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The Organic Center for Education & Promotion

Elevating Antioxidant Levels in Food Through Organic Farming and Food Processing

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Shift Toward Organic Production and Food Processing Increases Antioxidant Levels in Fresh Produce and Many Other Foods

Antioxidants are chemicals that help prevent or reduce tissue damage in cells caused by free radicals. Free radicals are oxygen and nitrogen-based molecules with unpaired electrons that are generated by a number of metabolic processes within the body. Antioxidants inhibit damaging reactions within human cells by providing the positively charged atoms needed to neutralize free radicals, which are also called "reactive oxygen species" (ROS), or "reactive nitrogen species." (For more on the key terms used in this SSR see the Glossary posted at the end of this summary.)

The total supply of antioxidants circulating in the body is the sum of antioxidant enzymes and acids manufactured by the body, plus antioxidants consumed in foods. The human body manufactures a wide range of antioxidants including enzymes, alpha-lipoic acid, coenzyme Q10, ferritin, uric acid, lactoferrin, and many others.

Plants produce more than 50,000 "secondary plant metabolites" (SPMs) as part of their normal growth processes and in response to stresses in the environment. Stress might arise from insects, plant diseases, chemical imbalances in the soil, or weather extremes. Some 4,000 SPMs are polyphenol flavonoids and many of these are antioxidants. Plants are the source of essentially all antioxidants in the diet, including the carotenoid antioxidants alpha- and beta-carotene, ascorbate, tocopherols, and lycopene. Plant-based animal feed is the source of antioxidants in milk, meat and poultry products.

By lessening free radical damage in human tissues, antioxidants reduce inflammation and can lessen joint and muscle pain. Through this mechanism, antioxidants can play a role in promoting cardiovascular health, lessen the risk and severity of neurodegenerative diseases like Alzheimer's and Parkinson's disease, and in general, help slow the aging process.

A wide range of studies has shown that plant antioxidants are also anti-proliferative (i.e., they slow the proliferation of cells). In this way, antioxidants can prevent or slow the growth of some cancerous tumors. And recent research suggests that some polyphenols in plants can increase the sensitivity of the body to insulin, thereby delaying the onset of Type 2 diabetes or slowing the progression of this increasingly common disease.

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Because of the many potential health benefits associated with antioxidant consumption, increasing average daily antioxidant intake through the diet has emerged as an important public health goal and is a major factor behind the U.S. government's broad-based effort to increase fruit and vegetable consumption.

The weight of the evidence reviewed in this State of Science Review (SSR) suggests that a shift toward organic farming methods can play an important role in increasing the total supply of beneficial antioxidants in the diet. By generating higher concentrations of antioxidants and polyphenols in fresh vegetables and fruit, grains, and dairy products, organic farming may help people increase average daily antioxidant consumption without a proportional increase in caloric intake.

While only a few studies have directly compared antioxidant levels in conventional and organic foods, the results of such studies to date are encouraging. Organic farming methods have increased antioxidant levels by a few percent to over three-fold compared to food grown using conventional production methods. On average, across seven studies that reported direct comparisons of the levels of antioxidants in conventional and organic foods, levels in organic food averaged about one-third higher.

Complex Linkages Between Antioxidants and Health

The degree of biological response and health benefits following consumption of antioxidants in a given food is a complex function of each person's health status and total diet and age, as well as exposures to other

chemicals, bacteria and viruses. The linkages between antioxidant intake and health promotion and disease prevention are complex and dynamic and are difficult to definitively prove. Moreover, consuming more fruits and vegetables is often associated with lessened consumption of other, often fatty and low-fiber foods. For this reason, some of the health benefits stemming from extra servings of fruits and vegetables may arise to some degree from a "substitution effect" in a person's overall diet.

So why not simply add antioxidant supplements to the diet? Dietary supplements do not appear to deliver the full range of health-promoting benefits that stem from consumption of whole foods that are rich in antioxidants. In addition, plant antioxidants help trigger and modulate a number of biosynthetic processes in the human body. To optimally promote health though, they must be present in the right proportions relative to a variety of other vitamins, minerals, fats and proteins. Excesses of certain nutrients and bioactive chemicals, including antioxidants, can be as damaging as inadequate levels. Some antioxidants become prooxidants at high doses and levels, and then increase the risk of cellular damage from reactive oxygen species, especially if the levels of other antioxidants in the body are depressed.

