Antioxidants and the Nutritional Quality of Organic Agriculture

By Alyson E. Mitchell, Ph.D., and Alexander W. Chassy

Consumer awareness of the relationship between foods and health, together with environmental concerns, has led to an increased demand for organically produced foods. In general the public perceives organic foods as being healthier and safer than those produced through conventional agricultural practices.[1] However, controversy remains regarding whether or not organic foods have a nutritional and/or sensory advantage when compared to their conventionally produced counterparts. Advocates for organic produce claim it contains fewer harmful chemicals, is better for the environment and may be more nutritious. There are fundamental differences in organic and conventional production practices, but limited information is available detailing how various practices influence the nutritional quality, especially in terms of health-related antioxidants of other food crops.

Fruits and vegetables are a focal point of this controversy, since these foods are a significant source of phenolic antioxidants, as phenolic acids and flavonoids, in the diet. Epidemiological studies consistently indicate an inverse correlation between the consumption of fruits and vegetables and the risk of human cancers, cardiovascular disease, diabetes and age-related declines in cognition.[2-7] These chronic diseases are linked to the oxidation of critical cellular macromolecules (e.g. proteins, lipids and DNA) by reactive oxygen species (ROS).[8] Phenolic antioxidants are thought to neutralize ROS before they cause damage and lead to diseases. Dietary guidelines set by the USDA now suggest increased consumption of fruits and vegetables (5-11 serving a day). Additionally, reports by WHO and the Food and Agriculture Organization (FAO) of the

United Nations emphasize the role of foods and nutrition in the prevention of noncommunicable diseases and point to a role for plant-derived phytochemicals in the prevention of heart disease and cancer.[9-10]

It is important to recognize that both conventional and organic agricultural practices represent dynamic systems that can vary greatly depending upon region, soil quality, prevalence of pests, crop, climate and farm philosophies. This makes comparisons very difficult. Conventional agriculture evolved globally in response to the availability of high-yield crop cultivars, chemical fertilizers and pesticides, and progressing irrigation and mechanization. Organic farming has also evolved, yet must adhere to National Organic Standards set by the USDA in 2000. Accordingly, organic crops must not be genetically engineered, irradiated, or fertilized with sewage sludge. Additionally, farmland used to grow organic crops is prohibited from treatment with synthetic pesticides and herbicides for at least three years prior to harvest. Disease-resistant varieties are often used and plant nutrients are supplied through crop rotation, cover crops and animal manure.

Fertilization is an important aspect to consider when comparing organic and conventional agriculture. Organic fertilization typically does not provide nitrogen in a form that is as readily accessible to plants as conventional fertilizers. The accessibility of nitrogen has the potential to influence the synthesis of phenolic antioxidants and soluble solids. For example, several studies demonstrate there is a decrease in the concentration of phenolic antioxidants in plants with increasing nutrient availability.[11-14] There are various overlapping hypotheses that attempt to explain this relationship including the carbon/nutrient balance (CNB) hypothesis, growth-differentiation balance (GDB) hypothesis and protein competition model (PCM).[15-17] In general, these theories state that high nutrient availability leads to an increase in plant growth and development, and a decreased allocation of resources towards the production of expendable metabolites such as the phenolic antioxidants.

The term phenolic antioxidant refers to both simple phenolic acids and flavonoids. They are products of secondary plant metabolism and are ubiquitous natural components of plants. Secondary plant metabolites are defined as those compounds that are not essential to the life of the plant (e.g. DNA, RNA, chlorophyll, amino acids and starch) and include phytochemicals such as caffeine, isoflavonoids and phenolic antioxidants. Plants produce secondary metabolites as a defense mechanism against photo-oxidation, herbivory (insect and animal predation), and for protection against pathogen attack. Additionally, they are critical components in the health of the plant, and many are pigments that help to attract pollinating insects. The composition of secondary plant metabolites differs between plants and within plant tissues. Genotype (i.e. the cultivar or variety) is the primary determinant of the composition of secondary plant metabolites, although their expression is strongly influenced by environmental pressures, climate and UV-light exposure.[18]

Scientists have recently begun to question whether the levels of phenolic antioxidants are lower in foods grown using conventional agricultural practices, since these practices utilize levels of pesticides and fertilizers that can result in a disruption of the natural production of plant-defense related metabolites. Differences between the content of phenolic metabolites in organically and conventionally produced fruits and vegetables allow for the possibility that organically grown produce may benefit human health more than corresponding conventionally grown produce.

