FRI BRIEFINGS

Natural and Organic Foods: Safety Considerations

A Brief Review of the Literature

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INTRODUCTION

Popularity of natural and organic foods is increasing as many consumers seek what they perceive as safer and more nutritious food produced under sustainable and ethical conditions. "Natural foods" have not been defined by FDA or USDA. They are generally considered to be minimally processed foods that do not contain any synthetic additives such as synthetic preservatives or artificial colorings. Synthetic fertilizers and pesticides may be used in production of natural foods but attempts are made to minimize their use.

"Organic foods" in the U.S.A. have been defined in the Code of Federal Regulations (7CFR205) with standards set for which processes and synthetic substances are acceptable for production and handling in order for foods to be certified as organic. Thus "organic" is a production claim and not a food safety claim. According to USDA there are four labeling categories for organic foods: (*a*) "100% organic" foods contain only certified organic ingredients and use certified organic processing aids. (*b*) "Organic" foods must contain at least 95% certified organic ingredients. (*c*) Foods "made with organic" (specified ingredients) must contain at least 70% organic ingredients. (*d*) Foods with less than 70% organic ingredients may not display the USDA "organic" seal on the package but may identify which ingredients are organic on the ingredient panel (*67*). Other countries and organizations may have somewhat different standards for defining foods as organic (*87*).

Consumers cite a number of reasons for interest in organic foods. Primarily, these are health-related concerns: (*a*) lack of or low levels of nitrates, veterinary drugs, hormones, and pesticide residues and (*b*) higher nutrient content, particularly vitamins and phenolic compounds. In addition, supporters of organic agriculture believe that these farmers use more environmentally responsible crop management methods that minimize pollution of ground and surface waters and avoid pesticide effects on non-target organisms. By eliminating use of synthetic pesticides and fertilizers, use of petroleum is also reduced. Animal husbandry methods that reject routine use of subtherapeutic antibiotics may prevent an increase of antibiotic-resistant bacteria (*74*). In general, treatment of animals on organic farms is considered more ethical than that on large intensive, factory farms.

Over 31 million hectares of farmland worldwide are managed organically according to a 2005–2006 survey and, in addition, another 19.7 million hectares of land produce certified organic forest products and wild-harvested plants. Australia has the largest amount of land, about 12 million hectares, under organic management but this represents a very small percentage of its total agricultural land and much of this land is used for organic, low intensity grazing. In the European Union, organic farming is supported with legislation and direct payments and the 5.8 million hectares under organic management represent 3.4% of the agricultural area. Although only 1.4 million hectares in North America (0.3% of total agricultural area) are managed organically, the market for organic products has experienced the most rapid recent growth in this region accounting for $14.5 billion dollars in 2005 (*94*).

This review is limited to food safety considerations related to natural and organic foods. Producers and processors of all types of foods are required to use good manufacturing procedures to produce safe foods. Producers of natural and organic foods may face special challenges because some drugs, pesticides and processing aids are not permitted under the definition of "organic." Economic issues, environmental effects, and ethical concerns related to animal husbandry will not be discussed here. Available data from the scientific literature will be summarized in an attempt to answer three questions:

- Are organic foods safer and more nutritious because pesticides, routine veterinary drugs, and other synthetic additives are not used and therefore residue levels are lower?
- Are organic foods less safe because pesticides, antibiotics, etc. are not used and therefore more pathogens and natural toxins are present?
- What natural antimicrobials and preservatives are available for use in processing organic foods?

SAFETY OF ORGANIC FOODS

Relative safety of natural and organic foods as compared to conventionally raised and processed foods remains controversial because there have been few well devised studies to compare these foods (*44, 68*). Contents of some nutrients and toxins, such as the mold toxin, aflatoxin, normally vary significantly even within a single plant variety depending on climatic conditions and soil type. Unless these factors are controlled, observed differences may not be the result of organic or conventional production methods. In addition, there are genetic differences among varieties. Comparative research studies include:

- **retail market studies** that analyze foods as they reach consumers. These studies can identify chemical differences, such as concentrations of residues and vitamins, but cannot definitively prove that the production method, and not other factors such as plant variety, weather conditions, and soil type, caused the observed differences between organic and conventional produce. In addition, it may be difficult to verify that on-farm and processing plant methods were organic. Accurate information on imported foods and food ingredients may be more difficult to obtain.
- **farm studies** that control for climatic conditions by studying nearby farms using conventional and organic production methods.
- **research center studies** that carefully control growing conditions and may be able to clearly identify factors responsible for differences in nutrients. These results, however, cannot necessarily be generalized to commercial production systems.

