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State of Science Review: Taste of Organic Food

Do Organic Fruits and Vegetables Taste Better than Conventional Fruits and Vegetables?

by Richard C. Theuer

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I. FOCUS STATEMENT

This State of the Science Review attempts to answer thw question "Do organic fruits and vegetables taste better than conventional fruits and vegetables?". There are several reasons why this question should be addressed.

First, 43% of consumers of organic food give "better taste" as a major reason for purchasing organic fruits and vegetables (MORI Poll 2001, cited by Heaton (Heaton, 2001)). It is important to know if the consumer conviction of "better taste" is due solely to the "halo effect"[1] of the organic label, and, if not, what accounts for the often-cited claim that organic produce tastes better.

Second, the levels of some phenolic compounds are known to be higher in organic fruits and vegetables (Benbrook, 2005). Plants create phenolic compounds for many reasons, but a major reason is to make plant tissues less attractive to herbivores, insects, and other predators. Some phenolic compounds actually taste bad (Drewnowski and Gomez-Carneros, 2000; Lesschaeve and Noble, 2005). The bitter taste and the tactile sensation of astringency in tea, cider, red wine, and chocolate are caused primarily by the flavonoid phenolics, including flavanols and flavonols (Lesschaeve and Noble, 2005). These phenolic compounds, like those in red grapes, are often responsible for the unique flavor of certain fruits. Accordingly, it is important to sort out if higher levels of phenolic compounds affect the taste of organic fruits and vegetables when compared to conventionally grown produce.

What Is "Organoleptic Quality?"

The dictionary defines "organoleptic" as "of or pertaining to the sensory properties of a particular food or chemical." Organoleptic quality includes the typical sensory properties of a food: its taste, appearance and color, aroma, size and firmness, and even sound (e.g., the "snap" or "crack" when biting into a crisp apple). But organoleptic measures also include mouth feel and any other sensations related to eating a food.

The term organoleptic quality is used broadly in this document to include storage properties ("storability"), since many fruits and vegetables are stored for various periods of time to enable "non-seasonal" retail availability. Clearly, produce that stores well will be more appealing to consumers than fruit with visible blemishes, soft spots, or lack of flavor. Organic cultivation practices can influence storability and thus alter the organoleptic qualities of produce at the point of sale and consumption.

[1] "Halo effect" is the term used to describe cognitive bias that arises when information about one quality attribute of a product serves to influence and bias the judgment of its other qualities.

Third, many sellers, distributors, and promoters of organic foods claim that organic foods taste better. When such assertions are included in advertising and promotional literature, they must comply with federal rules governing marketing claims and must be backed up by credible scientific evidence. As the organic industry moves toward more direct claims regarding comparative taste in advertising and product labeling, it will be essential to support such claims with a strong body of evidence from carefully designed and controlled experiments. Lacking such evidence, the industry will be vulnerable to critical investigations by government agencies and possible erosion in consumer confidence.

There actually are several ways that this "simple" question – Do organic fruits and vegetables taste better than conventional produce? – can be interpreted and answered.

- Does a fruit or vegetable labeled "organic" receive higher organoleptic scores than the "same" fruit or vegetable not so labeled?
- Do fruits and vegetables collected from organic markets receive higher organoleptic scores than the "same" fruits and vegetables collected from conventional grocery stores?
- Do fruits and vegetables grown organically in a certain geographical and climatic area have higher organoleptic scores than the "same" fruits and vegetables grown conventionally in the same geographical and climatic area?
- Do fruits and vegetables grown by different cultural practices show distinctive differences in organoleptic quality and, if so, to which specific factors and cultural practices can these differences be attributed?

While seemingly similar, these questions are in fact quite different. The purpose of this State of the Science Review is to help readers interpret the published literature on the comparative organoleptic characteristics of organic foods in the context of the questions posed above.

II. METHODS USED TO COMPARE ORGANOLEPTIC FOOD QUALITY

About a dozen reviews published in the past two decades have summarized primary research reports of the comparative sensory characteristics of organic and conventional foods. The primary reports date back as far as the middle of the Twentieth Century. Since both organic and conventional agricultural practices have evolved over the past fifty years, several of these reviews are especially useful because the authors critically evaluated the relevance, validity, and context of the primary research. For example, the Soil Association report of 2001 authored by Heaton pays close attention to cultivation methods to ensure that foods described as "organic" meet current "certified organic" standards (e.g., three years of organic management of the land) (Heaton, 2001). The classification of the types of comparisons of organically and conventionally produced foods described by Woese et al. continues to facilitate critical analysis and enable unbiased conclusions (Woese et al., 1997).

This State of the Science Review summarizes these reviews and adds the results of more recent primary research on the comparative organoleptic characteristics of organically and conventionally cultivated fruits and vegetables.

Measuring and describing the organoleptic characteristics of a food are much more difficult than measuring and describing its levels of specific chemical and nutritional components. In the future it may become routine to use an "electronic nose" to provide objective and quantitative data (Müller et al., 2003) but this methodology is not yet well established.

Heaton offered the following partial list of "difficulties" with published research on taste (Heaton, 2001).

- **Cooking**. Taste differences in one study were found in raw carrots but not when the carrots were cooked (Rembialkowska, 2000).

