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

Gene E. Lester

U.S. Department of Agriculture, Agricultural Research Service, Kika de la Garza Subtropical Agricultural Research Center, 2413 East Highway 83, Building 200, Weslaco, TX 78596

Additional index words. fruits, vegetables, production methods, research

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 data base, direct comparative studies of organic vs. conventional produce requires following rigorous guidelines which includes 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 friendlier 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 as is common with any debate involving public perception, proponents of either side have frequently cited scientific studies as evidence in support of their claims. As a result, numerous studies have sought to determine whether significant differences in yield and quality truly exist between organic versus conventionally grown foods (Asami et al., 2003; Baker et al., 2002; Blatt and McRae, 1998; Meier-Ploeger et al., 1989; Rembialkowska, 2004; Roinila et al., 2003; Warman and Harvard, 1997; Worthington, 2001). A common thread among these comparative studies is the huge variability (both magnitude and direction) in the available data. This complicates the task of interpreting the data and makes it difficult to reach meaningful conclusions. In most cases, it is clear that variability stems from the inability to control or standardize the basic environmental factors affecting plant development and yield such as soil physical, biological and chemical properties, rainfall, and radiation. Differences in crop nutrient and water management practices, pest and disease management, crops varieties grown, crop maturity and harvest dates, pre- and postharvest handling including storage, subsampling protocols, and processing meth-

odologies can individually and collectively contribute to the observed variability and opposing conclusions. Nonetheless, there is a wealth of information in the available data and with proper standardization, consistent conclusions may be extracted. The objective of this review is to highlight some of the inherent limitations of studies designed to compare the quality of organic versus conventionally grown produce and to propose guidelines for research comparison studies.

Within the last decade there have been a number of excellent reviews contrasting organic with conventionally grown foods for quality claims (Bourn and Prescott, 2002; Brandt and Molgaard, 2001; Magkos et al., 2003; Rembialkowska, 2004; Woese et al., 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 Woese et al. (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

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. One significant distinguishing feature among the studies in these reviews is that different methods of sampling were used in the investigations making it difficult to confidently draw meaningful conclusions from them (Woese et al., 1997). Even when the sampling methods were the same, many other factors were not taken into consideration, which may not impact the production system, but which influence food quality to a greater extent. For instance, Brandt and Molgaard (2001) remarked that if defense-related secondary metabolites are the most important determinant of the nutritional value of foods then products grown organically would be expected to contain more of these health-promoting compounds than conventional ones. Whether these differences are marginal or highly significant cannot be assessed with the present knowledge and in some cases, even when differences between the content of certain nutrients are statistically significant, they are only of minor nutritional importance (FAO, 2000). Opponents of organic farming have used these divergent reviews of quality to question the validity of claims made by proponents for organic farming (Ohlemeier, 2003).

This concern over whether organic food is better than conventionally grown was highlighted in a New York Times news service piece covering a debate on this issue between Katherine DiMatteo (Executive Director, Organic Trade Association, www.ota.com) and Alex Avery (Director of Research and Education, Hudson Institute's Center for Global Food Issues, www.cgfi.org) (Huston Chronicle, 2003). A scientific study by Asami et al. (2003) was at issue. This study was reported by the New York Times to have claimed that corn grown organically had 52 percent more ascorbic acid (vitamin C) and significantly more polyphenols than conventionally grown corn. The Organic Trade Association, in response to the scientific findings by Asami et al. (2003) stated "that recent preliminary evidence suggests that levels

This article was funded by the USDA-ARS under CRIS No. 6204-43000-014-00D. The author wishes to recognize the extremely helpful review/edits by John L. Jifon.

¹E-mail glester@weslaco.ars.usda.gov.

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

Fig. 1. Trusts, perceptions and risks associated with pesticides; abbreviated figure of Saba and Messina (2003).

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).

