**Frequently Asked Questions About the Study -- “Higher antioxidant concentrations and less cadmium and pesticide residues in organically grown crops: a systematic literature review and meta-analyses”**

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**Major Findings**

**Q: What are the main findings of the study published July 15, 2014 in the *British Journal of Nutrition*?**

**A:** This study has three main findings. The researchers found that (1) organic crops have, on average, higher levels of antioxidant than conventional crops, (2) organic crops have lower cadmium levels than conventional crops, and (3) pesticide residues are present much more frequently in conventional crops than organic ones.

**Nutritional Quality**

**Q: What were the nutritional benefits of organic crops reported in this study documents?**

**A:** Organic crops have, on average, significantly higher levels of antioxidants than conventional crops. Average total antioxidant activity was a 17% higher in organic versus conventional crops. For some individual antioxidants, the differences were much greater -- 69% higher levels of flavanones, 28% higher levels of stilbenes, 50% higher levels of flavonols, and 51% higher levels of anthocyanins.

**Q: Why do organically grown, plant-based foods generally have higher levels of antioxidants than conventionally grown food?**

**A:** Published studies point to two primary explanations – the “dilution effect” in conventional foods triggered by higher crop yield levels, and greater dependence on natural plant defense mechanisms in crop fields growing on organic farms.

Plant breeders and agronomists have recognized the “dilution effect” for about a half-century. When more intensive fertilization and/or irrigation are relied upon to drive crop yields upward, plants typically utilize the extra energy to produce starch and carbohydrates. The size of fruit, vegetables, nuts, and grain become larger, and sugar levels tend to rise. But in most cases, the uptake of minerals and production of complex, plant phytochemicals, including vitamins and antioxidants, does not increase proportionally to fruit size and weight, and hence the concentrations of minerals, antioxidants and some other health-promoting phytochemicals are lower in high-yield conventional production systems.

Since nitrogen levels and yields are typically somewhat lower on organic farms, the impact of the dilution effect is lessened on organic farms. So, based on this explanation, the differences in mineral and antioxidant levels in organic food vs. conventional are actually mostly driven by reductions over time in conventional crops, rather than increases in organic crops.

The second explanation is that on most organic farms, plants are placed under more frequent and intense pressure as a result of insect feeding and plant diseases. Pest attacks, in turn, trigger natural plant-defense mechanisms, all of which are regulated by, and entail production of, plant phytochemicals, most of which are antioxidants.

In the real world, it is highly likely that complex combinations of the above two explanations determine the degree to which the nutrient content in a given organic food differs from the nutrients in the same food grown nearby, but using a conventional management system, higher levels of readily available nitrogen, and contemporary pesticides.

**Q: Why are antioxidants important?**

**A:** Antioxidants protect our cells against the effects of oxidation. Oxidation is a normal chemical process that takes place in the body, but can be accelerated by many factors, such as exposure to UV light, exposure to pollution, stress, processed food, and smoking. The oxidation process can trigger the formation of free radicals, which can damage cells in the body and trigger disease. Free radicals have been linked to heightened risk of certain cancers, heart disease, Alzheimer's, arthritis, cataracts, diabetes, kidney disease, and age-related blindness.

Antioxidants made by the body, and others ingested in food, chemically bond to free radicals and neutralize them, protecting cells from damage. The specific antioxidants that this study found to be higher in organic versus conventional crops have been associated with decreased risk of cardiovascular disease, neurodegenerative diseases, and certain cancers. These findings are why the Institute of Medicine’s Panel on Dietary Antioxidants and Related Compounds recommended that people increase their intake of antioxidants.

Some studies suggest the average American would need a three-fold increase in total antioxidant intakes to fully counteract the damaging effects of free radicals. These proven health benefits of antioxidants are among the primary reasons that the U.S. government recommends at least a doubling of average daily intakes of fruits and vegetables.

**Q: Are the nutritional differences between organic and conventional crops meaningful in terms of altered human health outcomes?**

**A:** The paper explains that no one really knows because the necessary, long-term dietary intervention studies have not been done. While the magnitude of the health benefits is unknown, there is compelling evidence (see next question) supporting the link between higher antioxidant intakes and improved health outcomes. And based on the findings of this study, if an individual were to switch from conventional to organic plant-based foods, he or she could expect over time an average 20-40% increase in crop-based antioxidant intake, and without a simultaneous increase in caloric intake.

The team reports this expected range in the increase of antioxidants because different plant-based foods, and especially fruits and vegetables, can have markedly different levels of specific antioxidants as a result of organic versus conventional production, plant genetics, the weather in a given growing season, and how farmers manage fertility and pests.

