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Organic Food: Buying More Safety or Just Peace of Mind? A Critical Review of the Literature

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Consumer concern over the quality and safety of conventional food has intensified in recent years, and primarily drives the increasing demand for organically grown food, which is perceived as healthier and safer. Relevant scientific evidence, however, is scarce, while anecdotal reports abound. Although there is an urgent need for information related to health benefits and/or hazards of food products of both origins, generalized conclusions remain tentative in the absence of adequate comparative data. Organic fruits and vegetables can be expected to contain fewer agrochemical residues than conventionally grown alternatives; yet, the significance of this difference is questionable, inasmuch as actual levels of contamination in both types of food are generally well below acceptable limits. Also, some leafy, root, and tuber organic vegetables appear to have lower nitrate content compared with conventional ones, but whether or not dietary nitrate indeed constitutes a threat to human health is a matter of debate. On the other hand, no differences can be identified for environmental contaminants (e.g. cadmium and other heavy metals), which are likely to be present in food from both origins. With respect to other food hazards, such as endogenous plant toxins, biological pesticides and pathogenic microorganisms, available evidence is extremely limited preventing generalized statements. Also, results for mycotoxin contamination in cereal crops are variable and inconclusive; hence, no clear picture emerges. It is difficult, therefore, to weigh the risks, but what should be made clear is that 'organic' does not automatically equal 'safe.' Additional studies in this area of research are warranted. At our present state of knowledge, other factors rather than safety aspects seem to speak in favor of organic food.

Keywords organic food, organic farming, food safety, food risks, food hazards

INTRODUCTION

Nowadays, food safety is receiving more attention than ever before by governments and policy makers, health professionals, the food industry, the biomedical community, and last but not least, the public (Crutchfield and Roberts, 2000; Crutchfield and Weimer, 2000; Kaferstein and Abdussalam, 1999; Woteki et al., 2001). For most consumers in the United States (Food Marketing Institute, 2000) and Europe (Food Marketing Institute, 1995), safety has become one of the most important attributes of food. Their concern over food quality has intensified in recent years, and prompted heated debate about the integrity and safety of the produce. Consumer concern, fuelled by several food scares, has influenced food purchasing patterns, as well as several aspects of the political arena, international trade, and the farming industry (Buzby, 2001). One such aspect has been the expansion of demand for organically grown food. Although only a small market sector until recently, organic farming became one of the fastest growing segments of US (Greene, 2000) and European (Food and Agriculture Organization (FAO), 1999) agriculture during the 1990s, and is rapidly 'gaining ground' in many other parts of the world as well (Willer and Yussefi, 2004).

Many surveys of consumer attitudes and characteristics have been conducted to identify the reasons for this increased trend (Thompson, 1998). The preference for organic food has been associated with multiple factors that, in general, reflect an increased interest towards personal health, animal welfare, and environmental protection (Makatouni, 2002; Magnusson et al., 2001; Schifferstein and Oude Ophuis, 1998; Wilkins and Hillers, 1994; Tregear et al., 1994; Torjusen et al., 2001; Harris et al., 2000; Davies et al., 1995; Magnusson et al., 2003; Saba and Messina, 2003). Health-related issues seem to assume greater importance than other concerns, and notions about food safety

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are fundamental for purchasing organics (Magnusson et al., 2003; The United Kingdom Parliament, 1999; Lohr, 2001; Harper and Makatouni, 2002; Beharrell and MacFie, 1991). Consumers are questioning the ability of the modern food system to provide safe food (Anderson, 2000), and perceive relatively high risks associated with the consumption of conventionally grown produce compared with other public health hazards (Williams et al., 2000; Williams and Hammitt, 2001). Highly publicized food safety issues such as the use of genetically modified organisms and irradiation in food production, as well as the outbreaks of Bovine Spongiform Encephalopathy (BSE) and *Escherichia coli* (*E. coli*) O157 infections, contribute to increased awareness and stimulate the interest for 'safer' alternatives, and most notably organically grown food (Hansen et al., 2002; Birchard, 2001; Cummins, 2001; Mitchell and Normile, 1999; Schmidt, 1999; Kirk et al., 2002).

There is a widespread belief that organic food is substantially healthier and safer than conventional food, and consumers are willing to pay significant price premiums to obtain it (Beharrell and MacFie, 1991; Collins et al., 1992; Hammitt, 1990, 1993; Hutchins and Greenhalag, 1997; Gil et al., 2000; Piyasiri and Ariyawardana, 2002; Zehnder et al., 2003). This perception is mainly due to the principles associated with organic food production. Organic farming is a production system that avoids or largely excludes the use of synthetic fertilizers, pesticides, growth regulators, and livestock feed additives (The United Kingdom Parliament, 1999; Soil Association, 1997; Codex Alimentarius Commission, 2001). To the maximum extent feasible, organic farming systems rely on crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, and aspects of biological pest control to maintain soil productivity, supply plant nutrients, and control insects, weeds and other pests (The United Kingdom Parliament, 1999; Soil Association, 1997; Codex Alimentarius Commission, 2001). The specific regulations governing organic production, however, vary across countries as well as between certifiers (Nelson et al., 2004). The non-use of synthetic chemicals and a number of other environmentally sound techniques practiced by organic farmers remain part of the allure of the organic movement, and underlie consumer belief that organic food is virtually free of the hazards found in conventional produce (Marcus, 2001). It is the consumer perception of the quality and safety that primarily drives the continuously growing demand for organic food products (Shukla, 2001). In fact, in some cases (e.g. organic baby food), the organic label is by far the most important characteristic that consumers value in food, its nutrient content being far less appreciated (Harris, 1997).

However, scientific evidence in support of this perception, i.e. the belief that the environmentally friendly techniques of organic agriculture are synonymous to the production of safe food, is scarce, while anecdotal reports and personal testimonies abound, inasmuch as the information available rarely finds its way into public discussions. Historically, this has led to several unsubstantiated claims about the properties of organic produce. For example, probably the greatest assertion of the organic movement concerns the ability of organic food to cure cancer (Bishop, 1988). In one of his studies, Dr. D. Collins reported that five patients, who had metastasized cancers during their lifetimes, and who subsequently begun eating organically grown food, showed no evidence of previous malignancy at autopsy after their deaths, many years later and from unrelated causes (Finesilver et al., 1989). In another case, J. I. Rodale reported the complete cure of four cancer patients after the adoption of a 100% organic diet (Jukes, 1974). As expected, the medical community has criticized the validity and truthfulness of such assertions (Jukes, 1974; Jukes, 1975). Still, several cancer treatment centers "now offer patients and their families fresh organic fruits and vegetables to help promote cancer nutrition," (Cancer Treatment Centers of America (CTCA), 2002) despite there being no compelling reason to recommend consumption of organic food in order to reduce the risk of cancer (Saffron, 1997). There seems to be a great deal of emotional conviction, therefore, that organic food is indeed superior.

Along this line, addressing the question of safety of organic produce becomes of major importance, especially in the face of such high consumer expectations. Although there have been several attempts in the literature to review the existing evidence regarding the quality of organically and conventionally grown food, all have dealt with comparisons of nutritional value, providing none or only isolated results regarding safety characteristics of the produce (Jukes, 1977; Bourn, 1994; Lecerf, 1995; Woese et al., 1997; Worthington, 1998; Heaton, 2001; Worthington, 2001; Bourn and Prescott, 2002; Williams, 2002; Magkos et al., 2003a). The present article extends and updates our previous work (Magkos et al., 2003b). As such, it does not aim at making a judgment about the best approach to agricultural development, nor does it intend to compare the environmental impact and sustainability of the two farming systems. Rather, the objective is to present a critical and transparent overview of organic food safety, to identify potential drawbacks in organic food production, and to highlight issues that require attention and merit further research. An extensive referral to the well-documented problems associated with conventional systems is spared. Safety of the produce has been evaluated with respect to several known and/or potent food risks, namely synthetic agrochemicals, environmental pollutants, nitrate content, contaminants in feedstuffs, and food products of animal origin, natural plant toxins, biological pesticides, microbial pathogens, and mycotoxins. The available literature comparing organic and conventional food products for each of the hazards listed above has been reviewed. An attempt to delineate the relative importance of each food hazard for human health, as well as to consider food safety within the general context of food quality has also been made.

At this point, a note should be made of the fact that, direct, comparative studies of organic and conventional produce are believed to be difficult to construct and evaluate, because of several extraneous variables that are difficult or even impossible to control (Adam, 2001). Most comparative studies to date fall into one of three basic categories, depending on the origin of the foods that have been tested (Magkos et al., 2003a). Food products have been purchased either from retail markets (retail market studies), or directly from organic and conventional production units (farm studies). Alternatively, the scientists themselves grew the food samples in special land pots, using methods corresponding to the two different cultivation systems (cultivation studies). Each study design has several advantages and disadvantages. For instance, although there is little or no information regarding the actual growing conditions in the retail market studies, these studies actually refer to the product exactly as it reaches the consumer. Farm and cultivation studies, on the other hand, may provide much better control over cultivation methods; yet, the relevance of their findings to the actual quality and safety of the produce is more obscure. Overall, each study design compromises between accuracy (i.e. how well it represents the food production system) and realism (i.e. how applicable are the results).

FOOD HAZARDS IN ORGANIC AND CONVENTIONAL FOOD

Synthetic Agrochemicals

Modern conventional agriculture uses a wide range of synthetic chemicals that inevitably leave residues in the produce. There are more than 130 different classes of pesticides containing some 800 entries (Table 1) (Plimmer, 2001). Pesticide residues enter the food chain via 4 main routes: on-farm pesticide use, post-harvest pesticide use (accounts for the largest part), pesticide use on imported food, and cancelled pesticides that persist in the environment (Kuchler et al., 1996). Extensive toxicological testing of food for the presence of pesticide residues has been carried out for almost 40 years now (Duggan et al., 1966), but whether or not dietary exposure to such chemicals indeed consists of a potential threat to human health is still the subject of great scientific controversy. It is certainly true that

(1) acute, massive exposure to pesticides can cause significant adverse health effects;
(2) food products have occasionally been contaminated with pesticides, which can result in acute toxicity; and
(3) most, if not all, commercially purchased food contains trace amounts of agricultural pesticides.

What does not follow from this, however, is that chronic exposure to the trace amounts of pesticides found in food results in demonstrable toxicity (Atreya, 2000; Wallace and Suchard, 2000). This possibility is practically impossible to study and quantify.

The results of several monitoring programs for contaminants in the diet indicate low and acceptable levels of food contamination in industrialized countries (Baht and Moy, 1997), but without proper control, some pesticide residues that remain on food can create potential health risks (Fan and Jackson, 1989). Although most of these chemicals are carcinogens in rodents when tested in high-dose animal cancer tests (Gold et al., 1992), and others are endocrine-, reproductive-, and immune system disruptors (Colborn et al., 1993), the significance of their presence in the diet is difficult to evaluate. This is mainly due to the unresolved issues and the complexity of hazard characterization of chemicals in food and diet (Table 2) (Dybing et al., 2002). From a simplistic point of view, toxicity is a function of exposure, and exposure in turn is a function of dose and time (Rozman et al., 2001). At low levels of human exposure, and despite the lack of a single methodological approach that would allow for health risk assessment of low-dose chemical mixtures, it has been suggested that no real cause for concern exists (Carpy et al., 2000). Nevertheless, although hard evidence is scarce, some scientists report that certain residues in conventional food could, over many years, raise the risk of cancer and other diseases in humans (Groth et al., 1999; White, 2001; Trevino, 1999; Bolognesi and Morasso, 2000; Kenney et al., 1998). Heightened scientific and public awareness put considerable pressure on reduced synthetic pesticide use in arable fields, and many food processors have entered the organic market in an attempt to satisfy this demand (Levidow and Bijman, 2002).

Synthetic agrochemicals are not permitted in organic production (The United Kingdom Parliament, 1999; Soil Association, 1997; Codex Alimentarius Commission, 2001), and long-term experiments under controlled conditions indicate that, synthetic pesticide input in organically cultivated fields (presumably, from sources other than direct application, e.g. via soil, water, and air) can be approximately 96.5% lower than in conventional ones (0.21 vs. 6 kg of active ingredient per acre per year, respectively)

Table 1 Major categories of synthetic pesticides

- Organophosphates
- Carbamates
- Pyrethroids
- Insect juvenile hormones and analogues
- Compounds that affect other metabolic pathways
- Compounds that affect insect behavior
- Aryloxyalkanoic acids
- 2-(4-aryloxyphenoxy)propionic acids
- Triazines
- Fungicides
- Metabolites

Derived from Plimmer (2001).

Table 2 The elements of hazard characterization of dietary chemicals

- Establishment of the dose-response relationship for critical effects.
- Assessment of external vs. internal dose.
- Identification of the most sensitive species and strain.
- Identification of potential species differences (qualitatively and quantitatively).
- Characterization of the mode of action/the mechanism for the critical effects.
- Extrapolation from high to low dose and from experimental animals to humans.

Derived from Dybing et al. (2002).

(Mader et al., 2002). Organic foods grown and processed properly, however, are not necessarily free from pesticides and other synthetic chemicals of conventional farming (Jukes, 1977). Indeed, such produce can be contaminated due to cultivation on previously contaminated soil, percolation of chemicals through soil, especially on sloping fields, unauthorized use of pesticides, cross-contamination with wind drift, spray drift from neighboring conventional farms, contaminated groundwater or irrigation water, or even during transport, processing and storage (Saffron, 1997; American Dietetic Association, 1990a,b; Tamm, 2001; Ahrenhofer, 1986). While regulations demand that farms should be free from the use of prohibited substances for a time period of two (Europe) to three (US) years in order to be certified suitable for organic farming, it is argued that the soil of some land is so contaminated from previous use that even after three years it may not be appropriate for organic production (Fisher, 1999). Part of the responsibility, therefore, lies with the organic certifiers, as to whether or not they would allow use of such land for organic production.

For example, a recent study reported that a number of organochlorine pesticide (OCP) residues were present in the soil environment and tomatoes cultivated in line with the organic standards, and despite that such chemicals have never been applied on the farm (Gonzalez et al., 2003). Wind dispersion, surface runoff, and volatilization and subsequent redeposition by precipitation of pesticides applied in the surrounding areas have been suggested to contribute to pollution of "non-target" areas such as organic farms (Gonzalez et al., 2003). Nevertheless, a nationwide study on pesticide residues in raw and prepared organic food products, conducted in France during 1996–1997, provided more than encouraging results for the organic industry: of more than 9,100 samples from 10 types of products (two-thirds of which were cereals), 90.4% contained none or trace levels of pesticides (Bitaud, 2000). Unfortunately, the practical significance of this finding is questionable, since more than 97% of the analyses were performed on insecticides, whilst 66% of the pesticides applied were herbicides and fungicides, meaning that the majority of the pesticides used on typical conventional crops were not analyzed for in the organic samples (Bitaud, 2000). Another study carried out by a private organic food company found low levels of agrochemical residues in approximately 21% of the samples; this contamination was attributed to environmental pollution and/or processing mishandling, or even to the fraudulent use of synthetic agrochemicals on organic food (Lo and Matthews, 2002). In a large survey from New Zealand during 2002-2003, over 300 samples of 60 different types of certified organic fruit, vegetables, nuts, herbs, and grain were tested for the presence of 45 different chemicals; more than 99% of the organic produce had no detectable residues (McGowan, 2003).

Although there has been very little documentation of residue levels from well-designed and controlled experiments (Bourn and Prescott, 2002), pesticides and/or other contaminants can occasionally be found in measurable amounts in certified organic food. Presence, however, does not necessarily preclude that the food can be described as organic, providing all requirements related to the production process have been fulfilled (Greene, 2001). In particular, ingredients of agricultural origin not satisfying the standards of organic production may be present within the limit of maximum level of 5% of the total ingredients (mass-to-mass) (Codex Alimentarius Commission, 2001). Indeed, several studies have verified the presence of synthetic agrochemicals in organic food; frequency and actual levels of contamination were generally lower compared with conventional produce, but differences were usually small and not always evident (Lecerf, 1995; Woese et al., 1997; Ahrenhofer, 1986; Reinhard and Wolff, 1986; Andersson and Bergh, 1995; Slannia, 1995; Andersen and Poulsen, 2001; Poulsen and Andersen, 2003). The conclusions from two recent review articles support a gradually strengthening trend towards lower levels and less frequent presence of pesticide residues in both vegetables and fruits produced organically (Bourn and Prescott, 2002; Kumpulainen, 2001). Still, this cannot be generalized for other organic foods, due to limited number of studies and shortcomings in test design and evaluation. At this point, it is important to note that the presence or absence of a specific residue also depends on the analytical detection levels. For example, it has been shown that the proportion of pesticide-free organic wine (i.e. residues below detection limits) shifts from approximately 80% to less than 10% if the detection level is lowered from 0.01 parts per million (ppm, i.e. mg/kg) to 0.001 ppm (Tamm, 2001). Therefore, one should always take into account the sensitivity of the analytical method used when attempting to interpret or compare the results of such studies.

