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Scientific Status Summary

Organic Foods

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The Inst. of Food Technologists has issued this Scientific Status Summary to update readers on the organic foods industry.

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The growth of the organic foods industry in the United States has been dramatic in the past 2 decades. It is estimated that organic sales have increased by nearly 20% annually since 1990, with consumer sales reaching $13.8 billion in 2005 (Figure 1). While initial organic food production primarily involved small farms and local distribution of fresh produce, today's organic food system is a complex combination of small and large food producers, local and global distribution networks, and a wide variety of products, including fruits, vegetables, meats, dairy, and processed foods (Figure 2).

This rapid growth may be traced to increased consumer confidence in organic foods as well as to concern about possible health risks and environmental impacts of conventional food production methods. Recent food crises such as mad cow disease and foot-and-mouth disease have lessened consumer confidence in foods in general and especially in conventionally produced foods that may use pesticides, antibiotics, and other chemicals in food production (Dreezens and others 2005; Siderer and others 2005). Surveys indicate that many consumers purchase organic foods because of the perceived health and nutrition benefits of organic products. In one survey, the main reasons consumers purchased organic foods were for the avoidance of pesticides (70%), for freshness (68%), for health and nutrition (67%), and to avoid genetically modified foods (55%) (Whole Foods Market 2005). Such consumers appear to be willing to pay the typical 10% to 40% price premium that organic products command.

Organic Practices

Organic production can be defined as an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain, and enhance ecological harmony. U.S. regulations require that organic foods are grown without synthetic pesticides, growth hormones, antibiotics, modern genetic engineering techniques (including genetically modified crops), chemical fertilizers, or sewage sludge.

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Organic farming uses various methods to enhance or maintain soil fertility, such as crop rotation, tillage and cultivation practices, cover crops, and natural products (such as natural fertilizers, pesticides, and so on). The use of synthetic materials is not allowed in organic farming unless the materials are on the Natl. List of Allowed and Prohibited Substances. A synthetic material can be defined as a substance that is formulated or manufactured by a chemical process or by a process that chemically changes a substance extracted from a naturally occurring plant, animal, or mineral source. Organic farmers use animal and crop wastes, botanical, biological, or nonsynthetic pest controls, and allowed synthetic materials that can be broken down quickly by oxygen and sunlight. Organic farmers also use specific methods to minimize air, soil, and water pollution.

It takes several years to convert a field from conventional farming to organic farming since land can have no prohibited substances used on it for 3 y before the harvest of an organic crop. Animal herds can be converted to organic by feeding them 80% organic feed for 9 mo, followed by 3 mo of 100% organic feed. Animals must consume only 100% organic feed for their products to be sold as organic, but the animals can receive vitamin and mineral supplements. Preventive management practices such as vaccinations can be administered when absolutely necessary to keep animals healthy, but those animal products cannot be sold as organic. Antibiotics cannot be used on products to be sold as organic.

Organic Legislation and Regulation

The U.S. Dept. of Agriculture (USDA) introduced the Organic Foods Production Act (OFPA) as part of the 1990 Farm Bill. The 3 main goals of the OFPA were to establish standards for marketing organically produced products, to assure consumers that organic products meet a consistent standard, and to facilitate interstate commerce.

The OFPA called for the establishment of the 15-member Natl. Organic Standards Board (NOSB), whose purposes are to make recommendations to the Natl. Organic Program about whether a substance should be allowed in organic production or handling, to assist in the development of standards for substances to be used in organic production, and to advise the Secretary of Agriculture on other aspects of the OFPA. Appointed by the Secretary of Agriculture, members of the NOSB represent all aspects of the organic food spectrum.

The OFPA also created the Natl. List of Allowed and Prohibited Substances, which lists synthetic substances and ingredients that

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are allowed in, and natural substances and ingredients that are prohibited from, organic production and handling. No allowed or prohibited substance can remain on the Natl. List for a period exceeding 5 y unless the substance is reviewed and recommended for renewal by the NOSB and adopted by the Secretary of Agriculture. The Natl. List contained over 170 substances on October 21, 2002, when it was implemented. The 1st expiration (sunset) of the Natl. List requires a review process that is currently under way and that must be concluded by October 21, 2007.

The OFPA mandated that the USDA establish Natl. Organic Program Standards. Announced in late 2000 and fully implemented in 2002, the standards specified the methods, practices, and substances that could be used to produce, process, and handle organic foods. After the standards became effective, USDA Secretary Dan Glickman clarified that organic certification expressed a production philosophy and that organic labeling did not imply a superior, safer, or healthier product than food not labeled as organic.

