. Ribaud, H. Lafont, and J. Hauton. 1984. Effect of organic and mineral nitrogen fertilization on yield and nutritive value of butterhead lettuce. Qual. Planta. _ Plant Foods Human Nutr. 34:97-108.

Leclerc J., M.L. Miller, E. Joliet, and G. Rocquelin. 1991. Vitamin and mineral contents of carrot and celeriac under mineral or organic fertilization. Biol. Agr. Hort. 7:349-361.

Lombardi-Boccia, G., M. Lucarini, S. Lanzi, A. Aguzzi, and M. Cappelloni. 2004. Nutrients and antioxidant molecules in yellow plums (Prunus domestica L.) from conventional and organic productions: a comparative study. J. Agr. Food Chem. 52:90-94.

Lucarini, M., M. Carbonaro, S. Nicoli, A. Aguzzi, M. Cappelloni, S. Ruggeri, G. Di Lullo, L. Gambelli, and E. Carnovale. 2005. Endogenous markers for organic versus conventional plant products. Session VI Quality assessment. Agri-Food Quality II: Quality management of fruits and vegetables. 306-310.

Lumpkin, H.M. 2005. A comparison of lycopene and other phytochemicals in tomatoes grown under conventional and organic management systems. Tech Bulletin AVRDC. 34:48.

Mader, P., L. Pfiffner, U. Niggli, U. Balzer, F. Balzer, K. Plochberger, A. Velimirov, and J.M. Besson. 1993. 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 Hort. 339:10-31.

Malusà, E., E. Laurenti, E. Ghibaudi, and L. Rolle. 2004. Influence of organic and conventional management on yield and composition of grape cv. 'Grignolino.' Acta Hort. 640:135-141.

Meier-Ploeger, A., R. Duden, and H. Vogtmann. 1989. Quality of food plants grown with compost from biogenic waste. Agr. Ecosys. Environ. 27:483-491.

Mercadante, A.Z. and D.B. Rodriguez-Amaya. 1991. Carotenoid composition of a leafy vegetable in relation to some agricultural variables. J. Agr. Food Chem. 39:1094-1097.

Mikkonen,T.P., K.P. Maatta, A.T. Hukkanen, H.I. Kokko, A.R. Torronen, S.O. Karenlampi, and R.O. Karjalainen. 2001. Flavonol content varies among black currant cultivars. J Agr. Food Chem. 49:3274-3277.

Mitchell, A., Hong, Y-J., Koh, E., Barrett, D.M., Bryant, D.E., Dension, R. F., and S. Kaffka. 2007. Ten-year comparison of the influence of organic and conventional crop management practices on the content of flavonoids in tomatoes. Journal of Agricultural and Food Chemistry, Vol. 55: 6154-6159.

Montagu, K.D. and K.M. Goh. 1990. Effects of forms and rates of organic and inorganic nitrogen fertilisers on the yield and some quality indices of tomatoes (Lycopersicon Esculentum Miller). New Zealand J. Crop Hort. Sci. 18:31-37.

Mozafar, A. 1994. Enrichment of some B vitamins in plants with application of organic fertilizers. Plant Soil. 167:305-311.

Muller, K. and J. Hippe. 1987. Influence of differences in nutrition on important quality characteristics of some agricultural crops. Plant Soil. 100:35-45.

Nørbaek, R, D.B.F. Aaboer, I.S. Bleeg, B.T. Christensen, T. Kondo, and K. Brandt. 2003. Flavone C-glycoside, phenolic acid, and nitrogen contents in leaves of barley subject to organic fertilization treatments. J. Agr. Food Chem. 51:809-813.

Ogbadu, G.H. and J.P. Easmon. 1989. Influence of inorganic and organic fertilizers on the chemical composition of three eggplant cultivars. Tropical Sci. 29:237-246.