It is of interest to refer to a recently published, large-scale comparative study of residue levels in organic and conventional fruits and vegetables (Baker et al., 2002). The authors obtained data on pesticide residues in organically grown foods and foods with no market claim (assumed to be conventionally grown) from three independent US sources: the Pesticide Data Program of the US Department of Agriculture, the Marketplace Surveillance Program of the California Department of Pesticide Regulation, and private tests conducted by the Consumers Union. The collected data represented tests of over 94,000 food samples, and were subjected to statistical analyses of residue patterns. With respect to the frequency of detection of positive samples, it was clearly shown that organically grown fruits and vegetables typically contain pesticide residues (at least one type) only one-third as often as conventional ones (Figure 1) (Baker et al., 2002). This difference remained relatively stable over time (Figure 2); the apparent increase in the frequency of detection of residues in both organic and conventional produce in recent years has been attributed to advances in analytical methodology that lowered the limit of detection for many residues, rather than to changes in pesticide use or other variables (Baker et al., 2002). Organic crops were also far less likely to contain multiple pesticide residues (i.e. two or more types), with overall rates of contamination being approximately 10-fold greater in conventional (26.7% of 60,642 samples) than in organic (2.6% of 803 samples) produce (Baker et al., 2002). Comparison of specific residues on specific crops revealed that residue concentrations in organic fruits and vegetables were generally lower than those

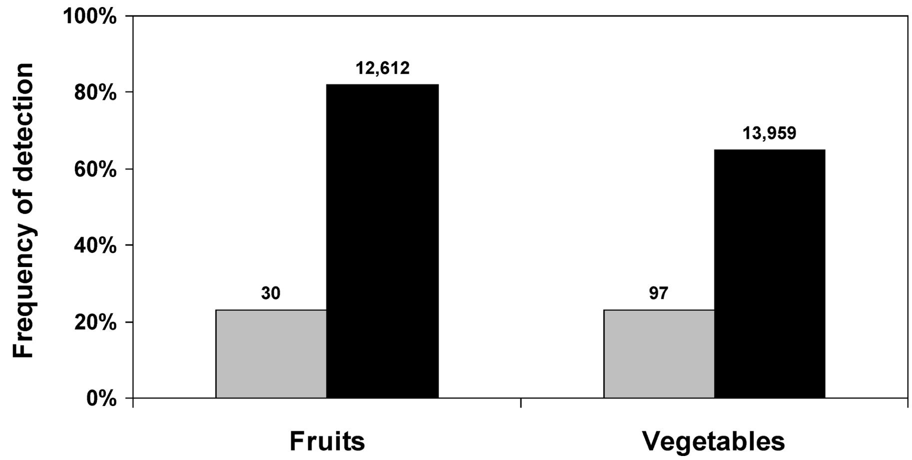

Figure 1 Frequency of detecting at least one type of pesticide residue in organic and conventional fruits and vegetables. Data on pesticide residues in organically grown foods (gray bars) and foods with no market claim (assumed to be conventionally grown; black bars) were collected from the Pesticide Data Program of the US Department of Agriculture. The total number of samples tested is shown on top of the respective bars. Derived from Baker et al. (2002).

in conventional ones, although in some instances the reverse was also true; based on pooled data from the three data sets, organic samples were found to have significantly lower residue levels in approximately 69% of cases (Baker et al., 2002).

An additional interesting finding of that study is that when banned OCPs were removed from the analysis, the percentage of organic vegetable samples testing positive for one or more residues (not including OCPs) decreased by more than half, but that of conventional produce was only modestly altered; the percentage of positive fruit samples from either cultivation type did not change (Baker et al., 2002). Drawing on these data, some have suggested that occurrence of banned OCPs was more frequent among organic vegetables, as rates of contamination appeared to be 3-fold higher in organic than in conventional produce (Figure 3) (Benbrook, 2002). However, this interpretation of data is confounded by the failure to take into account the almost 10-fold more frequent presence of multiple pesticide residues (two or more types) in conventional compared with organic vegetables (Baker et al., 2002). For example, an organic sample containing a single OCP would be classified in the “only OCP” category, while by contrast, a conventional sample containing one OCP and one non-OCP (i.e. multiple residues) would still be classified in the “non-OCP” category (Figure 3). At best, therefore, these data merely provide evidence for the presence of OCPs in both types of produce. This kind of contamination cannot be attributed to either organic or conventional farming practices, since use of OCPs in agriculture has not been permitted for many years in developed countries. These compounds,

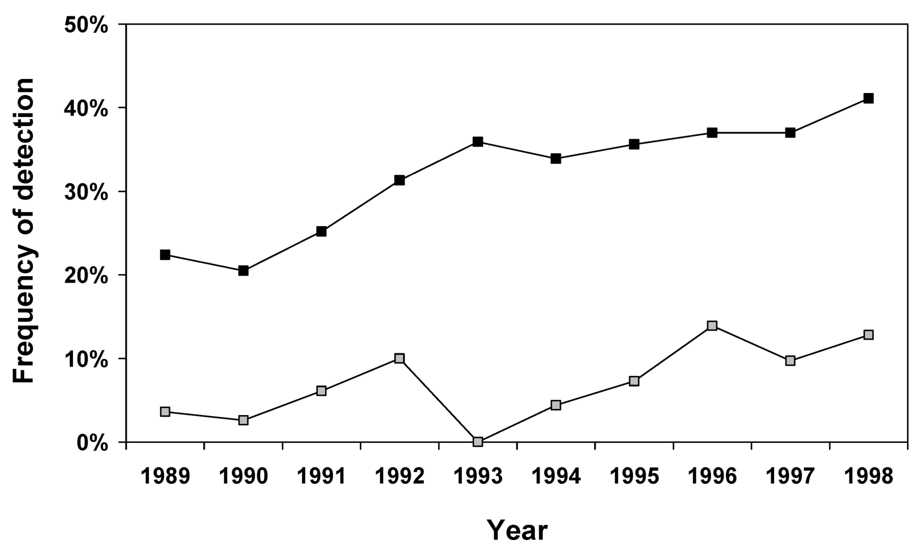

Figure 2 Ten-year trends of contamination rates with pesticides of organic and conventional fruits and vegetables. Data on pesticide residues in organically grown foods (gray squares) and foods with no market claim (assumed to be conventionally grown; black squares) were collected from the Marketplace Surveillance Program of the California Department of Pesticide Regulation. A total of 67,154 samples (1,097 organic and 66,057 conventional) were examined. Derived from Baker et al. (2002).

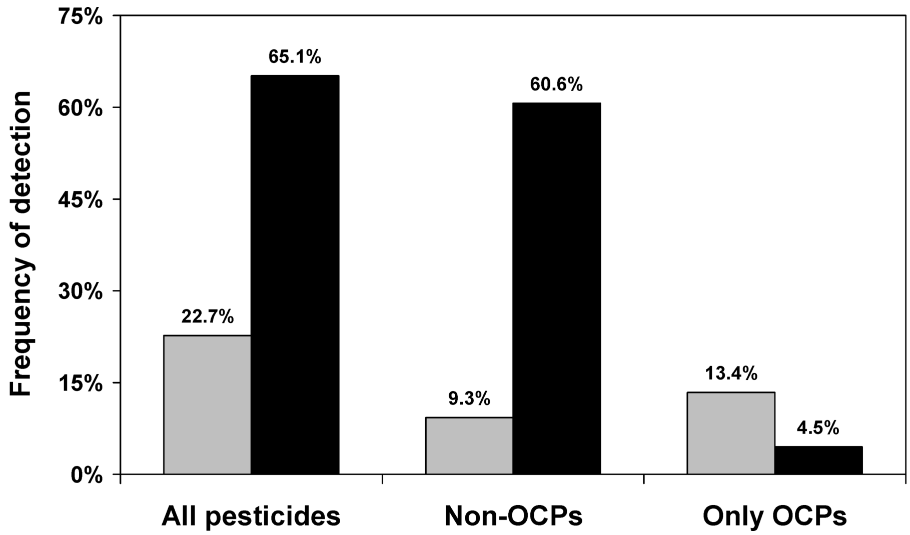

Figure 3 Organochlorine and non-organochlorine pesticide residues in organic and conventional vegetables. Data on organochlorine pesticide (OCP) and non-OCP residues in organically grown vegetables (97 samples, gray bars) and those with no market claim (assumed to be conventionally grown; 13,959 samples, black bars) were collected from the Pesticide Data Program of the US Department of Agriculture. Residue detection frequencies are shown on top of the respective bars, and have been determined for all the pesticides combined, for pesticides other than the OCPs, and for the OCPs only. The latter category, therefore, represents food samples containing only OCP residues. Derived from Baker et al. (2002).

however, remain persistent in the environment and accumulate in plant and animal tissues, hence they may pose serious dietary risks (Benbrook, 2002). In fact, recent data are alarming in that OCP residues were reported to be surprisingly abundant in the US food supply, despite being off the market for over twenty years (Schafer and Kegley, 2002). This illustrative example stresses the considerable influence that several other aspects of the production chain may have on food safety.

In spite of all the abovementioned findings, it is important to note that residue levels of permitted pesticides in both organic and conventional food are often below detection/allowable limits (Woese et al., 1997; Kumpulainen, 2001; Moore et al., 2000). For instance, a total of 9,438 samples of several food commodities (vegetables, fruits, grains, and grain products, milk and dairy products, eggs, fish, and aquatic products, and other) from 92 countries were analyzed for pesticide residues by the US Food and Drug Administration in 1999 (Food and Drug Administration, 2000). The samples were analyzed for the presence of 366 pesticides; 90 of them were actually found. No residues were detected in 60–65% of samples, while another 35–40% contained residues in low but acceptable levels; only 1–3% had violative levels, i.e. residues which exceed a tolerance, or residues at a level of regulatory significance for which no tolerance has been established in the sampled food (Food and Drug Administration, 2000). Similarly, approximately 30% of the food consumed in the UK between 1994–1998 contained measurable pesticide residues, and only less than 1% contained violative concentrations (Shaw, 2000). In the European Union, out of some 40,000–46,000 samples (approximately 95% of which were fresh fruit, vegetables, and cereals) analyzed annually during 1996–2002 for 140–170 different pesticides, approximately 32–38% had detectable residues and 3.0–5.5% had violative levels (European Commission Health and Consumer Protection, Directorate-General (DG SANCO), 2004). In New Zealand, the Victorian Produce Monitoring Program for 2002 included a total of 8,958 analyzes for some 85 agrochemical residues on 329 samples of 30 different types of plant products (fresh fruit, vegetables and field crops); approximately 31% of samples had detectable residues and less than 4% had violative levels (McGowan, 2003). These findings demonstrate that the frequency of food contamination by pesticides is remarkably stable, and residue levels in conventional food are generally well below established tolerances.

This view is also supported by a recent comparative study from Greece. Although mean concentrations of fenthion and dimethoate pesticides were greater in conventional compared with organic olive oil by a factor of less than 2.5 to more than 48.5 (Figure 4), actual concentrations in all samples were lower than the maximum residue levels set by the FAO/WHO Codex Alimentarius (Tsatsakis et al., 2003). Also, the apparent widening of the difference between organic and conventional produce over the 3-year observation period (see Figure 4) was mainly due to a gradual reduction of pesticide concentrations in organic olive oils, rather than an increase in conventional ones, in which residue levels remained relatively stable (Tsatsakis et al., 2003). This decline was attributed to the switch from conventional to organic cultivation, as olive oils were produced from olive trees grown in organic fields in transition, i.e. during the initial 3 years following the introduction of the organic cultivation method (Tsatsakis et al., 2003). In light of the fact that regulatory systems for pesticides are gradually becoming more stringent (Tait, 2001), one could predict a significant decline in residue concentrations in conventional produce as well. It has been suggested, therefore, that no meaningful difference

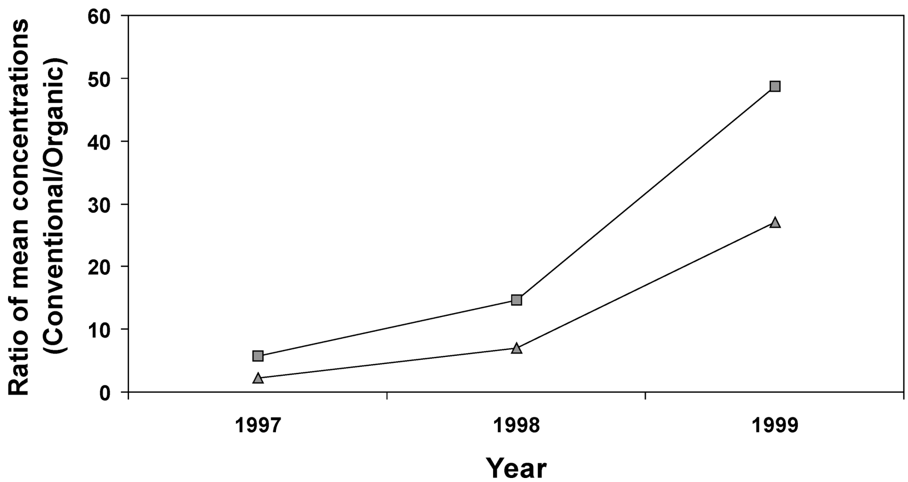

Figure 4 Pesticide residues in organic and conventional olive oil. Residues of fenthion (squares) and dimethoate (triangles) pesticides were determined in organic and conventional olive oils from Crete during 1997–1999. The ratio of the mean concentration of conventional to that of organic produce is shown. Derived from Tsatsakis et al. (2003).

between organic and conventional crops will be evident in the foreseeable future in this respect, and that residue levels may become less important over other issues in the decision of consumers to purchase organic food (Bourn and Prescott, 2002).

For the time being, however, consuming a diet comprising of mainly (>75%) organic fruits and vegetables may be able to reduce dietary exposure to organophosphorus pesticides compared with a "conventional" diet (Curl et al., 2003). While health risks associated with dietary agricultural chemicals are still uncertain and subject to debate, risk is relative, and lower exposure undoubtedly translates into decreased risk (Baker et al., 2002). On the other hand, from the perspective of risk management, the levels of human exposure to dietary pesticides are thought to be more of a regulatory rather than of health significance (Krieger, 2002). For example, contrary to initial reports regarding higher sperm density in organic farmers (Abell et al., 1994), and higher sperm concentrations in members of organic food associations (Jensen et al., 1996), no physiologically significant differences have been identified between the semen quality of farmers consuming mainly organic or conventional fruits and vegetables, corresponding to groups with low and high, respectively, synthetic pesticide intake (Larsen et al., 1999; Juhler et al., 1999). Despite the widely held view of many advocates of organic farming that male fertility is deteriorating due to environmental factors like agricultural chemicals (Colborn et al., 1996), a more close examination of data refutes such an assertion. Rates of infertility in the US have remained constant during the period 1965–1990 (at 8 to 11%), and male infertility has accounted for approximately one-third of cases (Sherins, 1995). Moreover, while a review of 61 papers published from 1938 through 1990 (analyzing a total of 14,947 men) concluded that the quality of semen had declined by almost 50% during that period and speculated that environmental factors might be responsible (Carlsen et al., 1992), a reanalysis of data from 48 of the papers published from 1970 onwards revealed a statistically significant increase in sperm concentration (Brake and Krause, 1992). Although certain occupational exposures to environmental chemicals may indeed contribute to the severity of male infertility and worsen the effects of pre-existing genetic or medical risk factors (Oliva et al., 2001), there is no evidence to date that dietary exposure to such agents may also be responsible.

