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PERSPECTIVE

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# Organically versus Conventionally Grown Produce: Common Production Inputs, Nutritional Quality, and Nitrogen Delivery between the Two Systems

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**ABSTRACT:** One distinguishing conclusion found in most reviews of research studies comparing organically and conventionally grown produce is that variables shared alike by organic and conventional produce during production, harvest, and postharvest handling and storage were not applied. As a result, accurate and meaningful conclusions comparing the nutritional quality of organic and conventional produce are difficult to ascertain. Pairing common production variables such as the physical, biological, and chemical/nutritional attributes of soils, the irrigation sources and amounts, crop varieties, crop maturities and harvest dates, pre- and postharvest processing, handling, and/or storage methods, individually and collectively, provide greater clarity as to how inputs unique to organic and conventional systems affect produce quality. Variables to be paired during production, harvest, and postharvest handling and storage studies comparing organic and conventional produce are discussed along with findings indicating that organic crops often have higher dry matter, ascorbic acid, phenolic, and sugar and lower moisture, nitrate, and protein contents and yields than conventionally grown crops. Recent studies of nutritional quality in organic versus conventional produce also indicate that soil nitrogen delivery rates strongly affect nutritional quality. Nitrogen profiling is a promising new approach to improving the nutritional quality of both organic and conventional produce.

**KEYWORDS:** phytonutrients, sensory quality, soil nitrogen availability

## INTRODUCTION

Organic production of foods (herbs, fruits, vegetables, meats, grains, nuts, and milk), fibers, leathers, and agricultural byproducts (wine and beer) is currently increasing at an annual rate due to an ever-increasing consumer demand, but demand for organic agricultural products can be traced back to the early 1900s in Austria.[1] Consumption of organic products has grown at a rate of 20−30% per year in the United States[2] and by 30−50% per year in Europe.[3] The two most important international markets for organic foods are the United States and Germany. The reasons for this increasing demand in organic products differ among consumers, but in general, consumer demand in the United States and Europe stems from a growing concern about eating foods with the fewest possible additives that are produced in an environmentally friendly way with ethical and political considerations for the welfare of animals.[4,5] Organic farming has been shown to be eco-friendly,[6,7] that is, characterized by inputs of nonsynthetic fertilizers and biologically sustainable pest management practices. Organic foods also are considered to be safer than conventional agricultural foods that are produced using synthetic fertilizers and pesticides forbidden in organic production systems.[5] Consumers in the United States also have a sense of assurance that they are getting a safe, high-quality product because the U.S. Department of Agriculture controls the certification system for organic foods,[8] thus guaranteeing that the organically produced foods in the market place are at least 95% organic. This highly controlled, "healthier-environment", "safer" production and market place assurance have led both U.S. and European consumers to believe that organic foods are safer, and therefore healthier, and have greater nutritional and sensory qualities than conventional foods.[5,9−14] This has led current-day purchasing of organic foods to transcend into a lifestyle choice, which is practiced even during periods of economic downturn such as the recent "Great Recession". In the March 28, 2011, issue of *The Packer*, a produce industry newspaper, it was reported that "in spite of the global economic decline, sales of organics continue to ring up profits. People who choose to eat organic foods have made a lifestyle choice, and this lifestyle is not abandoned even during challenging economic times. Thus the choice to consume organic foods is based on the belief that organic foods and organic food by-products are superior in quality to conventionally grown foods". In deference to *The Parker* article − that consumers choose organics based on 'belief' − this is where science can intervene by interjecting reproducible facts into the debate: is the quality of organic food higher than that of conventional foods.

## QUALITY

The quality of fruits and vegetables can be categorized into (1) market, (2) sensory, and (3) nutritional attributes. *Market quality* attributes are primarily visual such as size, shape, color, and defects: punctures, insect wounds, diseased areas, and scarring. In many instances, particularly fruits, market quality can include firmness and some chemical determinants: soluble solids (sugars) and acidity levels. *Sensory quality* attributes are those that affect consumption, which include flavor, texture, mouthfeel, and color.

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**Table 1. Preharvest, Harvest, and Postharvest Factors To Be Paired in both Organically and Conventionally Grown Production Systems That Allow for a Comparable Produce Quality Study**