- **Ripeness**. An agriculturally valid study that reported inconsistent or not significant differences between organic and conventional fruits and vegetables found that taste was more dependent on the level of ripeness or maturity of the samples (which had not been fully controlled) (Basker, 1992).

- **Subjectivity**. Taste is a personal thing and individual preferences vary.

- **Preconceptions**. Consumer may have preconceived notions about the superior taste of organic produce (i.e., the "halo effect") (Hansen, 1981).

Other "complications" include:

- **Peeling**. A preference for organic potatoes disappeared when the cooked potato sections were peeled (Wszelaki et al., 2005).

- **Variety**. Differences in choices of cultivars between the two systems might explain differences in taste (Heaton, 2001).

- **Taste panel composition.** Trained panelists typically provide more consistent and objective data than untrained tasters, yet studies often do not clearly explain whether panels are trained, and if so, how and to what degree.

The significance of these "difficulties" and "complications" can be best exemplified by analyzing the questions posed above.

Question: Does a fruit or vegetable labeled "organic" receive higher organoleptic scores than the "same" fruit or vegetable not so labeled?

The answer to this question is, generally, **YES**. Experimental research indicates that labeling a food as "organic" increases the consumer acceptability of the food. As indicated above, "halo effect" is the term used to describe cognitive bias that arises when information about one quality attribute of a product serves to influence and bias the judgment of its other qualities.

Providing information about cultivation method affects consumer preferences for organic versus conventional vegetables (Johansson et al., 1999; Schutz and Lorenz, 1976). In both studies, products labeled as organic generally showed increases in preference scores. In taste tests using identical tomatoes with different labels, consumers perceived taste differences based on the labeling alone (Alvensleben and Meier,

<u>Question</u>: Do fruits and vegetables collected from organic markets receive higher organoleptic scores than the "same" fruits and vegetables collected from conventional grocery stores?

The answer to this question is **SOMETIMES**, but it is important not to generalize the results.

Market-oriented supply studies attempt to answer this question from the perspective of the retail consumer. Typically, foods on sale in a given day are collected from shops selling organic food and other shops selling conventional food. Woese et al. pointed out the major limitation to this kind of study: the origin of the samples is unknown, and consequently information about growing conditions (climate, soil type, management practices, cultivars, etc.) is not available (Woese et al., 1997). Furthermore, the samples can differ in ripeness and variety, which can markedly affect several quality parameters.

In a classic market-oriented supply study with all of the limitations described above, Bordeleau et al. compared specific internal and external quality parameters for organic and conventional Golden Delicious apples purchased in shops in Denmark (Bordeleau et al., 2002). The organic apples were grown in Italy and packaged in plastic bags in April 2002; the conventional apples were grown in France and packaged in cartons in March 2002. All the apples appeared to be of similar maturity when purchased but the date of purchase was not disclosed. No other cultural details were available. Obviously this comparison is highly relevant for the Danish consumer in the market at the time the samples were purchased, but it has limited value otherwise.

Harker described his experience in apple marketing to support his contention that industry regulations and regulatory quality standards work to undermine the reliability of organic food claims substantiated by testing of samples intercepted in the marketplace (Harker, 2004).

Market supply studies may become more scientifically defensible in the future. Organically produced foods have grown in popularity in the past few decades, are now subject to well-defined production standards, and have gained distribution in high-volume supermarkets. In many cases, organic produce has been picked at similar levels of ripeness, and processed and marketed in systems similar to conventional produce. Indeed, some farms are growing organic and conventional produce on the same types of farmland, are planting and harvesting at about the same time, and are handling produce in similar ways. Both organic and conventionally produced fruits and vegetables must adhere to the retailer's internal quality standards. Future market-based supply studies will provide more reliable comparative data to the extent that quality control, regulatory, and certification programs enhance the traceability of both organic foods and conventional foods to their source and allow access to more detailed information on where and how the food was produced, stored, and shipped to retail markets.

Question: Do fruits and vegetables grown organically in a certain geographical and climactic area have higher organoleptic scores than the "same" fruits and vegetables grown conventionally in the same geographical and climatic area?

The answer to this question also is **SOMETIMES,** but it is important to make sure that the tested samples are well matched.

Woese et al. offered the following critique of these kinds of surveys (Woese et al., 1997). Products are taken from selected organic farms, and neighboring conventional or integrated farms are chosen in order to make sure that the climate and weather are the same and that soil types are reasonably matched. Even when weather and soil type are properly matched, other differences may exist, such as plant genetics, the effectiveness of irrigation practices, and harvest timing. For these reasons, it is difficult to select truly matched-pairs of organic and conventionally farmed fields where the differences in organoleptic food quality can be attributed solely to the unique characteristics of organic production. Nonetheless, this experimental design is currently the best available for evaluating differences between organic and conventional foods.

Scientists from Washington State University (WSU) pick strawberries, in 2005, for a study comparing organic and conventional fruit quality.

Most published surveys of this type provide limited information on soils, climate, and farming systems and the accuracy of reported information typically cannot be verified. Many published survey studies were found to be agriculturally invalid (Heaton, 2001). An organic system must be in place for three years to build the soil and achieve "organic" status. Heaton considered invalid those studies that combined the crop results from two years of transition with those from the first year of certifiable organic stewardship.