Environmental Pollutants

Chemical contaminants in food that result from general environmental pollution [cadmium (Cd), mercury, copper, arsenic, zinc, lead, dioxins, polychlorinated biphenyls (PCBs), radioactive nuclides, OCPs] are also potent and may pose serious acute and/or chronic health risks (Bernard et al., 1999; Moffat and Whittle, 1999; Office of Technology Assessment (OTA), 1979). Environmental contamination of food may manifest itself in one of two forms: long-term, low-level contamination resulting from gradual diffusion of persistent chemicals through the environment, and relatively shorter term, higher level contamination stemming from industrial accidents and waste disposal (Office of Technology Assessment (OTA), 1979). The fate of these pollutants is remarkably complex, so that several multicompartmental modeling approaches have been recruited in the attempt to describe contaminant kinetics in the environment (Wania, 1998). It is generally accepted that persistent pollutants in the soil such as chlorinated hydrocarbons and certain heavy metals cannot be avoided through organic farming practices (Slanina, 1995; Food and Agriculture Organization (FAO), 2000; During and Gath, 2002a). Further, some of these contaminants (e.g. PCBs, OCPs) are also present in air at various concentrations (Harner et al., 2004). Therefore, the absence or presence and the relative amount of these toxic agents in food, organic and conventional, depend mainly on farm location. Areas of high contamination may occur due to industrial activity (e.g. chemical manufacturing, mining, refining, and smelting operations), agricultural practices, energy production, and disposal of hazardous toxic wastes (Office of Technology Assessment (OTA), 1979; Tirado and Schmidt, 2001; Vallack et al., 1998). In accordance with this view, most studies indicate similar levels of contamination by these pollutants in a variety of both organic and conventional food products; where differences have shown up, they don't consistently give the edge to either type of food (Lecerf, 1995; Woese et al., 1997; Worthington, 2001; Slanina, 1995; Kumpulainen, 2001; Jorhem and Slanina, 2000; Malmauret et al., 2002). It may be that the variability within a given crop is greater than the variability between one cultivation system and another (Jorhem and Slanina, 2000). Similarities in the levels of the various environmental contaminants in organic and conventional food are to be expected in the future, as well, given the opportunities for uptake into both types of agricultural produce.

Food contamination with Cd, a known carcinogen, is widely debated and often controversial. The main sources of Cd in soils are phosphate fertilizers, particulates from atmospheric pollution, sewage sludge (i.e. municipal waste), and farmyard manure (Linden et al., 2001). Use of phosphate fertilizers has declined in organic farming (most organic certifiers specify maximum Cd levels permitted in the various farming inputs), which may result in lower Cd levels in the long-term (Horner and Kurfuerst, 1987). Still, some argue that organic farmers are permitted to use crude phosphate rock containing variable amounts of Cd, while inorganic phosphate fertilizers are cleaned of most Cd prior to application on conventional crops (Kirchmann and Thorvaldsson, 2000; Witter, 1996). On the other hand, utilization of sewage sludge as fertilizer in conventional agriculture creates further concern about possible contamination by Cd (and other heavy metals) of conventionally grown crops and especially vegetables (During and Gath, 2002b). Surprisingly though, soil chemical analysis often cannot fully account for the Cd added with sludge (Jones et al., 1987). Moreover, trace element accumulation, particularly of Cd, has been anecdotally reported to be higher in the soil of organic farmland (Moolenaar, 1999), while pig manure from organic production has been shown to contain higher levels of Cd than that from conventional production (Linden et al., 2001).

Increased metal levels in soil, however, do not necessarily result in increased metal contents in the plants grown in the field (Moolenaar and Lexmond, 1999), and thus in food produced by these plants. Indeed, although comparative analyses of organic and conventional foodstuffs are limited, the few studies published to date show no consistent difference in Cd levels; results vary considerably according to type of crop, variety, geographical location, time of sampling, etc. (Lecerf, 1995; Woese et al., 1997; Worthington, 2001; Slanina, 1995; Kumpulainen, 2001; Jorhem and Slanina, 2000; Malmauret et al., 2002; Oliver et al., 1997). Only one preliminary report from the Greek market documented significantly higher Cd concentrations in a wide variety of conventional food products compared with organic ones (Karavoltsos et al., 2002). On the whole, however, differences in Cd content between the two types of produce have been inconsistent, and where they have shown up, they have been attributed to various other factors rather than the cultivation system per se (Figure 5). For example, one study reported significantly higher Cd concentrations in conventional than in organic grains, but this difference was due to the significantly higher soil pH at the organic site (due to liming), that would be expected to minimize Cd availability for plant uptake (Oliver et al., 1997). Another study from Sweden examined wheat samples grown in organic and conventional fields at two geographical locations; while Cd levels at one site were significantly lower in organic vs. conventional wheat, the reverse was true at the other site (Jorhem and Slanina, 2000).

Nitrate

Nitrate is the main form of nitrogen supplied to crops from soil, and its content in food has historically been an ambiguous issue. Two potentially deleterious effects of high gastric concentrations of nitrate are methemoglobinemia among young children and infants (Craun et al., 1981; Avery, 2001b), and formation of carcinogenic N-nitroso compounds (Bruning-Fann and Kaneene, 1993; Vermeer and van Maanen, 2001). Nitrate per se has not been shown to produce a carcinogenic effect in animals, but can be converted into nitrite by bacteria in human saliva and in the intestine, which in turn may react with certain amines and amides, normally present in the body, to produce nitrosamines (Bruning-Fann and Kaneene, 1993; Vermeer and van Maanen, 2001). About 300 nitrosamines have been tested for carcinogenicity in high-dose animal cancer tests, and roughly 90% of them have been found to be carcinogenic (Havender and Coulombe, 1996). Nitrosamines are capable of both initiating and promoting the cancer process.

Whether or not, however, dietary nitrate significantly contributes to human cancer is debatable. There is no hard evidence

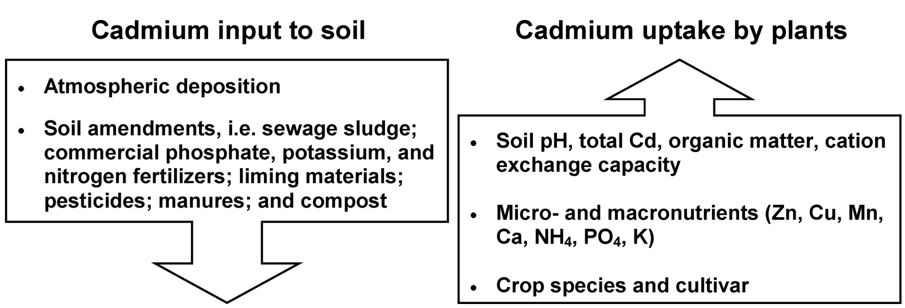

Figure 5 Factors affecting cadmium input to soil and uptake by plants. Derived from Linden et al. (2001) and Moolenaar and Lexmond (1999).

of a significant association between nitrate intake and gastric cancer risk in humans (van Loon et al., 1998), while consumption of vegetables has been shown to be highly protective and independent of their estimated low or high nitrate content (Pobel et al., 1995). In addition to the lack of evidence from epidemiological studies regarding a causative role of dietary nitrate in gastrointestinal cancer, it is also tempting to refer to its potential role in cardiovascular protection and intestinal host defence, through its connection to nitric oxide production (McKnight et al., 1999; Vallance, 1997). Supporting the latter notion, a recent study has demonstrated that daily intake of nitrate may exert a protective effect against experimentally-induced gastritis in rats by releasing nitric oxide in the stomach (Larauche et al., 2003). It is, therefore, difficult to conclude whether dietary nitrate is harmful or by contrast beneficial to human health, and if both, at what levels of consumption.

Regardless of the abovementioned uncertainties, a number of studies have addressed the question of nitrate content in organically and conventionally grown food. Most, if not all previous review articles on the nutritional quality of the produce have concluded that organically cultivated nitrophillic vegetables (i.e. those with a high nitrate accumulating potential), and especially leafy vegetables such as spinach and lettuce, but some root and tuber vegetables as well, have lower nitrate content compared with conventionally grown alternatives (Bourn, 1994; Lecerf, 1995; Woese et al., 1997; Worthington, 1998; Worthington, 2001; Bourn and Prescott, 2002; Williams, 2002). It has been estimated that organic vegetables are approximately 3 times more likely to contain less nitrates than conventional crops (Figure 6) (Worthington, 2001), and that on average, their nitrate levels may be approximately 15% (Worthington, 2001) to as much as 50% (O'Doherty Jensen et al., 2001) lower. With respect to other crops, such as cereals, fruit, seed and bulb vegetables, which have low nitrate accumulating potential, available data do not indicate any consistent difference.

Still, there remains a high level of uncertainty regarding the aforementioned conclusions, taking into account the large number of factors that are irrelevant to the farming system and may affect the nitrate content of crops (e.g. cultivar, soil type, planting and harvest dates, nitrate in irrigation water and groundwater, geographical location, climate, storage conditions and post-harvest processing, plant disease, etc.) (Magkos et al., 2003b). For example, a recent study reported higher nitrate content in conventional than in organic tomatoes (19 vs. 1 mg/kg, respectively; $P < 0.05$) and spinach (1,591 vs. 1,135 mg/kg, respectively; not significant), but non-significantly higher levels in organic than in conventional carrots (394 vs. 113 mg/kg, respectively) and lettuce (1,221 vs. 804.5 mg/kg, respectively) (Malmauret et al., 2002). Another investigation found significantly higher nitrate concentrations in organically than in conventionally grown chicory (4,395 vs. 3,350 mg/kg, respectively; $P < 0.05$) and green salad (3,076 vs. 1,343 mg/kg, respectively; $P < 0.05$), and a similar strong trend for rocket lettuce (3,400 vs. 3,147 mg/kg for organic and conventional produce, respectively; $P = 0.07$) (De Martin and Restani, 2003). For all these reasons, the notion that "organic farming methods can substantially reduce dietary intake of nitrate and thus the risk of in vivo formation of carcinogenic nitrosamines" (Vogtmann and Biedermann, 1985) seems like a gross oversimplification.

Animal Feed Contaminants, Disease Patterns, and Veterinary Drugs

Contaminants in animal feeds, such as pesticide residues, agricultural and industrial chemicals, heavy metals and radioactive nuclides, can give rise to safety hazards in food of animal origin (Johnston, 2000). Organic livestock are fed on organically produced feedstuff, thus the potential for contamination with pesticide residues and other agricultural chemicals is thought

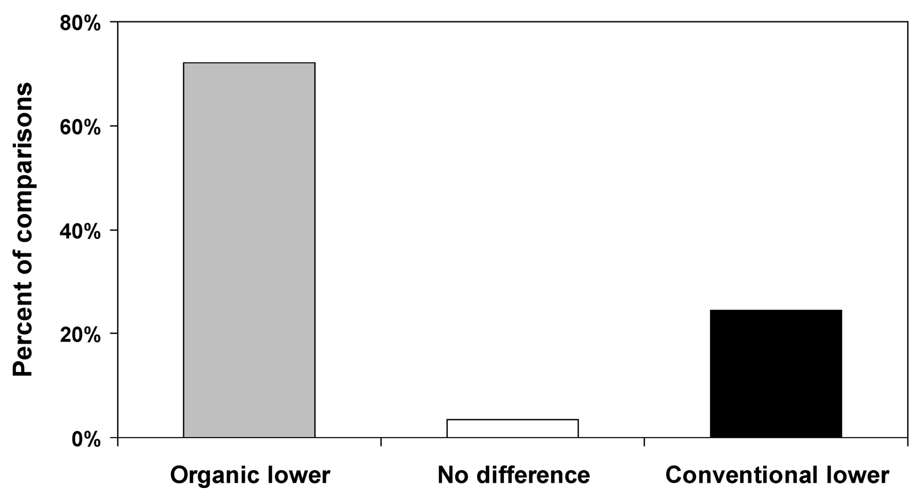

Figure 6 Nitrate content of organic and conventional crops. The results from 18 published studies including a total of 176 comparisons on the nitrate content of organic and conventional crops, including beetroot, cabbage, carrot, celeriac, chard, corn salad, endive, kale, leek, lettuce, potato, radish, spinach, and turnip, are presented. The percent of total comparisons indicating lower (gray bars), equal (white bars), or higher (black bars) nitrate content in organic compared with conventional produce is shown. Derived from Worthington (2001).

to be reduced compared with conventional farming methods. It should be pointed out, however, that several synthetic but highly unstable chemicals (i.e. degrading fast enough to leave minimal residues) are currently available to guarantee safe feed for conventional livestock as well. On the other hand, contamination of animal feed ingredients with potentially harmful substances (e.g. mycotoxins) has been documented in both types of feedstuff (Scudamore et al., 1997), while neither organic nor conventional farm management can reduce the levels of persistent environmental pollutants, that may occasionally be found in feedstuffs and hence in endproducts of animal origin of both farming systems (Food and Agriculture Organization (FAO), 2000).

For illustrative purposes, a recent incident of large-scale food contamination in Mecklenburg-West Pomerania, east Germany, will be described (Tuffs, 2002; Achilles, 2002). Grain feed (mainly wheat and corn) for animals on organic farms was stored in a depot, which, up to 1990, had been used for storing agricultural chemicals, including Nitrofen, DDT, lindane and Methoxichlor. The European Union had banned Nitrofen several years ago due to its documented carcinogenicity, but unfortunately, it remained persistent and contaminated several hundreds tonnes of organic animal feedstuff. As a result, a large number of chicken and turkey meat products and eggs from organic farms in many German states were found to contain potentially dangerous levels of this herbicide, and were thus recalled from the market. Certainly, both farming systems could be affected by such an incident, which demonstrates the considerable influence that several other aspects of the production chain may have on food safety, beyond the production system per se. Another relevant example could be identified in the presence of OCP residues in both organic and conventional milk, probably as a result of the persistence and accumulation of these contaminants in the environment and animal tissues. One study (cited in Kouba, 2003) reported that mean levels of DDT and lindane were approximately 4- and 2-fold lower, respectively, in organic than in conventional milk, while others did not demonstrate any difference in OCP residue concentrations between the two types of milk (von Knoppler and Averdunk, 1986; Lund, 1991).

Administration of veterinary drugs (e.g. antibiotics and growth hormone) in food-producing animals is another serious public concern in terms of food safety. Animal management in organic farms precludes the use of chemically synthesized allopathic medicines, although vaccines are conditionally permitted (the exact regulations may vary between certifiers and across countries) (Codex Alimentarius Commission, 2001; United States Department of Agriculture (USDA), 2000). Animal health in organic systems should be maintained and promoted mainly through preventive measures, including appropriate selection of breeds and strains, balanced high-quality diet, and favorable environment, especially with respect to animal density (Codex Alimentarius Commission, 2001; United States Department of Agriculture (USDA), 2000). As a consequence, however, demands on management are substantially greater in organic than in conventional systems, in that the aforementioned practices demand precise knowledge, extensive experience and constant inspection in order to meet the desired conditions (Gade, 2002; Sundrum, 2001; Cabaret, 2003; von Borell and Sorensen, 2004). Hence it can be argued that avoidance of animal disease in organic farms, as well as the safety of organic food originating from these animals, are much more dependent on individual farmers than in conventional systems. While intensive farming practices have indeed been linked to the rise in foodborne illness in humans, it is interesting to note that the rise has continued even when there has been a shift to less intensive production systems (Johnston, 2000). In addition, refraining from vaccines and antibiotics gives rise to concerns about animal disease outbreaks and zoonoses, should other contributing factors be present (Thamsborg, 2001). Although incidences of contamination with various pathogens in both organic fish (Ogbondeminu and Okaeme, 1986) and poultry (Engvall, 2001) have been documented, the few available comparative studies on animal products (milk, butter, cheese, beef, pork, eggs) from organic and conventional production do not indicate any difference with respect to their microbiological condition (Woese et al., 1997; Lund, 1991; Zangerl et al., 2000; Honikel, 1998).

There are several other issues related to aspects of the production process, and ultimately linked to food safety, that need to be addressed. Although there have been many investigations into the occurrence and transmission of microbial pathogens in conventional systems, little relevant information is available regarding organic livestock. Absence of data, however, does not necessarily translate into absence of hazard and, as more information becomes available, the assertions of healthfulness and superiority of organic livestock seem to fly in the face of evidence. The prevalence rates of *Campylobacter* species (spp.) in broiler chickens reared in organic and conventional systems have been compared recently (Heuer et al., 2001). The investigators examined the organisms in birds from 79 flocks from conventional broiler houses at 18 farms and from 22 organic flocks at 12 free-range farms. Whereas *Campylobacter* spp. were isolated from only 36.7% of the conventionally reared flocks, the organism was present in 100% of the organic flocks (Heuer et al., 2001). It has been suggested that conventional broiler houses provide a controlled environment designed to minimize the spread of pathogens, while by contrast, organic broiler fowls have free access to soil and water in the open, where they can pick up a number of microbes (Dixon, 2001).