Olsson, M.E., C.S. Andersson, S. Oredsson, R.H. Berglund, and K.E. Gustavsson. 2006. Antioxidant levels and inhibition of cancer cell proliferation in vitro by extracts from organically and conventionally cultivated strawberries. J. Agr. Food Chem. 54:1248-1255.

Pascale, S.D., R. Tamburrino, A. Maggio, G. Barbieri, V. Fogliano, and R. Pernice. 2006. Effects of nitrogen fertilization on the nutritional value of organically and conventionally grown tomatoes. Acta Hort. 700:107-110.

Peck, G.M., P.K.Andrews, J.P. Reganold, and J.K. Fellman. 2006. Apple orchard productivity and fruit quality under organic, conventional, and integrated management. Hortscience 41:99-107.

Perez-Lopez, A.J., Lopez-Nicolas, J.M., Nunez-Delicado, A., del Amor, F.M., and A.A. Carbonell-Barrachina. 2007. Effects of agricultural practices on color, carotenoids composition, and minerals contents of sweet peppers, cv. Almuden. Journal of Agricultural and Food Chemistry, Vol. 55: 8158-8164.

Perretti, G., E. Finotti, S. Adamuccio, R.D. Sera, and L. Montanari. 2004. Composition of organic and conventionally produced sunflower seed oil. J Amer. Oil Chem Soc. 81: 1119-1123.

Pfeilsticker, K. 1992. Quality of organic-grown food: An experimental multifactorial approach on vegetables for example. p. 331-337. In: U. Kopke and D.G. Schulz (eds.) Organic agriculture, a Key to a sound development and a sustainable environment. Proceedings of the 9th IFOAM Conference. Nov.16-21, Sao Paulo, Brazil.

Pimpini, F., L. Giardini, M. Borin, and G. Gianquinto. 1992. Effects of poultry manure and mineral fertilizers on the quality of crops. J. Agr. Sci. 118:215-221.

Podwall, D., J. Lipetz, and J.J. Steinberg. 1999. Variation in the deoxynucleotide composition between organic and nonorganic strawberries. Ecotoxic. Environ. Safety 44:259-270.

Porretta, S. 1994. Qualitative comparison between commercial “traditional” and “organic” tomato products using multivariate statistical analysis. Acta Hort. 376:259-270.

Premuzic, Z., M. Bargiela, A. Garcia, and A. Iorio. 1998. Calcium, iron, potassium, phosphorus and vitamin C content of organic and hydroponic tomatoes. HortScience 33:255-257.

Raupp, J. 1998. Examination of some microbiological and biochemical parameters and tests of product quality used in a long-term fertilization trial. Amer. J. Altern. Agr. 13:138-144.

Raupp, J. 1997. Yield, product quality and soil life after long-term organic or mineral fertilization. p. 91-101. In: W. Lockeretz (ed.) Agricultural Production and Nutrition. Tufts University School of Nutrition Science and Policy, March 19-21, Boston, MA.

Reeve, J.R., L. Carpenter-Boggs, J.P. Reganold, A.L. York, G. McGourty, L.P. McCloskey. 2005. Soil and winegrape quality in biodynamically and organically managed vineyards. Amer. J. Enol. Viticul. 56:367-376.

Rembialkowska, E. 1999. Comparison of the contents of nitrates, nitrites, lead, cadmium, and Vitamin C in potatoes from conventional and ecological farms. Polish Journal of Food and Nutrition Sciences. Vol. 8/49, No. 4, pp 17-26.

Rembialkowska, E. 2003. Organic farming as a system to provide better vegetable quality. Proc. Int. Conf. Quality in Chains, Acta Hort. 604, ISHS, pp. 473-479.

Rembialkowska, E., Hallmann, E., and A. Rusaczonek. 2007. Influence of processing on bioactive substances content and antioxidant properties of apple puree from organic and conventional production in Poland. Pp. 139-143.

Ren, H., H. Endo, and T. Hayashi. 2001. Antioxidative and antimutagenic activitities and polyphenol content of pesticide-free and organically cultivated green vegetables using water-soluble chitosan as a soil modifier and leaf surface spray. J. Sci. Food Agr. 81:1426-1432.

