Chapter 11
Organic Food Production and Its Influence on Naturally Occurring Toxins

Carl K. Winter

Abstract The levels of natural plant toxins and mycotoxins in foods may be influenced by the methods used (organic vs. conventional) for agricultural production. Research findings suggest that organic foods may possess higher levels of natural plant toxins than conventional foods based upon mechanistic similarities between natural plant toxin production and the production of plant secondary metabolites of nutritional interest. Specific field research confirming such differences has not yet been conducted. Mycotoxin levels in organic foods may also be higher as a few studies have demonstrated that synthetic fungicides and insecticides used in conventional production can reduce plant pathogen populations. Food product analysis, however, has not demonstrated consistent findings of higher levels of mycotoxins in organic foods as compared with conventional foods. In the event that subsequent research does conclusively demonstrate that differences exist in the levels of naturally occurring toxins in organic versus conventional foods, the toxicological significance of the differences, if any, still requires determination.

Keywords Natural toxins · Mycotoxins · Plant secondary metabolites · Plant stress · Pesticides

11.1 Introduction

The organic foods industry in the U.S. has grown dramatically in the past 20 years with annual sales reaching $13.8 billion in 2005 and growth averaging about 20 percent pear year (Organic Trade Association 2006). The adoption of U.S. national standards for organic food production in 2002 has likely led to increases in consumer confidence in organic products. Several surveys indicate that consumers purchase organic foods for a variety of reasons including the minimization of pesticide residues, perceived increases in nutritional value, and the avoidance of genetically

C.K. Winter (✉)
Department of Food Science and Technology, University of California Davis, CA 95616, USA
e-mail: ckwinter@ucdavis.edu

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modified foods (Whole Foods Market, 2005). Worker safety and environmental concerns are also frequently cited. Another study indicated that over 90 percent of organic and conventional food consumers perceived a reduction in pesticide residue risk in organic foods while 50 percent perceived that organic foods had lower microbiological safety risks and 50 percent perceived that the risks from naturally occurring toxins in foods would be lower in organic foods (Williams and Hammitt, 2001).

The presence of naturally occurring toxins in food has been well established and many food toxins of plant and fungal origin have been identified (Ames et al., 1990; Beier and Nigg, 1994; Coulombe, 2000; Park et al., 2000). Comparative risk assessment studies focusing upon carcinogenic effects have indicated that the relative health risks posed by naturally occurring food toxins may exceed those from synthetic chemicals found in food (Ames et al., 1987, 1990; Ames and Gold, 1991). A National Academy of Sciences panel concluded that "natural components of the diet may prove to be of greater concern than synthetic components with respect to cancer risk, although additional evidence is required before this conclusion can be drawn with certainty" (NRC, 1996).

While considerable research has been conducted investigating the potential nutritional differences between specific organic and conventional foods (Winter and Davis, 2006), very little direct investigation has compared organic and conventional foods with respect to naturally occurring toxins. This chapter considers the potential differences in naturally occurring toxin levels in organic and conventional foods and discusses the potential influences of such differences on human health.

11.2 Naturally Occurring Toxins

11.2.1 Plant Toxins

Plants have been known to produce hundreds of different chemicals, known as plant secondary metabolites, that do not appear to be necessary for basic plant health (Beier and Nigg, 1994). While the roles of many of these secondary metabolites remain unknown and most have not been appropriately studied for their potential toxicological effects, several are considered to be of possible human health concern. Celery plants, for example, frequently produce elevated levels of linear furanocoumarins when grown under conditions of stress (Beier and Oertli, 1983; Dercks et al., 1990); these secondary metabolites are considered possible human carcinogens and are also associated with the ability to cause contact dermatitis in workers handling celery plants (Seligman et al., 1987). Plants such as potatoes and tomatoes are capable of synthesizing glycoalkaloids that serve as effective natural insecticides and inhibit the same types of enzymes in insects and in humans as do the synthetic organophosphate and carbamate insecticides (Friedman and McDonald, 1997).