Increasing the amounts of antioxidants consumed in food will not guarantee good health. Antioxidant intake is just one piece in the complex puzzle linking dietary choices to health outcomes. Epidemiological evidence has confirmed that diets rich in fruits and vegetables are associated with reduced frequency and severity of several health problems. Scientists have been searching intensely for decades to identify the specific ingredients in fruits and vegetables that account for their many health-promoting benefits. Increasingly, that search points to combinations of essential vitamins, minerals, fiber, and antioxidants.

Because antioxidants cannot substitute for each other and some do not last long once ingested, people need to consume antioxidants in plant-based foods with most meals in order to sustain optimal levels in the body. A variety of strategies should be pursued to increase average antioxidant intakes including, first and foremost, eating additional servings of a diverse selection of fruits and vegetables. Buying locally grown and fresh produce that has been harvested relatively ripe is another proven strategy to increase antioxidant intake.

Antioxidant Levels Vary Widely Across Foods

The ten foods richest in antioxidants include blueberries, plums, broccoli, strawberries, and red cabbage. These antioxidant-dense foods provide, on average, 35 times more antioxidant capacity per calorie than the ten foods that rank lowest on the scale of antioxidant capacity per calorie. Low-antioxidant foods include cucumbers, granola, cereal, canned corn, and lima beans.

The USDA has classified foods into four groups as a function of antioxidant content per typical serving and per gram or per calorie: very high, high, moderate, and low. Just a five-to-ten percent increase in the antioxidant capacity in a food already high in the ranking of antioxidant capacity per calorie would deliver a bigger boost to daily antioxidant intake than a full serving of most low-antioxidant foods. A thirty percent average increase in the antioxidant capacity of a single serving or a food in the USDA's "very high" antioxidant category would increase total antioxidant intake by over 1,800 H-ORAC units (a common measure of a food's total antioxidant capacity). It would take an additional 5.6 servings of a typical food in USDA's "low" antioxidant category in order to increase total antioxidant intake by a comparable amount. These enormous differences support a common recommendation made by nutritionists to consumers – select a variety of brightly colored fruits and vegetables in the course of increasing overall fruit and vegetable intake.

Later this year, the U.S. Department of Agriculture is scheduled to release revised Dietary Guidelines for Americans. The recommendation for consumption of fruits and vegetables is expected to rise from five to eleven or more servings per day. By selecting additional servings of fresh organic produce from foods that rank high in antioxidant content per calorie, consumers can double or even triple their average daily antioxidant intake, and without triggering a significant increase in calories.

Average Antioxidant Capacity for Foods per Calorie in the "Very High", "High", "Moderate" and "Low" Antioxidant Groups Established by the USDA Researchers

Group	*Low*	*Moderate*	*High*	*Very High*
Average Antioxidant Capacity	*16*	*31.6*	*40.4*	*84.5*

Source: Table 3, "Elevating Antioxidant Levels in Food Through Organic Farming and Food Processing"

Minimal cooking and food preparation tends to preserve most of the antioxidants in food when harvested. As a rule of thumb, the more processed and heavily cooked food is, the greater the average loss of antioxidants.

Another promising option is to identify combinations of plant varieties and farming systems that routinely increase the levels of antioxidants in food. Even relatively modest increases in antioxidant levels, like those that appear attainable through organic farming methods, could have a substantial impact on public health, especially if coupled with progress toward more healthy diets and lifestyles.

Existing Studies Show That Organic Farming Methods Increase Antioxidant Levels Compared to Conventional Production Systems

A wide range of factors can influence the mix and levels of antioxidants that a plant manufactures. In general, factors that impose stress on plants tend to trigger innate defense and wound-healing mechanisms, and these mechanisms are driven by and/or entail the synthesis of various polyphenols, many of which are antioxidants. These well-known facts led many scientists to hypothesize that plants on organic farms produce higher levels of polyphenols and antioxidants because the plants on organic farms are grown without the added protection provided by synthetic pesticides. Several studies have directly tested this hypothesis and supported its basic premise. None have rejected it.