Outdoor husbandry is the "gold standard" in organic livestock production (The United Kingdom Parliament, 1999; Soil Association, 1997; Codex Alimentarius Commission, 2001; United States Department of Agriculture (USDA), 2000). A number of studies conducted in Scandinavian countries, however, have provided some cause for serious concern. Outdoor husbandry has been associated with the high rates of parasitic infections by several helminth species in organic pigs (Carstensen et al., 2002). On the contrary, in intensive indoor production systems with slatted floors and no straw bedding, helminth infections have become less frequent and most species occur only sporadically (Nansen and Roepstorff, 1999). Although the current prevalence rates of helminth infections in organic pigs are generally lower than those 10 years ago, they still remain substantially higher compared with conventional ones (Carstensen et al., 2002; Roepstorff et al., 1998). Similar results have been documented for sheep, cattle, laying hens, and poultry: the prevalence and intensity of parasitic infections were higher in organically than in conventionally raised animals, and helminth species diversity was also much higher among the former (Cabaret et al., 2002b; Thamsborg et al., 1999; Permin et al., 1999). Outdoor rearing and organic husbandry may be confronted with serious problems in the future, because of particularly favorable conditions for helminth transmission (Nansen and Roepstorff, 1999), in addition to limited treatment alternatives (Cabaret et al., 2002a). Drawing these conclusions together, it has been suggested that organic farmers start off their production with helminth-free animals, i.e. animals originating from conventional systems that are pretreated with anthelmintics (Carstensen et al., 2002). Use of disease-resistant animals could also provide a solution, although there are several issues related to organic animal breeding that need to be addressed first (Boelling et al., 2003). How exactly will all these practices coincide with organic farming principles is at the present unclear. What becomes apparent, however, is that some regulations for organic production encourage practices which may also have negative consequences for human health, insofar as extended access to outdoor areas exposes organic animals to general environmental pollutants and disease-promoting microorganisms (O'Doherty Jensen et al., 2001). In any case, the impact of different levels of infection on final food quality and safety, as well as on consumer health, remains unknown. Further, with the exception of parasite-related diseases referred to above, it was concluded recently that health and welfare in organic herds appears to be the same or slightly better than in conventional herds (Lund and Algers, 2003), although organic livestock production is certainly no guarantee (von Borell and Sorensen, 2004).

Regarding animal health status and disease patterns (e.g. mastitis) among organically and conventionally raised dairy cows, most comparative studies to date indicate that there seems to be no fundamental difference between the two production methods (Sundrum, 2001; Bennedsgaard et al., 2003; Rosati and Aumaitre, 2004). It should be pointed out, however, that disease in animals is inevitable on farms, no matter how good the husbandry (Johnston, 2000; Vaarst et al., 2003). When animals in organic farms become sick or injured, they are treated by giving preference to phytotherapeutic or homeopathic medicinal products (Codex Alimentarius Commission, 2001; United States Department of Agriculture (USDA), 2000). The therapeutic use of synthetic allopathic medicines is not prohibited in organic systems; their use, however, is restricted to the minimum possible (Codex Alimentarius Commission, 2001; United States Department of Agriculture (USDA), 2000). Nevertheless, the efficacy of homeopathic and phytotherapeutic medicinal products for animal treatment is for the most part undocumented and under debate (Cabaret et al., 2002a; Loken, 2001), thus giving cause for concern regarding increased use of synthetic medicines. Key points here include the lack of scientific evidence concerning homeopathy in animals (Hammarberg, 2001), the lack of experience of most veterinarians to work with homeopathy (Hammarberg, 2001), the differences in interpretation of the regulations between animal owners and veterinarians (Hammarberg, 2001), and the lack of information about biosecurity, disease detection and disease prevention (Berg, 2001). Still, more than half of the organic producers in the US never use herbal remedies or homeopathy to manage animal disease; they mostly rely on pasture foraging, rotational grazing, mineral or vitamin supplementation, and vaccine administration (Walz, 1999).

The above points notwithstanding, use of synthetic veterinary drugs and growth hormone is more extensive in conventional livestock farming. As a result, the levels of such chemicals in organic food of animal origin are expected to be lower than in conventional food, although no relevant research is currently available to support this assumption (Saffron, 1997). In one study, however, no antibiotics to the level of detection were found in either organically or conventionally produced milk (Lund, 1991). Also, fear that livestock drug residues could remain in final food products and cause human illness may be unsubstantiated, since the generally rapid breakdown of active ingredients in drugs and the specified periods between last administration of the drug and slaughter are believed to have limited this threat (Mathews et al., 2001). Therefore, while the restricted use of veterinary drugs can be expected to yield a lower incidence of residues in organic animal products, this problem would seem to be a very minor one even in conventional animal production (O'Doherty Jensen et al., 2001). By contrast, the major concern associated with the administration of low levels of antimicrobial drugs to food-producing animals is the potential for antibiotic resistance to develop in or be transferred to pathogens; these antibiotic-resistant microorganisms could then be transmitted to man and cause various diseases (Gorbach, 2001; Hamer and Gill, 2002). Scientific bodies indeed acknowledge that there might be a link between the use of antibiotics in livestock, development of bacterial resistance to these drugs, and human disease, but the incidence of such disease is very low (National Research Council and Committee on Drug Use in Food Animals, 1999). Still, the only relevant study that could be identified found no major differences in the antimicrobial susceptibility patterns (that is, antibiotic resistance) of Staphylococcus aureus isolated from bulk tank milk in organic and conventional dairy farms (Sato et al., 2004).

Natural Plant Toxins

Much emphasis has been put on the difference between natural and synthetic chemicals, the idea being that the former are in one way or another different from the latter, and thus by definition harmless, while synthetic chemicals are likely to be harmful at all dose levels (Aitio, 2002). Plants have endogenous defense mechanisms resulting in toxin production, that serve to protect them against predators. There is a wide range of such natural toxins (Beier, 1990), but only a small percentage has been tested in high-dose animal cancer tests. Of those tested, almost half have shown carcinogenic action in rodents (Ames and Gold, 1990). It has been estimated that nearly all pesticide residues in diet are of natural origin (99.99% natural vs. 0.01% synthetic), thus the daily average consumption of natural pesticides, carcinogenic or not, exceeds that of synthetic by almost 10,000 times (Ames et al., 1990a). Hence the assertion that natural pesticides do not jeopardize human health could be a fallacy, especially when taking into consideration that many natural chemicals are equally as potent carcinogens and mutagens as their synthetic counterparts (Ames et al., 1990b). In fact, on a molecular basis, the most acutely toxic chemicals known (classified according to the lethal dose in common houseflies) are among natural chemicals (Aitio, 2002).

It may seem that the aforementioned discussion puts forth the idea that human exposures to low-dose synthetic chemicals via diet are relatively unimportant causes of cancer. Denying potential harm of such residues in food, however, is not scientifically defensible nor a prudent public health position. Both natural and synthetic chemicals display great variability in their toxicity, carcinogenic potency, and interdependence, and collective exposures to certain compounds may be important causes of cancer, especially to those individuals who are at greatest risk (Tomatis et al., 2001). Therefore, the data provided herein aim not at casting doubt on the relative importance of synthetic chemicals in the etiology of human cancer; rather, they underscore the importance of natural chemicals. The potential risks posed by these compounds should be pursued with both better residue data and more extensive toxicity testing. Until recently, however, there was no regulatory agency or body designated to oversee potential toxicological issues associated with naturally occurring chemicals (Beier, 1990). In addition, decision-making bodies and legislative authorities seem to be concerned about the health risks associated with synthetic chemicals only, regardless of their proportional contribution to total human exposure, and regulate on the basis of such concerns (Silkworth and Brown, 1996). This is quite surprising, since many toxicological endpoints (neurotoxicity, hepatotocity, respiratory and reproductive toxicity, carcinogenicity, hormone-like activities) are common to both natural and synthetic chemicals at comparable levels of exposure (Aitio, 2002). Furthermore, historically, natural rather than synthetic toxicants have been associated with toxicity episodes of epidemic proportions, attributed to food contamination (Shull and Cheeke, 1983). For a more detailed discussion on the presence and significance of natural and synthetic chemicals in the human diet, the interested reader is referred to an elegant report by the National Research Council (National Research Council and Committee on Comparative Toxicity of Naturally Occurring Carcinogens, 1996).

Comparative studies have not been conducted to investigate the relative presence of natural chemicals in organic and conventional food, probably due to the lack of sensitive analytical methods to detect these substances. Only indirect evidence is available, but still, interesting implications arise. When plants are stressed from infection and/or predation, they characteristically respond with a rapid increase in defensive chemicals, and synthetic pesticides are used to reduce plant stress (Mattsson, 2000). Consequently, it can be argued that natural toxin production is suppressed in the presence of synthetic chemicals, while induced in their absence, in order to maintain defensive integrity. Moreover, the mechanical damage caused by insects, birds, reptiles, and rodents, leads to a significant increase in secondary metabolites that act as precursors of natural toxins (Harborne, 1990). It is obvious that elimination of synthetic agrochemicals in arable areas leads to increased populations of insects and other biota (MacKerron et al., 1999). Indeed, increased populations of birds (25% more at the field edge, 44% more in-field in autumn and winter), invertebrate arthropods (1.6 times as many), spiders (1 to 5 times greater number and 1 to 2 times as many species), and other insects have been reported on organic farms (Soil Association, 2000). Although beneficial for the environment and the ecosystem's biodiversity, they also serve as additional sources of stress to plants and hence, are an additional cause for toxin production.

Of relevance, a recent study reported that soups prepared from organically cultivated vegetables (purchased directly from retail sale) had almost six times as much salicylic acid (median, 117 ng/g; range, 8–1040 ng/g) than conventional soups (median, 20 ng/g; range, 0–248 ng/g) (Baxter et al., 2001). Salicylic acid is a chemical signal in plants infected by pathogens, and although the higher content of organic soups was interpreted by the authors within the context of the anti-inflammatory action of aspirin (i.e. protection against heart attack, stroke, and cancer), this finding also provides evidence for increased stress on organic crops, resulting in higher concentrations of secondary metabolites (phenolic acid in this case). In fact, more recent work has indeed demonstrated that organically cultivated marionberries, strawberries, and corn have approximately 30–50% higher levels of phenolic compounds than conventional ones (Asami et al., 2003). This study, however, was heavily criticized with respect to the appropriate delineation of the production methods used to grow the plants (i.e. whether or not they accurately reflected the organic and conventional systems), as well as for issues relevant to sampling and statistical analysis (Felsot and Rosen, 2004). Other investigators have confirmed these results in strawberries (total phenolics were 12% higher in organic), but only for one out of three cultivars tested (only in 'Jonsok,' but not in 'Polka' or 'Honeyone') (Hakkinen and Torronen, 2000). The latter finding could possibly reflect cultivar-specific differences between organically and conventionally grown crops, and may also illustrate the considerable influence of the plant's genetic make-up. Increased levels of phenolics were attributed to higher ellagic acid (+12%) and especially kaempferol (+150%) concentrations in organic crops (but not quercetin or p-coumaric acid) (Hakkinen and Torronen, 2000), i.e. compounds with antimicrobial properties that are synthesized by plants in response to stress induced by pathogen attack (Dixon and Paiva, 1995). Furthermore, whether or not salicylic acid derived from dietary sources is beneficial to health has not yet been established. It has been suggested that because usual daily intake might be less than 10 mg, and not in the form of aspirin, its effects are unlikely to be significant (Janssen et al., 1996). Incidentally, the recommended dose of salicylic acid for improving cardiovascular health, taken as aspirin, is between 100–300 mg/day. For adequate cardiovascular protection, therefore, this would translate into consuming 1,000 liters of organic soup daily (Trewavas, 2002b).

Another fundamental technique of organic agriculture, practiced regularly by 53% of the organic growers in the US (Walz, 1999), is the use of resistant crop varieties in order to minimize damage and avoid disease. Resistance is mediated by primary plant attributes, especially improved physical structure, and defense-related products, such as secondary chemicals and natural toxins (Agrawal, 2000). Thus, the selection of pest-resistant varieties in organic farming could also mean that these plants have higher levels of natural toxins, or levels of greater potency. Relevant in this respect, previous attempts to increase disease resistance in potato, celery and parsnip varieties by use of wild type plants and resistance breeding programs, led to increased natural toxin concentrations and the withdrawal of these foods from retail sale (Ames and Gold, 1989; McGregor, 1998; Fenwick et al., 1990). Whereas organic farmers prefer crop varieties that are resistant to disease, by contrast, conventional farmers focus on high-yielding strains. It is not unreasonable, therefore, to suggest that conventional agriculture leads to a shift of the plant's energy use towards growth and higher yield, rather than the production of natural chemicals. Taking together some scattered results that can be considered relevant, it has been proposed that the levels of plant defense-related secondary metabolites in organic vegetables could be 10–50% higher than in conventional ones (Brandt and Molgaard, 2001). Nevertheless, adequate experimental evidence to support this assumption is lacking.

These lines of reasoning, however, clearly imply that organically grown crops may have increased concentrations of natural toxins. Still, in the absence of comparative data, only speculations can be made; concrete documentation in this field of study is extremely deficient. Also, it should not be forgotten that knowledge of the specific naturally occurring chemicals that are involved in cancer causation, the mechanisms by which they act, which types of cancer they affect, and the magnitude of these effects, is inadequate (National Research Council and Committee on Comparative Toxicity of Naturally Occurring Carcinogens, 1996). On the other hand, it is certainly true that some (or even the same but at different dose) plant defense-related secondary metabolites may instead be beneficial for human health (Brandt and Molgaard, 2001). This should not sound surprising, since Paracelsus noted as early as the 16th century that "all substances are poisons, and it is only the dose that differentiates a poison from a remedy" (Eason, 2002). This has now become known as the first law of toxicology. The margin between actual or beneficial intake and potentially toxic levels, however, is often small for many of the chemicals found naturally in food (Essers et al., 1998). Thus, contemporary tools for risk management and regulation of synthetic pesticide residues (like the Acceptable Daily Intake, ADI) are not readily applicable to inherent plant toxicants, because in many instances they would preclude consumption of the food (Essers et al., 1998). Only recently have some standardized laboratory tests been developed in an attempt to determine the potential risk posed to animals and humans from eating these plants (Charles et al., 2002). At present, therefore, it is difficult to evaluate the significance of the presence of natural toxins in the diet, much more than it is to compare the effects of organic and conventional cultivation systems in this respect. However, the notion that a 'poison,' by virtue of occurring naturally, is somehow better, safer, or gentler to the consumer is hardly logical.

Biological Pesticides

Little attention has been paid to various other "organic" farming treatments, and while organic proponents claim that synthetic pesticides are dangerous, more than twenty different botanical chemicals are currently available for organic food production and processing, of which nicotine, pyrethrins, rotenone, and warfarin are among the most widely used (Ware, 1996). Organic growers have several different active ingredients with pesticidal properties to choose from, either freely (permitted use) or prior to justification (restricted use); some of these are shown in Table 3 (Fookes and Dalmeny, 2001). It is true that natural sources have yielded a diverse array of effective pesticides including nicotine, pyrethrins, rotenoids, lipid amides, phorbol esters, and many others (Crombie, 1999). A misconception held by some advocates of biological chemicals, however, is that because they are "natural" they are inherently safe (Dewhurst, 2001). Based on "long" experience, it is asserted that organic pesticides are unstable, biodegradable, environmentally friendly, and that their external application on crops entails no

Table 3 Pesticides approved for use in organic farming

Active ingredients	Use	Properties
Copper ammonium carbonate	Banned after 2002*	Copper salts are effective against some fungal disease
Copper sulfate	≫	
Copper oxychloride	≫	
Sulfur	Permitted	Used for control of some fungal disease
Soft soap	Permitted	Used for aphid control
Rotenone	Under review	Naturally occurring plant-based insecticide Asserted to decompose rapidly in the environment
Biological control agents (e.g. predatory lacewings)	Permitted	Used for control of microbial disease outbreaks
Bacillus thuringiensis (Bt) spores	Restricted	Used for pest control
Other insecticides (e.g. natural pyrethrins)	Permitted	Asserted to have no systemic activity

Derived from Fookes and Dalmeny (2001).
*By the European Commission.

Table 4 The health risks of some organic pesticides

Substance	Adverse effects	Reference
Rotenone	• Causes death in fish.	MacKenzie, 1993
	• Induces Parkinson's disease.	Betarbet et al., 2000
	• Inhibits the mitochondrial electron transport chain.	Bashan et al., 1993
	• Induces hepatocyte apoptosis.	Isenberg and Klaunig, 2000
Bacillus thuringiensis (Bt)	• Remains persistent in soil and plant leafs.	Smith and Barry, 1998
	• Produces *Bacillus cereus*-like cytolytic toxins.	Tayabali and Seligy, 2000
	• Causes cutaneous inflammatory lesions in immunosuppressed mice after subcutaneous injection.[a]	Hernandez et al., 1998
	• Causes lung inflammation, internal bleeding and death in immunocompetent mice after administration by the pulmonary route.[a]	Hernandez et al., 1999
	• Infects wounds from traumatized (and probably immunosuppressed) human patients.	Hernandez et al., 1998; Damgaard et al., 1997
	• Has been implicated in a gastroenteritis outbreak, along with *Bacillus cereus* and Norwalk virus.	Jackson et al., 1995
Natural pyrethrins[b]	• Although some are equally toxic against houseflies (the expected effect), the toxicity to mammals can be more than 40-fold higher for certain pyrethrins than for the respective pyrethroids.	Aitio, 2002
	• Most pyrethrins are less effective than the respective pyrethroids and have to be used at higher doses.	Trewavas, 2001
	• Several pyrethrins and pyrethroids are equally neurotoxic in rodents.	Dorman, 1991
	• Residues of both types have been detected in food, but in acceptable amounts.	Nakamura et al., 1993

[a]The doses used to invoke these results in mice were relatively high: a single human exposure to doses of such magnitude is unlikely, especially since the implicated Bt serotype (H34) is not used in commercial pesticides.
[b]Pyrethrins are natural insecticides that were used as basis for the development of synthetic analogues, called pyrethroids.

hazards. Still, most such preparations have not received proper biological investigation in terms of their impact on human health (Dewhurst, 2001), although some may carry previously unrecognized risks (Table 4) (Walz, 1999; Aitio, 2002; MacKenzie, 1993; Betarbet et al., 2000; Bashan et al., 1993; Isenberg and Klaunig, 2000; Smith and Barry, 1998; Tayabali and Seligy, 2000; Hernandez et al., 1998; Hernandez et al., 1999; Damgaard et al., 1997; Jackson et al., 1995; Trewavas, 2001; Dorman and Beasley 1991; Nakamura et al., 1993). The key point here is to emphasize that the safety of biological pesticides cannot be automatically assumed by virtue of their natural presence and/or origin.

