Organic versus Conventionally Grown Produce: Quality Differences, and Guidelines for Comparison Studies

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Abstract. Organic and conventional fruits and vegetables contain compounds with important human health promoting effects. Whether fruits and vegetables grown via organic versus conventional production systems are superior in taste and nutrition, at present, is difficult to say with complete certainty. To ascertain possible quality differences and develop a definitive database, direct comparative studies of organic vs. conventional produce require following rigorous guidelines which include 1) appropriate study approaches (retail market vs. farm vs. research center studies), and 2) standardized preharvest production site, harvest procedural, postharvest handling, and analytical methodology constraints.

Worldwide demand for organic food products continues to expand rapidly especially in developed countries. Demand is fueled in part by increased consumer awareness of the link between health and diet, highly publicized food safety cases such as the incidence of E. coli-contaminated produce and the perceived environmental benefits of organically grown foods. More and more consumers are thus prepared to pay premium prices for organic produce thanks to the perception that organic products are safe, clean, more nutritious, healthy, better-tasting and environmentally friendly than conventionally grown foods (FAO, 2000; Saba and Messina, 2003). Accordingly, the debate over the quality and safety of organic versus conventionally grown food has intensified and is common with any debate involving public perception, proponents of either side have frequently cited scientific studies as evidence in support of their claims. However, as a result of the methods of sampling and different cultivation systems employed in the studies, it is difficult to reach meaningful conclusions. In most cases, it is clear that variability is one of the main factors affecting the quality of organic crops but found little or no hard evidence of differences in vitamin content, and no significant differences with respect to minerals or heavy metals could be identified. There was a slight trend towards lower protein concentrations but of higher biological value in organic versus conventionally grown crops. Evidence of quality differences has been anything but corroborative. In the review comparing organic to conventionally grown foods (Asami et al., 2003; Warman and Harvard, 1997; Worthington, 2001). Many of the studies in these reviews have been carried out to compare the nutritional quality of organically grown foods with those produced by conventional methods. The conclusions of these reviews concerning food quality claims have been anything but corroborative. In the review comparing organic to conventionally grown foods (Asami et al., 2003; Warman and Harvard, 1997) lamented “what is noticeable, as in the case with apples, that differences between varieties had a far greater influence on fruit quality attributes than did the different cultivation systems.” Excerpts from some of these reviews clearly highlight the differences in their conclusions. For instance, Worthington (2001) concluded that organic crops contained significantly more vitamin C, iron, magnesium and phosphorus and significantly less protein, nitrates, and lower amounts of heavy metals than conventional crops. Similarly, Rembialkowska (2003) concluded that although organic crops had less protein than conventionally grown crops, the protein was of higher quality. They further conclude that organic crops contain higher total sugars, more vitamin C, calcium, iron, magnesium, phosphorus, potassium, less protein and nitrates, no clear impact on β-carotene, and have a better taste, smell, shelf life, and a more positive impact on animal and human health. In contrast, Magkos et al. (2003) stated that organically grown crops have higher dry matter and less moisture than conventionally grown crops but found little or no hard differences in vitamin content.
of certain nutrients, especially vitamin C, some minerals, and some polyphenols (naturally occurring antioxidants that may help the immune system) are higher in organically grown crops." Avery, on the other hand remarked that "the "...corn study did not involve proper statistical analyses... the data came from a single year, and a single farm". Additionally, the organic corn was produced on clay soil versus the conventional corn produce on sandy soil. Soil type alone can have a very significant effect in the mineral and phytonutrient content of produce even when the production practice is the same (Lester and Eischen, 1996; Lester and Crosby, 2003). As a result of these concerns the Organic Trade Association has created the nonprofit Center of Organic Education and Promotion to oversee research that could verify whether organic foods do provide greater health benefits than conventional food. DiMatteo added that "we want to take the knowledge to the next level until there is a solid body of research that we can stand behind. There needs to be more rigor."