The standards state that a USDA-accredited inspector must certify all organic operations. Certification provides 3rd-party assurance that a product was raised, processed, and distributed to meet the official organic standards. This process also reduces the practice of falsely labeling products as organic. In the United States, manufacturers can receive penalties of up to $10000 for inappropriate use of the organic label. The certification process is clearly defined so that, theoretically, all inspectors certify according to the same standards.

All foods labeled with the USDA organic seal must come from a certified farm or handling operation. All products labeled as "100% organic" must contain only organically produced ingredients; products labeled as "organic" must contain at least 95% organically produced ingredients. The other 5% of ingredients may come from the Natl. List of Approved Substances. One hundred percent and 95% organic products may use the USDA organic seal (Figure 3). Products that contain at least 70% organic ingredients can be labeled "made with organic ingredients" and list up to 3 of those ingredients on the principal display panel; however, such products may not use the USDA organic seal. Products with less than 70% organic ingredients may only list which ingredients are organic on the information panel.

The USDA developed a financial assistance program, the Natl. Organic Cost-Share Program, for organic farmers in 15 states to help pay for their organic certification, which is required for organic farms whose income is higher than $5000 a year. This practice has continued since 1990, and in 2005, $1 million in funds were available to 15 states (Connecticut, Delaware, Maine, Maryland, Massachusetts, Nevada, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Utah, Vermont, West Virginia, and Wyoming) to reimburse producers for the cost of organic certification. Producers can be reimbursed for up to 75% of their certification costs, not to exceed $500.

The European Commission recently adopted a proposal for new regulations on organic production. The new rules, effective January 1, 2007, are meant to be easier to understand for both producers and consumers and will be slightly flexible for the different regions in the European Union (EU). Organic products in the EU must contain at least 95% organic ingredients. Imported organic products must comply with EU standards or the country of origin must have equivalent guarantees. The United States also accepts products from countries that have equivalent guarantees, such as the EU.

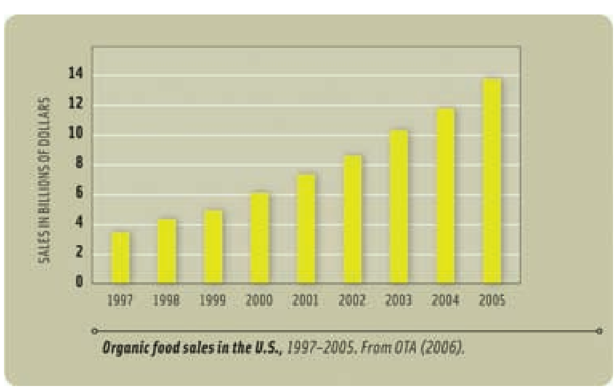

Figure 1 — Organic food sales in the United States from 1997 to 2005 (Source: Organic Trade Assn., 2006)

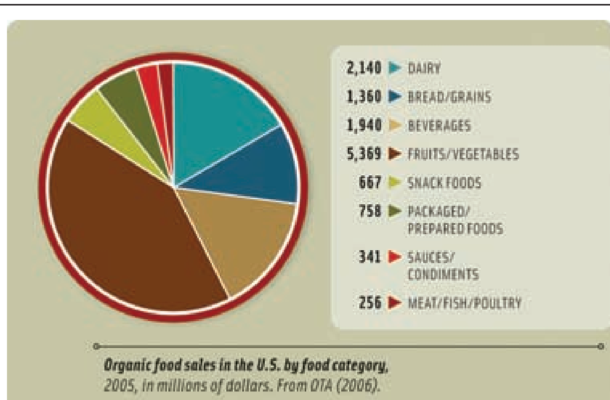

Figure 2 — Organic food sales in the United States by food category, 2005 (Source: Organic Trade Assn., 2006)

Figure 3 — The USDA organic seal

Quality and Safety Comparisons of Organic and Conventional Foods

Pesticides

According to a recent survey, 70% of consumers said that they purchased organic foods to avoid pesticides (Whole Foods Market 2005). Clearly one of the drivers of the organic food industry is the differentiation between organic foods and conventional foods with respect to pesticide use and perceived food residues. Synthetic substances can be used in organic production if they are on the Natl. List. The use of such substances is permissible only when they do not contribute to contamination of crops, soil, or water and when other recommended organic pest management practices prove insufficient to prevent or control pests. The list includes several synthetic substances allowed for use on organic crop production. Among the types of synthetic substances approved for use on organic crops are soap-based herbicides; water disinfectants such as calcium hypochlorite, sodium hypochlorite, and copper sulfate; and insecticides such as boric acid, lime sulfur, elemental sulfur, copper sulfate, and oils.