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|---|
| **preharvest**[17] |
| organic site must be certified as organic/or strictly follow NOSB[6] protocols |
| conventional production protocols should adhere to current crop management standards |
| identical soil textures throughout the root growth profiles |
| similar soil qualities (e.g., mineral, organic matter, cation exchange capacity) |
| identical previous crops or field with a similar history for all plots; similar crop rotation/overwintering crop if utilized |
| similar irrigation source, amount, and scheduling |
| study sites should be as close as legally allowed by NOSB;[6] if conducted in a greenhouse, a suitable barrier to inhibit pesticide drift |
| identical cultivars |
| same aged plants (e.g., fruit trees) |
| number of years or growing seasons must be identified |
| repeat study by season if crop is commonly grown/harvested in different seasons (i.e., spring and autumn); establish appropriate replications with a statistician prior to conducting the study |
| record and report production system's inputs (e.g., fertilizers and mineral amounts, herbicide/weed controls, insecticide controls) |
| **harvest**[17] |
| same method of harvesting |
| same size of fruit or vegetable |
| same time of day |
| same location on plant(s) or canopy |
| same size and maturity of fruit or vegetable |
| hold/transport identically |
| **postharvest**[26] |
| wash/clean identically |
| store for the same period of time, under identical atmospheres |
| process under identical temperatures, humidities, and light (both intensity and quality) and time of day |
| use identical analytical analyses and methods for quality determination |

*Nutritional quality* attributes encompass all phytochemicals or phytonutrients that influence human health or wellness, that is, vitamins, minerals, antioxidants, drug-interactive compounds, and secondary metabolites. Nutritional quality attributes and nitrogen fertility will be the focus of this perspective on the comparison of organically versus conventionally grown produce.

## ■ METHODOLOGY IN COMPARATIVE STUDIES

Within the past decade, a number of excellent reviews have contrasted the quality of organic with conventional foods.[15−23] With two reviews in particular, contrasting conclusions were made: the review by Lairon[24] strongly supported the claim that organic fruits and vegetables are of higher nutritional quality than conventionally grown produce, whereas the one by Dangour et al.[25] concluded that there is little to no evidence supporting such a difference in nutritional quality. However, Dangour et al.[25] and Larion[24] also indicated a need for greater scientific rigor in organic versus conventional produce comparison studies. Many of the scientific studies found in the aforementioned reviews were designed to contrast qualities of organically grown foods with those produced by conventional methods. Quality claims of organic foods being superior to conventional foods have frequently relied on inaccurate comparisons. This led one reviewer[26] to lament "what is noticeable, as in the case with apples, [is] that differences between varieties had a far greater influence on fruit quality attributes than did differences between organic versus conventional production systems". One conclusion made in many of these reviews is that differing sampling methods used in many of the comparison studies made it difficult to confidently draw meaningful conclusions. Even when sampling methods were the same, many other production factors, common between the two systems, were not considered or rigorously implemented.[27] A. Avery, the past Director of Research and Education, Hudson Institute's Center for Global Food Issues (www.cgfi.org), and a separate study by J. Rosen[21] have rightly questioned the validity of scientific claims that organic foods are more nutritious or better tasting than corresponding conventional foods.

A common thread among published organically versus conventionally grown produce studies is the huge variability in the presented data. This complicates interpretation of the findings and makes it difficult to demonstrate conclusive differences. In almost every study in which claims of large nutritional and sensory quality differences were made between organically and conventionally grown produce, the experimenters clearly failed to control or to "pair-up" similar environmental and cultivar inputs that affect plant and fruit development, yield, and quality. Harker[28] was the first to address this disparity of adequately controlled comparison studies and highlighted the most egregious problem: comparison sampling from grocery stores versus direct field-sampling surveys. Lester[19] also addressed matching or "pairing" common production and postharvest[29] methodologies of organically and conventionally grown produce (Table 1). Pairing common production variables such as the physical, biological, and chemical/nutritional concentrations of soil types, irrigation sources and amounts, crop cultivars, crop maturities and harvest dates, and pre- and postharvest handling, processing. and storage methods will, individually and collectively, affect variability and any significance the inputs unique to organic and conventional systems may have on product quality. Recent 2010 and 2011 reviews[30−32] of organic versus conventional agrosystem management practices, and their produce nutritional claims, conclude "that more studies are needed before it is possible to make any firm conclusions about the potential consequences of any differences for human health".[30] The above-cited references by Harker,[28] Lester,[19] and Perkins-Veazie and Lester[29] serve as examples of the type of studies that still need to be performed.

## ■ NUTRITIONAL VALUE

As a general rule, in studies that have paired common production variables and methodologies, organic crops tend to have more vitamin C, sugars, and phenolics and fewer nitrates[33−37] than conventionally grown produce, which corroborates findings of the aforementioned nutritional reviews. Organic crops also tend to have more dry matter and less moisture, less protein, and lower yields.[38,39] Patterns of differences between organic and conventional foods with respect to heavy metals or specific minerals are not apparent. However, individual studies show differing levels of some minerals, but differences are dependent upon the particular fruit, leafy vegetable, or root crop. For example, when organically versus conventionally grown produce samples were compared, carrots (*Dacus carota* L.) had higher B, Cu, Mn, and N,[40] potatoes (*Solamun tuberosum* L.) had higher Mg,[41] cabbage (*Brassica oleracea* L. var. *capitata*) had higher Mn, N, and Zn,[40] and sweet corn (*Zea mays* L.) had higher Ca, Cu, Mg, and P, [41] whereas tomatoes (*Lycopersicon esculentum* Mill.) were higher in Ca, N, Na. and P.[42] Juice from organically versus conventionally grown grapefruit (*Citrus paradisi* Macf.) early in the harvest season (November) had higher levels of K, Mg, and N, but by harvest season's end (March) there were no differences in the levels of those minerals or in B, Ca, Cl, Cu, Fe, Mn, Na, P, or Zn levels.[43]