But what about the consumer, why do they have trust issues concerning organic food? Considerations as to why consumers choose organic vs. conventionally grown food will be helpful to plant scientists in focusing their comparison studies (Conklin and Thompson, 1993). Solid scientific evidence and expert knowledge can only go so far in settling the debate over organic versus conventional produce quality. Innate consumer attitudes and beliefs are also important in shaping their perception of whether organic is better than conventionally grown produce (Saba and Messina, 2003). An analysis of the level of trust between people who consume organic produce on a daily basis (high consumers) and those who do so only occasionally (or not at all) reveals that both groups have a genuine mistrust or concern over pesticide use on food production (Fig. 1). Both high- and non-consumers of organic foods believe that 1) pesticides are not responsibly dealt with, 2) that risks and dangers to human beings from pesticides are underrated, and 3) that fruits and vegetables produced without pesticides are healthier. With these findings, it would appear that the public would, en masse, consume organic produce. However, only 23% of the U.S. population consume organic produce on a daily basis (www.organicconsumers.org). Understanding consumer concerns over organic as well as conventionally grown produce will help scientists (specifically horticulturists) in designing experiments that address those key issues without compromising the overall scientific validity of the endeavor. Experiments that take into account consumer attitudes and beliefs toward consumption of organic fruits and vegetables will probably shed more light on the validity of claims from both sides of the debate. Both high- and non-consumers of organic foods almost equally believe that organic produce is expensive not always available, and that organic foods could be healthier and more environmentally friendly (Fig. 2). However, non-consumers of organic food are not so convinced that organic fruits and vegetables taste better or are more nutritious than conventionally grown produce. Contrasting organic vs. conventionally grown produce by specifically addressing taste and nutrient content should be the focus of the much needed rigor that scientific studies should consider.

However, direct comparative studies of organic vs. conventional produce are difficult to design and execute due to unpredictable and uncontrollable production variables such as year-to-year weather variation (Magkos et al., 2003). But implementation of appropriate statistical design and manipulation can have a significant role in controlling these extraneous effects. All comparative studies will fall into one of three basic categories (Table 1). The ideal study would incorporate both "farm" and research center study approaches. But the real issue in constructing a study that focuses on...
To eat organic fruits and vegetables is good

By eating organic fruits and vegetables I get a health food

By eating organic fruits and vegetables I get a food that is environmentally friendly

By eating organic fruits and vegetables I get a food that has a better taste

By eating organic fruits and vegetables I get a food that is more nutritious

To eat organic fruits and vegetables means to pay more

To eat organic fruits and vegetables means to have difficulties finding them in the market

Fig. 2. Attitudes and beliefs of organic foods; abbreviated figure of Saba and Messina (2003).

Table 1. Study approaches used in comparison of organically and conventionally grown produce. (Magkos et al., 2003).

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<tr>
<th>Method</th>
<th>Description</th>
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<td>Retail market studies</td>
<td>They are relatively small in number. They refer to the product as it reaches the consumer. The collection method is simple and fast. The certification of the production method is impossible. Pseudo-organic and pseudo-conventional products may be included. They can identify differences in the chemical composition of the product. They cannot conclude whether the differences are due to the production method.</td>
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<td>Farm studies</td>
<td>They record the exact conditions under which the food is produced. Sample size is large enough. Environmental conditions (climate, soil type, etc.) can be controlled by the selection of neighboring farms. Information regarding the production method comes directly from the farmers. The selection of farms that accurately and realistically reflect the two production systems can be difficult.</td>
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<td>Research center studies</td>
<td>They are considered the most accurate and valid method of comparison. They can definitively identify if there are any differences in the nutrient composition of the food products. They can identify the factors that are responsible for nutrient differences. Sample size can be limited. Results cannot be generalized as reflective of the commercial production system.</td>
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nutrient content and taste which incorporate critical preharvest, harvest and postharvest constraints (Table 2); is to reduce the influence of production, handling, and storage variables on the nutrient content of foods (Goldman et al., 1999).

An example of a study with the comparison constraints listed in Table 2 in place, is a 3-year organic vs. conventionally grown grapefruit (Citrus paradisi) study that compares taste preferences and nutritional/fruit quality parameters (Table 3), which was established in 2003 at the USDA–Agricultural Research Service, Subtropical Agricultural Research Center, Weslaco, Texas. Data from this preliminary study indicated that organic grapefruit was no different from conventionally grown grapefruit with respect to the concentrations of many of the fruit quality components (Table 4). Having more of a given compound, as was the case with lycopene in conventional grapefruit is a positive finding as it demonstrates that conventional ‘Rio Red’ fruit are more red than organically grown ‘Rio Red’ fruit. Similarly, increased levels of naringenin in organic fruit was a new and a positive finding; naringenin is a compound that significantly clears serum urea and creatinine concentrations, both highly associated with heart disease (Badary et al., 2005). Another positive finding for organic grapefruit was that fruit bergamottin content was significantly lower than in conventional grapefruit. Bergamottin interferes with the
Table 2 Preharvest, harvest and postharvest constraints used in comparison of organically and conventionally grown produce for nutrition and taste.