The practices used to classify plant secondary metabolites as naturally occurring toxins are arbitrary and inconsistent. Ames et al. (1990) referred to all plant secondary metabolites as “nature’s pesticides” while others (Winter, 1990; Coulombe, 2000) have more narrowly defined natural plant toxins as chemicals produced by plants for which studies have been conducted to demonstrate toxicological effects. Complicating the classification process further, it is clear that some of the naturally occurring toxins may also have potential health benefits for humans. Glycoalkaloids found in potatoes, for example, are of potential toxicological concern due to their ability to inhibit human cholinesterase enzymes and cause effects upon the nervous system (Friedman and McDonald, 1997); they have also been shown to possess antiallergic, antipyretic, and anti-inflammatory effects in humans, glycemic effects in rats, and antibiotic activities against pathogenic bacteria, viruses, protozoa, and fungi (Friedman, 2006).

Most studies comparing organic and conventional foods with respect to levels of plant secondary metabolites have focused upon secondary metabolites considered to be nutritionally beneficial rather than potentially hazardous. One review suggested that organic foods may possess elevated levels of vitamin C compared with conventional foods (Worthington, 2001) although other reviews (Woese et al., 1997; Bourn and Prescott, 2002) concluded that study designs and results were too variable to provide definitive conclusions concerning the influence of agricultural production methods (i.e. organic vs. conventional, synthetic vs. non-synthetic fertiliser use) upon nutrient and vitamin levels in the plants. It has been concluded that nitrate levels in organic foods are lower than nitrate levels in conventional foods, presumably because the use of synthetic fertilisers in conventional production provides more nitrogen capable of conversion into nitrates than is provided in organic fertilization practices (Woese et al., 1997; Worthington, 2001). The health significance of these differences in nitrate levels is debatable. While nitrates have been implicated as precursors to carcinogenic nitrosamines and can form methemoglobin following ingestion by humans, other research indicates that nitrates are converted to nitrites that provide protection in the oral cavity against infectious diseases (Duncan et al., 1997).

In the past decade, there has been a large increase in the number of controlled field studies that compare organic and conventional foods with respect to plant secondary metabolite nutrients such as organic acids, flavonols, carotenoids, vitamin C, and plant phenolics (Winter and Davis, 2006). Many of these plant secondary metabolites are considered to play a role as possible antioxidants in humans.

While some of these comparative studies failed to show differences between conventional and organic production methods with respect to plant secondary metabolites of nutritional interest (Hakkinen and Torronen, 2000; Mikkonen et al., 2001; Young et al., 2005), other studies have demonstrated elevated levels of the same plant secondary metabolites in organic products relative to conventional products. These include studies done by Asami et al. (2003) that demonstrated higher levels of phenolics and ascorbic acid in organic marionberries, corn, and strawberries. Peaches and pears grown organically had higher levels of total phenolics and polypholoxidase enzyme activity than their conventional counterparts (Carbonaro and Mattera, 2001). Veberic et al. (2005) demonstrated higher phenolic levels in organic apple pulp than conventional apple pulp, while another study showed that organic tomatoes had higher levels of vitamin C, carotenoids, and polyphenols than conventional tomatoes (Caris-Veyrat et al., 2004). Recently, a ten-year comparison of organic and conventional production systems in tomatoes showed that organic production systems resulted in the production of 79 percent higher levels of the flavonoid quercetin and 97 percent higher levels of the flavonoid kaempferol than those found in conventional systems (Mitchell et al., 2007).

Two plausible primary scientific explanations have been advanced to explain the relative increase in production of plant secondary metabolites of nutritional interest in organic foods compared with conventional foods (Winter and Davis, 2006). The first considers the impacts of different types of fertilisation practices upon plant secondary metabolite production. The synthetic fertilisers available to conventional producers make nitrogen more available to the plants than organic fertilisers; this may accelerate plant growth and allocate plant resources for growth functions at the expense of other functions such as the production of plant secondary metabolites including organic acids, flavonols, carotenoids, vitamin C, and plant phenolics.

