STATE OF SCIENCE REVIEW
EXECUTIVE SUMMARY

Number 3

The Organic Center

Breaking the Mold

Impacts of Organic and Conventional Farming Systems on Mycotoxins in Food and Livestock Feed

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September 2005

Organic Farming Can Enhance Food Safety by Lessening Risk of Mycotoxin Contamination

Fungi play vital roles as decomposers, breaking down all kinds of organic matter from roots and leaves to crop residues, wood, and dead animals. The decomposition process releases the nutrients stored within organic matter. In short, fungi help make it possible for one generation of life to sustain the next.

Most fungi pose little or no risk to humans and some are delicacies, including morel and chanterelle mushrooms. Patches of fungal spores create the distinctive flavor and blue splotches in blue cheese, and without fungi, there would be no beer or wine. *Penicillium* and *Streptomyces* fungi produce antibiotics widely used in treating bacterial infections in humans and animals.

However, a few fungi are poisonous, even deadly, to humans. Others produce molds and mold spores that can trigger human allergies and induce asthma. Most fungi thrive by attacking plants, trees, or insects and slowly consuming their tissues. Others break down the integrity of cell walls, causing damage that can prove fatal. This is sometimes a good thing, such as when *Beauveria bassiana* fungi attack Colorado potato beetles in a farmer's field. (see photo on right, page 4)

There are more than 300 species of fungi with the ability to produce mycotoxins. Mycotoxins are secondary metabolites produced by fungi in response to environmental conditions. Fortunately, only about 20 mycotoxins produced by five genera of fungi *(Aspergillus, Penicillium, Fusarium, Alternaria,* and *Claviceps)* are found periodically in food at levels posing threats to people. Still, mycotoxins cost American agriculture between $630 million and $2.5 billion annually, largely because of market rejection of grain that contains mycotoxins at levels above either government or company standards.

Some individuals and organizations critical of organic farming claim that organic food and animal feed are more frequently and heavily contaminated with mycotoxins than conventional food and feed. Those making such arguments typically highlight a few, isolated instances where mycotoxins were detected in organic or "naturally" grown food at levels higher than in other foods. They explain the differences by pointing out that organic farmers are not allowed to apply synthetic fungicides.

Mycotoxins have also become part of the global debate over the benefits of genetically-engineered (GE) crops. Studies showing that GE, insect-protected field

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corn is less prone to mycotoxin contamination than corresponding conventional corn are frequently cited as evidence that organic farming poses greater mycotoxin risk than "modern" agriculture that utilizes genetically engineered seeds.

production tends to increase when fungal growth rates slow down. The purpose of the mycotoxins might be to combat the factors reducing the growth rate of fungi. Alternatively, fungi may produce mycotoxins to protect dormant molds and fungal spores from other, surviving fungal species and bacteria.

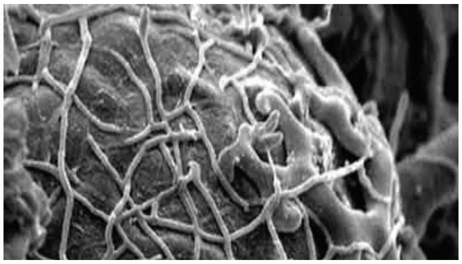
"Mycotoxins produced by fungi play a major role in the biochemical warfare that unfolds among competing species in virtually every environment on Earth."

This State of Science Review (SSR) analyzes the basis and validity of these assertions. It reviews the relatively few well-designed studies that have compared mycotoxin levels in conventional and organic foods grown under similar circumstances. Factors unique to organic farming systems that impact mycotoxin levels are highlighted.

This SSR also describes steps that conventional and organic farmers and food processors should take to assure that mycotoxin exposure episodes are infrequent and inconsequential. Our goal is to identify insights from each system of farming and food processing that will help all farmers and the food industry more effectively prevent mycotoxins from reaching potentially damaging levels.