Preharvest
- Organic site must be certified as organic
- Identical soil textures throughout root growth profiles
- Determine soil quality (e.g. minerals, organic matter, cation exchange capacity)
- Identical previous cops
- Similar irrigation source, amounts, and scheduling
- Study sites should be as close as legally allowed by Organic standards
- Identical cultivars
- Same aged plants (e.g. fruit trees)
- Repeat study ≥ 3 years
- Repeat study by season if crop is harvested over multiple seasons
- Record all production inputs (e.g. fertilizers and mineral amounts, herbicides, insecticides)

Harvest
- Same method of harvesting
- Same size of fruit
- Same age of fruit
- Same time of day
- Same location on plant(s)
- Hold/transport identically

Postharvest
- Wash/clean identically
- Store for the same period of time
- Process under identical temperatures, humidity, and light (both intensity and quality) and time of day
- Use identical analytical analyses and methods.

Table 3. Standardized preharvest, harvest and postharvest constraints and analyses for establishing a taste and nutrition comparison study of organic vs. conventionally grown grapefruit.

Preharvest
- Three-year study
- Organic site is a highly profitable certified organic commercial orchard
- Conventional site is a highly profitable commercial orchard
- Both orchards are 15 years old
- Both orchards have been in continuous production for greater than 15 years
- Both orchards grow only ‘Rio Red’
- Orchards are 76.2 M apart
- Irrigation source: Rio Grande
- Soil texture: sandy loam
- Soil mineral, organic matter and cation exchange was determined prior to each harvest season.
- Production inputs were either organic or non-organic for each respective orchard
- A complete list of organic and non-organic inputs are documented

Harvest
- Harves were 1 Nov., 1 Jan., and 1 Mar. each year
- Fruit size was ‘medium’, 36-40 count, using a sizing ring
- Fruit were harvested by commercial harvesters
- Fruit were harvest from mid-canopy, just inside the canopy from each cardinal point
- Harvest time: 8:00 AM
- Fruit were packed in clean, commercial grapefruit shipping boxes to transport to the lab in an enclosed, climate-controlled van

Postharvest
- All fruit were washed in reverse osmosis running water, air dried in a climate-controlled room
- All fruit were juiced immediately under low light (to protect light sensitive compounds)
- All juice samples were stored at —80 °C

Analyses
- Fruit: weight, volume, specific gravity, peel thickness, external/internal color
- Juice: percent juice, pectin, sucrose, glucose, fructose, free and dihydroascorbic acid, pH, lycopene, soluble solids concentration, titratable acidity, NO3, total bergamottin, naringinin, N, P, K, Na, Ca, Mg, Fe, Mn, Cu, Cl, B, Zn
- Taste: untrained panel rated their preference based on a scale anchored by dislike extremely to like extremely from juice in translucent red cups to camouflage color differences
- Statistics: mixed model analyses with years treated as reps

Table 4. Preliminary findings (2 years data) from a taste and nutrition comparison study of organic vs. conventionally grown grapefruit.

Differences (significant)
- Organic > conventional: naringenin, and Mn, and Zn only in Nov. fruit,
- Organic < conventional: fruit weight, fruit volume, fruit specific gravity, peel thickness, soluble solids concentration, pH, lycopene, total bergamottin, taste, Na, and Mg, and K only in Nov. fruit
- No differences: Juice volume, juice specific gravity, pectin, sucrose, glucose, fructose, free and dihydroascorbic acid, titratable acidity, N, P, Fe, Cu, Cl, Ca, B, and NO3

absorption of certain drugs including lipid-lowering medications. This has prompted precautionary warnings on grapefruit consumption while under these medications (Fukuda et al., 2000).

Weibel et al., (2000) have similarly used standardized production, sampling, and processing protocols to show that organic apple internal fruit quality aspects were either similar or slightly better than conventional fruit. Additionally, they did not find significant differences in fruit total vitamin C content between the two production systems.

In conclusion, critics of organic vs. conventional produce comparisons for nutrition and taste will be quick to point out that one study does not define an industry. But the process to impose the scientific rigor, which has been called for by proponents and nonproponents of organic vs. conventional nutritional comparisons, has been delineated (Table 2). As more and more rigorous scientific studies are conducted and analyzed, we soon will be able to “verify what small-scale research may sug-
gest: organic food may provide greater health benefits than conventional food” (Katherine DiMatteo, Organic Trade association). And this benefit my not be due to antioxidants like carotenoids, but due to secondary plant metabolites (Brandt et al., 2004) like naringin. But claiming that organic produce is more or less tasty/nutritious than conventional produce is only part of the purpose of these comparisons. 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. This is one compelling reason for horticulturist to be involved in these scientific studies. Another compelling reason, in addition to helping consumers confidently decide whether or not to eat more organic vs. conventionally grown produce, is to assure the public that their wellness, and likely happiness is directly related to eating 400 g or more of fruits and vegetables daily.

**Literature Cited**