The adoption of these practices by the organic community for many years indicates the power of "assertion" rather than scientific knowledge. It is also surprising that the Reduced Risk Program of the US Environmental Protection Agency (EPA) applies for synthetic pesticides only, and does not include biological ones (Tinsworth, 2000). Most of these chemicals have not been tested with respect to their influence on food safety and the risks, if any, remain unknown. Potential hazards, however, are not associated with organic food production only, because botanical pesticides may be used to an extent by conventional farmers as well. Unfortunately, and despite that sensitive and accurate laboratory procedures for the determination of such compounds have already been developed (Zang et al., 1998), only a few relevant comparative studies have been carried out. The limited data available do not indicate any difference between organic and conventional food products (fruit- and vegetable-based baby foods purchased from local retailers) with respect to the levels of some botanical pesticides, like nicotine, pyrethrins I and II, warfarin, and rotenone; in fact, residue concentrations in both types of produce were undetectable (Moore et al., 2000).

Another issue of attention is the use of copper salts, and especially Bordeaux mixture (a liquid solution of copper sulfate and calcium oxide), as fungicides in organic agriculture. It has been reported that although organic farmers were advised to use these substances sparingly, more frequent treatments of crops with copper sulfate were applied on organic farms (Trewavas, 2001). Despite the fact that use of copper salts was banned after 2002 by the European Commission (this decision may vary around the world), they remain persistent in soil and produce, thus raising concern over food contamination with copper. Perhaps relevant in this respect, a recently published review paper concluded that, on average, organically grown crops contain approximately 10% more copper than conventional ones (Worthington, 2001). It is impossible, however, to determine whether higher copper levels in organic food entail a risk to human health, or are by contrast beneficial, since the author considered the percent (%) difference only and did not provide the actual contents. Even so, it would still be difficult to interpret this finding, since dietary requirements and upper tolerable levels of copper intake are still subject to conjecture (Buttriss and Hughes, 2000). Copper is normally subject to effective homeostatic control, but excess dietary intake can occasionally be toxic (Bremner, 1998). Finally, the US Department of Agriculture's (USDA) Rule on National Organic Standards, finalized in December 2001, also allows the use of sodium fluoride in organic food production. Fluoride is a persistent and non-degradable toxic compound that accumulates in soil, plants, wildlife, and humans (Connett and Connett, 2001). Existing data indicate that subsets of the population (elderly, people with deficiencies of calcium, magnesium, and/or vitamin C, and people with cardiovascular and kidney problems) may be unusually susceptible to the toxic effects of fluoride and its derivatives (Connett and Connett, 2001). This potential food hazard, however, has not been considered to date, hence no data are currently available in respect to fluoride content in organic and conventional food products.

Despite the scarcity of research regarding the levels of such chemicals in organic and conventional food, whether or not biological pesticides are more intensively used than their synthetic counterparts, due to their lower potency and effectiveness, is widely publicized and often controversial. Unfortunately, most information comes from anecdotal and non-peer reviewed reports. For example, an analysis of US data on national pesticide use has revealed that organic fungicides like copper and sulfur are applied at significantly higher rates of active ingredient than synthetic ones (average application rates for synthetic fungicides, copper and sulfur were 1.6 vs. 4.2 vs. 35.5 pounds/acre, respectively) (Avery, 2001a). This interpretation of the data, however, is biased by the author's failure to distinguish between the amounts of copper and sulfur used on organic and conventional fields. Copper and sulfur are used in conventional farming as well, and although it is reasonable to assume that their application rate is minimal, due to the availability of more effective synthetic fungicides, one cannot rule out a serious distortion of the figures referred to above, since even a minimal rate of application multiplied by the proportionally greater conventional land could significantly contribute to the total application rate of these compounds. Nevertheless, it was recently reported that sulfur had to be applied in amounts 40% higher than a corresponding synthetic fungicide, in order to produce apples of the same marketable quality: over 3 years of testing, the conventional fungicide program resulted in an average of 9 and 5 applications per year for McIntosh and Liberty apple varieties, respectively, compared with 12.6 and 7 applications, respectively, for the sulfur program (Ellis et al., 1998).

Pathogenic Microbes

Although both publicity and research have focused on preharvest food safety in animal foods, fresh produce has been implicated in major foodborne illness outbreaks (Beuchat and Ryu, 1997; Keene, 1999). An increasing number of these cases has been directly linked to fecal contamination of fresh or minimally processed food (lettuce, potatoes, and unpasteurized apple cider) (Armstrong et al., 1996). Most frequently, but not always, the implicated food was produced locally on a small scale (Cody et al., 1999). Animal manure may contribute several disease agents to soil, and while some die off in time, others persist for long periods (Pell, 1997). Use of untreated manure on produce crops carries a higher risk of contamination compared with treated manure, which has markedly reduced levels of pathogens (Pell, 1997). Nevertheless, composted manure is not free of microbes as well, because conditions that effectively destroy them are not well defined (Institute of Food Technologists (IFT), 2002), and new emerging pathogens with changing epidemiological characteristics are difficult to control (Tauxe, 1997). Contamination with fecal pathogens poses a potential threat for foodborne illness if sufficient levels of viable pathogens are contained in the produce.

The use of manure rather than chemical fertilizers unequivocally contributes to an increased risk of food microbial contamination (Beuchat and Ryu, 1997; Tauxe et al., 1997). Utilization of treated and untreated manure as a source of crop fertilizer, however, is common in both organic and conventional agriculture, hence potential risks seem to apply equally. Nevertheless, conventional farmers have a variety of effective synthetic fertilizers at their disposal, along with manure, while organic farmers do not. In fact, it is generally accepted that the importance of manure as an alternative source of plant nutrients is greater in organic production than in conventional systems (Albihn, 2001). Thus, it can be argued that manure application in organic farmland is much more intensive and widespread. Moreover, the increased populations of several biota species on organic fields (Mader et al., 2002; Soil Association, 2000; Chamberlain et al., 1999) may serve as additional contamination sources, since contact with reptiles, rodents, insects, and birds offer various other portals through which fecal pathogens can access produce (Beuchat and Ryu, 1997).

Decontamination of food by means such as irradiation, antimicrobial agents, chemical washes, and other synthetic disinfectants is prohibited in organic production, while more widely accepted practices, like pasteurization and the use of chlorinated water, are only optional. Adoption of potentially 'risky' organic farming practices varies widely among growers (Figure 7) (Walz, 1999; Magleby, 1998), and one cannot rule out the possibility that not all organic farmers practice pasteurization and chlorinated washing. Consequently, it can be argued that organic crops may carry a relatively higher risk of microbial contamination compared with conventional ones, due to increased presence of pathogens via manure and plant predators, in addition to fewer decontamination alternatives. Whether organic produce is indeed more susceptible to microbial contamination, however, is highly controversial (Schmidt, 1999; DiMatteo, 1997; Stephenson, 1997). Many of the assumptions behind this assertion, which is responsible for most of the organic food's bad press, are debatable. Although it has been claimed that organically grown plant foods are 8 times more likely to be contaminated by *E. coli* O157:H7 (Avery, 1998), no data were ever presented to support this statement. Such claims remain unproven, and two relevant investigations reported zero occurrence of *E. coli* O157:H7 in both organic and conventional vegetables (Mukherjee et al., 2003; Bailey et al., 1999).

The UK Food Standards Agency's (FSA) view is that there is currently no firm evidence to support the assertion that organic produce is more or less microbiologically safe than conventional food (Food Standards Agency (FSA), 2000). In addition, a recent review by the UK Ministry of Agriculture, Fisheries and Food (MAFF) also concluded that there is insufficient information at present to state categorically whether the risk of pathogen transfer to produce on organic farms differs significantly from that associated with conventional farming practices (Nicholson et al., 2000). Finally, the bulk of available evidence from comparative studies shows no significant differences in the bacterial status of organically and conventionally grown cereal (wheat, rye) and vegetable (carrots, spring mix, Swiss chard, salad vegetables) crops (Figure 8) (Marx et al., 1994; Phillips and Harrison, 2001; Hamilton-Miller and Shah, 2001; Moreira et al., 2003; Ponce et al., 2002; Ponce et al., 2003; Rosenquist and Hansen, 2000).

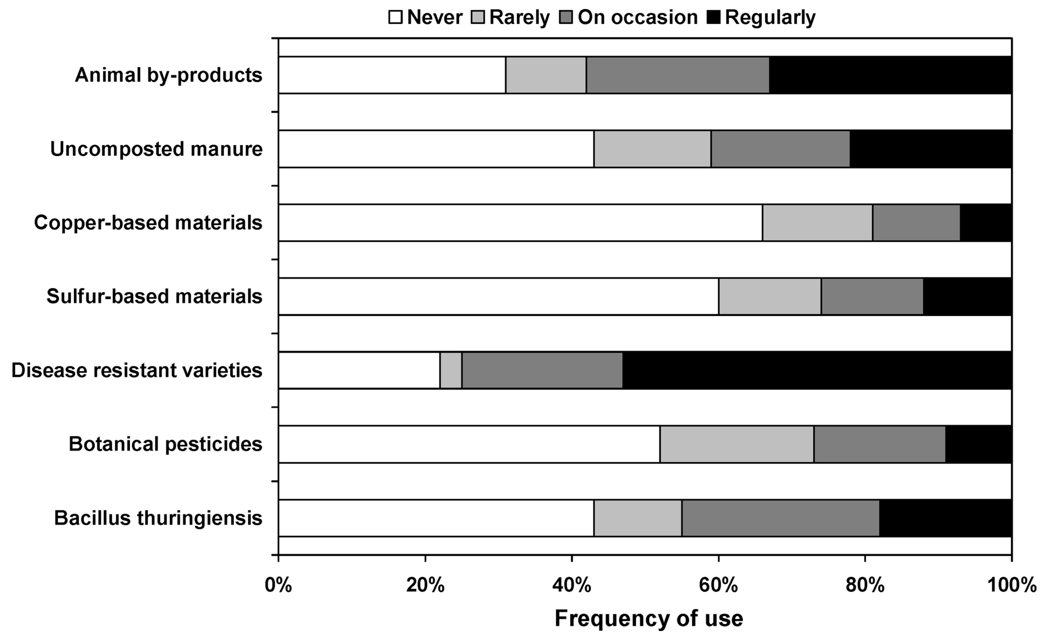

Figure 7 Use of potentially hazardous practices among organic producers. During December 1997 and January 1998, a fifteen-page questionnaire was mailed to 4,638 certified organic producers throughout the US, asking for information about a variety of topics corresponding to their farms. For the practices shown in the figure, respondents (approximately 1,060 for each category) were asked to indicate their frequency of use pertaining to each of the management strategies or materials shown. Derived from Walz (1999).

Nevertheless, unpublished work carried out in the Center for Food Safety and Quality Enhancement at the University of Georgia (reported in Doyle, 2000) indicated that *Salmonella* spp. were detected in 7.7% (3 of 39 samples) of organic sprouts but not in any of the 39 samples of conventional sprouts. Generic *E. coli*, which is an indicator of fecal contamination, was detected in 16.7% (8 of 48 samples) of organic spring mix (mesclun lettuce) at an average count of 10^6 *E. coli* per gram, whereas the bacterium was detected in 8.3% (4 of 48 samples) of conventional spring mix at an average count of 10^4 *E. coli* per gram (Doyle, 2000). Others, too, have detected several *E. coli* strains (not O157:H7) and *Salmonella* spp. more frequently in organically than in conventionally grown vegetables (Mukherjee et al., 2003; Bailey et al., 1999). Although no

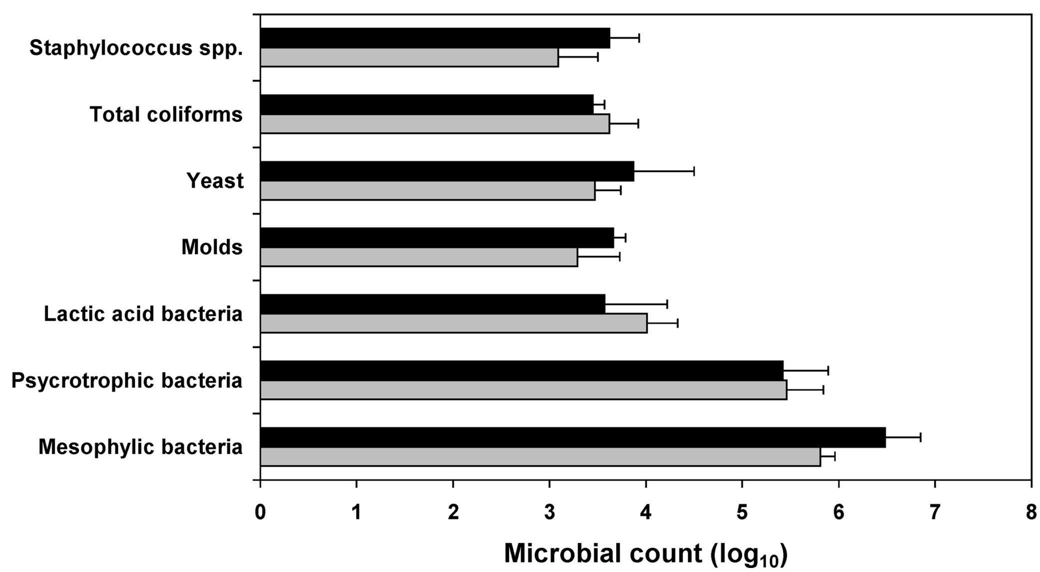

Figure 8 Microbiological status of organic and conventional chard. The native microflora of fresh Swiss chard (Beta vulgaris, type cicla) cultivated by organic (Ponce et al., 2003) (gray bars) and conventional (Ponce et al., 2002) (black bars) methods was quantified and characterized from 28 different samples of each type. Values are shown as mean ± standard deviation. No significant differences in the microbial populations between the two types of produce were identified. Derived from Ponce et al. (2002, 2003).

meaningful conclusions can be drawn from just a few studies, it is clear that organic produce is not immune to contamination incidents. For instance, out of 86 commercially available organic vegetables that were tested for several enteric pathogens, *Aeromonas* spp. were isolated from 34% of the total number of samples examined (McMahon and Wilson, 2001). Interestingly, the organism was present in 41% of the so-called ready-to-eat (i.e. minimally processed) vegetables (McMahon and Wilson, 2001). A large-scale microbiological study of a variety of uncooked ready-to-eat organic vegetables (21 different types) on retail sale, however, carried out jointly by LACOTS (Local Authorities Coordinating Body on Food and Trading Standards) and the PHLS (Public Health Laboratory Service), found most of the samples to be of satisfactory (3,146 of 3,200; 98.5%) or acceptable (39 of 3,200; 1%) quality with respect to the presence of pathogens likely to cause food poisoning; only 15 samples (0.5%) were of unsatisfactory microbiological quality (Public Health Laboratory Service (PHLS) and Communicable Disease Surveillance Centre (CDSC), 2001; Sagoo et al., 2001). Still, ready-to-eat fruits and vegetables, irrespective of origin (i.e. organic or conventional), may pose serious health risks, hence the potential—if any—of organic farming to modify in any way the pattern of food contamination with pathogens has to be acknowledged and further investigated by the scientific community (European Commission Health and Consumer Protection, Directorate-General (DG SANCO) 2002).