Organic versus conventional crops show lower levels of chlorophylls,[44] $\beta$-carotene,[45] and lycopene.[43] Evidence for B-complex vitamins being higher in organic versus conventional foods is inconclusive, whereas levels of antioxidant compounds tend to be higher in organic foods compared with conventional foods. Organically versus conventionally grown kiwifruits (*Actinidia deliciosa* Liang et Ferguson) were 15% higher in total phenolics,[46] and in organically versus conventionally grown sweet pepper fruit (*Capsicum annuum* L.), phenolics were 20−25% higher depending on the degree of ripening.[47] Caris-Veyrat et al.[48] found that tomatoes grown organically were higher on a fresh weight basis for some phenolics, but when the data were expressed on a dry weight basis, no differences in individual phenolic levels were detectable. Thus, the higher moisture content of conventionally grown food likely provides not only greater weight, that is, higher yields (tonnage) but also the possibility of nutrient dilution relative to drier organically grown crops. The expression of data on both fresh and dry weight bases is imperative in the comparison of these two agrosystems. Zhao et al.[49] in their review of organic versus conventional production enhancement of antioxidants, phenolics, and other phytochemicals stated that "evidence seems to favor enhancement by organic production systems". However, they hastily cautioned that "there has been little systematic study of the factors that contribute to increased phytochemical content in organic crops and it remains to be seen whether consistent differences will be found, and the extent to which biotic and abiotic stresses, and other factors such as soil biology, contribute to those differences".

## SENSORY EVALUATIONS

Few organically versus conventionally grown produce comparison studies include consumer or trained sensory tests, and even fewer have also "paired" common production variables. Consumer sensory tests generally consist of nontrained panelists with no prior knowledge of the objectives of the sensory test. For statistical purposes, consumer sensory tests should consist of at least 60 panelists.[50] In contrast, trained sensory tests usually consist of 9−15 panelists who have been trained to describe their sensory experiences using words they generate in previous training sessions. These words are often more detailed than those used by consumer panelists. Whereas Moskowitz[10] has indicated that produce quality essentially can be defined by the overall acceptability of a product by consumer sensory tests, many of the sensory evaluations of organically and conventionally grown produce have been done using trained panelists.

Talavera-Biachi et al.,[51] comparing the effect of organic versus conventional production practices and fertilizer variables on the sensory attributes of bok choi (*Brassica rapa* L.) and tomato, found that the production system had little effect on the major sensory markers of the aforementioned vegetables. However, only six trained panelists were employed, and common production practices were not always well matched: specifically, the initial applied nitrogen in the organic system was about 6% compared to the conventional system. In another sensory comparison of organically versus conventionally grown tomatoes,[52] 10 trained panelists were not able to detect differences in color, aroma, or flavor. In this study, the applied nitrogen was better matched but still lower (about 57%) in the organic system compared to the conventional system. In contrast to this study, Johannson et al.,[53] using 7 trained panelists, detected differences between organically and conventionally grown tomatoes for a number of sensory quality attributes, including firmness and juiciness (both lower in organically grown) and red color (lower in conventionally grown). Those differences sometimes increased when the panelists were provided information about the growing system. Providing information to panelists about the product being tested increases the complexity of the sensory evaluation but also provides additional information about the preferences of consumers for the product in a real-life situation. The practical importance of the differences detected in this study, however, was compromised by the lack of information about applied-nitrogen growth conditions.

In a sensory comparison of organically and conventionally grown redskin potatoes with paired common production inputs, including nearly equal amounts of applied nitrogen, a 15-member consumer panel perceived a difference between tubers from the different production systems, with organically grown potatoes described as having a more intense and bitter taste than conventionally grown potatoes.[54] Glycoalkaloids naturally occur in potatoes, which have antimicrobial and insecticidal properties, and can impart a bitter flavor. The glycoalkaloid, solanidine, which was measured in this redskin potato study, was 2-fold higher in the skin and flesh of organically versus conventionally grown tubers.