Such limitations in available pesticides and the restrictions on their use should intuitively result in fewer pesticide residues in organic crops relative to conventional crops. Interestingly, though, only a small number of studies have looked at specific differences between pesticide residues on organic and conventional foods. Baker and others (2002) conducted the most comprehensive study looking at the relationship between pesticide residues in conventional foods and those in organic foods. This study relied on 3 distinct pesticide residue databases: USDA's pesticide data program (PDP), the marketplace surveillance program of the California Dept. of Pesticide Regulation (CDPR), and a Consumers Union private residue-testing program. Each program differed markedly in sensitivity, analytical scope, and sample collection techniques, thus rendering comparisons of findings between the residue databases inappropriate. Nevertheless, each individual database showed similar relationships between residues of conventional and organic produce and, taken together, demonstrate that the occurrence of pesticide residues on organic produce is considerably lower than the occurrence on conventional produce.

The largest database is that of the PDP, which includes results of the sampling of 26893 foods for pesticide residues from 1994 to 1999. Nearly 99% of the samples (26591) made no market claim about the method of production, and 73% of these samples contained detectable residues of pesticides. A small number of samples (127) made organic production claims; nonetheless, residues of pesticides were present in 23% of these samples. In addition, 195 samples made claims of having been either produced using integrated pest management (IPM) practices or certified to contain no detectable residues (NDR). Pesticide residues were present in 47% of the IPM/NDR samples.

Some of the residues encountered in all of the sample pools represented environmentally persistent chlorinated hydrocarbon insecticides that have been banned for use for several decades but are still present in small amounts in many agricultural fields and can result in food residues. By omitting the detections of such banned pesticides, the percentage of organic foods showing residues dropped from 23% to 13% while foods making no market claim dropped from 73% to 71%.

CDPR's marketplace surveillance program analyzed 66057 produce samples that made no market claim of their production methods and 1097 samples of produce labeled as organic between 1989 and 1998. Pesticide residues were detected in 30.9% of the produce samples for which no market claim was made and in 6.5% of the organic samples.

The Consumers Union sampled small numbers of apples, peaches, peppers, and tomatoes grown under organic IPM/NDR certification and no-market-claim practices. Of the 68 samples for which no market claim was made, residues were present in 79% of the cases. Of the 45 IPM/NDR samples, 51% contained residues, and 27% of the 67 organic samples had pesticide residues. From an international standpoint, Pussemier and others (2006) cited results from Belgium between 1995 and 2001 in which pesticide residues were detected in 49% of conventional produce samples and in 12% of organic produce samples.

A summary of the findings from the various monitoring programs is in Table 1. Sampling and analytical methods of the cited monitoring programs varied considerably, making comparisons of the percentages of samples containing residues difficult to interpret. Perhaps more appropriate is the determination of the ratio of conventional produce to that of organic produce with respect to the percentage of pesticide residue detection. Pesticide residues were 3.2 times more likely to be found in conventional produce than in organic produce, according to the PDP data; 4.8 times more prevalent in the CDPR data; 2.9 times greater in the Consumers Union data; and 4.1 times more likely than organic samples in the Belgian data. Such values among the 4 monitoring programs are in reasonable agreement and provide strong evidence that pesticide residues are much more likely to be detected in conventional foods than in organic foods.

The levels of pesticide residues in organic foods also appear to be lower than those in conventional foods. An analysis of the PDP data showed that in the 22 cases where organic and conventional (no market claim) samples contained the same pesticide residue on the same commodity, residues in the organic samples were lower 68% of the time (Baker and others 2002) but not quite statistically significant ($P = 0.067$).

The findings of pesticide residues at lower frequencies and at lower levels in organic foods suggest that organic foods may be less risky than conventional foods with respect to pesticides. However, it is important to consider the risks, if any, currently posed by pesticide residues in foods before determining the incremental health benefits from consuming organic produce.

Traditionally, the potential risks posed by pesticides in food have been approximated using the simplistic method of comparing residue levels with established regulatory limits known as tolerances in the United States and maximum residue limits (MRLs) for much

Table 1—Detection of pesticide residues in conventional and organic produce: summary of different monitoring programs

	USDA pesticide data program	CDPR marketplace surveillance program	Consumers Union	Belgium
Conventional—percentage detected	73	31	79	49
Organic—percentage detected	23	6.5	27	12
Ratio—conventional/organic	3.2	4.8	2.9	4.1

Sources: Baker and others 2002; Pussemier and others 2006.

of the rest of the world. Findings using this approach have been fairly consistent throughout the years, with the majority of regulatory monitoring samples showing no detectable residues, the vast majority of detected residues having levels well within the allowable ranges, and residues found in excess of the allowable limits being relatively infrequent.