The second hypothesis considers the mechanisms by which plants may respond to stressful environments that exist when plants are attacked by insects, weeds, and plant pathogens. Synthetic pesticides provide one tool for conventional food producers to use as a means to reduce pest pressures and stress on their plants. Reducing plant stresses through the use of synthetic pesticides is not an option for organic food producers and raises the possibility that such stresses, if not controlled using other methods, could result in increases in plant secondary metabolites. The increase in plant polyphenolics in organic foods in the study by Asami et al. (2003), for example, was attributed to plant defense characteristics.

It is logical to conclude that the same mechanisms that increase the production of plant secondary metabolites of nutritional interest under organic production practices (slower and more complex biochemical growth, plant defense) might also be expected to cause increases in the production of natural plant toxins. Unfortunately, no studies have yet been reported that simultaneously examined differences in secondary metabolite levels for both plant nutrients and for plant toxins when comparing organic and conventional production methods. Studies demonstrating a decrease in natural plant toxin production resulting from the use of synthetic pesticides have also not been published although one study documented increases in the production of plant secondary metabolites in broad beans, pinto beans, peas, celery, and cotton resulting from sublethal plant exposure to the herbicide aciflourfen (Komives and Casida, 1983).

11.2.2 Mycotoxins

Mycotoxins represent an additional class of naturally occurring toxins that present potential health risks. Mycotoxins are produced when fungi colonize food crops and synthesize their own toxins. Common classes of mycotoxins include aflatoxins, fumonisins, and tricothecenes (Murphy et al., 2006). Aflatoxins are frequently detected in many food products including peanuts, corn, and grains, and have been shown to be potent mutagens, carcinogens, and teratogens. Fumonisins have been linked with the development of human esophageal cancer and cause a number of other effects in animals such as liver damage in rats, pulmonary edema in pigs and leukoencephalomalacia in horses (Sydenham et al., 1990; Murphy et al., 2006). Tricothecenes are commonly found in grain products and low to moderate consumption of tricothecenes such as deoxynivalenol (DON) in laboratory animals may lead to immunological and gastrointestinal effects (Murphy et al., 2006).

Since conventional agricultural production methods allow for the use of synthetic pesticides such as fungicides to control plant pathogen growth or insecticides to prevent insect damage that might allow subsequent colonization of plants by plant pathogens, it seems reasonable to assume that mycotoxin levels might be higher in organic foods than in conventional foods. Some studies have, in fact, demonstrated that synthetic pesticide use can decrease mycotoxins levels. Aflatoxin B_1 levels from cultures of *Aspergillus flavus* were reduced in the presence of the fungicides chlorothalonil, dichloran, and mancozeb (Chourasia, 1992). The fungicides iprodione, propionic acid, and cuprosan have also been associated with reductions in mycotoxin production (Arino and Bullerman, 1993; Calori-Domingues and Fonseca, 1995). Application of the insecticides/nematicides fenamiphos, carbofuran, and aldicarb reduced the occurrence of *Fusarium* species in the roots and fruits of tomato plants while also inhibiting or reducing production of the mycotoxin zearalenone (El-Morshedy and Aziz, 1995).