Question: Do fruits and vegetables grown by different cultural practices show distinctive differences in organoleptic quality and, if so, to which specific factors and cultural practices can these differences be attributed?

Cultivation tests and field trials are the most effective means of learning the effects of specific cultural practices. Cultivation tests try to determine whether there is a linkage between a given farming practice and one or more organoleptic qualities. In such studies, scientists usually alter only one variable at a time, in the hope that such a study design will make it possible to isolate specific linkages. Cultivation tests attempt to determine whether food harvested from different forms of production show distinctive differences in organoleptic quality and, if so, which factors and production methods account for these differences. Nonetheless, Woese et al. expressed some valid reservations about these kind of studies (Woese et al., 1997). For example, the results of these studies only apply to specific locations and specific management practices, although some generalizations may be justified.

It is important to remember that there is considerable diversity within organic management systems and that an organic farmer's level of skill and experience often plays a large role in food product quality. In addition, different situations and different production seasons can require different practices. Different practices can have specific effects on food quality. Likewise, conventional management practices also have evolved over the years, and continue to do so, and include more and more sustainable and eco-friendly practices. Experience and skill levels also matter greatly on conventional farms. For example, data compiled by the U.S. Department of Agriculture's Economic Research

An organic tomato farm in Taiwan uses an advance trellis system to assure good air movement throughout the crop canopy, in order to reduce plant disease losses. Such trellis systmes can also impact taste by altering the solar radiation reaching fruits.

Service (ERS) show that for many crops, the most successful 10% of farmers have per bushel, or per unit, production costs one-third or less than the costs on the 10% of farms with the highest cost structures (ERS, 2004). ERS points to management skills and experience as one of the most important factors driving differences in costs. Management skill and experience is probably even more important on organic farms than conventional ones, since organic farms depend so heavily on a host of farming-system-based preventive practices, while conventional farmers tend to rely more heavily on the purchase of off-farm inputs to deal with pests or soil fertility-related production problems.

We think of the taste of food as being something that only we humans can appreciate. However, several studies have used experimental animals as the "tasters", by giving hens, rats, or mice free-choice access to organic foods and conventionally grown foods and measuring how much of each type of food they consume. Woese et al. concluded from their review of food consumption behavior studies that "animals distinguish between the foods on offer from the various agricultural systems and almost exclusively prefer organic produce" (Woese et al., 1997).

III. LITERATURE REVIEWS ON THE COMPARATIVE TASTE OF ORGANIC AND CONVENTIONAL FOODS

In a widely cited study conducted in the late 1980s in Israel, Basker used tasters who had some experience in taste panel procedures in the hope of minimizing panelist subjectivity (Basker, 1992). Overall, he produced 460 assessments of 29 samples covering five organic and conventional fruits and four vegetables. In the end, he found no significant pattern of preference between organic and conventional products. However, after analysis, he discovered that the fruits and vegetables were not all at the same stage of ripeness, which might seriously affect their taste, and thus the results of the experiment. In addition, scant information was reported regarding the source or production systems used to grow the foods included in this study. Hence it is not known how representative these foods were of high quality organic or conventional foods.

Samples of conventional and organic strawberries ready for a taste panel at Washington State University. Panels in both 2005 and 2006 preferrred the organic strawberries over the conventionally-grown fruit.

Woese et al. published an extensive literature review for the German Federal Institute for Consumer Health Protection and Veterinary Medicine in which they summarized and evaluated the results from more than 150 investigations comparing the quality of conventionally and organically produced food, or of foods produced with the aid of different fertilization systems (Woese et al., 1995). In 1997, a comprehensive summary of this work was published in an English language journal (Woese et al., 1997). Most of the studies evaluated were investigations of concentrations of desirable and undesirable ingredients, pesticide residues, and contaminants, sensory analyses, and feed experiments with animals. Nutritional studies in humans were reviewed, as were novel, holistic methods of analysis (for example, the ascending-imaging method, copper chloride crystallization and ultraweak photon emissions; these methods are not generally used or understood by U.S. scientists).

Despite great variability in the types of studies reviewed, some quality differences in food produced using conventional and organic farming methods were identified (Woese et al., 1997). These quality differences include a lower protein content in organic wheat, leading to an undesirable impact on baking quality; a desirable trend toward higher Vitamin C and lower nitrate values in organic potatoes related to use of manure rather than mineral fertilization; much lower nitrate levels in organic leaf, root, and tuber vegetables; and higher dry matter and a trend toward slightly more Vitamin C, particularly in leaf vegetables (lettuce, cabbage, spinach, and chard). There was no clear trend in sensory properties between organic and conventional vegetables. However, food preference