As an example, in its 2003 regulatory monitoring program, the U.S. Food and Drug Administration (FDA) analyzed 2344 domestic and 4890 imported foods for pesticide residues (FDA 2005). Residues were detected in 37.3% of the domestic samples and in 28.2% of the imported samples. Violative residues were detected in 2.4% of the domestic samples and in 6.1% of the imported samples, but most of the violations occurred because residues were present on commodities for which a tolerance had not been established. Only 9 (0.38%) of the domestic samples and 26 (0.53%) of the imported samples had residues detected in excess of tolerance levels.

Similar findings have been reported for residue monitoring in the EU, Norway, Iceland, and Liechtenstein (European Commission 2003). In 2003, 40577 food samples were analyzed in the combined monitoring programs of 17 national governments. Overall, residues were present in 36% of the samples and violative residues were detected in 4.3% of the samples.

Care must be taken when extrapolating the results of national monitoring programs to possible risks to human health from consumption of pesticide residues in foods. Although it may seem counterintuitive, regulatory levels (tolerances and MRLs) exist as enforcement tools designed to ensure compliance with pesticide use regulations (Winter 1992). Regulatory levels represent the maximum residues anticipated from the legal use of the pesticides and are not barometers of possible health risks. While illegal pesticide applications have occasionally led to illnesses when the consumption of food improperly treated with pesticides occurs (Goldman and others 1990; Ferrer and Cabral 1991), the vast majority of violative residues are of no apparent health concern (Winter 1992).

Regulatory risk assessments are conducted prior to establishing allowable levels for pesticides on commodities. In the United States, the Environmental Protection Agency (EPA) is responsible for ensuring that consumer exposure to pesticides poses a “reasonable certainty of no harm” (Winter 2001). The Food Quality Protection Act requires that EPA consider the potential greater susceptibility and exposure of infants and children to pesticides via pesticide residues in food and water, residential pesticide use, and the cumulative effects of pesticide groups that share a common mechanism of toxicological activity. Generally, risks meeting the “reasonable certainty of no harm” standard occur when the lifetime cancer risk to pesticide exposure—using conservative (risk-enhancing) assumptions of cancer development—are below 1 excess cancer per 1 million persons exposed. For noncancer effects, a reasonable certainty of no harm occurs when exposure, either on an acute (short-term) or chronic (long-term) basis, is below the reference dose (RfD) 99.9% of the time. The RfD is not a toxicological threshold but is typically a derivative of finding the most sensitive toxicological effect observed in animal toxicology studies by determining the highest dose level that does not cause such an effect and dividing that level by a factor of 100 or more. If EPA is confident that the consumer risks from a pesticide represent a reasonable certainty of no harm, then it establishes tolerances at levels high enough to ensure that pesticide applications made in accordance with directions will not result in residues above tolerance levels (Winter 2001).

The European Commission uses “acceptable daily intake” (ADI), a term analogous to the RfD, as its minimal level of toxicological concern. To estimate dietary risks from pesticides, residue levels from monitoring studies can be multiplied by food consumption estimates to predict daily exposure levels. Comparing estimated exposure levels with ADI levels provides an evaluation of the relative margin of safety between pesticide exposure and potential health concern. Based on findings by the European Commission in 2003, chronic exposures to individual pesticides ranged from 0% to 0.2% of ADI. The majority of acute exposures at the upper 97.5th percentile were below established acute RfDs, although acute exposure estimates ranged from 0% to 257% of the acute RfD for adults and from 1% to 1035% of the acute RfD for toddlers. The European Commission (2003) qualified the fact that some acute exposures did exceed RfDs by stating, “It must be borne in mind that the above results emerge from an assessment of the worst-case scenarios, based on the maximum level of residues detected, combined with high food consumption data and the highest variability factors.”

Dietary exposure to pesticides is clearly not limited to the consumption of fresh fruits and vegetables. Factors such as washing, peeling, baking, frying, and processing can significantly affect the amount of pesticide available to consumers at the time of consumption. Market basket surveys can account for these postharvest effects on residue levels and are therefore more accurate than regulatory monitoring programs in predicting consumer exposure to pesticides. A typical market basket survey involves the purchase of a wide variety of foods at retail outlets, preparation of the food items into ready-to-eat forms, and residue analysis of the final food forms. By combining the residue findings with estimates of the consumption of various food items, an estimate of typical dietary exposure to pesticide residues is possible.