Direct comparisons of food products produced organically with those produced conventionally have yielded mixed results with respect to the relative levels of mycotoxins detected. In one study, DON was found in more than 80 percent of both organic and conventional foods purchased from Italian supermarkets while fumonisin B_1 was detected in 20 percent of organic foods and in 31 percent of the conventional foods and fumonisin B_2 was found in more than 32 percent of both the organic and conventional foods. With respect to median concentration levels, DON was highest in conventional rice-based foods while fumonisin B_1 was highest in conventional maize-based foods and fumonisin B_2 was highest in organic wheat-based foods (Cirillo et al., 2003). Finamore et al. (2004) showed that organic wheat contained higher levels of the mycotoxins DON and ochratoxin A than did conventional wheat although bioassays demonstrated that rats fed the conventional wheat were at a higher risk of lymphocyte damage than rats fed the organic wheat. Median DON levels from wheat flour produced in southwest Germany were consistently higher from conventionally-produced wheat than from organically-produced wheat (Schollenberger et al., 2002) while organic winter wheat produced in Germany showed lower DON contamination and lower rates of *Fusarium* ear blight infection (Birzele et al., 2002). In contrast, an exposure simulation of French consumers indicated significantly greater exposure to DON from consumers of organic foods as compared to conventional food consumers (Leblanc et al., 2002).

A comparison of ochratoxin A levels in Polish cereals produced from conventional or organic farms showed considerably greater contamination of rye, wheat, and barley produced from organic farms (Czerwiecki et al., 2002), while Jorgensen and Jacobsen (2002) showed that organic rye and wheat samples contained higher levels of ochratoxin A than did conventional samples. Another study in red table wines showed reduced levels of ochratoxin A in organic wines relative to conventional wines (Miceli et al., 2003).

11.3 Summary and Conclusions

From a theoretical standpoint, it is logical to assume that levels of naturally occurring plant toxins and mycotoxins might be higher in organic foods than in conventional foods. Significant scientific evidence has been developed to demonstrate that plant secondary metabolites of nutritional interest are frequently produced in higher concentrations from food grown organically than from food grown conventionally. These differences between organic and conventional plant secondary metabolite levels are explained by two different but not mutually exclusive theories. Plants grown conventionally may be stimulated to grow through the use of synthetic fertilisers that make nitrogen more readily available and allocate more plant resources towards plant growth than to biosynthesis of more complex plant secondary metabolites. In addition, the use of synthetic pesticides in conventional food production may serve to alleviate plant stress due to the presence of pests such as insects, weeds, or plant diseases. Organic food production practices do not allow synthetic pesticides to be used to reduce plant stress, and, unless other production approaches are available to control pests, plants grown under organic conditions may increase their synthesis of plant secondary metabolites as a means of chemical defense. While studies have not specifically looked at the influence of production methods (organic vs. conventional) upon natural plant toxins, it is reasonable to assume that the same factors that increase the production of plant secondary metabolites of nutritional interest under organic production methods would lead to similar increases in the production of natural plant toxins.

It can also be argued that the use of synthetic pesticides such as insecticides and fungicides in conventional food production can reduce the potential for plant pathogen growth and subsequent production of mycotoxins, and some studies have demonstrated this effect. In other studies comparing mycotoxins levels found in organic and in conventional foods, however, the levels of mycotoxins were found to be lower in organic foods, and it has also been suggested that organic practices such as longer crop rotation, and substitution of animal or green manures for synthetic fertilisers my reduce the risk of plant infection by pathogens (Van Bruggen, 1995).

Scientifically, it is very challenging to be able to perform appropriate field tests to determine if there are differences in the chemical composition of organic foods and conventional foods. Natural variations in plant secondary metabolite levels exist, and adequate studies need to ensure that the organic and conventional foods are produced using similar conditions with respect to cultivar (variety), soil type and quality, and climate. Sample collection, handling, and analytical procedures need to be standardized for the two different production methods as well.

It is premature to state that either organic or conventional food production practices are safer with respect to naturally occurring toxins. Theoretical arguments suggest that naturally occurring toxins in organic foods may be higher, but these arguments have not been conclusively demonstrated to date from comparative studies in the field. Even in the event that one production method was associated with higher levels of naturally occurring toxins in foods than the other, any health impacts stemming from these differences would be based upon the differential doses of the toxins consumed. In general, the toxicological significance of the possible doses of naturally occurring toxins that humans may be exposed to from either conventional or organic foods has not yet been established.

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