**Q: What is some of the “compelling evidence” cited in the paper that supports the conclusion that heightened intakes of antioxidants will improve health outcomes?**

**A:** Only two small, short-term and inconclusive studies have compared heath outcomes among individuals consuming predominantly organic versus conventional food diets. But many studies in humans and animals have shown significant health improvements as a result of higher dietary antioxidant intakes. This is a major reason why governments and health professionals worldwide recommend substantially greater daily intakes of fruits and vegetables.

One study involving rats fed a conventional versus organic ration documented multiple indications of improved health status among the animals on an organic diet. Redundancy analysis was used to determine the nutritional differences in the rat feed accounting for the improved health outcome. Total polyphenols was the strongest driver. The team concludes that the positive results in this and other animal experiments support the linkage between human consumption of organic foods and lessened risk of a variety of health problems.

**Food Safety**

**Q: What kind of toxic metal did the study find was higher in conventional as opposed to organic crops? Why is this metal dangerous?**

**A:** This study found that organic crops had on average 48% lower cadmium (Cd) levels than conventional crops. Cadmium is a highly toxic metal that can cause kidney failure, bone softening, and liver damage. Cadmium can accumulate in the body, and people can be exposed through many routes, e.g. food and drinking water, air pollution, and second-hand cigarette smoke. Even at low levels in food, chronic exposure can be dangerous. Concern over its toxicity led the European Commission (EC) to set maximum residue levels (MRL) in foods. Cadmium is one of only three toxic metal contaminants for which the EC has set such levels (the other two are lead and mercury).

**Q: Why are cadmium levels generally higher in conventionally grown food?**

**A:** While the team notes more research is needed to explain the surprisingly large differences in cadmium levels, it is known that certain synthetic fertilizers applied on conventional farms alter soil microbial communities, and the biochemistry of the soil, in ways that increase the bioavailability of cadmium to plant roots. Moreover some conventional fertilizers containing phosphorous are contaminated with cadmium, thereby elevated levels in the soil.

**Q: What did the study conclude about pesticides in organic versus conventional plant-based foods?**

**A:** The occurrence, or frequency of pesticide residues in conventional food is about four-times higher than in organic food. While data from around the world on pesticide residues in conventional versus organic food are relatively clear and consistent on the question of the frequency of residues, this variable is a poor indicator of pesticide dietary risk levels.

Pesticide dietary risk to humans is a function of six key factors:

* The frequency of exposure to a given pesticide in any given day,
* The number of pesticides to which a person is exposed per day,
* The level of each pesticide in the foods consumed by an individual in a day,
* The amount of each food consumed in a day containing one or more pesticide residues,
* The toxicity of the pesticides in food consumed in a day, and
* The timing of pesticide exposures relative to the person’s age and health status.

The present study covers only the first of these six factors. Other pesticide residue and dietary risk data accessible through the <M2M website; link to <http://csanr.wsu.edu/program-areas/m2m/research-areas/pesticide-dietary-risks/pesticide-dietary-risk-analytical-system/>> shows that, for example, (a) multiple residues are common in several conventionally grown fruits and vegetables, and the average number of residues per sample of organic food is far lower, and (b) residue levels in a given organic food, e.g. fresh apples are much lower than the corresponding residues in conventionally grown apples (typically 10-fold to 100-fold lower).

For example, the USDA last tested organic and conventional fresh apples in 2010. Two common post-harvest fungicides were found in nearly two-thirds of the domestically grown organic samples, from residual contamination in packing sheds. But the levels of pyrimethanil and thiabendazole were 120-fold and 82-fold lower, respectively, in the organic apple samples compared to the conventional samples (0.479 ppm vs. 0.004; and, 0.326 ppm vs. 0.004 ppm).

Accordingly, the difference in the occurrence of residues in conventional versus organic plant-based foods addressed in this study substantially underestimates the actual differences in pesticide dietary risk levels following consumption of conventional vs. organic foods.

**Q: Are there health risks associated with dietary exposures to pesticides?**

**A:** Unfortunately, yes. Even at low doses, pesticides can disrupt prenatal development and pose unique risks to infants, children, and adults with compromised immune systems or certain genetic polymorphisms (e.g., there is a genetic variant that reduces the body’s ability to metabolize organophosphate insecticides that increases risks 10- to 100-fold among certain individuals).

Common levels of exposure to certain organophosphate insecticides can reduce a child’s IQ by 4 to 7 points, a reduction comparable to that triggered by lead exposure levels common during most of the post-WWII period, until major steps were taken nation-wide to remove lead from gasoline and paint. A growing body of evidence links prenatal and early-life pesticide exposures to heightened risk of autism, ADHD, asthma, food allergies, diabetes and overweight.