The FDA annually conducts its own market basket survey, the total diet study, which involves a market basket of 285 distinct foods analyzed for pesticide residues at the time the foods are ready for consumption. While the results for the total diet study have consistently shown low levels of pesticide residues in food samples, the FDA discontinued estimating dietary exposure to specific pesticides after 1991. From the 1991 total diet study, the highest daily average pesticide intake among different population subgroups (6- to 11-mo-old infants, 14- to 16-y-old men, and 60- to 65-y-old women) was compared directly with the United Nations Food and Agricultural Organization/World Health Organization ADI values for 38 pesticides (FDA 1992). Estimated exposures were less than 1% of the ADI values for 34 of the pesticides, with the remaining 4 pesticides contributing 1%, 1.8%, 2.7%, and 4.8% of the ADI values. To put such values in perspective, the ADI typically represents a value 100 times lower than the highest level of exposure to a pesticide given to the most sensitive animal species on a daily basis throughout its lifetime that has not caused any noticeable toxicological effect. A typical human exposure at 1% of the ADI represents an exposure 10000 times lower than levels that do not cause toxicity in animals. Such findings suggest that typical dietary exposure to pesticide residues in foods poses minimal risks to humans. From a practical standpoint, the marginal benefits of reducing human exposure to pesticides in the diet through increased consumption of organic produce appear to be insignificant.

Occupational exposure to pesticides presents a much greater health risk than consumer exposure to pesticides. In 2004, 828 documented cases of occupational pesticide illnesses were reported in California, including 552 definite/probable cases and 276 possible cases (CDPR 2005). Of the 552 definite/probable cases, 12 people were admitted to hospitals and 95 lost time from work. A total of 71 cases involved mixers/loaders of pesticides, 196 cases involved pesticide applicators, 22 cases were mechanics, and 68 cases involved field workers. Among field worker illnesses, the most (24 cases) occurred while working with grapes, including 13 possible cases of skin injury. A pesticide frequently implicated as a cause of grape-field-worker skin rashes is sulfur, which is permissible for use in organic agriculture (Winter and Kurtz 1985). Nevertheless, it is clear that illnesses and injuries in agricultural workers can be reduced significantly by producing foods organically rather than conventionally. Organic production, which limits pesticide use, may also have a more positive environmental impact than conventional production, which uses more synthetic pesticides. Pesticides are frequently detected in water and air samples and may potentially affect nontarget organisms such as birds, mammals, and fish.

Nutritional components

Many consumers have indicated that they consider organic foods to be more nutritious than conventional foods (Whole Foods Market 2005) and frequently maintain that the methods commonly used to increase yields of conventional foods, such as use of pesticides and fertilizers, may limit the natural ability of plants to incorporate or synthesize nutrients. Indirect evidence supporting this argument comes from the recent work of Davis and others (2004), who compared USDA nutrient content data for 43 garden crops between 1950 (before many modern methods of agricultural production had achieved widespread adoption) and 1999. Statistically reliable declines were noted for 6 nutrients (protein, calcium, potassium, iron, riboflavin, and ascorbic acid), with declines ranging from 6% for protein to 38% for riboflavin. However, Davis and others attributed the decreases in nutrient content to changes in the cultivars (plant varieties) used. They maintained that cultivars are frequently selected for their yield characteristics, growth rate, and pest resistance but are not chosen because of their nutrient content. Selection of cultivars for specific resource-using functions such as growth rate, yield, pest resistance, or other nonnutrient characteristics might be subject to tradeoffs that result in limitations in the cultivars' abilities to incorporate soil minerals, transport them within the plant, or synthesize nutrients such as proteins and vitamins. The authors did not attribute the nutrient losses between 1950 and 1999 to increased pesticide or fertilizer use.

Three major review articles have been published that make comparisons of the nutritional quality of organic and conventional foods. Woese and others (1997) reported on an extensive literature base of 150 comparative studies published between 1926 and 1994 that examined the quality of foods grown under different production methods. This review included foods such as cereals, potatoes, vegetables, fruits, wine, beer, bread, milk and other dairy products, meat and meat products, eggs, and honey. The authors concluded that no major differences in nutrient levels were observed between the different production methods in some cases while in other cases contradictory findings did not permit definitive conclusions about the influence of production methods on nutrient levels.

Worthington (2001) reviewed 41 studies that compared crops produced with organic fertilizer or by organic farming systems to crops produced using conventional farming systems. It was reported that organic crops contained 27% more vitamin C, 21.1% more iron, 29.3% more magnesium, and 13.6% more phosphorus than did conventional crops.

Bourn and Prescott (2002) summarized a number of studies that compared the effect of inorganic and organic fertilizers on the nutritional value of crops. They concluded that the study designs and results were too variable to provide any definitive conclusions concerning the effect of fertilizer type on mineral and vitamin content of crops. They also concluded that the studies' authors occasionally reported statistical differences when no statistical techniques had even been employed to examine such differences.

In recent years, researchers have conducted several controlled studies to compare organic and conventional foods with respect to nutritional composition (Table 2). Some studies have concluded that organic production methods lead to increases in nutrients, particularly organic acids and polyphenolic compounds, many of which are considered to have potential human health benefits as antioxidants. However, other studies did not demonstrate differences in nutrients between organic and conventional production methods.