Residues of Pesticides and Drugs

A wide range of synthetic chemicals are used in conventional agriculture and some of these persist as residues in foods. Small amounts of pesticide residues are unavoidable on organic crops because farmers cannot control all environmental sources. Wind or water may spread pesticides and some pesticides may persist for several years in soil and be taken up by plants even after the land has been switched to organic production. Residue levels in crops are monitored by government agencies; most samples test below regulatory limits. Nevertheless, there is some concern that long term exposure to very small amounts of pesticides may have detrimental effects. Nearly all samples of organic foods have significantly lower levels of these chemicals than their conventional counterparts (*33, 50*).

Analyses of data from the USDA Pesticide Data Program (http://www.ams.usda.gov/science/pdp/), the California Marketplace Surveillance Program, and private tests by Consumers Union indicated that organic foods consistently had about one third as many pesticide residues as conventionally grown produce and were far less likely to contain multiple pesticide residues. Concentrations of specific residues on particular crops were also consistently lower in organic foods. A few positive organic samples contained significant concentrations of pesticides which may have resulted from mislabeling or fraud (*8*).

A survey of N-methyl carbamate residues in infant foods in Canada detected very low levels of carbaryl and methomyl (maximum level of 18 ng/g) in some samples of conventionally produced meats, fruits, and deserts but no detectable residues in organically produced foods (*73*).

Lower levels of organophosphorus residues in organic foods decrease dietary exposure of children to these pesticides as shown by urinary biomonitoring of metabolites of malathion and chlorpyrifos during consumption of conventional and organic produce. These metabolites were not detectable after children were switched to a diet containing only organic vegetables (*49*).

Toxic and Antinutritional Compounds

Potato tubers contain glycoalkaloids to repel insects and these compounds can also be toxic to humans, if they are present in high enough concentrations (recommended maximum level is 200 mg/kg fresh weight). A farm study in Portugal compared glyco-alkaloid levels in organic and conventional potatoes. No difference was observed for one potato variety but in the other variety glycoalkaloid levels were greater in conventionally grown (79.5 mg/kg) than in organically grown (44.6 mg/kg) potatoes (*2*). In another study, glycoalkaloid levels were reported to be higher in some varieties when grown organically. However, there were also significant year-to-year variations in these compounds (*36*).

High intakes of nitrate from drinking water have been shown to cause methemoglobinemia in infants and it has been suggested that high nitrate intakes can form carcinogenic nitrosamines in the stomach. However, dietary nitrate may also exert a protective effect by releasing nitric oxide. Therefore, it is not certain whether high nitrate concentrations in vegetables should be considered detrimental to adults. A number of studies have demonstrated lower nitrate levels in organically grown leafy vegetables (*34, 50*).

Mycotoxins, produced by fungi on plants during growth in the field or on grains during storage, are known to have toxic and carcinogenic effects. It has been suggested that plants grown without pesticides will be subject to more fungal infections and therefore have higher mycotoxin levels. However, the numerous studies that surveyed mycotoxin levels in organic and conventional grains and grain products have yielded inconsistent results. Significant year to year variations in mycotoxin levels occur even when the same strains are grown on the same land with the same agricultural practices because of variations in temperature and rainfall. Recent results for different mycotoxins have shown:

- **Deoxynivalenol (DON):** no significant differences between organic and conventional cereal products (*41*) or higher levels in conventional wheat and cereal products (*15, 69, 80*) and in organic beer in one year but not the next (*5*)
- **Zearalenone (ZEN):** higher levels in conventional wheat (*69, 80*)
- **Ochratoxin A (OTA):** higher levels in organic wheat (*69*) and in organic beer in one year but not the next (*5*) and no differences across several organic and conventional cereal products (*10*)
- **Fumonisins (FUM):** no differences between organic and conventional corn flakes (*62*) and higher levels of FUM B2 and lower levels of FUM B1 in organic cereal products (*15*)
- **Patulin:** more frequent and higher concentrations in organic fruit juices and purees (*66*)
- **Aflatoxin M1:** higher levels in some, but not all, samples of organic milk in Italy (*33*)

Pathogenic Bacteria and Antibiotic Resistance

Since antibiotics are not routinely fed to organically raised animals, it has been suggested that these animals may harbor higher levels of pathogenic bacteria. On the other hand, bacteria present in these animals may be more susceptible to antibiotics because they have not developed resistance. Other factors, such as density of animals, confinement vs. free-range management, and hygiene practices, may also affect persistence and spread of bacteria in a flock or herd.