An Overview of Mycotoxin Diversity, Toxicity, and Regulation

When a fungal spore comes into contact with organic material, it sends out filament-like structures called hyphae, which help attach the fungus to its new home. When the fungus senses conditions are right, it initiates the decomposition process by secreting enzymes into its new food source. These enzymes break down complex organic molecules in the host tissues into simpler molecules that are more readily available to the fungi, as well as to other microorganisms.



Fungal hyphae on a leaf. Photo courtesy of Kevin MacKenzie, University of Aberdeen©

The secondary metabolites produced by fungi during the course of digestion are mycotoxins. Fungi produce these biochemicals for a wide array of reasons. Mycotoxin

This report focuses on the mycotoxins that appear most frequently in food: aflatoxins, ochratoxin, fumonisins, deoxynivalenol, patulin, and the ergot alkaloids.

Weather, Grain Handling, and Farming Practices

The moisture level of grain when it is harvested is a critical variable driving mycotoxin formation. Wet conditions, followed by hot and dry periods, can stimulate mycotoxin production, especially aflatoxin.

Several studies have shown that plants experiencing stress from excessive heat are more vulnerable to fungal and mycotoxin infections. In tomatoes, fungi can proliferate in sun-damaged tissues, causing black rot lesions and producing a number of mycotoxins.

Drought conditions coupled with some insect damage, followed by wet, humid weather near harvest optimally set the stage for fungal infections and mycotoxin production. Many studies suggest that organic and sustainable farming systems that increase organic matter levels in soil lessen the severity of heat stress, thereby reducing the frequency and levels of mycotoxin contamination.

In general, plants bred to be resistant to fungal diseases tend to be less likely to become contaminated with mycotoxins. There is strong evidence that high levels of readily available nitrogen (N), in particular, promotes mycotoxin formation in cereal grains and row crops, compared to crops produced in organic systems. The reasons why include:

- Changes in the rate of decomposition of crop residues;
- Physiological stress on fast-growing plants;
- An enhanced supply of readily available energy sources for fungal pathogens; and
- Alterations in the crop canopy structure that give rise to higher levels of fungal infections and/or mycotoxin formation.

The extensive evidence linking fertilization methods to mycotoxin levels is important because of differences in how organic and conventional farmers supply plant nutrients to crops. In general, conventional farmers apply high rates of nitrogen in readily available forms early in the crop year to eliminate any chance that a shortage of N might limit crop yields. In most years, farmers apply N well in excess of crop needs as a sort of insurance policy.

Organic farmers focus on enriching the soil by building up soil organic matter and increasing the pool of nitrogen that is cycling through the soil. They use nitrogen-fixing legumes, cover crops, manure, compost, and relatively slow-release natural fertilizers to meet crop needs. In most crops, markedly lower levels of N are applied per acre on organic farms compared to nearby conventional farms. While this is a clear benefit in terms of mycotoxin formation and water quality, a lack of N on organic farms does periodically reduce yields, especially in years when climatic conditions support vigorous plant growth.

Surface mold on stored wheat. Photo: Cereal Research Centre - Agriculture and Agri-Food Canada

Regulation of Mycotoxins in Food

Many developed countries have established standards or guidelines governing mycotoxins in food. At this time, there are no widely acceptable international standards for mycotoxins in any specific food.

The official status and impact of "guidance levels," in contrast to "allowable levels," or "standards," varies around the world. The United States is among a set of countries that have established unenforceable "guidance levels" that are intended to trigger actions by private companies if and when the levels are exceeded.

With the exception of patulin in apple juice, European Union (E.U.) standards for mycotoxins in food and feed are two to fifteen times stricter than those in the United States.

Frequency and Levels of Mycotoxins in Conventional and Organic Foods

In a search of the peer-reviewed literature, nine studies were identified that report 24 direct comparisons of mycotoxins in conventional and organic foods purchased and/or grown in a given year, in the same region. Two assessed patulin in apples, one focused on ochratoxin in milk, and 21 assessed four mycotoxins in grain-based products. All these studies were carried out by European research teams and reflect food production in the 1997 through 2002 seasons.