Two major hypotheses explaining the possible increases in organic acids and polyphenolics in organic versus conventional foods have been proposed. One hypothesis considers the impacts of different fertilization practices on plant metabolism. In conventional agriculture, synthetic fertilizers frequently make nitrogen more available for the plants than do the organic fertilizers and may accelerate plant growth and development. Therefore, plant resources are allocated for growth purposes, resulting in a decrease in the production of plant secondary metabolites (compounds not essential to the life of the plant) such as organic acids, polyphenolics, chlorophyll, and amino acids.

The second hypothesis considers the responses of plants to stressful environments such as attacks from insects, weeds, and plant pathogens. It has been argued that organic production methods—which are limited in the use of insecticides, herbicides, and fungicides to control plant pests—may put greater stresses on plants and may require plants to devote greater resources toward the synthesis of their own chemical defense mechanisms. Increases in antioxidants such as plant polyphenolics have been attributed to their production in plant defense (Asami and others 2003), although the same mechanisms may result in the elevations of other plant secondary metabolites that may be of toxicological rather than nutritional significance.

While the 2 hypotheses may explain the potential increases in nutritional compounds in organic foods relative to conventional foods, as seen in a few studies, the impact on human health of consuming greater levels of organic acids and polyphenolics has yet to be determined. Studies using organically and conventionally cultivated strawberries demonstrated that extracts from organic strawberries showed higher antiproliferative activity against colon cancer and breast cancer cells than did extracts from conventional strawberries (Olsson and others 2006). While these results suggest a possible mechanism by which organic foods could reduce human cancer risks compared with conventional foods, such results were obtained from *in vitro* studies and not from human or rodent feeding studies. One *in vivo* feeding study failed to demonstrate any differences in plasma levels of the antioxidants vitamin C and lycopene in human subjects who had consumed tomato purees from either organic or conventional sources for 3 wk. This study did find that organic tomatoes showed higher vitamin C levels and that organic tomato purees showed higher levels of vitamin C and polyphenols than did conventional tomatoes and purees (Caris-Veyrat and others 2004).

Nitrates

While nutritional comparisons of organic and conventional foods provide quite variable data when considering the possible differences in plant secondary metabolites and minerals, it appears that organic production of foods does result in lower nitrate levels. Worthington (2001) summarized the results of 18 studies comparing nitrate levels of organic and conventional foods and found 127 cases where nitrate levels were higher in conventional foods, 43 cases where nitrate levels were higher in organic foods, and 6 cases where no difference was observed. The ratio of nitrate levels in conventional foods relative to organic foods ranged from 97% to 819%. A review by Woese and others (1997) also concluded that "conventionally cultivated or minerally fertilised vegetables normally have

Table 2—Summary of recent studies comparing organic and conventional foods with respect to nutrient levels

Foods	Chemicals studied	Results	Reference
Strawberries, blueberries	Flavonols, phenolic acids	Organic cultivation had no consistent effects on phenolic levels	Hakkinen and Torronen (2000)
Vegetable soups	Salicylic acid	Organic soups had significantly higher content of salicylic acid	Baxter and others (2001)
Qing-gen-cai, Chinese cabbage, spinach, Welsh onion, green pepper	Flavonoids	Organic foods generally had higher levels of flavonoids	Ren and others (2001)
Peach, pear	Polyphenoloxidase enzyme activity, total phenolics	Organic peaches and pears had higher phenolic and polyphenoloxidase levels	Carbonaro and Mattera (2001)
Black currants	Flavonols	No consistent differences were noted between flavonol levels in organic and conventional black currants	Mikkonen and others (2001)
Peach, pear	Polyphenoloxidase enzyme activity, total phenolics, organic acids	Organic peaches and pears had higher phenolic and polyphenoloxidase levels, organic peaches had higher levels of ascorbic acid and citric acid	Carbonaro and others (2002)
Marionberries, corn, strawberries	Phenolics and ascorbic acid	Phenolics and ascorbic acid higher in organics than in conventional; highest levels of phenolics and ascorbic acid in crops grown "sustainably"	Asami and others (2003)
Tomatoes	Vitamin C, carotenoids, polyphenols	Organic tomatoes had higher levels of Vitamin C, carotenoids, and polyphenols than conventional when results were expressed as fresh matter	Caris-Veyrat and others (2004)
Grapes	Polyphenoloxidase and diphenolase enzymes	Polyphenoloxidase enzyme levels in organic and conventional grapes did not differ; diphenolase activity 2 times higher from organic grapes than from conventional grapes	Nunez-Delicado and others (2005)
Lettuce, collards, pac choi	Phenolics	No difference in phenolic levels between organic and conventionally grown lettuce and collards; phenolics higher in organic pac choi	Young and others (2005)
Apples	Phenolics	Phenolics higher in organic apple pulp than in conventional; no differences between organic and conventional apples with respect to phenolics in apple peels	Veberic and others (2005)

a far higher nitrate content than organically produced or fertilised vegetables." Data obtained for foods sold in Belgium showed a mean nitrate value of 1703 mg/kg for organic products and 2637 mg/kg for conventional products (Pussemier and others 2006).