Although several foodborne disease outbreaks have been associated with organic food or food produced in line with organic standards, e.g. ascariasis (Oppenheim, 1971), gastroenteritis, hemolytic uremic syndrome, thrombotic thrombocytopenic purpura, and even death (Cieslak et al., 1993; Tschape et al., 1995), it remains unclear whether organic farming practices per se are to blame. Contamination of produce can occur in the field or orchard; during harvesting, post-harvest handling, processing, shipping, marketing, or at home (Beuchat and Ryu, 1997; Brackett, 1999). For example, in a case of contamination of organically grown spinach with *Salmonella* spp., the microbiological testing of the spinach for the presence of pathogens was negative when it was harvested and on arrival at the processing plant, but positive after packaging (Public Health Laboratory Service (PHLS) and Communicable Disease Surveillance Centre (CDSC), 2002). Another such incident was due to laboratory cross-contamination: in the aforementioned LACOTS/PHLS study, *E. coli* O157 was isolated from one sample of organic mushrooms, which were immediately withdrawn from sale by the retailer. Further microbiological investigations, however, proved that the mushroom sample was not the source of the pathogen, but became contaminated in the laboratory by a strain of *E. coli* O157 used for quality control testing (Public Health Laboratory Service (PHLS), 2000). Apparently, microbiological food safety is a complex, fundamental issue of continuing concern; contributing to this complexity are ongoing changes in demographics, geographic origin of food, food production and processing, food consumption patterns, and microorganisms themselves (Institute of Food Technologists (IFT), 2002). Hence, it probably extends far beyond the mere effects of the cultivation system per se.

Mycotoxins

The presence of fungi gives cause for another serious concern regarding food safety. Mycotoxins are toxic by-products of certain molds. There are several subgroups of mycotoxins, of which the major one are aflatoxins. Aflatoxins are a group of closely related toxic substances, produced mainly by the fungi *Aspergillus flavus* and *Aspergillus parasiticus*, which grow on peanuts, corn and other grains, particularly under hot, humid conditions (Havender and Coulombe, 1996; Peraica et al., 1999). The most toxic and carcinogenic member of this family, aflatoxin B_1, is acutely poisonous, highly mutagenic and intensely carcinogenic in rodents and other animals (Havender and Coulombe, 1996). In humans, aflatoxin B_1 and its major animal metabolite, aflatoxin M_1, can induce hepatocellular cancer at low doses if ingested over a prolonged period of time (National Toxicology Program, 2002). Other mold toxins sometimes found in specific foods include fumonisins, sterigmatocystin, ochratoxin A, deoxynivalenol, T-2 toxin, patulin, penicillic acid, and griseofulvin (Havender and Coulombe, 1996; Peraica et al., 1999). All have shown carcinogenic activity in animal tests. Mycotoxins can enter the human food chain by two major routes: direct contamination resulting from the growth of fungi on the food or indirect contamination resulting from the incorporation of contaminated ingredients into food (Wood et al., 2001).

Fungal attack and mycotoxin contamination in organically and conventionally grown produce is an extremely controversial issue on theoretical grounds. Since effective synthetic fungicides are not allowed in organic production, it is logical to assert that organic crops may be more susceptible to fungi contamination. Also, lower nitrogen application in organic crops is likely to increase their sugar content, since these two variables are quite often negatively related (Poulsen et al., 1995; Eppendorfer and Eggum, 1992), and thus, make them more susceptible to fungal attack. In accordance with this notion, a recent investigation has demonstrated an inverse relationship between aflatoxin B_1 levels in corn and nitrogen application rates, i.e. the lower the nitrogen fertilization the higher the level of contamination (Tubajika et al., 1999). By contrast, post-harvest production of ochratoxin A in barley was previously reported to positively correlate with protein accretion resulting from higher nitrogen application rates (Haggblom and Ghosh, 1985). Also, organic supporters advocate that increased nitrogen fertilization in conventional crops, in order to speed up growth, results in thinner plant cell walls that, in turn, are more susceptible to fungal attack (Heaton, 2001; Watts, 2001). In addition, tilling the soil between crop applications is indispensable in organic systems as a weed control technique, since use of fungicides is prohibited (Fookes and Dalmeny, 2001). Compared with no-tillage, however, plough tillage has been shown to reduce the incidence of fungal attack and the concentration of the respective toxins in cereal crops (Krebs et al., 2000). These are the counter arguments supporting the claim that organic produce may be less prone to mycotoxin contamination than conventional produce.

Adding to this profound confusion of principles, some studies have documented that organic cereal crop fields may sometimes act as fungi reservoirs (Eltun, 1996), with some mycotoxin-producing species being found approximately 5 times more frequently in organically than in conventionally farmed soil (35 vs. 7% of the soils examined, respectively) (Elmholt, 2002). On the contrary, others have reported that abundance of pathogenic fungi in organic wheat was less than half of that found in conventional crops (Birzele et al., 2002). Finally, some have observed no significant differences in the total viable fungal content between organically and conventionally grown cereals and cereal-based foodstuffs (Marx et al., 1994; Mislivec et al., 1979). It has been suggested, therefore, that the organic farming system as such does not present problems associated with mycotoxin contamination; rather, it is certain management practices in relation to home grown seed, crop rotations, organic fertilizers, exclusion of fungicides, as well as drying and storage facilities, that are inappropriate and may be more prevalent in organic food production (Elmholt, 2002).

With respect to arable crops other that cereals, available data are scarce. In one study, organically grown potatoes were found to suffer more intensively from potato blight than conventional ones, and became secondary sources of infection resulting in a spreading of molds to adjacent fields (Zwankhuizen et al., 1998). In addition, it was recently reported that occurrence of fungi in soils from arable organic fields was significantly higher compared with conventional ones, but no differences could be identified between the field margins of the two cropping systems (Klingen et al., 2002). Some have suggested that organic farms are protected from the full effects of a disease outbreak, only because they are surrounded by conventional farms that use effective synthetic fungicides (Trewavas, 2001). Moreover, the moderate success to date in avoiding fungal disease in organically grown crops, and especially potato blight, has been partly attributed to Bordeaux mixture (MacKerron et al., 1999). Approval for the use of Bordeaux mixture in crops was withdrawn after 2002 across Europe, however, so that the organic system is now left with few means other than genetic resistance to combat disease. Since organic farming and genetic engineering are two diametrically opposite philosophies (Koechlin, 2002), the organic industry will have to seek other alternatives. Work being carried out on a purple potato variety that appears to have high natural resistance to the disease holds out great hope of a natural remedy to counter the blight in organic potatoes (Chaffey, 2001). Nevertheless, as already mentioned, disease-resistant crop varieties may contain higher levels of natural toxins; yet, the molecular basis of the natural resistance of the purple potato variety has not been clarified to date.

For human health and the economy, mycotoxins are by far the most important contaminants of the food chain (van de Venter, 2000). Given that they constitute a major health hazard, their relative presence in food produced organically or conventionally has been the subject of several studies. From a review of the evidence, however, it cannot be concluded that either type of farming leads to increased risk of mycotoxin contamination; to facilitate processing by the reader, the main findings are summarized in Table 5 (Malmauret et al., 2002; Birzele et al., 2002; Marx et al., 1995; Schollenberger et al., 1999; Beretta et al., 2002; Czerwiecki et al., 2002; Doll et al., 2002; Jorgensen and Jacobsen, 2002; Schollenberger et al., 2002, 2005; Lucke et al., 2003; Biffi et al., 2004). The majority of available studies have been carried out in cereals and cereal-based products, as these crops are more susceptible to fungal attack than others. Apparently, results vary greatly among different crops and for different mycotoxins. Organically grown food has been reported to be either more, less, or equally contaminated compared with conventional food (see Table 5). Unfortunately, data are not directly comparable even within the same crop, because different cultivars exhibit quite distinct patterns of contamination. For example, among twelve different varieties of conventional wheat, all of which were grown in the same year and geographical location, deoxynivalenol contamination varied approximately 6-fold with respect to frequency (from 17 to 100%), 15-fold with respect to mean levels (from 160 to 2,390 μg/kg), and 65-fold with respect to maximum levels (from 180 to 11,660 μg/kg) (Doll et al., 2002). Geographical location and time of harvest are also important when examining differences between the two cultivation systems (Czerwiecki et al., 2002). Overall, however, in respect to cereal crops, one should bear in mind that only minor mycotoxin contamination can occur before harvest; the main source of human exposure are improper post-harvest storage conditions that foster mold growth (Havender and Coulombe, 1996). Thus, it is not clear which and how much of the differences referred to above and shown in Table 5 can be attributed to the cultivation system per se.

Besides cereals and cereal-based products, comparative data regarding the frequency and level of contamination by various mycotoxins in other food groups are scarce. One highly publicized incident is that of higher patulin concentration in organic apple juice compared with conventional one, with reported maximum levels of this mycotoxin being more than 10-fold greater in the former than in the latter type of cider [approximately 45,000 vs. 4,000 μg/kg, respectively (note that these concentrations are extremely high compared with the recommended limit of 50 μg/kg)](Jukes, 1990; Lovejoy, 1994; Lamberts, 2003). It has been argued, however, that rotten organic fruit were not removed prior to processing (Tamm, 2001). Such an omission could probably account for much of the difference mentioned above, since it was recently shown that, in rotten apples, not only is the amount of patulin extraordinarily high in the rotten area, but the mycotoxin also spreads to the unaffected parts of the fruit (Beretta et al., 2000). Regardless of the previous confusion, contemporary experiments again provide evidence of increased patulin contamination in organically produced fresh apples (Malmauret et al., 2002) and apple juice (Beretta et al., 2000) compared with conventional ones (Figure 9). For instance, mean and maximum levels of this mycotoxin were approximately 7.6-fold and

Table 5 Mycotoxin contamination in organic and conventional cereal crops

Food sampled	Mycotoxins	Main findings	Reference
Wheat ($n = 22$) and barley ($n = 10$).	DON 3-ADON 15-ADON NIV T-2 HT-2 ZEA DAS FB_1 OTA	• Incidence of DON contamination was lower in Org. vs. Conv. wheat (54.5 vs. 90.9%, respectively) and barley (60 vs. 80%, respectively). • Median levels of DON were higher in Org. vs. Conv. wheat (106 vs. 55 μg/kg, respectively) and barley (69 vs. 41 μg/kg, respectively). • Incidence of 3-ADON contamination was higher in Org. vs. Conv. wheat (9.1 vs. 0%, respectively); it was not detected in either barley type. • Incidence of NIV contamination was higher in Org. vs. Conv. wheat (90.9 vs. 0%, respectively) and barley (80 vs. 20%, respectively). • Median levels of NIV were higher in Org. vs. Conv. barley (83 vs. 10 μg/kg, respectively); median levels of NIV in Org. wheat were low (10 μg/kg). • Incidence of HT-2 contamination was higher in Org. vs. Conv. wheat (9.1 vs. 0%, respectively) and barley (40 vs. 0%, respectively). • Median levels of HT-2 in both Org. wheat and barley were 50 μg/kg. • Incidence of ZEA contamination was lower in Org. vs. Conv. barley (0 vs. 40%, respectively); it was not detected in either wheat type. • Median levels of ZEA in Conv. barley were low (1.25 μg/kg). • None of the remaining mycotoxins were detected.	Malmauret et al., 2002
Winter wheat during 1997 and 1998.	DON	• Mean levels of DON contamination for 1997 were lower in Org. vs. Conv. crops (approximately 100 vs. 150 μg/kg, respectively), but the reverse was true for 1998 (approximately 300 vs. 150 μg/kg, respectively).	Birzele et al., 2002
Rye ($n = 100$) and wheat ($n = 101$).	DON ZEA	• Incidence of DON contamination was higher in Org. vs. Conv. rye (56 vs. 40%, respectively), but the reverse was true for wheat (76 vs. 88%, respectively). • Mean levels of DON were higher in Org. vs. Conv. rye (427 vs. 160 μg/kg, respectively), but did not differ in wheat (486 vs. 420 μg/kg, respectively). • Mean levels of ZEA were higher in Org. vs. Conv. rye (51 vs. 4 μg/kg, respectively) and wheat (24 vs. 6 μg/kg, respectively).	Mark et al., 1995
Cereal-based foods ($n = 237$), including bread and bread-related products ($n = 96$), noodles ($n = 29$), breakfast cereal ($n = 32$), baby food ($n = 25$), rice ($n = 26$), and other cereal-based products ($n = 29$).	DON 3-ADON 15-ADON NIV FUS-X T-2 HT-2 ZEA α-ZOL β-ZOL	• Incidence of DON contamination was lower in Org. vs. Conv. food (55 vs. 77%, respectively). • Median levels of DON were lower in Org. vs. Conv. food (28 vs. 62 μg/kg, respectively). • Mean levels of DON were similar between Org. and Conv. food (128 ± 304 and 97 ± 103 μg/kg, respectively). • Maximum levels of DON were higher in Org. vs. Conv. food (1,670 vs. 624 μg/kg, respectively). • FUS-X, ZEA, α- and β-ZOL were not detected. • Results for other toxins are not reported. No difference?	Schollenberger et al., 1999
Cereal-based baby food ($n = 164$), including semolina ($n = 40$), rice ($n = 48$), multi-cereal ($n = 42$), and maize and tapioca ($n = 34$) formulas.	OTA	• Overall incidence of OTA contamination was lower in Org. vs. Conv. food (15 vs. 33.3%, respectively). However, it varied among individual foods: it was lower in Org. vs. Conv. semolina (10 vs. 60%, respectively) and multi-cereal (0% vs. 80%, respectively) formulas, but higher in rice formulas (45.5 vs. 0%, respectively), and not different in maize/tapioca formulas, where no OTA was detected. • Levels of OTA were generally not different: 0.18 and 0.14–0.65 μg/kg for Org. and Conv. semolina formulas, 0.1–0.4 μg/kg for Conv. multi-cereal formulas, and 0.24–0.74 μg/kg for Org. rice formulas.	
Cereal crops ($n = 237$), including rye ($n = 100$), wheat ($n = 71$), and barley ($n = 66$).	OTA	• Overall incidence of OTA contamination was higher in Org. vs. Conv. produce (19.9 vs. 3.6%, respectively). This finding was consistent among all three individual crops, i.e. rye (37.5 vs. 5.8%, respectively), wheat (19.9 vs. 0%, respectively), and barley (7.9 vs. 3.9%, respectively). • Overall mean levels of OTA were higher in Org. vs. Conv. produce (5.7 vs. 1.11 μg/kg, respectively). This finding was consistent among both rye (3.17 vs. 1.38 μg/kg, respectively) and especially barley (25.73 vs. 0.3 μg/kg, respectively); mean OTA levels in Org. wheat were low (0.83 μg/kg).	Czerwiecki et al., 2002a
Cereal crops ($n = 207$), including rye ($n = 83$), wheat ($n = 71$), and barley ($n = 53$).	OTA	• Overall incidence of OTA contamination was similar between Org. and Conv. produce (15.5 vs. 20.9%, respectively), but varied among the individual crops. It was similar in Org. vs. Conv. rye (10.9 vs. 10.8%, respectively), lower in wheat (23.5 vs. 48.6%, respectively), and higher in barley (11.8 vs. 5.5%, respectively). • Overall mean levels of OTA were 25.5-fold lower in Org. vs. Conv. produce (7.92 vs. 202 μg/kg, respectively). This finding was due to the large difference in Org. vs. Conv. wheat (1.17 vs. 267 μg/kg, respectively), while OTA levels in rye and barley were higher in Org. crops (14.5 and 18.4 μg/kg, respectively) compared with Conv. ones (6.75 and 5.45 μg/kg, respectively).	Czerwiecki et al., 2002b

(Continued on next page)

Table 5 Mycotoxin contamination in organic and conventional cereal crops *(Continued)*