The President’s Cancer Panel has suggested avoiding food grown with pesticides to decrease the risk of environmentally-induced cancers.

Developmental and cancer risks are especially worrisome for infants and growing children, because children eat more relative to their body weight than adults, and a child’s organs are less efficient in detoxifying pesticides than adults.

Exposure to pesticides is also a known-risk factor for women and men of reproductive age, because pesticides can undermine reproductive health and birth outcomes. For example, a joint report by the American College of Obstetricians and Gynecologists and the American Society for Reproductive Medicine reports that environmental chemicals such as pesticides can increase the risk of spontaneous abortions, certain birth defects, and undermine long-term neurological health.

**Q: Why are pesticide residues less common, and dietary risks lower, in organic food?**

**A:** Lower occurrence and reduced pesticide risk levels in organic versus conventional crops are easily explained: under organic certification rules, farmers are not allowed to apply toxic, synthetic pesticides. Sometimes residues of pesticides prohibited for use on organic farms are found on nearby organic crops because of drift, carryover of residues in the soil, or contaminated irrigation water, but the levels found on organic crops are typically 10-fold to 100-fold lower than in crops harvested from fields that were sprayed with pesticides.

A surprisingly large share of prohibited residues in organic fruits and vegetables – over one-third -- stem from post-harvest uses of fungicides in packinghouses when conventionally grown fruit is being packed. Despite adherence to National Organic Program rules calling for the clean out of fruit packing lines and facilities before organic fruit is packaged, enough residues often remain inside the facilities to result in very low-level residues in organic fruit.

A recently published, <open-access paper; link http://www.mdpi.com/2071-1050/6/6/3552> in the journal *Sustainability* provides a detailed analysis of pesticide residues and risks in organic food, based on residues detected over the last decade by the U.S. Department of Agriculture’s Pesticide Data Program. The reasons behind differences in residues and risk levels are discussed in an <associated blog; <http://csanr.wsu.edu/pesticide-residues-in-organic-food/>>.

**Q: Are all pesticides found in organic food a reflection of prohibited applications?**

**A:** No. There are a few organically approved, natural pesticides that are routinely detected in organic food samples. By far the most common residues arise from use of the bioinsecticide spinosad. As long as the residues of spinosad are below applicable tolerances, the residues are both legal and permitted under organic farming rules.

In the U.S, a growing percentage of the residues found in organic food are either from pesticides allowed for use on organic farms, or stem from residues carried over in the soil from legacy uses of persistent insecticides banned in the early 1970s. These classes of residues accounted for about 50% of all residues detected in organic food in recent testing by the USDA (see above cited *Sustainability* paper for details).

**How This Study Improves Upon Earlier Ones**

**Q: Why does this study find that organic crops are nutritionally beneficial and reduce some food safety risks, while other studies have reported no significant differences?**

A: The main reason boils down to “science marches on.” This study draws upon 343 peer-reviewed studies published through the end of 2012, and includes more than 100 additional studies compared to other recent reviews.

Plus, about 100 of the 343 studies have been published in the last five years, and utilize more sophisticated and sensitive experimental designs (e.g., the <strawberry fruit quality study; http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0012346> carried out by a Washington State University team led by John Reganold). The higher quality of many recent studies makes it possible to more accurately quantity differences.

**Q: Did the methods used in this study impact the findings?**

**A:** The statistical methods used in the current study are more rigorous and sophisticated than those used in earlier meta-analyses. The methods in this study: (a) allowed the team to gain deeper insights into the degree to which nutrient density and safety parameters vary across organic and conventional foods, and (b) increased the level of statistical significance of many findings (i.e., renders the conclusions more reliable).

For example, the present study used weighted meta-analyses based on standardized mean differences, which is an approach that is recommended when combining data from studies that measure the same parameter (e.g., the major phenolic compounds found in a given crop), but use different scales. The methods deployed in this study also take into account the average levels of a given nutrient in organic versus conventional apples, for example, as well as the variance in the levels in both organic and conventional apples. This is the first meta-analysis focused on organic and conventionally grown foods to utilize recommended techniques that incorporate both mean nutrient levels and the variance in nutrient levels in the calculations of differences across quality parameters.

**Q: The paper says eight meta-analyses were done. Why eight, and how did they differ?**

**A:** One of the issues explored in this project, and addressed in the paper, entails how different approaches in conducting a meta-analysis impact the results. In previous studies, different methods have been used, and the team wondered if differences in findings might be explained mostly by how the statistical analysis was conducted.