Naturally occurring toxins

While the apparent increase in polyphenolic compounds in organic foods may be considered a positive nutritional outcome due to the presumed health benefits of consuming such compounds, increases in the amounts of other plant secondary metabolites may be of health concern. Hundreds of different plant secondary metabolites have been identified and their occurrence has been comprehensively reviewed (Beier and Nigg 1994). Many of these plant secondary metabolites have not been studied for their toxicological effects, although several are considered to be of possible human health concern. For example, glycoalkloids are naturally occurring toxins produced from plants such as potatoes and tomatoes, and they provide insect resistance. High levels of exposure to these chemicals can inhibit cholinesterase enzymes in humans and other mammals. Studies have shown that glycoalkaloid levels can increase in potatoes that are damaged or exposed to light. A breeding program to develop an insect-resistant potato variety was abandoned when it was determined that glycoalkaloids were detectable at levels that could potentially cause acute toxicity in humans.

Celery plants have been noted for their ability to synthesize linear furanocoumarins at elevated levels under stressful conditions such as fungal attack and acidic fog. Linear furanocoumarins are known for their ability to cause contact dermatitis and are considered possible human carcinogens. Breeding programs to confer pest resistance to celery plants have resulted in 10- to 15-fold increases in linear furanocoumarin levels, which can cause photophytodermatitis in grocery-store workers.

Mycotoxins are another example of naturally occurring toxins that could have their levels influenced by pesticides. The development of mycotoxins in food crops could be altered through the use of fungicides as well as through the use of insecticides to prevent primary insect damage, thereby minimizing the opportunities for secondary fungal colonization of damaged plant tissue.

Aflatoxins are frequently detected in several food products, including corn and peanuts, and can be potent mutagens, carcinogens, and teratogens. Fumonisins have been implicated epidemiologically as mycotoxins that could cause human esophageal cancer and have been shown to cause cancer and liver damage in rats, pulmonary edema in pigs, and leukoencephalomalacia in horses. Tricothecene mycotoxins frequently contaminate grain products, and low to moderate consumption of these toxins, particularly deoxynivalenol, may cause immune-system problems and gastrointestinal toxicity in animals (Murphy and others 2006).

Winter (1999) published a review summarizing the influence of pesticides on the levels of naturally occurring toxins in food and concluded that very few studies had been conducted that directly related pesticide use to the levels of naturally occurring toxins, particularly in the case of plant secondary metabolites. The review cited examples showing reductions in mycotoxin levels in foods and fungal cultures treated with fungicides. In addition, studies of insecticides and nematicides demonstrated reductions in fungal populations on tomatoes, sunflower seeds, and decayed fruits.

A few studies showed increases in naturally occurring toxins after pesticide application. Levels of the mycotoxin nivalenol increased after the treatment of winter wheat with fungicides, although the incidence of *Fusarium* headblight was reduced, suggesting that the fungus may itself respond to stress by increasing its synthesis of mycotoxins (Gareis and Ceynowa 1994). The application of herbicide to a variety of plants increased the production of several plant defense chemicals in broad beans, pinto beans, peas, celery, and cotton; in these cases, sublethal doses of herbicides appeared to stimulate the synthesis of certain plant secondary metabolites (Komives and Casida 1983).

Results indicate that plant stress is likely related to the levels of naturally occurring toxins in foods and that pesticides may lessen plant stress, thus reducing the levels of naturally occurring toxins in some cases while increasing levels in other cases where plant stress is increased: for example, plants receiving sublethal doses of herbicides. In fact, a number of chemical, biological, and mechanical practices are frequently used in both organic and conventional agriculture to reduce pest pressures and plant stress, so one should not automatically assume that plants grown organically are subject to greater stresses than plants grown conventionally. In cases where naturally occurring toxin levels may differ between organic and conventional foods, the toxicological significance of such differences, if any, has yet to be determined.

Microbiological safety

The use of animal manure as fertilizer presents potential microbiological risks if the manures have not been properly composted: they can contaminate foodstuffs. While both conventional and organic agriculture frequently use animal manure for fertilization, manure use is more widespread in organic production since organic producers cannot use synthetic fertilizers. Interestingly, organic standards require that animal manures be composted according to specific procedures or applied more than 90 d before harvest; conventional food production does not have such requirements.