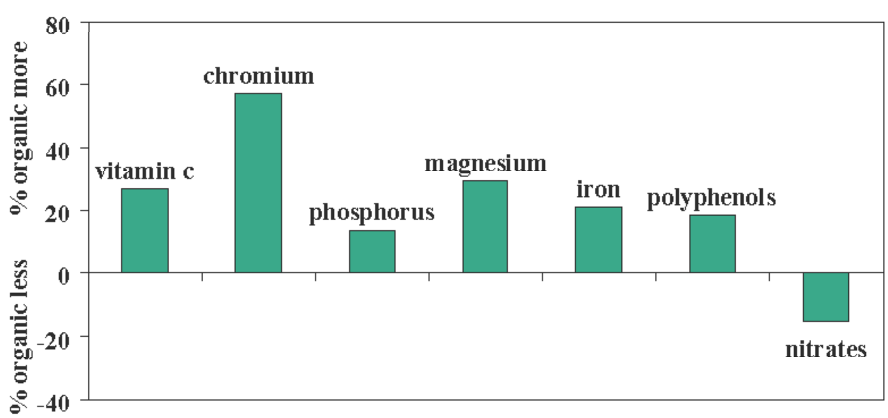


Figure 1. Organic compared to conventional crops. Percent difference in nutrient content, selected nutrients. V. Worthingon, 1998

studies in several species of animals (hens, mice, and rats) showed a significant and consistent preference for organic produce.

Alföldi et al. summarized the published literature on differences between organic and other management systems (Alföldi et al., 1998). Of seven studies comparing taste with organic management versus conventional management, they judged that there was positive impact of organic management in two: apples in Austria (Velimirov et al., 1995) and potatoes in Finland (Varis et al., 1996). In the other five studies no differences were found.

Worthington reviewed the literature produced over the last 50 years comparing the nutritional quality of organic with conventional crops (Worthington, 1998). She concluded that the evidence for nutritional superiority of organically versus conventionally grown crops based on nutrient content alone is suggestive, though not conclusive. An overall trend showed higher nutrient content in organically grown crops, possibly due to lower water content in organic crops. Only vitamin C and nitrates were clearly affected by fertilization method, with higher levels of vitamin C and lower levels of nitrates occurring in organically grown crops. Protein quality may be better in organically grown crops as well. Insufficient or conflicting data exist for other nutrients. Evidence from farm animals and controlled animal feeding studies strongly suggested that organically grown crops are superior to conventionally grown crops for promoting health. Worthington did not address taste or other sensory characteristics.

Worthington surveyed existing literature comparing nutrient content of organic and conventional crops, using a unique statistical approach to identify significant differences and trends in the data (Worthington, 2001). Published comparative measurements of organic and conventional nutrient content were entered into a database for calculation. For each organic-to-conventional comparison, a percent difference was calculated: (organic - conventional)/conventional x 100. For nutrients where there were adequate data, the Wilcoxon signed-rank test was used to identify statistically significant differences in nutrient content. For the most frequently studied vegetables, mean percent difference values were also calculated for each nutrient, by study and by vegetable. According to her analysis, which did not consider differences in moisture content, organic crops contained significantly more vitamin C, iron, magnesium, and phosphorus and significantly less nitrates than conventional crops. There were non-significant trends showing less protein, but better quality protein in organic foods compared to conventional foods, as well as a higher content of nutritionally significant minerals and lower amounts of some heavy metals. Worthington did not review sensory data (Worthington, 2001).

The Food and Agriculture Organization of the United Nations (FAO, 2000) summarized the sensory differences as follows: "Many sensory analysis studies have been carried out to investigate differences in selected organoleptic parameters between organically and conventionally grown products, and on the whole these indicate that there is no clear difference between the two (Conklin and Thompson, 1993; Woese et al., 1997). Certain studies have shown significant differences for selected products, as in the case of the sensory differences between organically and conventionally grown apples of the Golden Delicious variety. The organically grown apples were found to be firmer and received higher taste scores than conventionally grown apples. The content of flavanoids in the organic apples was higher (Weibel et al., 2000). Another study showed that organic tomatoes were sweeter and conventional carrots had more 'carrot taste' (Haglund and Johansson, 1995)."

Brandt and Mølgaard examined possible differences between organic and conventional plant products, with emphasis on possible human health effects (Brandt and Mølgaard, 2001). They concluded that nutritionally important differences relating to contents of minerals, vitamins, proteins and carbohydrates are not likely, primarily since none of these are deficient in typical First World diets, nor are present levels of pesticide residues in conventional products a cause for concern. However, they expressed their belief that contents of many plant defense-related secondary metabolites in the diet are lower than optimal for human health. There is ample, but circumstantial, evidence that, on average, organic vegetables and fruits most likely contain more of these secondary metabolites than conventional ones. For a detailed analysis, see the Organic Center's "State of Science Review" on antioxidants in organic and conventional foods (Benbrook, 2005). Thus it is possible that organic plant foods may in fact benefit human health more than the corresponding conventional ones. The authors did not investigate taste effects, other than to mention that many secondary metabolites act as anti-nutrients that can retard growth and reduce the bioavailability of nutrients in food.

The Soil Association in the United Kingdom published two reports in 2001. Fookes focused on general allegations made against organic agriculture (which did not involve sensory quality of the foods) (Fookes, 2001). Heaton's review is relevant to this review and includes a specific section on taste (Section 3.4.3) (Heaton, 2001). According to Heaton:

> "Although differences in taste are difficult to confirm in controlled studies, of the six agriculturally valid studies reviewed here, five reported better taste qualities in organic produce:
>
> - **Basker** - Inconsistent and non-significant differences in the taste of nine different fruits and vegetables (Basker, 1992).
> - **Dlouhy** - Better taste in organically grown, peeled potatoes after four months storage (Dlouhy, 1981).
> - **Hogstad et al.** - Better total flavour strength, sweet taste and sugar content in organically grown carrots (Hogstad et al., 1997).
> - **Reganold et al.** - Organically grown apples were sweeter and less tart (Reganold et al., 2001).
> - **Rembialkowska** - Taste and smell better in organically grown raw carrots and sauerkraut (cabbage) (Rembialkowska, 2000).
> - **Weibel et al.** – '15 per cent better taste in organic apples' (Weibel et al., 2000)."