Recent research provides some data that support these theories but results are not always clear-cut. *Salmonella typhimurium* was isolated from 61% of organically raised chickens and 44% of conventionally raised birds. Antibiotic resistance was higher in bacteria from conventionally raised chickens (*18*). Another study found no difference in *Salmonella* levels in chickens according to how they were raised but *Campylobacter* levels were higher on organic birds (*91*). Eggs from organically raised hens had higher counts of total aerobic bacteria but lower counts of Gram negative bacteria (*20*). *Yersinia enterocolitica* was detected in 18% of organically raised swine and in 29% of conventionally reared swine (*59*). Some studies with dairy cattle have reported more antibiotic resistant bacteria from conventionally raised animals (*37, 74, 79*) while others reported similar incidences of resistance in bacteria from animals in both breeding systems (*76, 78*).

Manure used to fertilize organic produce may contain pathogenic bacteria and it has been suggested that organically grown vegetables will potentially have greater numbers of foodborne pathogens because synthetic fertilizers are not used. However, a study of spring mix (mesclun) from California demonstrated that mean populations of bacteria and molds were similar on organic and conventional greens. Of 13 samples found to contain *E. coli*, nine were from conventional fields (*65*). Another study reported similar levels of coliform bacteria on conventional and organic fruits and vegetables. Prevalence of *E. coli* on certified organic produce was not statistically different from that on conventional produce. Use of manure or compost that was aged <12 months was associated with much higher levels of *E. coli* on produce than that seen on farms using older materials (*54, 55*).

Nutrient Concentrations

Some organically cultivated produce appears to have higher amounts of some nutrients and protective compounds, such as vitamin C, lycopene, and phenolic compounds. However, concentrations of these protective compounds also vary with variety and climate and soil conditions. Data on significance of elevated levels of these nutrients to human health is limited (*13, 33, 50, 60, 95*).

Phenolic compounds may act as antioxidants and exert other protective effects in the body. Concentrations of total phenolics and of particular phenolic compounds vary with climate and plant variety but have also been reported to be higher in organically grown berries (*6*), some varieties of tomatoes (*13, 14*), apples (*38*), yellow plums (*46*), and pac choi (*93*). No differences in phenolic compounds were observed for organically grown bell peppers (*14*) or oats (*25*) as compared to their conventionally grown counterparts.

Vitamin C (ascorbic acid) levels have been reported to be higher in organically grown potatoes (*36*), some tomatoes (*13, 14*), yellow plums (*46*), and strawberries (*60*).

A three-year study of commercially grown conventional versus organic grapefruit is being conducted by USDA in Texas. Numerous factors that might affect fruit quality were controlled: soils, irrigation source, variety, size of fruit, position on tree, time of harvest, and handling and treatment after harvest. Preliminary findings do not demonstrate great differences between the organic and conventional fruit but conventional fruit had higher levels of lycopene and bergamottin (which decreases metabolism of certain drugs including statins) and lower levels of naringenin, an antioxidant. No differences were observed in vitamin C levels (*44*). In another study, higher total antioxidant activity, including total phenolics and ascorbic acid, was reported for red oranges that were cultivated organically (*84*).

Milk from organic dairy farms in England was found to have higher levels of n-3 fatty acids and a consistently higher, beneficial ratio of n-3 to n-6 fatty acids as compared to conventionally produced milk. As with studies on organic produce, cattle breed and factors other than farming system also affected fatty acid content of the milk. Conjugated linoleic acid concentrations did not differ between organic and conventional milk (*28*).

NATURAL ANTIMICROBIALS, PRESERVATIVES, AND PROCESSING

Animal Products

Lactoferrin, derived from bovine milk, is a glycoprotein that binds iron thereby restricting or preventing bacterial growth. It can be sprayed on beef and other meats to inhibit growth of foodborne pathogens (*58, 85*) and may also be useful in controlling growth of spoilage bacteria (*3*).

Lysozyme, isolated from eggs, has well known antimicrobial effects against Gram-positive bacteria. Some peptides produced by limited protease digestion of lysozyme also have antibacterial effects and are also effective against some Gram-negative organisms. Commercially available lysozyme peptides (LzP) were reported to effectively inhibit both spores and vegetative cells of some food spoilage strains of *Bacillus* (*1*).

Lactoperoxidase system (LPS) is an antimicrobial system, naturally present in milk, that has been used to preserve quality of raw milk when adequate refrigeration is not available. The lactoperoxidase enzyme, present in relatively high amounts in milk, can oxidize thiocyanate ions in the presence of hydrogen peroxide. The products of this reaction bind to sulfhydryl groups of bacterial enzymes, inhibiting their activity. Use of LPS in dairy products and potential applications in other food systems were recently reviewed (*81*). LPS has been shown to strongly inhibit growth of pathogenic bacteria on beef cubes at 12ºC and reduced viable counts of bacteria at refrigeration temperatures (*27*). LPS in combination with monolaurin inhibited *E. coli* O157:H7 and *Staphylococcus aureus* in broth, meat, and milk (*51*).