Studies reviewed in this State of Science Review provide evidence that several core practices on organic farms — use of compost, cover crops, slow release forms of nitrogen — can increase antioxidant and polyphenol content compared to conventional practices that depend on commercial fertilizers and pesticides. Scientific interest in exploring the links between farming practices, plant genetics, and food quality is growing, especially in Europe.

Seven studies making direct comparisons of levels of antioxidants in organic versus conventional produce are reviewed in this SSR. Each study sought to isolate the impact of organic farming methods on antioxidant levels by selecting matched pairs of organic and conventional crops that were similar in every respect, except for use of organic versus conventional production practices. In general, the crops were grown from the same plant varieties, on similar soils, and under the same weather conditions. The major differences in farming practices arose from the use of commercial fertilizers and pesticides on the conventional crops, in contrast to biologically-based soil fertility and pest control practices on the organic fields.

These studies report fifteen cases where there were statistically significant differences in antioxidant levels in organic food compared to conventional food grown nearby using similar genetics and production practices. Organically grown produce had higher antioxidant levels in thirteen out of fifteen cases, and in two cases, the levels were higher in conventional produce. On average where there were differences, the organic crops contained about one-third higher antioxidant and/or phenolic content than the comparable conventional produce.

Several studies have found levels of specific vitamins, flavonoids or antioxidants in organic foods to be two or three times the level found in matched samples of conventional foods.

Given the many factors affecting antioxidant levels, more research must be done to sort out the relative importance of each individual factor. More sophisticated experimental designs are needed and will help control for confounding variables. Improved and more consistent antioxidant testing methods are needed in order to produce data in multiple studies that can be compared across regions, crops, and over time. The characterization of conventional and organic farming systems also needs to be sharpened.

Despite limits in existing studies and the need for more research, the available evidence is encouraging and provides hope that widespread adoption of organic farming methods will increase average antioxidant levels in many foods. Harvesting fruits and vegetables at optimal ripeness and consuming them in less-processed forms, without removing skins, will preserve a greater portion of the antioxidants in these foods as they leave the farm. This is because the outer layers of fruits and vegetables typically contain the highest concentrations of antioxidants.

Like antioxidant levels, pesticide residues are also most common on the skin of fresh produce. Some consumers peel produce as a precautionary step to reduce pesticide intake. Seeking out organic produce can therefore deliver a dual benefit to consumers by maximizing antioxidant intake and minimizing pesticide dietary

"Although very few studies directly addressed the issue, the polyphenol content of vegetables produced by organic or sustainable agriculture is certainly higher than that of vegetables grown without stress, such as those grown in conventional or hydroponic conditions."

Manach, et al. "Polyphenols: food sources and bioavailability." *American Journal of Clinical Nutrition Volume* 79(5), 2004.

Dr. Preston Andrews (left) and Dr. John Reganold (right) of Washington State University (WSU) select organic strawberries under production near Watsonville, California for antioxidant, vitamin, and sensory testing in the summer of 2004. This is one of several fields of organic strawberries that have been matched with nearby conventional fields producing the same variety under comparable agronomic, irrigation, and harvesting practices. The WSU strawberry fruit project is led by Preston, Reganold, and Dr. Lynne Carpenter-Boggs and is funded by the Organic Center.

Dr. Brigitte Graf, scientist at the Human Nutrition Resource Center at Tufts University, is demonstrating the preparation of samples for antioxidant testing to the Organic Center Board President Theresa Marquez. Brigitte is one of several scientists working in Dr. Jeffrey Blumberg's lab at Tufts University, analyzing the antioxidant capacity of organic v. conventional fruits with funding from The Organic Center for Education and Promotion.

exposure. (For more on pesticide residues in conventional and organic food, see the Center's first SSR "Minimizing Pesticide Dietary Exposure Through Consumption of Organic Foods").