Kumpulainen reviewed the literature and found no taste difference in potatoes, lettuce, green beans, broccoli and spinach (Kumpulainen, 2001). He noted that most of the studies showing differences in flavor were studies of leafy vegetables.

Bordeleau et al. reviewed sensory comparisons and earlier reviews of organic and conventional foods (Bordeleau et al., 2002). They concluded that, in general, there is no trend of better taste in organic fruits or vegetables. In vegetables such as carrots, where high water content is preferred, organic vegetables may rate lower in preference tests.

Bourn and Prescott provide a detailed and extensive analysis of the sensory qualities of organically and conventionally grown food (Bourn and Prescott, 2002). After reciting the many issues with sensory evaluation techniques – discrimination tests, descriptive analysis techniques, and preference/acceptability measures – they concluded that there is yet to be convincing evidence that organic produce differs in sensory terms from conventional produce, let alone that there is any taste advantage.

Tauscher et al. evaluated food produced by different methods and found a slight advantage for organically grown produce (Tauscher et al., 2003).

IV. NEW RESEARCH FINDINGS ON ORGANOLEPTIC FOOD QUALITY

A number of studies have appeared in the literature in the last five years that provide new insights into differences in organoleptic food quality.

Apples

Weibel et al. (Weibel et al., 2000) analyzed Golden Delicious apples from five pairs of a biologic (organic) and a neighboring integrated fruit farm in Switzerland. Organic orchards were less than a kilometer away from the matched conventional orchard. No other details of production are described. Organic apples had significantly firmer fruit flesh (14% at harvest; 12% higher after 40-43 days of cold storage) and 19% higher phenolic content (mainly flavanols) than integrated apples. Trained taste panelists gave organic apples 15% higher taste marks.

Integrated production has essentially eliminated "conventional production" of fruit in Switzerland and now accounts for 94% of apple production. Five percent of Swiss apples are grown according to organic guidelines (Bertschinger et al., 2002). Four different apple varieties with three block replicates were produced in Switzerland under either organic or integrated management systems on a single plot of land. Yields and the proportion of apples meeting market quality standards were lower under organic management but the fruit was firmer, sweeter, and less acidic (Bertschinger et al., 2002).

Reig et al. compared the quality of organically and conventionally grown Fuji and Golden Delicious apples in Lleida, Spain (Reig et al., 2006). No other details on the farms or management practices were disclosed. Golden Delicious apples were harvested at two different dates and the differences in total antioxidant activity were determined at harvest and related to the changes in color, firmness, acidity and soluble solids content (SSC). No differences in antioxidant activity were found between organic and non-organic Golden Delicious apples at harvest. However, significant differences in quality were found. Organic Fuji apples showed a significant increase in firmness, acidity, SSC, and were brighter and more yellow based on the readings from a HunterLab Colormeter. Organically grown Golden Delicious apples exhibited the same increases but only when the fruit were picked at a more mature stage (2nd harvest date). At both harvest dates, organic Golden Delicious apples were significantly less mature (lower starch index) than conventional Golden Delicious, but organic and conventional Fuji apples did not differ in terms of maturity. Collectively these results showed that organic management may delay on-tree fruit ripening and also improve fruit eating quality.

Four apple cultivars were grown in experimental organic or integrated orchards at Debrecen University in Hungary (Róth et al., 2004). Acoustic stiffness (a non-destructive measure of firmness) was used to measure the same apples before and after six months of cold storage. There were no significant differences between the growing systems. The Liberty cultivar, a scab-resistant cultivar popular for organic orchards, had the least change in firmness during storage.

Róth et al. examined whether there was a difference in the quality (texture, taste, flavor) and post-harvest behavior of apples from integrated versus organic orchards in three different regions of Belgium (Róth et al., 2006). In each region organic and integrated orchards had the same climatic and soil capabilities. Apples were harvested at the end of September in 2004 and stored in air and also under ULO (ultralow oxygen) conditions (1% O_2, 2.5 % CO_2) for 6 months. Acoustic stiffness (firmness), soluble solids content, acid content, sugar content and the aroma profile were studied. Quality parameters were analyzed immediately after harvest and after storage. At both times an additional shelf-life experiment (14 days) was carried out, simulating retail store conditions. There was a considerable softening during storage in air and a reduction in shelf-life, but not under controlled atmosphere conditions. Apples coming from different regions and different production systems did not differ in the studied parameters. Freshly harvested apples had high malic acid, quinic acid, and sucrose contents and were clearly different from stored apples that had high glucose and citric acid contents. Fresh apples had a different aroma profile compared with apples that had been on the shelf for 14 days, except for air-stored apples immediately after storage. The volatile compound responsible for the typical apple aroma, (2-methylbutyl-acetate), had the highest relative abundance at harvest, after shelf-life and storage in air. The authors concluded that the effect of storage condition is much greater than that of the production systems on the quality of apples.