Ren, H., H. Endo, and T. Hayashi. 2001. The superiority of organically cultivated vegetables to general ones regarding antimutagenic activities. Mutation Res. 496:83-88.

Ryan, M.H. J.W. Derrick, and P.R. Dann. 2004. Grain mineral concentrations and yield of wheat grown under organic and conventional management. J. Sci. Food Agr. 84:207-216.

Samuel, A.M. and J. East. 1990. Organically grown wheat - the effect of crop husbandry on grain quality. Aspects App. Bio. 25:199-208.

Schultz, D.G., K. Koch, K.H. Kromer, and U. Kopke. 1997. Quality comparison of mineral, organic and biodynamic cultivation of potatoes: contents, strength criteria, sensory investigations, and picture-creating methods. p. 115-120. In: W. Lockeretz (ed.) Agricultural Production and Nutrition. Proceedings of an International Conference. Tufts University School of Nutrition Science and Policy, March 19-21, Boston, MA.

Schulz, D.G., E. Zedow, and U. Kopke. 1992. Determining the quality of organic produce: Extended quality parameters and quality index. p. 338-348. In: U. Kopke and D.G. Schulz (eds.). Organic agriculture, a key to a sound development and a sustainable environment. Proceedings of the 9th IFOAM Conference. Nov.16-21, Sao Paulo, Brazil.

Schulzova, V., J. Hajslova, J. Guziur, and J.A. Velisek. 1999. Assessment of the quality of potatoes from organic farming. Agri-Food Quality II: quality management of fruits and vegetables from field to table. 73-75.

Shier, N.W., J. Kelman, and D.J. Wharton. 1984. A comparison of crude protein, moisture, ash and crop yield between organic and conventionally grown wheat. Nutr. Reports Intern. 30:71-77.

Smith, B.L.. 1993. Organic foods vs. supermarket foods: Element levels. J. App. Nutr. 45:35-39.

Sousa, C., P. Valentão, J. Rangel, G. Lopes, J.A. Pereira, F. Ferreres, R.M. Seabra, and P.B. Andrade. 2005. Influence of two fertilization regimens on the amounts of organic acids and phenolic compounds of tronchuda cabbage (Brassica oleracea L. Var. costata DC). J. Agr. Food Chem. 53:9128-9132.

Srikumar, T.S. and P.A. Ockerman. 1991. The effects of organic and inorganic fertilization on the content of trace elements in cereal grains. Food Chem. 42:225-230.

Srikumar, T.S. and P.A. Ockerman. 1990. The effects of fertilization and manuring on the content of some nutrients in potato (var. Provita). Food Chem. 37:47-60.

Starling, W. and M.C. Richards. 1993. Quality of commercial samples of organically grown wheat. Asp. Appl. Biol. 36:205-209.

Starling, W. and M.C. Richards. 1990. Quality of organically grown wheat and barley. Asp. Appl. Biol. 25:193-198.

Storey, T., R. Hogan, and J. Humphreys. 1993. The growth, yield and quality of winter wheat and winter oats grown under an organic conversion regime. Aspects App. Bio. 36:199-204.

Tarozzi, A., A. Marchesi, G. Cantelli-Forti, and P. Hrelia. 2004. Cold-storage affects antioxidant properties of apples in Caco-2 cells. J. Nutr. 134:1105-1109.

Tarozzi, A., S. Hrelia, C. Angeloni, F. Morroni, P. Biagi, M. Guardigli, G. Cantelli-Forti, and P. Hrelia. 2006. Antioxidant effectiveness of organically and non-organically grown red oranges in cell culture systems. European J. Nutr. 45:152-158.

Tejada, M., J.A. Espejo, C. Benitez, and J.L. Gonzalez. 1995. Influence of organomineral fertilization on wheat yield and flour quality under dry conditions. Agricoltura Mediterranea 125:138-149.