Mukherjee and others (2004) performed the most comprehensive study comparing microbiological safety of organic and conventional produce. In this study, 476 organic produce samples and 129 conventional produce samples were collected in Minnesota and analyzed for *Escherichia coli, Salmonella,* and *E. coli* 0157:H7. No samples contained the pathogen *E. coli* 0157:H7, and only 2 samples (1 from organic lettuces and 1 from organic green peppers) contained *Salmonella*. Generic *E. coli* was detected in 9.7% of the organic samples and in 1.6% of the conventional samples. In certified organic produce, the rate of generic *E. coli* detection was reduced to 4.3%, and this amount was not statistically different from the detection rate found from conventional produce. The corresponding generic *E. coli* detection rate for noncertified organic produce (from noncertified organic farms that report the use of organic practices) was 11.4%. Lettuce was the produce item containing the highest rates of generic *E. coli* contamination. Certified organic lettuce did not show any generic *E. coli* in the 10 samples collected while noncertified organic lettuce had 12 positive results out of 39 samples (30.8%), and 1 of 6 conventional lettuce samples (16.7%) was positive. The results from the study clearly indicate differences in the microbiological safety of noncertified and certified organic produce but do not demonstrate that certified organic produce is at a higher microbiological risk than conventional produce. A similar research study compared the microbiological safety of iceberg lettuce fertilized with inorganic fertilizer, compost, firm manure, and slurry and did not indicate any differences among the various fertilizer treatments (Johannessen and others 2004).

Organic animal producers are generally prohibited from using antibiotics, and there is an argument that this prohibition could theoretically result in increased pathogen levels and elevated microbiological safety risks. However, research findings in this area are inconsistent. In a Wisconsin study, the incidence of *Campylobacter* spp. isolates from bovine feces was 26.7% in organic farms and 29.1% in conventional farms (Sato and others 2004). Such results are not in agreement with those from a Danish study in which 100% of 22 organic broiler-flock samples were positive for *Campylobacter* spp. compared with 36.7% of 79 conventional broiler-flock samples (Heuer and others 2001).

The prohibition of antibiotic use in organic animal production also appears to be responsible for the lower incidence of antimicrobial resistance in bacterial isolates from organically raised food animals compared with conventionally raised food animals. This has been demonstrated in several studies and is concisely summarized in an IFT expert report (IFT 2006).

Conclusion

The popularity of organic foods continues to grow dramatically: organic foods now constitute more than 2% of all food sales, and sales of organic foods in the United States surpassed $13.8 billion in 2005 (Organic Trade Assn. 2006). Consumers purchasing organic foods may do so for a number of reasons, including perceived benefits to the environment, animal welfare, and worker safety, and the perception that organic foods are safer and more nutritious.

This review discusses the differences between organic foods and conventional foods with respect to food safety and nutritional composition and makes clear that several qualitative differences exist. Organic fruits and vegetables possess fewer pesticide residues and lower nitrate levels than do conventional fruits and vegetables. In some cases, organic foods may have higher levels of plant secondary metabolites; this may be beneficial with respect to suspected antioxidants such as polyphenolic compounds, but also may be of potential health concern when considering naturally occurring toxins. Some studies have suggested potential increased microbiological hazards from organic produce or animal products due to the prohibition of antimicrobial use, yet other studies have not reached the same conclusion. Bacterial isolates from food animals raised organically appear to show less resistance to antimicrobial agents than those from food animals raised conventionally (IFT 2006).

While many studies demonstrate these qualitative differences between organic and conventional foods, it is premature to conclude that either food system is superior to the other with respect to safety or nutritional composition. Pesticide residues, naturally occurring toxins, nitrates, and polyphenolic compounds exert their health risks or benefits on a dose-related basis, and data do not yet exist to ascertain whether the differences in the levels of such chemicals between organic foods and conventional foods are of biological significance.

This review illustrates that tradeoffs exist between organic and conventional food production. Organic fruits and vegetables rely upon far fewer pesticides than do conventional fruits and vegetables, which results in fewer pesticide residues, but may also stimulate the production of naturally occurring toxins if organic crops are subject to increased pest pressures from insects, weeds, or plant diseases. Because organic fruits and vegetables do not use pesticides or synthetic fertilizers, they have more biochemical energy to synthesize beneficial secondary plant metabolites such as polyphenolic antioxidants as well as naturally occurring toxins. In some cases, food animals produced organically have the potential to possess higher rates of bacterial contamination than those produced conventionally since organic production generally prohibits antibiotic use. The prohibition of antimicrobial agents also explains the apparent lower incidence of antimicrobial resistance in bacterial isolates of organic food animals, as some studies have shown a correlation between increased rates of antibiotic use and increased antimicrobial resistance.

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