Organic management yielded sweeter and less tart Golden Delicious apples in Washington State compared with conventional and integrated systems. The apples were grown in four replicate plots for each management system in a randomized complete block design (Reganold et al., 2001).

Peck studied Gala apples grown during the ninth and tenth growing seasons under organic, integrated, or conventional management in the Yakima Valley of Washington State (Peck, 2004). Organic apples had 6-10 Newtons (a Newton -- "N" -- is a measure of force) units higher flesh firmness than conventional apples, and 4-7 N units higher firmness than integrated apples. Additionally, consumers consistently rated organic apples to be firmer and to have better textural properties. Few consistent results were found for fruit flavor as measured by soluble solids concentration or titratable acidity, and this was also reflected in consumer panels. These Gala apples were slightly smaller in some years but were as firm, or firmer, and had consistently superior storability compared to conventionally grown apples (Peck et al., 2006). After six months of controlled atmosphere storage, only 10% of the organic apples failed to meet the minimum firmness standard, compared to 36% of conventional management apples and 54% of integrated management apples.

Bordeleau et al. compared specific internal and external quality parameters for organic and conventional Golden Delicious apples purchased in shops in Denmark (Bordeleau et al., 2002). The conventional apples were 24% bigger, averaging 156.5 mL in volume compared to 126.7 mL for the organic apples. Soluble solids (sugars, Brix) and acid levels did not differ significantly but the ratio of Brix to acid was slightly higher in the organic apples. There was no difference in flesh firmness in this market survey.

Strawberries

Ecologically cultivated strawberries and conventionally cultivated strawberries were grown in adjacent plots in Spain under identical environmental conditions (Cayuela et al., 1997). The conventional plots had a 76% greater yield. The ecologically grown fruit had superior quality to the conventionally grown fruit, showing a more intense color, higher sugar and dry matter contents, and better organoleptic characteristics. Ecologically grown fruits had a higher resistance to deterioration during simulated marketing conditions, and thus better keeping quality. Organic strawberries grown in California were slightly smaller but sweeter, better-looking, and preferred by consumers compared to conventionally grown strawberries (Andrews and Reganold, 2006).

Potatoes

Potatoes were among the earliest organically produced vegetables subjected to comparative evaluation. Of 22 published studies that evaluated the nutritional value and/or sensory properties of potatoes from conventional and organic cultivation, or from different fertilization systems, only six compared the sensory qualities of potatoes using trained panelists. Some sensory differences were noted between different kinds of potatoes but no clear statements could be made on the whole in favor of one kind of cultivation or another (Woese et al., 1997).

Heaton (2001) considered three of these publications to be "invalid agriculturally" because the results were obtained with "organic" potatoes grown on soil with less than three years of organic cultivation (Dlouhy, 1977; Pettersson, 1977; Pettersson, 1978; Svec et al., 1976). He considered the second report of Dlouhy (Dlouhy, 1981) to be "agriculturally valid"; Dlouhy (Dlouhy, 1981) reported better taste in organically grown peeled potatoes after four months of storage. Heaton did not critique all six studies evaluated by Woese et al. (1997).

The most recently published comparative sensory testing of organic and conventional potatoes does not improve our understanding of the relative taste of organic potatoes. In research at Ohio State University, triangle tests were used to determine if taste panelists could distinguish cooked wedges of potatoes grown organically, either with or without compost, and conventionally (Wszelaki et al., 2005). When the skin remained on the potatoes, panelists detected differences between conventional potatoes and organic potatoes, regardless of soil treatment. However, they did not distinguish between organic treatments with or without compost when samples contained skin, or between any treatments if wedges were peeled prior to preparation and presentation.

Tomatoes

Organic and conventional tomatoes grown in Florida in December 2003 and January 2005 were harvested at the breaker stage and ripened at 20ºC. When

tomatoes were determined to be fully ripe by visual inspection, samples were collected for quality analyses (color, firmness, total soluble solids, pH and total acidity). In each year, no significant differences in color or total soluble solids were detected between treatments. In 2003, total acidity was the only quality parameter that differed significantly (0.40% vs. 0.44% total acidity) between conventional and organic fruit, respectivey. In 2005, conventional tomatoes had significantly higher soluble solids (4.4 vs. 4.0 °Brix) and were firmer (2.5 mm vs. 3.4 mm deformation) than organic fruit. Sensory evaluation (duo-trio test with balanced reference) was conducted in 2005 to determine whether consumers could perceive a difference between tomatoes grown conventionally or organically. Panelists could perceive a difference between conventional and organic tomatoes by smell or taste with high reliability (P<0.001). Organic tomatoes were perceived by some of the panelist to be softer, and were preferred because of their taste, flavor, texture and juiciness. Alternatively, conventional tomatoes were described as "not as ripe", "dry", and having "less aroma" (McCollum et al., 2005).