Microbial Products

Bacteriocins are compounds produced by some species of bacteria to inhibit the growth of other, competing bacteria, usually by attacking their cell membranes. Attempts have been made to use these compounds for controlling foodborne pathogens with some success. **Nisin** has been tested for use in a variety of foods with positive results particularly in cheese products and also in canned foods. Nisin is generally most effective against Gram-positive spoilage organisms. Other bacteriocins are under investigation for use in certain foods. Use of some of these compounds is limited by their sensitivity to heat and/or acidity.

Reuterin (*45*) and other compounds produced by bacteria such as Microguard® are more effective against Gram-negative bacteria, yeasts, and molds.

Natamycin is an antifungal compound produced by *Streptomyces* spp. bacteria that has been commercialized as a preservative for cheese and sausages. Natamycin does not inhibit bacterial activity and therefore will not affect fermentation bacteria (*24*).

Organic acids, such as acetic, citric, sorbic, and lactic, are produced by microbes and have been used as preservatives in a variety of foods. These may be introduced by addition of bacterial cultures in sausage and yogurt fermentations, or may be added as chemical compounds for example, for the preservation of bread (*63*), juices (*17*) and meats (*26, 32, 82*).

Chitosan is a polysaccharide derived from the exoskeleton of crabs and shrimp that inhibits growth of some bacteria and molds. Proposed applications in food safety include: inhibition of spoilage bacteria on cheese (*4*), in fermented cabbage (*40*), in cooked rice (*86*), and inhibition of *Clostridium perfringens* spore germination and outgrowth in ground beef and turkey (*42*).

Plant Products

Compounds present in cranberry are known to exert antimicrobial effects. Many other berries also inhibit pathogenic bacteria and may be useful in food preservation (*70–72*). Extracts of garlic and onions have demonstrated marked antibacterial and antifungal activity against a broad spectrum of organisms (*9, 19*).

Essential oils of some herbs and spices have antibacterial effects on foodborne pathogens with Gram-positive bacteria generally more susceptible. Concentrations of 0.1–10 mμl/ml are generally required to inhibit bacteria in laboratory media and when used to rinse fresh produce while 0.5–20 mμl/ml are required to achieve the same effect in foods. Some of the active ingredients that have been identified include: cinnamaldehyde, cinnamic acid, eugenol, perillaldehyde, thymol, and carvacrol and its precursor p-cymene. As natural extracts, these essential oils may have applications in organic products if they are selected appropriately for different types of food to avoid undesirable flavors (*11*).

Potency and effectiveness of plant essential oils as antibacterial and antifungal agents have recently been reviewed. Most of the active compounds in these oils appear to interact with and disrupt cell membranes. Examples of a number of herbs and spices and their potential uses in foods were described (*39*). Recent reports describing the antimicrobial effects of some essential oils or their principal constituents include:

- twenty-eight oils tested against *E. coli* O157:H7, *S. typhimurium*, *S. aureus*, and *L. monocytogenes* (*61*)
- three oils tested against *E. coli, Listeria innocua*, and *S. enteritidis* in fruit juices (*75*)
- ten essential oils tested against *E. coli* O157:H7 (*52*)
- capsicum extract tested against *S. typhimurium* and *P. aeruginosa* in raw beef (*12*)
- eight spices tested against *E. coli* (*16*)
- three herbs tested against *E. coli* O157:H7 in meat (*35*)
- eleven herbs tested against *B. cereus* in carrot juice (*88, 89*)
- rosemary and eucalyptus tested against *E. coli* (*53*)
- vanillin tested against *Listeria* in media (*21*) and in juices (*17*)
- vanillin tested against food spoilage yeasts and molds (*29–31*) and spoilage organisms on apples (*77*)
- mustard and its active ingredient, allyl isothiocyanate, tested against *E. coli* O157:H7 in ground beef (*56, 57*) and against fungal contaminants in cheese (*92*)
- carvacrol and cymene tested against *E. coli* O157:H7 in apple juice (*43*)
- thymol and carvacrol tested against *Bacillus megaterium* (*64*)
- thymol and cymene on *B. cereus* in media and foods (*22, 23*)
- five herbs tested against *Aspergillus flavus* (*47, 48*)
- inhibition of aflatoxin production on sorghum by sweet basil (*7*)
- nine herbs tested against spoilage fungi in bread (*83*)
- eugenol, menthol and thymol tested against spoilage fungi on grapes (*90*)

Natural antimicrobial compounds are potentially very useful in preserving foods and inhibiting foodborne pathogens. Some of these compounds may show promise when tested in the laboratory but are not nearly as effective in foods. Others may alter the flavors or textures of foods in some undesirable fashion. Therefore, it will be important to test these compounds or extracts in real foods under expected conditions of use and of potential abuse.

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