Termine, E., D. Lairon, B. Taupier-Letage, S. Gautier, R. LaFont, and H. LaFont. 1987. Yield and content in nitrates, minerals and ascorbic acid of leeks and turnips grown under mineral or organic nitrogen fertilizations. Plant Foods. Hum. Nutr. 37:321-332.

Tinttunen, S. and P. Lehtonen. 2001. Distinguish organic wine from normal wines on the basis of concentrations of phenolic compounds and spectral data. European Food Res. Technol. 212:390-394.

Veberic, R., M. Trobec, K. Herbinger, M. Hofer, D. Grill, and F. Stampar. 2005. Phenolic compounds in some apple (Malus domestica Borkh) cultivars of organic and integrated production. J. Sci. Food Agr. 85:1687-1694.

Velimirov, A., K. Plochberger, U. Huspeka, and W. Schott. 1992:The influence of biologically and conventionally cultivated food on the fertility of rats. Bio. Agr. Hort. 8:325-337.

Verde-Mendez, C.M., M.P. Forster, M.A. Rodriguez-Delgado, E.M. Rodriguez-Rodriguez, and C. Diaz-Romero. 2003. Content of free phenolic compounds in bananas from Tenerife (Canary Islands) and Ecuador. European Food Res Tech. 217:287-290.

Vogtmann, H. 1988. From healthy soil to healthy food: An analysis of the quality of food produced under contrasting agricultural systems. Nutr. Health 6:21-35.

Vogtmann, H., K. Matthies, B. Kehres, and A. Meier Ploeger. 1993. Enhanced food quality: Effects of composts on the quality of plant foods. Compost Sci. Utiliz. 1:82-100.

Warman, P.R. and K.A. Havard. 1998. Yield, vitamin and mineral contents of organically and conventionally grown potatoes and sweet corn. Ag. Ecosys. Environ. 68:207-216.

Warman, P.R., and K.A. Havard. 1997. Yield, vitamin and mineral contents of organically and conventionally grown carrots and cabbage. Agr. Ecosys. Environ. 61:155-162.

Warman, P.R. and K.A. Havard. 1996. Yield, vitamin and mineral content of four vegetables grown with either composted manure or conventional fertilizer. J. Veg Crop Prod. 2:13-25.

Weibel, F.P., R. Bickel, S. Leuthold, and T. Alfoldi. 2000. Are organically grown apples tastier and healthier? A comparative field study using conventional and alternative methods to measure fruit quality. Acta Hort. 517:417-426.

Wolfson, J.L. and G. Shearer. 1981. Amino acid composition of grain protein of maize grown with and without pesticides and standard commercial fertilizers. Agron J. 73:611-613.

Yldrm, H.K., Y.D. Akcay, U. Güvenc, and E.Y. Sözme. 2004. Protection capacity against low-density lipoprotein oxidation and antioxidant potential of some organic and non-organic wines. 2004. Intl. J. Food Sci. Nutr. 55:351-362.

Young, J.E., X. Zhao, E.E. Carey, R. Welti, S. Yang, and W. Wang. 2005. Phytochemical phenolics in organically grown vegetables. Mol. Nutr. Food Res. 49:1136-1142.

Zhao, X., Iwamoto, T., and E. Carey. 2007. Antioxidant capacity of leafy vegetables as affected by high tunnel environment, fertilization and growth stage. J. Science of Food and Agriculture, 87:2692-2699.

Bibliography

Bourn, D., and J. Prescott. 2002. A Comparison of the Nutritional Value, Sensory Qualities, and Food Safety of Organically and Conventionally Produced Foods," *Critical Reviews in Food Science and Nutrition*, Vol. 42(1): 1-34.

Brandt, K., and J.P. Molgaard. 2001. Organic agriculture: does it enhance or reduce the nutritional value of plant foods?", *Journal of the Science of Food and Agriculture*, Vol. 81: 924-931.