Heeb et al. compared conventional tomatoes fertilized with varying ratios of nitrate and ammonium nitrogen with organically grown tomatoes fertilized with manure or grass and clover mulch. Significantly higher scores were achieved for sweetness, acidity, flavor, and acceptance for the tomatoes grown with the organic or the ammonium-dominated treatments compared with the tomatoes grown with the nitrate-dominated nutrient solution. They suggest that tomato plants supplied with reduced nitrogen levels, or slower-release forms such as ammonium or organic nitrogen have improved tomato fruit taste (Heeb et al., 2005).

Organic catsups contained significantly more of the carotenoid lycopene than conventional catsups (Ishida and Chapman, 2004). The authors concluded that organic catsups could typically be distinguished from conventional catsups by comparing the deepness of the catsups' red color. Unfortunately no information was provided on the tomato cultivars used to make the catsups. Different tomato cultivars can have different lycopene levels.

Other vegetables

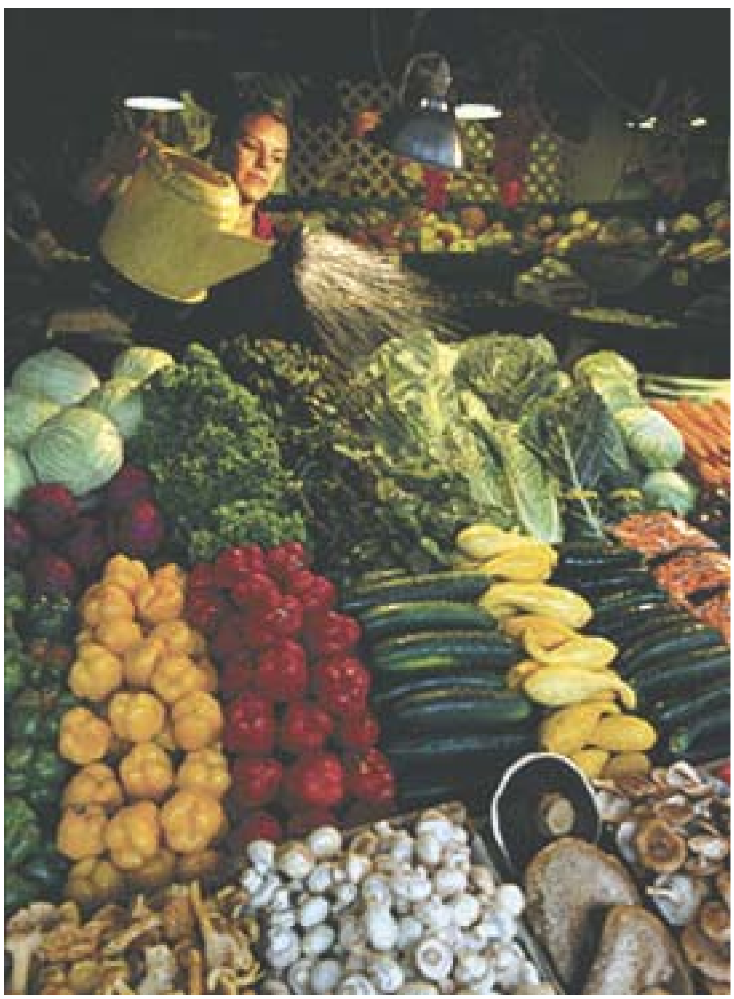
Succop and Newman grew greenhouse basil plants fertilized with nutrient solutions derived from either organic or conventional salt-based fertilizer sources. Two-thirds of trained tasters could differentiate between the organically fertilized basil and the conventionally fertilized basil, but they had no taste preference (Succop and Newman, 2004).

Taiwo et al. grew okro (okra) in the green house with organic fertilizer (composted sawdust and decayed chicken manure) or chemical fertilizer. Soups produced from the harvested okro fruits were subjected to sensory evaluation tests. Soups made with organically fertilized okro were judged more acceptable (Taiwo et al., 2002).

V. CONCLUSIONS

Several conclusions can be drawn from published research on the organoleptic quality of organic food compared to conventional food:

- Most studies report no consistent or significant differences in taste and organoleptic quality.
- Of those studies reporting differences, the vast majority conclude that organic produce is superior or preferred when compared to conventional produce, or produce grown using "integrated" production systems.
- It is extremely rare that the taste of organically grown fruits and vegetables is found to be poorer than that of fruits and vegetables grown conventionally or with integrated techniques.



Organic apples especially are usually preferred over conventional or integrated apples; this finding has been replicated in closely controlled comparisons, which increases our confidence that organic apples may truly taste better than conventional apples. In addition, several studies have reported that organic produce stores better and has longer shelf life than conventional produce. This finding appears to be linked to the lower level of nitrate that is usually found in organic produce.

Future Challenges that Require Further Research

Many studies have found that lower yields, better taste, more Vitamin C, and higher antioxidant levels in organic fruits and vegetables are correlated with lower levels of readily available nitrogen. A major focus on many organic farms is increasing the supply of nitrogen for crops, in order to narrow the differences in yields between conventional and organic production systems. Will success in increasing the nitrogen available to plants on organic farms erase the quality advantages of organic produce? Stated differently, are lower yields nature's "quid pro quo" for the quality advantages of organic produce?