Food sampled	Mycotoxins	Main findings	Reference
Wheat ($n = 196$) and rye ($n = 69$).	DON ZEA	• Incidence of DON contamination was lower in Org. vs. Conv. wheat (54 vs. 69%, respectively), and rye (11 vs. 34%, respectively). • Mean levels of DON were lower in Org. vs. Conv. wheat [760 vs. 1,540 μg/kg dry matter (dm), respectively], and rye (130 vs. 490 μg/kg dm, respectively). • Median levels of DON were similar between Org. and Conv. wheat (230 vs. 270 μg/kg dm, respectively); median levels in both types of rye were below detection limit. • Maximum levels of DON were lower in Org. vs. Conv. wheat (4,220 vs. 11,660 μg/kg dm, respectively), and rye (130 vs. 3,090 μg/kg dm, respectively). • Incidence of ZEA contamination was low and similar between Org. and Conv. wheat (4 vs. 7%, respectively); rye was not analyzed. • Mean levels of ZEA were lower in Org. vs. Conv. wheat (47 vs. 74 μg/kg dm, respectively). • Median levels of ZEA for both types of wheat were below detection limit. • Maximum levels of ZEA were lower in Org. vs. Conv. wheat (55 vs. 250 μg/kg dm, respectively).	Doll et al., 2002
Wheat kernels ($n = 419$) and flour ($n = 276$) and rye kernels ($n = 422$) and flour ($n = 320$) during 1992–1999.	OTA	• Multiyear incidence of OTA was generally low and similar between Org. and Conv. wheat grains (0 vs. 1.2%, respectively) and flour (0.8 vs. 0.6%, respectively). • Multiyear mean concentration of OTA was similar between Org. and Conv. wheat grains (0.3 vs. 0.3 μg/kg, respectively) and flour (0.5 vs. 0.3 μg/kg, respectively). • Multiyear incidence of OTA was higher in Org. vs. Conv. rye grains (11.8 vs. 3.2%, respectively), but it was similar in flour (5.2 vs. 3.6%, respectively). • Multiyear mean concentration of OTA was higher in Org. vs. Conv. rye grains (3.9 vs. 0.9 μg/kg, respectively) and flour (1.8 vs. 0.8 μg/kg, respectively).	Jorgensen et al., 2002
Wheat flour ($n = 60$).	DON 3-ADON 15-ADON NIV FUS-X T-2 HT-2 ZEA α-ZOL β-ZOL	• Incidence of DON contamination was high but similar between Org. and Conv. samples (96 vs. 100%, respectively). • Median levels of DON were lower in Org. vs. Conv. samples (120 vs. 295 μg/kg, respectively). • Mean levels of DON were not significantly different between Org. and Conv. samples (131 ± 150 and 394 ± 341 μg/kg, respectively). • Maximum levels of DON were lower in Org. vs. Conv. samples (756 vs. 1,379 μg/kg, respectively). • FUS-X, α- and β-ZOL were not detected. • Results for other toxins are not reported. No difference?	Schollenberger et al., 2002
Winter wheat ($n = 130$) during 1997–2001.	DON	• Overall incidence of DON contamination was low and not different between Org. and Conv. crops (8.3 and 13.2%, respectively). • Maximum DON levels recorded each year throughout the observation period were also similar between Org. and Conv. crops (60–698 vs. 104–880 μg/kg, respectively).	Lucke et al., 2003
Cereal-based foods ($n = 346$). Cereals included wheat, hard wheat, rice, spelt, barley, oats, and rye. The food products included flours, bakery products (mainly crackers), and baby foods.	OTA	• With respect to commercial flours and their derivatives, there were no significant differences between Org. and Conv. samples. • Some baby foods (semolina) from conventional production had higher content of OTA than the corresponding Org. products, while the reverse was true for rice formulas.	Biffi et al., 2004
Various types of bread from rye, wheat, or mixed cereals ($n = 101$).	DON	• Incidence of DON was higher in Conv. than in Org. samples (96 vs. 82%, respectively). • There was a strong trend ($P = 0.059$) for DON concentration (in μg/kg) to be higher in Conv. samples (median = 161; mean = 184; range = 15–690) than in Org. (median = 46; mean = 62; range = 15–224). • These results were similar for all types of bread examined.	Schollenberger et al., 2005

Org. is organic and Conv. is conventional; n represents the total number of organic and conventional samples analyzed.
Mycotoxins: DON is deoxynivalenol, ZEA is zearalenone, 3-ADON is 3-acetyl-deoxynivalenol, 15-ADON is 15-acetyl-deoxynivalenol, NIV is nivalenol, FUS-X is fusarenon-X, T-2 is T-2 toxin, HT-2 is HT-2 toxin, α-ZOL is α-zearalenol, β-ZOL is β-zearalenol, OTA is ochratoxin A, DAS is diacetoxyscirpenol, and FB_1 is fumonisin B_1.
Mean levels of the various mycotoxins have been derived from the positive samples only, while median refers to all samples, and maximum refers to the sample with the highest concentration.

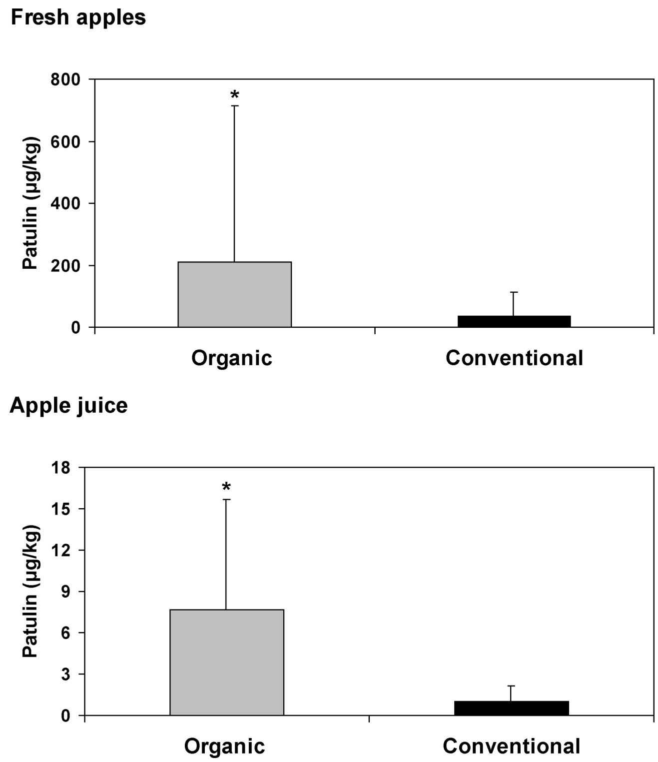

Figure 9 Patulin contamination in organic and conventional fresh apples and apple juice. Twelve samples of fresh apples (2 kg/sample) (Malmauret et al., 2002) and twenty-one commercially available apple juices (Beretta et al., 2000) from organic and conventional production were analyzed for the presence of patulin. Values are shown as mean ± standard deviation. *$P < 0.05$ vs. conventional produce. Derived from Malmauret et al. (2002) and Beretta et al. (2000).

9.3-fold greater, respectively, in organic than in conventional cider (Beretta et al., 2000). Others, however, do not support this finding: patulin levels in conventional apple-based products ranged from 5.8 to 56.4 μg/kg with an average of 24.76 μg/kg, while in organic products they ranged from 1.4 to 74.2 μg/kg with an average of 28.34 μg/kg (Ritieni, 2003). Readers should not take any of this information as an indictment of organic produce, because patulin concentrations in apples are very sensitive and responsive (both upwards and downwards) to several harvesting techniques, storage conditions, and other processing practices that are irrelevant to the farming system per se (Sydenham et al., 1997; Jackson et al., 2003).

Finally, two earlier studies have reported on increased levels of aflatoxin M_1 contamination in conventional compared with organic milk (Woese et al., 1997). Other investigators have detected this toxin in a few samples of conventional milk (less than 10%), but not in any of the organic samples; actual alflatoxin concentrations, however, were considerably below acceptable levels (Lund, 1991; Food Standards Agency (FSA), 2001). Similarly, no differences in the frequency and levels of contamination by ochratoxin A were observed between the two types of milk (Food Standards Agency (FSA), 2001; Skaug, 1999). The limited number of studies and the lack of conclusive evidence preclude generalization of these results.

It is important to note that both frequency and actual levels of contamination have to be considered along with consumption patterns since, as mentioned above, toxicity is a function of exposure (Rozman et al., 2001). To clearly illustrate this point, a recent study has demonstrated that the rate of contamination of organic wheat samples with deoxynivalenol was lower than that of conventional ones (54.5 vs. 90.9%, respectively), but median, mean, and maximum levels of this mycotoxin were 2–3 fold higher in organic than in conventional crops (106 vs. 55, 250 vs. 80, and 494 vs. 215 μg/kg, respectively) (Figure 10) (Malmauret et al., 2002). On the basis of these results, a follow-up study used the probabilistic approach (a statistical method aiming at providing the most realistic description of exposure) to simulate consumer exposure to deoxynivalenol, taking into account the frequency and levels of wheat consumption by consumers (Leblanc et al., 2002). It was concluded that individuals

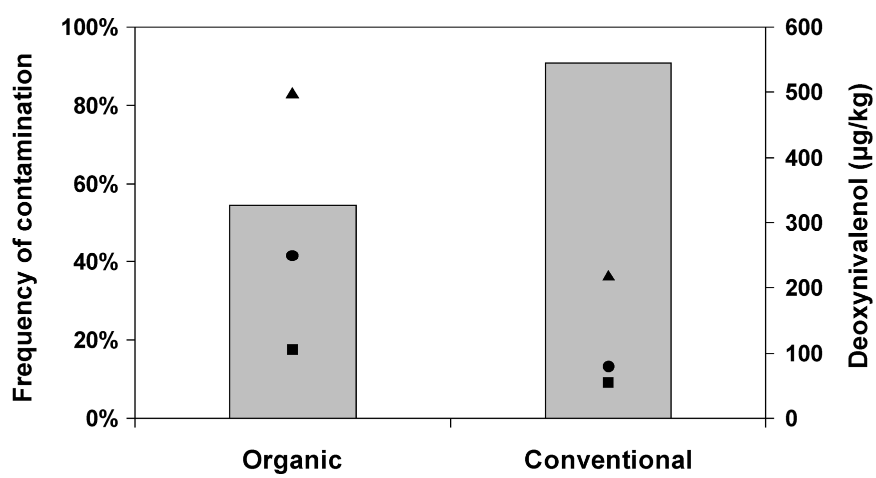

Figure 10 Deoxynivalenol contamination in organic and conventional wheat. Eleven conventional and eleven organic samples of wheat (1 kg/sample) were tested for the presence of deoxynivalenol. Median (black squares), mean (black circles), and maximum (black triangles) levels of contamination are shown, along with the frequency of detection of positive samples (gray bars). Derived from Malmauret et al. (2002). Mean levels are reported in Leblanc et al. (2002).

who consume organic wheat are more likely to be exposed to this toxin at levels above the provisional maximum tolerable daily intake compared with those consuming conventional wheat (Leblanc et al., 2002).

PROTECTIVE FOOD COMPONENTS

Food can be considered as an extremely complex and variable chemical mixture estimated to consist of thousands of compounds (macro- and micronutrients, plant metabolites, and numerous low molecular weight chemicals). Such chemicals may have simple similar action (dose addition) or simple dissimilar action (independent action), or they may interact resulting in a stronger effect (synergism, potentiation, supra-additivity) or a weaker effect (antagonism, inhibition, sub-additivity) (Dybing et al., 2002). In addition, exposure to dietary hazardous compounds is generally accompanied by ingestion of substances that exert a mitigating effect. For instance, polyphenols may inhibit the formation of N-nitroso compounds (nitrosamines) from ingested (nitrate) or endogenously formed (nitrite) precursors (Bartsch and Spiegelhalder, 1996). Other dietary compounds may provide protection against co-ingested mycotoxins (Galvano et al., 2001). In general, it is believed that when small amounts of mutagenic and/or carcinogenic compounds (both synthetic and natural) are consumed, they are neutralized by antioxidants in the body (Kiraly, 1996).

Information regarding such non-nutrient food components with potential protective health effects (polyphenols, flavonoids, phytoestrogens, and glucosinolates) could provide some further insight into the safety of the produce, but unfortunately, it is disappointing to note the almost complete lack of comparative studies between organic and conventional food products in this area of research (Williams, 2002). Nevertheless, a recent report prepared for the Soil Association of the UK concluded that certain organic crops appear to have higher contents of phytonutrients, such as lycopene in tomatoes, polyphenols in potatoes, flavonols in apples, and resveratrol in red wine (Heaton, 2001). Also, some organically cultivated vegetables (Welsh onion, Chinese cabbage, carrot, green pepper, Japanese radish) were found to demonstrate significantly higher antimutagenic activity than the respective conventional crops (Ren et al., 2001). Organically grown fruit (peaches and pears) were also reported to have increased concentrations of total polyphenols (between 10% and 36% higher; $P < 0.05$) compared with the respective conventional produce; this was interpreted in terms of improved antioxidant defense of the organically cultivated plants (Carbonaro et al., 2002).

It is also useful to refer to an elegantly designed recent study, in which plums grown in the same farm using organic and conventional methods were examined for the content of a number of phenolic compounds (Lombardi-Boccia et al., 2004). Organic fields were placed at 600 meters from the conventional fields and encircled by a thick hedge; conventional fields were fertilized with synthetic fertilizers, while organic fields were manured with organic fertilizers. The organic cultivation was performed under three different types of soil management: tilled soil (i.e. the same as that utilized for conventional farming), soil covered with *trifolium subterraneum*, and soil covered with natural meadow. For the organic and conventional fruit under tilled soil management, total polyphenol content was significantly higher (+38%) in conventional compared with organic plums, but results with respect to individual phenolic acids and flavonols varied greatly. Among the phenolic acids, protocatecuic and neo-chlorogenic acids were higher in conventionally grown plums, while concentrations of caffeic, p-cumaric, ferulic, and chlorogenic acids were all higher in the organic plums (all differences were significant at $P < 0.05$). Among the flavonols, quercetin levels were higher in conventional plums, whereas the reverse was true for myrecitin and kaempferol (all differences were significant at $P < 0.05$). These results illustrate a wide variability in the response of individual phenolic compounds to different cultivation types (organic or conventional). The authors also observed large and significant differences in the content of phenolics in the organic fruit grown under the three different types of soil management (trifolium and meadow treatments resulted in generally higher concentrations compared with tilling), suggesting that, under the same cultivar and climate conditions, this factor could be of primary importance in influencing the concentration of phenolic compounds (Lombardi-Boccia et al., 2004).

In addition to phenolics, there are many other dietary constituents that can modify the metabolism of carcinogens by inducing enzymes involved in xenobiotic metabolism; these enzymes detoxify carcinogens (phase II enzymes) and this is one well-established mechanism for modulating the risk of cancer. A survey of extracts of a variety of commonly consumed, organically grown vegetables for such enzyme inducer activity identified crucifers (and particularly those of the genus brassica) as particularly rich sources (Prochaska et al., 1992). Unfortunately, no comparison with conventional plant extracts was made. Nevertheless, caution is warranted when interpreting results from isolated studies. For example, although crucifers may provide some protection against cancer when taken prior to a carcinogen, they act as promoters of carcinogenesis when taken after a carcinogen (Beier, 1990).

The scarcity of relevant research is clearly illustrated by the fact that only 4 out of some 400 papers considered in the aforementioned Soil Association report (Heaton, 2001) dealt with phytonutrient content in organically and conventionally grown food. It is also of interest to refer to a recent nutrition intervention study in humans, where 16 healthy volunteers received either an organic or a conventional diet for 22 days (Grinder-Pedersen et al., 2003). The content of some, but not all flavonoids (quercetin and, to a lesser extent, kaempferol) was higher in the organic than in the conventional diet, and this was also reflected in higher urinary excretion of these compounds after the organic regimen. The authors commented that the differences in flavonoid content between the two diets could actually be due to varietal differences, because different varieties of fruits and vegetables comprised each regimen. These different varieties, however, were representative of the organic and conventional varieties of fruits and vegetables available on the market and thus, were asserted to reflect a realistic composition of each diet (Grinder-Pedersen et al., 2003). Despite the higher levels of these flavonoids in the organic regimen, however, most markers of antioxidative defense in these subjects did not improve, and in fact, the organic diet resulted in increased protein oxidation and decreased total plasma antioxidant capacity (Grinder-Pedersen et al., 2003). Until more data become available, it is prudent not to further comment on the significance of these findings. What becomes apparent, however, is that our understanding of the factors that regulate phytonutrient content in plants, and of the effects these food components may have on human health, is far from complete.

CONCLUSIONS

Addressing food safety of organic versus conventional produce is difficult, especially in the face of limited and conflicting data. In order to carry out a valid comparison between organic and conventional food products, it is required that the plants be cultivated in similar soils, under similar climatic conditions, be sampled at the same time and pre-treated similarly, and analyzed by accredited laboratories employing validated methods (Kumpulainen, 2001). In terms of foods of animal origin, animals would have to be fed on plants meeting the above production criteria (Kumpulainen, 2001). In spite of the heterogeneity of the material and research methodology, however, some differences can be identified (Table 6); still, overrating or generalizing these trends is not advisable. For reasons of comparison, the reader should recall that the determination of differences in the nutritional content of crops originating from organic or conventional farming has been the objective of scientific research since the first quarter of the 20th century (McCarrison, 1926). Although a vast number of relevant studies have been carried out to date, reviews of the past decade on the nutritional value of these crops have reached equivocal conclusions (Bourn, 1994; Lecerf, 1995; Woese et al., 1997; Worthington, 1998, 2001; Bourn and Prescott, 2002; Williams, 2002; Magkos et al., 2003a). Taking into consideration the substantially less extensive testing of organic crops with respect to their safety characteristics, the need for prudence and caution in the interpretation of the results becomes readily apparent.