Reviews of existing literature demonstrate inconsistent differences in the nutritional quality of conventionally and organically produced vegetables with the exception of potentially higher levels of certain minerals, ascorbic acid and less nitrates in organic foods.[19-22] However, these data are difficult to interpret, since cultivar selection and growing conditions varied widely and different methods of sampling and analysis were used in the investigations reviewed. Additionally, the majority of these studies did not assess levels of phenolic antioxidants, as their role in human health was not yet appreciated. However, it is generally agreed that the levels of secondary metabolites have the potential to differ the most between these two agricultural practices, since they are produced in response to stress.[22]

Recent studies (Table 1) have begun to examine the role of agriculture in the context of influencing the production of phenolic antioxidants in plants.[23-28] For example, in two studies conducted by Carbonaro et al., higher levels of total phenolics were found in organic peaches and pears when compared with their conventional counterparts.[23-24] In a study of five vegetables common in the Japanese diet, Ren et al. demonstrated that organically grown spinach contained 120 percent higher antioxidant activity while Welsh onion, Chinese cabbage and qing-gen-cai contained 20-50 percent higher antioxidant activity compared to their conventionally grown counterparts.[25] In our own studies, we have found consistently higher levels of total phenolics and ascorbic acid in organic strawberries, marionberries and sweet corn.[26] Conversely, Hakkinen and Torronen report that organic cultivation had no consistent effect on the levels of phenolic compounds in strawberries.[27] In more recent, unpublished studies at the University of California Davis, we have found higher levels of total phenolics, soluble solids and ascorbic acid, as well as the flavonoid aglycone quercetin in two organically produced tomato cultivars. Interestingly, the same differences were not seen in organic bell peppers grown concurrently with the tomatoes. This demonstrates the important point that differences in agricultural practices will not affect all plants and all secondary metabolites equally. Research is needed to determine whether differences in agricultural practices affect the levels of phenolic antioxidants in soybeans.

Contemporary literature illustrates an apparent trend toward higher levels of phenolic antioxidants, ascorbic acid and soluble solids in organic foods. However, there are still far too few studies completed to establish a consensus regarding the health benefit of organic foods. Ultimately, more research examining relationships between agricultural production and the synthesis of phytochemicals in specific crops is needed. Future studies should emphasize the potential for agricultural manipulations to alter levels of both beneficial and potentially toxic phytochemicals in foods. The ability to manage and control levels of beneficial phenolic antioxidants in plants through cultivation has the potential to enhance the nutritive quality of foods.

Table 1. Review of Recent Findings

Study	Experiment Material	Parameters Analyzed	Findings	Reference
Asami et al., 2003	Marionberry, strawberry, corn	Total phenolics (TP), ascorbic acid (AA)	Increased TP and AA in organic and sustainable practices	26
Carbonaro and Mattera, 2001	Peach, pear	Polyphenoloxidase activity (PPO), TP	Increased TP and PPO activity in organic fruit	23
Carbonaro et al., 2002	Peach, pear	PPO activity, TP, AA, citric acid (CA), α-tocopherol (TH)	Increased TP and PPO activity in organic fruit; AA and CA higher in organic peaches, α-TH higher in organic pear and lower in peach	24
Grinder-Petersen et al., 2003	Human excretion metabolites following organic vs conventional diets	Quercetin (Q), kaempferol (K), hesperetin (H), naringenin, isorhamnetin (I)	Organic foods had higher Q, trends of higher K and lower I; Higher urinary excretion of Q and K in organic diet	28
Häkkinen and Törrönen, 2000	Vaccinium berries, strawberry	Q, K, ellagic acid, p-coumaric acid	No consistent difference between organic and conventional techniques,	27
Ren et al., 2001	Qing-gen-cai, Chinese cabbage, spinach, welsh onion, green pepper	Antioxidant and antimutagenic activity, flavonoids (Q, K, H, caffeic acid, myricetin, quercitrin, hesperitin, apigenin, baicalein)	Higher antioxidant activity in organic spinach, onion, cabbage, qing-gen-cai, no difference in green pepper; antimutagenic activity higher in organic samples; Generally higher flavonoids in organic samples	25

ABOUT THE AUTHORS

Alyson E. Mitchell, Ph.D., is an assistant professor and food chemist at the University of California at Davis. Her lab specializes in assessing the levels of beneficial phytochemicals in food and developing strategies to enhance these levels. She received her B.S. with honors in environmental toxicology and her Ph.D. in pharmacology and toxicology from the University of California at Davis.

Alexander W. Chassy, B.S., is a food chemistry Master's student with Dr. Mitchell at the University of California, Davis. His research focuses on the potential differences between organic and conventional agriculture with respect to quality and health. He received his B.S. from the Department of Food Science at the University of Massachusetts at Amherst.

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