The absence of similar comparative studies in the United States is a reflection of the lack of consumer awareness of mycotoxin risks and government policies and priorities. No U.S. government agency routinely tests food for mycotoxins. Public funding invested in the development and promotion of GE foods has grown dramatically over the last decade, while support for food safety research has grown modestly, if at all.

In the nine comparative studies that have been published in peer-reviewed journals, mycotoxins were detected 1.5 times more frequently in conventional samples compared to organic samples. The levels of mycotoxins found in conventional and organic samples can be compared in 20 of the 24 cases. Across the 20 cases, the levels reported in conventional food exceeded those in organic food by a factor of 2.2.

"Conventional samples of food contained mycotoxins about 50% more frequently than the organic samples in a set of comparison studies, at average levels a little over twice as high."

The question at the heart of this State of Science Review is:

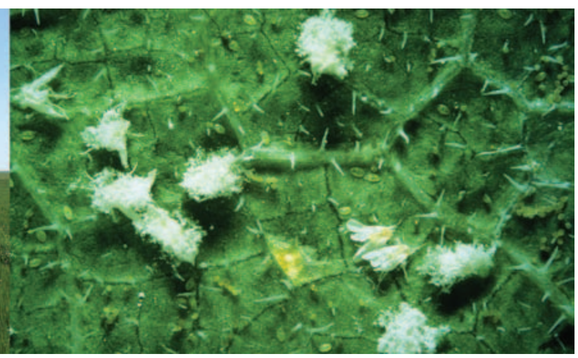
Are there factors intrinsic to organic and/or conventional production systems that increase susceptibility to fungal infection and the production of mycotoxins?

Many conventional farming systems control fungal infections by applications of one or more of over 40 registered fungicides. For many low-value crops, there are no cost-effective fungicide treatments. On fruits and vegetables, however, fungicides are frequently used to prevent disease losses. Often two to four different fungicides are applied up to 10 or more times.

Fungicides often dramatically reduce fungal infections, yet do not decrease mycotoxin levels to the same degree. Some fungi can actually utilize fungicides and insecticides as food sources. In one study, the concentration of the mycotoxin nivalenol increased 16-fold in wheat treated with a combination of two fungicides, despite reducing the severity of *Fusarium* infection. Treatment of grain fields with the strobilurin fungicide azoxystrobin can increase mycotoxin levels, even though it reduces *Fusarium* infection rates.

Sub-lethal applications of fungicides are known to stimulate mycotoxin formation. This likely occurs because the fungi are stressed, but not killed. The production of mycotoxins is a normal response to stress in many fungal species.

Organic farmers tend to promote greater diversity in microbial communities and strive for more complex plant nutrient and microbial food webs.



The degree of reliance on fungicides is a major difference between conventional and organic farms. Organic farmers have few fungicides to choose from – those containing copper and sulfur, and biopesticides manufactured from naturally occurring plants, fungi, and bacteria. The opportunity to rely on fungicides to deal with plant pathogens, including fungi, allows conventional farmers to select and manage varieties for maximum yield, even when yield-maximizing management strategies make crops more susceptible to disease.

Organic farmers have to place a premium on prevention. A variety of tactics on organic farms are typically woven into Integrated Pest Management systems. Depending on the crop, location, and levels of disease pressure, these practices include selection of resistant varieties, crop rotations, and limited applications of readily available sources of nitrogen.

One goal is to create what scientists call a "disease suppressive" soil – a soil characterized by low and largely inconsequential levels of root and plant disease, despite the presence of virulent pathogens and a susceptible host crop. Common practices to accomplish these goals include application of compost and animal manure, the planting of cover crops, and diverse crop rotations.