The paired organic versus conventional grapefruit study[43] conducted a 75-member consumer panel, which rated the taste intensity and overall acceptability of juices from organically and conventionally grown grapefruits. Although the juice from organically versus conventionally grown grapefruit had significantly higher levels of sugars, it also had higher citric acid levels, which resulted in a more acidic-tasting juice. The juice from organic versus conventional grapefruit also had higher levels of phenolic flavanoids, that is, naringin, narirutin, and neohesperidin, which contributed to a more bitter-tasting juice. The panelists rated organic juice less acceptable than juice from conventional grapefruit because organic juice was perceived as being more acidic- and bitter-tasting than juice from conventional grapefruit.

The potato and grapefruit studies illustrate that trade-offs exist between organic and conventional food agrosystems: although organic produce may have dramatically less pesticide residues than conventional produce, organic produce responses to likely increased pest pressure can illicit the production of naturally occurring toxins.[55]

## CAN BOTH ORGANICALLY AND CONVENTIONALLY GROWN PRODUCE BE IMPROVED? FUTURE STUDIES

In the aforementioned grapefruit study,[43] it was concluded that the practical benefit of their study was that specific fertility inputs unique to conventional and organic production systems were known, and with additional research, production system-associated quality factors likely can be improved so that both systems would provide great-tasting, highly nutritious grapefruit. The quality of organically versus conventionally grown grapefruit appears to be defined by the levels of phenolic compounds and nitrogen fertilization along with their associated roles in soil−plant interactions. Organic crops, which are not sprayed with synthetic pesticides, were generally assumed to have higher levels of phenolics due to higher insect and disease pressures.[47,54,56,57] In a greenhouse study where insects and disease were physically controlled, that is, no insect or disease pressures, del Amor et al.[47] found that phenolic compounds were 25% higher in organically versus conventionally grown sweet peppers due to slower release rates of nutrients in the organic system. Mitchell et al.,[58] looking at phenolic flavonoids (compounds that function in plant defense mechanisms against reactive oxygen species due to herbivory, pathogens, and UV-B radiation stress) in a 10-year comparison study of organically versus conventionally grown tomatoes, found more flavonoids were accumulated, regardless of the production system, when nitrogen was limiting versus tomatoes well-supplied with nitrogen. Their study also revealed that differences in flavonoid levels between organically and conventionally grown tomatoes reflect a fundamental difference in the behavior of soil nitrogen between the conventional and organic systems. Other studies[7,59−62] have also shown that differences in nutritional qualities of organic versus conventional crops are associated with the organic systems delivering limited rates of nitrogen. In a 10-year 'Hayward' kiwifruit production comparison of organic versus conventional orchards from 36 paired sites demonstrated that organic versus conventional crop yields were lower due to (1) a difference in fertilizer uptake by the two production systems and (2) an absence of a synthetic growth regulator in the organic system.[63] Lehesranta et al.,[60] in a potato trial produced in a Nafferton factorial system of long-term, replicated field experiments designed to study the effects of nitrogen management methods in organic and conventional production systems, found total nitrogen levels in conventionally grown tubers to be significantly higher even though similar amounts of nitrogen were applied to both organic and conventional systems. It was discovered in this tuber study that organically grown potatoes were under increased stress conditions because of insufficient nutrient supply due to organic-form nitrogen fertilizer being less immediately available compared to the immediately available, highly water-soluble, mineral (conventional) nitrogen fertilizer. In a recent meta-analysis of organic versus mineral nitrogen sources on corn, the levels of nitrogen in the two systems were comparable, but the organic system had lower agronomic nitrogen use efficiency.[64] Rapisarda et al.[65] has also discovered in organic and conventional production comparison systems utilizing $^{14}$N uptake that nitrogen distribution within the plant and nitrogen source affects the quality makeup of the resulting fruit or vegetable. In addition, removal of nitrogen from the soil via previous crops through crop rotation or overwintering can increase the content of phenylpropanoid defense compounds in the following test crop species.[30] Thus, it appears from the aforementioned referenced examples that placing a greater focus on nitrogen profiling in organic and conventional production systems, conducted under adequate comparison controls such as knowing previous crop/crop rotations and soil fertility and N supply and availability (Table 1) will assist science in finally finding the answer to the question: Are organically grown foods of better quality than corresponding conventionally grown foods, and, if so, can we make produce from both systems even more nutritious?

Essentially, the future of organic versus conventional studies should not be limited to measures of produce quality differences, but must focus on soil fertility/plant root interactions and controlling bacterial and mycotoxin contaminants, especially in organic produce, and postharvest methodologies to maintain quality. In addition, human-phytonutrient bioabsorptivity studies need to determine if heightened nutritional quality differences also have heightened human-health benefits. Currently there are no direct studies demonstrating human-health benefits from organically versus conventionally grown food. However, specific human bioactive nutrients and contaminants can be attributed to organic versus conventional produce, and when higher consumption patterns of the organic produce consumer are considered, increased specific nutrients and contaminants in humans is observed.[66]

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