Organic apples generally are firmer and have superior storage properties. Organic potatoes generally contain more ascorbic acid (Vitamin C) (Hajslova et al., 2005). Both of these phenomena are associated with lower plant tissue nitrate levels and correspondingly slower growth rates and greater physiological maturity at harvest. This highlights a major difference between organic management and conventional management: the nitrogen economy of the plant. Nitrogen economy has both a quantitative aspect – the amount of nitrogen applied – and a qualitative aspect – the source(s) of that nitrogen.

Organic cultivation frequently is a low-nitrogen input system. This probably is responsible for the generally lower yields of organically cultivated produce, even by technically capable organic farm managers. For example, organic citrus cultivation is expanding in Corsica, but yields can be 50% less than under traditional cultivation. Berghman et al. found that the low yields were related to inadequate nitrogen assimilation by roots from plant compost (Berghman et al., 1999). To achieve satisfactory yields it was necessary to use two complementary nitrogen-source products: seabird guano rich in soluble nitrogen and castor oil cake rich in organic carbon.

These workers established that providing more nitrogen, and more timely applications of nitrogen, increased total leaf nitrogen levels and yields of organic citrus trees to the normal range observed on conventional farms. It would have been very useful to determine if the tissue nitrate level in the organic fruit increased to the same level as in conventional fruit.

Field windrow turning of composted cattle manure with a Brown Bear auger turner.

It is established that high levels of nitrogen fertilizer applied in conventional cultivation of apples can have negative effects on fruit color and storage quality (Saitoh, 1995). Increasing the application rates of nitrogen by using more composted manure in organic cultivation has been shown to better meet the nitrogen demands of organic corn and tomato crops, and also to increase yields (Poudel et al., 2002). Unfortunately, the resulting corn and tomatoes were not subjected to organoleptic testing or nitrate analysis.

VI. RESEARCH RECOMMENDATIONS

Economically, organic fruit growing is comparatively healthy, but it depends on receiving a higher farm gate price for the product (Weibel et al., 2004). Organic management systems have higher costs due to additional expenses in composting, planting, cover crop management, and pest control. As organic produce becomes more widely available, it is likely that economic pressures will force down prices for organic produce. As Weibel et al. have commented, "this can/does feed back to the growers resulting in 'substitutional' production with disease-sensitive and pest-sensitive orchards managed with intensive 'organic' spray and fertilization programs. This certainly does not correspond with either the original concept of organic farming or with expectations of organic consumers." (Weibel et al., 2004)

The current rapid growth in the scale and technological sophistication of organic production will likely improve freshness and product choice for many fruits and vegetables, but it could also impair organoleptic food quality for the reasons considered above, and possibly because of other "food system" issues. For example, it will be a major challenge to sustain high levels of organoleptic quality in organic fruits and vegetables if reliance grows on imported produce that has to be shipped halfway around the world. Valid market surveys of food quality as a function of production system become more difficult when locally-grown produce that is harvested ripe and marketed immediately is compared to produce picked unripe and shipped thousands of miles, or produce stored for months prior to retail distribution. Several researchers have concluded that maturity at harvest and storage methods generally trump production systems with respect to organoleptic quality.

Evidence in support of superior taste in organic produce is strongest for apples. However, this superiority is found in **most** rigorously controlled studies but not in **all**. The critical question is why the effect is not universal or predictable.

Organic management involves diverse practices applied as specific solutions to specific on-farm problems. "Cultivation studies" are the tool to study the impact of these practices. Evaluations of specific organic management practices should include measurement of tissue nitrate levels and organoleptic quality, including product firmness and taste testing.

Market-oriented supply studies can be useful monitoring tools to gauge the relative organoleptic quality of organic and conventional produce available to the consumer in a given market at a given point in time. Regular periodic assessments can provide useful public information about trends in quality.

Survey research, where neighboring farms or experimental plots are compared, should assess alternate organic or conventional practices, in order to reduce the number of variables impacting study results. For example, Lombardia-Boccia studied the influence of different agronomic practices on yellow plums grown conventionally and organically on the same farm (Lombardi-Boccia et al., 2004). The conventional plums were grown on tilled soil. Three organic cultivations were performed: tilled soil, soil covered with trifolium (clover), and soil covered with natural meadow. Ascorbic acid, alpha-, gamma-tocopherols, and beta-carotene levels were higher in organic plums grown on soil covered with natural meadow. Carbonaro et al. studied peaches and pears organically grown on three different ground covers: subterranean clover, spontaneous weed cover, or tilled soil (Carbonaro and Mattera, 2001; Carbonaro et al., 2002). Conventional peaches and pears were produced on tilled ground. All organic peach samples showed a highly significant ($P < 0.001$) increase in polyphenols compared with conventional peaches, while, of the three organic pear samples, the weed cover and tilled samples displayed an increased polyphenol content with respect to the conventionally grown sample ($P < 0.05$). None of these studies included organoleptic testing.

The vast majority of research on the impact of harvest timing and storage technology on organoleptic food quality has been conducted with conventional foods. Research is needed to develop practices to enhance the organoleptic quality of organic fruit and vegetable crops at harvest. Published research suggests that organic fruits and vegetables respond differently to storage conditions than do conventional foods. Research is needed on optimizing storage of organic produce to retain its quality for as long as possible as food makes it way from the farm to the consumer.

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