Clancy, Kate. 2007. Greener Pastures: *How Grass-fed Beef and Milk Contribute to Healthy Eating*, Union of Concerned Scientists, Washington, D.C.

Davis, D., Epp, M.D., and H.D. Riordan. 2004. Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999, *Journal of the American College of Nutrition*, Vol. 23(6): 669-682.

Harborne, J.B. 1999. Classes and functions of secondary products from plants, In J.N. Walton and D.E. Brown (eds). *Chemicals from plants – Perspectives on plant secondary products*. Imperial; College Press, London: pp. 1-25.

Hertog, M.G.L., Hollman, P.C.H., and D.P. Venema. 1992. "Optimization of a Quantitative HPLC Determination of Potentially Anticarcinogenic Flavonoids in Vegetables and Fruits," *Journal of Agricultural and Food Chemistry*, Vol. 40: 1591-1598.

Huber, M., (editor). 2007. Organic, More Healthy? – A search for biomarkers of potential health effects induced by organic products, investigated in a chicken model. Louis Bolk Institute and FQH (Organic Food Quality and Health).

Jarrell, W.M., and R.B. Beverly. 1981. The dilution effect in plant nutrition studies, In N.C. Brady (ed.) *Advances in Agronomy*," Vol. 34: pp. 197-224.

Lester, G.E. 2006. "Organic versus Conventionally Grown Produce: Quality Differences, and Guidelines for Comparison Studies," *HortScience* Vol. 41(2): 296-300.

Magkos, F., Arvaniti, F., and A. Zampelas. 2003. Organic food: nutritious food or food for thought? A rview of the evidence," *Int. Journal of Food Sciences and Nutrition,* Vol. 54(5): 357-371.

Mayer, A-M. 1997. Historical changes in the mineral content of fruits and vegetables, British Food Journal, Vol. 99(6): 207-211.

Pollak, L.M., and M.P. Scott. 2005. "Breeding for Grain Quality Traits," *Maydica*, Vol. 50: 247-257.

Tonucci, L.H., Holden, J.M., Beecher, G.R., Khachik, F., Davis, C.S., and G. Mulokozi. 1005. "Carotenoid Content of Thermally Processed Tomato-Based Food Products," *Journal of Agricultural and Food Chemistry*, Vol. 43: 579-586.

Uribelarrea, M., Below, F.E., and S.P. Moose. 2004. "Grain Composition and Productivity of Maize Hybrids Derived from the Illinois Protein Strains in Response to Variable Nitrogen Fertilizer," *Crop Science*, Vol. 44: 1593-1600.

Van der Werf, E., Kariuki, J., and D.D. Onduru. 1997. "Methodological Issues in Comparative Agro-Economic On-farm Research Assessments of Organic Versus Conventional Farming Techniques," *Biological Agriculture and Horticulture*, Vol. 14: pp 53-99.

White, P.J., and M.R. Broadley. 2005. Historical variation in the mineral composition of edible horticultural products, *Journal of Horticultural Science & Biotechnology*, Vol. 80(6): 660-667.

Williams, C.M. 2002. Nutritional quality of organic foods: shades of grey or shades of green?", *Proceedings of the Nutrition Society*, Vol. 61: pp. 19-24.

Worthington, V. 2001. "Nutritional Quality of Organic Versus Conventional Fruits, Vegetables, and Grains," *Journal of Alternative and Complimentary Medicine*, Vol. 7(2): 161-173.

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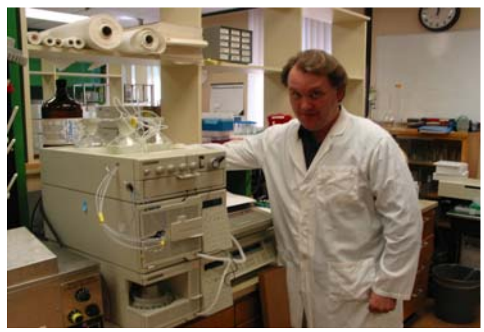

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