Organic Processing May Also Increase Antioxidant Levels

There are some significant differences between organic and conventional food processing technologies, especially those involving the extraction of oils from plant-based foods. Some of these differences are known to have an impact on antioxidant levels. For example, the synthetic chemical hexane is often used in extraction of oils from crops in conventional oil processing plants, but is prohibited in organic oil processing. Hexane is known to promote removal of lipid-soluble antioxidants such as the tocopherols. Polyphenol levels are typically reduced in alcoholic or aqueous extraction methods.

High-temperature and high-pressure processing technologies also tend to remove significant portions of the antioxidants present in foods, especially those that are water-soluble. Organic food processing plants often use lower pressure, cold-pressing methods to extract juices and oils. They use these methods to produce oils and juices that are richer in flavor and retain more nutrients, including antioxidants.

Increasing retention of antioxidants in foods as they are processed and prepared may offer some of the most cost-effective strategies to increase average antioxidant intakes, especially in the near term.

RESEARCH RECOMMENDATIONS

1. Refine research methods to compare the impacts of farming methods on antioxidant levels in harvested organic versus conventional crops.

2. Improve the accuracy and consistency of the analytical methods used to measure antioxidant levels in food and in animal and human studies.

3. Study and compare the impact of organically acceptable food processing methods on antioxidant retention.

4. Develop better ways to maximize the retention of antioxidants in the process of extracting and purifying juices and oils.

5. Explore factors impacting the levels of polyphenols and antioxidants produced during the normal course of plant development, including in the absence of pest pressure.

6. Identify the attributes and characteristics of antioxidants in food that can enhance nutritional quality and promote health.

The public health benefits from progress in these six areas are enormous and justify a sizable increase in public sector research funding. For this reason, the Organic Center also offers a set of policy recommendations to the USDA, the agency most directly responsible for conducting research on antioxidant levels in food.

USDA should carry out a quantitative assessment of the increases in antioxidant intake that might be achieved through various options, along with the pros and cons of alternative options.

Substantial extramural competitive grant funding should be dedicated to identifying cost-effective ways to increase average antioxidant intakes.

The USDA should issue antioxidant-focused dietary guidance, and possibly revised food pyramids, for people at different stages of life, for pregnant women, and for people looking for help in managing the progression of diseases through dietary interventions.

Conclusions

It is clear that consuming organic fruits, vegetables and whole grains promotes good health, and that the antioxidants in these foods play complex and important roles in enhancing human health and well being.

Current evidence suggests that organic farming methods increase average concentrations of phenolic antioxidants in selected fruits, vegetables, and grains. Increased consumption of organically grown, polyphenol-rich fruits, vegetables, and grains will have a positive impact on antioxidant status and human health, especially if produce is harvested relatively ripe and consumed in a relatively unprocessed form. For these reasons, research on antioxidant levels in organically grown food is among the Organic Center's top research priorities. The full "State of Science Review" on antioxidants and information on antioxidant-related projects initiated by the Organic Center in 2004 can be found on our web site: www.organic-center.org/stateofscience.htm.

Glossary

Antioxidant - An enzyme or other organic molecule that can counteract the damaging effects of oxygen in tissues
Carotenoids - Yellow, orange and red pigments in plans, often masked by chlorophyll and thought to function as antioxidants
Enzyme - A protein that catalyzes a chemical reaction. A substance that increases the speed of a chemical reaction without being changed in the overall process
Free Radical - An atom or a molecule with an unpaired electron, highly reactive with nearby molecules. Free radical damage may be countered with antioxidants
Oxidation - A chemical reaction that removes electrons from an atom or molecule
Oxidative Stress - A state in which the effects of prooxidants exceed the ability of antioxidant systems to neutralize them
Phytochemical - Substance derived from a plant. The term is generally reserved for molecules with biological activity
Prooxidant - An atom or molecule that promotes oxidation of another atom or molecule by accepting electrons. (free radicals, reactive oxygen species (ROS) and reactive nitrogen species (RNS)
Reactive nitrogen species (RNS) - Highly reactive chemicals, containing nitrogen, that react easily with other molecules resulting in potentially damaging modifications
Reactive oxygen species (ROS) - Highly reactive chemicals, containing oxygen, that react easily with other molecules resulting in potentially damaging modifications

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