Table 6 Comparison of organic and conventional products with respect to food hazards

Organic < Conventional	Organic = Conventional	Unknown
Synthetic agrochemicals[a]	Environmental pollutants[d]	Natural plant toxins
Nitrate[b]		Biological pesticides
Contaminants in feedstuffs[c]		Pathogenic microbes
Veterinary drugs[c]		Mycotoxins

[a] vegetables and fruits.
[b] nitrophillic vegetables.
[c] foods of animal origin.
[d] heavy metals (e.g. cadmium, lead), dioxins, polychlorinated biphenyls, radioactive nuclides.

Publicizing the findings of one or just a few studies, no matter how credible they may be, could be misleading and confusing for the public (Wellman et al., 1999). On top of that, many comparative studies on safety aspects of organic and conventional food suffer serious methodological limitations; hence their findings should be interpreted accordingly. For instance, most investigators provide only limited information about the actual production methods; the majority simply mentions that the samples tested were of 'organic' or 'conventional' origin. It has also been argued that, most agricultural and horticultural crops are subject to a number of preharvest, postharvest, and marketing factors that do not interfere with the organic status of a commodity, but may introduce systematic bias in the quality of food intercepted in the marketplace (Harker, 2004). It is, therefore, difficult—if not impossible—to determine whether and the extent to which the samples examined in some studies represent the food production system in an accurate but also realistic manner.

To summarize the key points, it seems that organic food may not be pesticide-free, but as far as fruits and vegetables are concerned, organic crops can be expected to contain agrochemical residues much less frequently and at lower levels than their conventional alternatives. This, however, cannot apply so far to other types of produce, because relevant data are extremely scarce. Another important issue is that the health risks associated with dietary exposure to such chemicals remain to be evaluated. Further, the weight of evidence suggests that organically cultivated nitrophillic vegetables, such as leafy, root and tuber vegetables appear to have lower nitrate content than the respective conventional ones; other crops, with low nitrate accumulating potential, would be expected to show no differentiation. Yet, whether dietary nitrate has harmful or beneficial effects on human health, and if both, at what levels of consumption, is an unresolved issue. Presumably, organic food of animal origin contains fewer veterinary drug and related chemical residues compared with conventional products, but adequate research to support this assumption is lacking. Environmental contaminants, on the other hand, are likely to be found in food from both production systems. Regarding natural plant toxins and biological pesticides, conclusions remain tentative in the absence of comparative research, even though it may be hypothesized that foods produced in the organic fashion have elevated levels of such compounds. By contrast, there is no firm evidence to date to support the notion that organic crops are more or less susceptible to microbial contamination. Finally, as far as fungal disease and subsequent mycotoxin production are concerned, there remains a high level of uncertainty in light of the great divergence of existing data.

Weighing the risks is therefore difficult, especially when considering the significant gaps in scientific knowledge with respect to evaluating the isolated and/or combined presence of synthetic chemicals, nitrates, pathogenic microbes, natural toxicants, environmental pollutants, and myxotoxins in food. If anything,

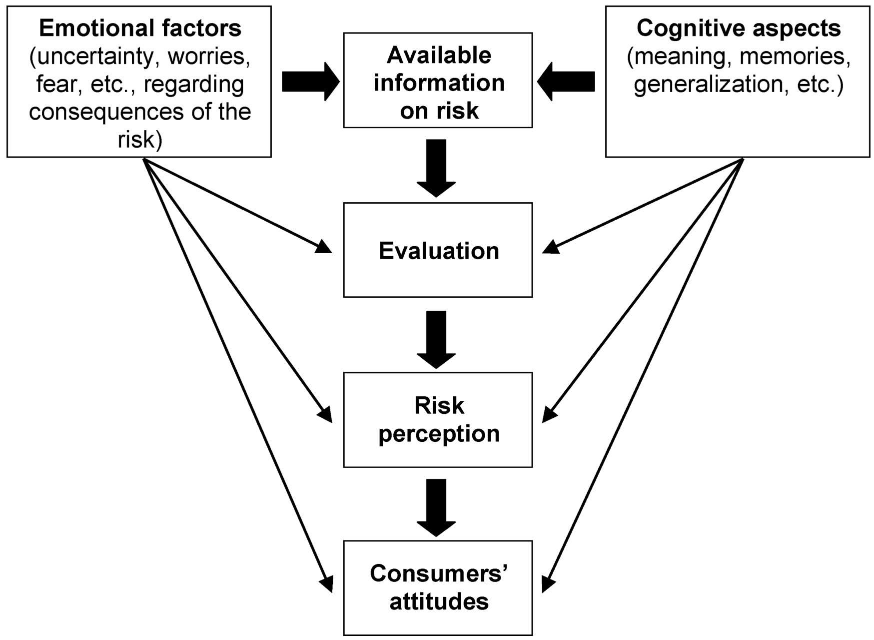

Figure 11 A simple and interpretative model for consumers' attitude toward food-associated risks. Redrawn with permission after Morasso et al. (2000).

however, consumers have to be aware that pursuit of zero risk is a chimera (Sharpe, 1999).

DISCUSSION

Despite all the inherent limitations, evidence in relation to food safety and human health in a more generalized sense is available, and permits some useful conclusions to be drawn. In contrast to the popular perception that chemical residues in food are the major source of food contamination (Morasso et al., 2000), recent foodborne disease outbreaks have demonstrated that microbial hazards are much more significant for food safety (Cliver, 1999). Social and ethical concerns, however, are formed more on the basis of cultural and social values than on scientific evidence, and consumers' attitude towards health hazards often follows an emotional route instead of a rational statement (Figure 11) (Morasso et al., 2000). This often leads to a marked discrepancy in the perception of risk between the public and the scientists (Slovic, 1987; Macfarlane, 2002). The risks due to pesticide residues and food additives are believed to be relatively minor compared with both acute and chronic effects caused by microbiological and other naturally occurring toxicants (Cliver, 1999; Kuiper-Goodman, 1999). While the most prominent emerging problems are of microbial origin, many other biological, chemical, and unconventional agents are a cause for concern (Table 7) (van de Venter, 2000). In general, foodborne diseases appear to cause more illnesses but fewer deaths than previously estimated (Mead et al., 1999); during the last fifteen years, outbreaks of human diseases associated with the consumption of raw vegetables and fruits, or unpasteurized food produced from them, have significantly increased in number (Beuchat and Ryu, 1997; Keene, 1999). There is no evidence, however, to indicate whether or not this increase is related to the significant increase in organic food consumption during the same period. Still, consumers' demand for minimally processed foods has had an apparent adverse influence on food safety (Zink, 1997).

On the other hand, during the post-World War II era of synthetic agrochemicals and despite the year-on-year increase in their worldwide rate of application, there has been little overall increase in the US (Ries et al., 2004) and European (Coggon

Table 7 Causative agents of foodborne diseases

Biological or chemical agents	Unconventional agents
Bacteria	Prions
• Enterohemorrhagic *Escherichia coli* (EHEC) (*E. coli* O157)	Mycotoxins
• Enteroaggregative *E. coli* (EAEC)	• Fumonisins
• *Listeria monocytogenes*	• Zearalenone
• Multidrug-resistant *Salmonella typhimurium* DT 104	• Trichothecenes
• *Salmonella enteritidis*	• Ochratoxins
• *Campylobacter jejuni*	Pesticide residues
• *Vibrio vulnificus*	Environmental contaminants
• *Streptococcus parasanguinis*	Veterinary drugs
Viruses	Biotechnology
• Hepatitis E (HEV)	Other agents
• Norwalk virus and Norwalk-like viruses	
Protozoa	
• *Cyclospora cayetanensis*	
• *Toxoplasma gondii*	
• *Cryptosporidium parvum*	
Helminths	
• The genus Anisakis	

Derived from van de Venter (2000).

and Inskip, 1994) cancer incidence and mortality, with the exceptions of lung and AIDS-related cancers. Moreover, stomach cancer mortality has significantly decreased (Ries et al., 2004; Coggon and Inskip, 1994), and a contributing factor to the declining incidence may have been the greater year-round availability of fresh fruits and vegetables, provided by conventional agriculture. Given the lack of epidemiological evidence to link dietary synthetic pesticides to human cancer, and taking into account public concerns about pesticide residues as possible causes of cancer, public policy with respect to pesticides has relied on the results of high-dose animal cancer tests as the major source of information for assessing potential cancer risks. This approach, however, has many limitations and underlying assumptions; hence it cannot be used to predict absolute human risks (Ames et al., 1987; Gold et al., 2002; 2001). No hard evidence currently exists that toxic hazards such as pesticides have had a major impact on total cancer incidence and mortality (Fisher et al., 1995), and this is especially true for diet-related exposures (World Cancer Research Fund (WCRF) and American Institute for Cancer Research (AICR), 1997; Commission on Life Sciences (CIL), 1989), while synthetic pollutants in general seem to account for less than 1% of human cancers (Ames and Gold, 1998). In addition, it is well known that populations with diets rich in fruits and vegetables have substantially lower risk of many types of cancer (Centers for Disease Control and Prevention, 1999), and this is despite the use of synthetic agrochemicals in conventional farming. Hence, the benefits may outweigh the risks. In fact, the US population may be more at risk due to inadequate or excess consumption of nutrients, rather than by increased intake of toxic substances (Egan et al., 2002). Organic food, on the other hand, may offer the same or even greater protection, but it is unknown whether price premiums ranging from over 40% to as high as 175%(Greene, 2001) will compromise or not consumption levels. A potential decrease in fruit and vegetable consumption due to higher prices would have a detrimental impact on public health status with respect to chronic disease incidence and mortality, especially since the "five-a-day" recommendation for vegetables and fruits cannot by met by a large proportion of the population in the US (Subar et al., 1995) and Europe (Naska et al., 2000).

It must be emphasized that the current food supply is much safer and healthier than it was in the past, and agricultural technological achievements have greatly contributed to reduced malnutrition and improved health (Institute of Food Technologists (IFT), 2002; Centers for Disease Control and Prevention, 1999; Trewavas, 1999). Agricultural production is becoming increasingly knowledge-based and science-intensive, and novel new technologies will help to satisfy future food requirements of a growing world population (global food demand is projected to double over the next 50 years (Tilman et al., 2002)), by providing adequate amounts of nutritive and safe food (Taeymans, 2000). Whether or not, however, genetic engineering assumes a significant role in this respect, as suggested by some (Trewavas, 2002a), is at present debatable and at least controversial. Likewise, organic farming may lead to reduced yields (though yields of organically produced crops have been shown to be highly variable (Mader et al., 2002; Martini et al., 2004; Tamis and van den Brink, 1999)) and thus, also fail to fulfill this task (Taeymans, 2000).

While there is no doubt that organic food is more "natural" than conventional food, "natural" on the other hand does not mean benign. Regardless of its organic or conventional origin, food must by law satisfy food safety requirements (The United Kingdom Parliament, 2004). The organic standard is not immune to health scares and does not exempt producers and processors from compliance with general regulatory requirements, such as food safety regulations, pesticide registrations, and general food and nutrition labeling rules. But neither is the organic label a seal of food safety. Organic only refers to a product that has been produced in accordance with certain standards throughout production, handling, processing and marketing stages; it does not refer to the characteristics and properties of the finished product. "Organic" is therefore a process claim, not a product claim (Kouba, 2002). The asserted health benefits are impossible to quantify and do not seem, as yet, to compensate for the increased price. It is also important to note that, at present, there is no scientifically tenable evidence that any differences observed between organic and conventional food would lead to any objectively measurable effects on human health. In fact, health benefits resulting from the consumption of a specific food or food ingredient are not unanimous, but most probably depend on the genetic background, dietary habits, and overall lifestyle of an individual (Eckhardt, 2001). Further, there are many limitations and lots of uncertainty in assuming that increasing the dietary level of any compound will necessarily improve health (Trewavas and Stewart, 2003). It has been suggested, therefore, that individual metabolism, as it relates to health, predisposes to disease, or other health outcomes, should guide future agriculture toward foods for improved health and nutrition (Watkins et al., 2001).

There is currently no evidence to support or refute claims that organic food is safer and thus, healthier, than conventional food, or vice versa. Assertions of such kind (Colborn et al., 1996; Avery, 1998; Rogers, 2002) are inappropriate and not justified, and remain groundless not only due to ethical considerations but also because of limited scientific data. The selective and partial presentation of evidence serves no useful purpose and does not promote public health. Rather, it raises fears about unsafe food. The lack of trust in agricultural and industrial methods of production and in food quality gives rise to nagging feelings of uncertainty and insecurity; consumers are left in confusion and ignorance, counting the widely publicized food scares. Available research, as presented herein, does not support nor refute consumer perceptions regarding the superiority of organic food. Unfortunately, knowledge of the differences between organic and conventional produce (see Table 6) is extremely limited with respect to the more potent food safety hazards, like microbial pathogens and mycotoxins (Figure 12). Still, for many years now, consumers perceive organic food as having certain intrinsic safety and quality characteristics (Hildebrand, 1972). Many

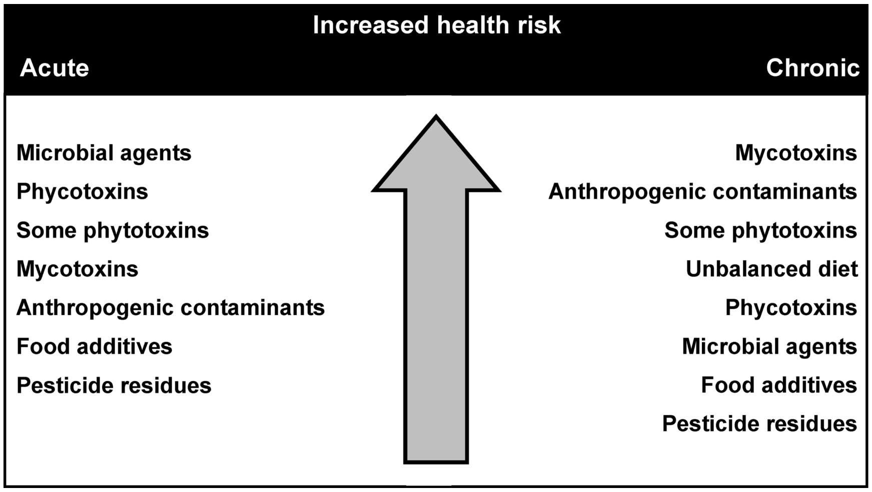

Figure 12 Relative importance of food hazards for human health. The figure ranks several food hazards according to their potency to cause an acute or chronic effect, regardless of cultivation origin (i.e. organic or conventional). Adapted with permission from Magkos et al. (2003b).

supporters of organic farming believe that an agricultural system is more than the sum of its parts, and rely on personal experiences and beliefs that make them more receptive to the idea that organic food is indeed superior (Morkeberg, and Porter, 2001). It is always logical to assume that food is healthier if not contaminated by pesticides, nitrates, and other toxic agents. It is also possible that some groups of consumers may draw psychological benefits from the knowledge that some organic products may occasionally contain slightly lower concentrations of potentially harmful substances (O'Doherty Jensen et al., 2001).

Food safety, of course, is only one aspect of food quality. Quality of the produce is not a single, well-defined attribute but comprises many properties or characteristics: it encompasses sensory attributes (appearance, texture, taste and aroma), nutritive values, chemical constituents, mechanical properties, functional properties and defects, in addition to safety characteristics (Abbott, 1999). Food quality may thus be defined in several different ways, either from a product orientation or a consumer orientation. From all the different definitions different measurement methods arise, as well as different theories about how quality actually relates to consumer satisfaction (Shewfelt, 1999). Quality for the consumer is subjective, seen partly in terms of visible features, such as the "pleasure" attributes of the product, and partly in terms of an awareness of invisible qualities, such as microbial and toxicological safety and nutritional value (Taeymans, 2000). In order to make useful comparisons between organic and conventional produce, food quality should be considered in a wider sense. Very often, in conventional food production systems, food quality is determined by properties that are easy to measure, quantify, or weigh, as for example nutrient content, microbiological safety, color, texture, shape, size, and price. Moreover, yield and profit are sometimes of greater importance than food quality (Thiermann, 2000). By contrast, the quality of organic food is believed to include social, environmental, and political dimensions, besides appearance, technological, and biological value (Browne et al., 2000; Blowfield, 2001). Focusing on one aspect of food quality only underscores the importance of other factors, and by no means provides evidence for the quality of the production system as a whole (Bourn, 1994).

The present article, therefore, did not make a complete comparison of all aspects of organic and conventional food production systems, nor did it attempt to assess their environmental impact and overall sustainability. Instead, it only presented a critical discussion of issues that relate to the safety of organic and conventional produce. The attempt to directly compare organic and conventional food safety is hampered by many difficulties with the scientific literature and the lack thereof that prevents from making any definitive conclusions. At our present state of knowledge, however, it seems that other factors, if any, rather than safety aspects speak in favor of organic food.

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