Retail market studies

- 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

Farm studies

- 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

Research center studies

- 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

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 param-

eters (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 con-

ventional ‘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 crops
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 harvest 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 great 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
Harvests 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, NO_3 , total bergamottin, naringenin, 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, peelthickness, 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 NO_3

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 may not be due to antioxidants like carotenoids, but due to secondary plant metabolites (Brandt et al., 2004) like naringenin. 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 horticulturists 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

- 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.
- Badary, O.A., S. Abdel-Maksoud, W.A. Ahmed, and G.H. Owieda. 2005. Naringenin attenuates cisplatin nephrotoxicity in rats. *Life Sci.* 76:2125–2135.
- Baker, B.P., C.M. Benbrook, and E. Groth. 2002. Pesticide residues in conventional, integrated pest management (IPM)-grown and organic foods: insights from three US data sets. *Food Add. Contam.* 19:427–446.
- Blatt, C.R. and K.B. McRae. 1998. Comparison of four organic amendments with a chemical fertilizer applied to three vegetables in rotation. *Can. J. Plant Sci.* 78: 641–646.
- Bourn, D. and J. Prescott. 2002. Comparison of the nutritional value, sensory qualities, and food safety of organically and conventionally produced foods. *Crit. Rev. Food Sci. Nutr.* 42:1–34.
- Brandt, K., L.P. Christensen, J. Hansen-Moller, S.L. Hansen, J. Haraldsdottir, L. Jespersen, S. Purup, A. Kharazmi, V. Barkholt, H. Frokiaer, and M. Kobaek-Larsen. 2004. Health promoting compounds in vegetables and fruits: A systematic approach for identifying plant components with impact on human health. *Trends Food Sci. Technol.* 15:384–393.
- Brandt, K. and J.P. Molgaard. 2001. Organic agriculture: Does it enhance or reduce the nutritional value of plant foods? *J. Sci. Food Agr.* 81:924–931.
- Conklin, N. and G. Thompson. 1993. Product quality in organic and conventional produce: is there a difference? *Agribusiness* 9:295–307.
- FAO 2000: Food safety and quality as affected by organic farming. ERC/00/7: URL: <http://www.fao.org/organicag/frame2-e.htm>.
- Fukuda, K., L. Guo, N. Ohashi, M. Yoshikawa, and Y. Yamazoe. 2000. Amounts and variation in grapefruit juice of the main components causing grapefruit—Drug interaction. *J. Chrom. B.* 741:195–203.
- Goldman, I.L., A.A. Kader, and C. Heintz. 1999. Influence of production, handling, and storage on phytonutrient content of foods. *Nutr. Rev.* 57(9):S46–S52.
- Houston Chronicle. 2003. Organic-food studies spark new debate. *Houston Chronicle*. 3 Dec. 2003 p. 5F. www.chron.com.
- Lester, G.E. and F. Eischen. 1996. Beta-carotene content of postharvest orange-fleshed muskmelon fruit: Effect of cultivar, growing location and fruit size. *Plant Foods Human Nutr.* 49:191–197.
- Lester, G.E. and K. Crosby. 2002. Ascorbic acid, folic acid, and potassium content in postharvest green-fleshed honeydew muskmelons: Influence of cultivar, fruit size, soil type, and year. *J. Amer. Soc. Hort. Sci.* 127:843–847.
- Magkos, F., F. Arvaniti, and A. Zampelas. 2003. Organic food: Nutritious food or food for thought? A review of the evidence. *Intl. J. Food Sci. Nutr.* 54:357–371.
- Meier-Ploeger, A., R. Duden, and H. Vogtmann. 1989. Quality of food plants grown with compost from biogenic waste. *Agriculture, Ecosys. Environ.* 27:483–491.
- Ohlmeier, D. 2003. TV ads for organics show work to be done. *The Packer* 110(22):A9.
- Rembalkowska, E. 2003. Organic farming as a system to provide better vegetable quality. *Acta Hort.* 604:473–479.
- Rembalkowska, E. 2004. Organic agriculture and food quality. *NATO Sci. Ser. Sci. Technol. Policy* 44:185–204.
- Roinila, P., J. Vaisanen, and A. Granstedt. 2003. Effects of different organic fertilization practices and mineral fertilization on potato quality. *Biological agriculture and horticulture* 21:165–194.
- Saba, A. and F. Messina. 2003. Attitudes towards organic foods and risk/benefit perception associated with pesticides. *Food Qual. Prefer.* 14:637–645.
- 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.
- Weibel, F.P., R. Bickel, S. Leuthold, T. Alfoeldi, and U. Niggli. 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.
- Worthington, V. 2001. Nutritional quality of organic versus conventional fruits, vegetables and grains. *J. Alt. Complem. Med.* 7:161–173.
- Woese, K., D. Lang, C. Boess, and K.W. Bogl. 1997. A comparison of organically and conventionally grown foods—Results of a review of the relevant literature. *J. Sci. Food Agr.* 74:281–293.