Accordingly, we conducted eight different meta-analyses, using different criteria for including studies, and a “standard,” unweighted mathematical approach, and a more sophisticated, and recommended, weighted meta-analysis. Weighted analyses can only be carried out for crop-nutrient combinations reporting the number of samples, means, and standard deviations/standard errors.

There were four standard, unweighted meta-analyses, and four weighted ones. Our major findings for the unweighted and weighted analyses:

* Averaged results across cultivars when a paper reported results on two or more cultivars; and
* Average values were calculated when data were reported on a given crop-nutrient combination for two or more years.

The team carried out three sensitivity analyses for both the unweighted and weighted meta-analyses. The three additional analyses for both weighted and unweighted cases varied as follows:

* Instead of averaging results across multiple years, the results for each crop-nutrient-year combination were included separately;
* To test just the impact of averaging across cultivars, results for each cultivar were included, and no other changes were made from the standard analysis; and
* Both results by individual cultivar and individual years were included as separate observations.

**Q:** **Did the results vary across the eight meta-analyses?**

**A:** Yes, especially between the unweighted and weighted analyses. In the case of some nutrients, the size of the differences reported declined, while others increased, when comparing the magnitude of differences between the weighted and unweighted analyses. But because weighted meta-analyses are regarded as more robust and reliable, the paper’s major results and discussion focus predominantly on the weighted results.

But the consistency across the eight analyses also drives home an important point – while different methods and inclusion criteria matter, the differences in nutrient levels in organic versus conventional crops are relatively consistent across multiple methods, and as a result can be regarded as more reliable, reflecting real and consistent difference in average nutrient levels across a variety of production environments.

**Q: What other studies have compared the nutritional quality of plant-based organic and conventional foods?**

**A:** Earlier meta-analysis, some of which reached different conclusions, include:

* Smith-Spangler et al., (2012), a Stanford Medical School study entitled “Are organic foods safer or healthier than conventional alternatives? A systematic review.” *Annals of Internal Medicine*. Vol.157: pages 348-366.
* Dangour et al., (2009), a UK-Food Standards Agency sponsored study entitled “Nutritional quality of organic foods: a systematic review.” *American Journal of Clinical Nutrition*, doi: 10.3945/ajcn.2009.28041
* Brandt et al., (2011), a University of Newcastle-led study entitled “Agroecosystem Management and Nutritional Quality of Plant Foods: The Case of Organic Fruits and Vegetables.” *Critical Reviews in Plant Sciences*, Vol. 30: pages 1-2, and 177-197
* Benbrook, et al., (2008), a study by The Organic Center entitled “New Evidence Confirms the Superiority of Plant-Based Organic Foods.” The Organic Center, Washington, D.C. Access at – <http://organic-center.org/reportfiles/> Nutrient\_Content\_SSR\_Executive\_Summary\_2008.pdf

For an overview of the methodological strengths and weaknesses of the above studies, see the <letters to the editors and critiques> of these studies posted on the WSU “Measure to Manage” website.

**About the Study**

**Q: Why was the study done?**

**A:** To address, and attempt to explain differences reported in a series of studies on the same, or related topics over the previous decade. Consumers often ask scientists, including this study’s co-authors, whether organic food is better for them and their families. Our study was done to provide answers based on the best data available, using state-of-the-art analytical methods.

**Q: Who funded the study?**

**A:** Most of the funding was provided by the European Community Sixth Framework Programme for Research, Technological Development and Demonstration Activities for the Integrated Project QUALITYLOWINPUTFOOD, via grant FP6-FOOD-CT-2003-506358. The Sheepdrove Trust, a private charity based in the U.K., provided additional funding.

**Q: How much did the study cost?**

**A:** About $429,000 (US); $316,000 (Euro); and, £250,000 (Pounds British Sterling).

**Q: Was the study peer-reviewed?**

**A:** Yes, and rigorously so following the standard procedures of the *British Journal of Nutrition*.

**Q: Why was the study published in the *British Journal of Nutrition*?**

**A:** Because it is one of the world’s oldest and most respected nutrition journals, and makes newly published papers available for free to anyone wishing to download a full copy.

**Q: Has the team taken any steps to further advance the scientific quality of studies comparing organic and conventional foods?**

**A:** Yes, two steps.

In addition to publishing the 18-page paper, the team also published 88-pages of SUPPLEMENTAL DATA. Further details covering data sources, methods, and results are presented in this material.

And second, in order to support further advances in studies of this kind, the team has also made its entire raw dataset available on a website managed by the University of Newcastle.