Ongoing competition among fungal species on organic farms, and between fungi and bacteria, helps keep any one fungus from reaching dangerous levels. In addition, low levels of mycotoxins in some crops can actually promote the biological control of some fungi. Deoxynivalenol (DON), for example, has significant biological activity against other plant pathogens, some with potential to produce other mycotoxins.

Findings and Conclusions

Several research teams in Europe have carried out comparative surveys of the frequency and levels of mycotoxins in conventional and organic foods, leading to nine peer-reviewed studies reporting results and/or assessing levels of risk. The results are surprisingly consistent.

Averaged across 24 direct comparisons of mycotoxins in conventional and organic foods in published studies, mycotoxins were detected in conventional food about 50 percent more often than in corresponding organic food.

Mycotoxin levels in conventional food averaged a little over twice as high as in the corresponding organic foods. Ten of the comparisons involved wheat or wheat-based products produced in Europe.

The probable explanation for the generally higher levels of mycotoxins in conventional wheat crops grown in Europe is the routine use of high levels of nitrogen fertilizer, coupled with fungicide applications to prevent disease losses. Input intensive, high-yield grain farming systems heighten crop susceptibility to fungal pathogens and can stimulate mycotoxin production, even in fields where fungicides reduce the severity of fungal infection.

Healthy wheat head (left)
Fusarium innoculated wheat head (right)
Photo USDA ARS (Keith Weller)

The role of fungicides in triggering higher levels of mycotoxins in European grain is ironic given the claim by critics of organic farming that conventional food is less frequently contaminated with mycotoxins because of the use of fungicides.

It is clear that relatively few food-mycotoxin combinations account for the majority of dietary risk associated with mycotoxins. These food-mycotoxin combinations warrant closer attention throughout the food chain:

- Ochratoxin in milk and grain-based products intended for human consumption, as well as pork products;
- Deoxynivalenol in wheat, barley, and rice-based foods;
- Fumonisin in corn-based products intended for humans, as well as in animal feeds;
- Patulin in apple-based products, especially processed products; and
- Aflatoxin in nuts and peanut-based products.

Organic and conventional farming practices do not fundamentally alter any of the environment, weather-related, and handling and storage factors that play such a major role in most serious mycotoxin contamination episodes.

Conventional farming systems increase the risk of fungal infections through a lack of diversity and reliance on monocultures, and because of heavy use of fertilizers that deliver plant nutrients in a readily available form. Applications of fungicides often dramatically suppress fungal pathogens and allow farmers to push yields higher, but routine and repeated applications can lead to problems associated with resistance. Fungicides can also trigger shifts in the population mix of fungi such that mycotoxin-producing strains are favored.

Organic farming systems reduce the prevalence of serious fungal infections, and hence mycotoxin risks, by promoting diversity in the microorganisms colonizing plant tissues and living in the soil; and by reducing the supply of nitrogen that is readily available to support plant – and pathogen – growth. Resiliency within diverse fungal and bacterial communities lessens but does not eliminate the risk that mycotoxin-producing fungi will become dominant. An excessive supply of nutrients almost always disrupts ecological communities in ways that favor certain fungi and can trigger or augment the production of mycotoxins.

The advantages of organic farming practices equal if not exceed any disadvantages in terms of mycotoxin prevention on well-managed organic farms. The evidence is strong that organic production of small grains, especially wheat, can reduce the frequency and severity of mycotoxin contamination compared to conventional farms, even including conventional wheat farms treated with fungicides.

Recommendations

Better information from research in the United States is needed on whether and to what extent mycotoxins are finding their way into organic foods. The collection and assessment of mycotoxin monitoring data will remain a necessary investment in building and holding consumer confidence in the safety of organic food.

The organic community should not wait for others to take on the challenges inherent in understanding more fully where and how mycotoxins enter the food supply. More systematic and routine monitoring is an essential first step.

Samples of organic and conventional milk, apple juice, corn meals, and whole wheat bread purchased in retail markets around the country should be tested for common mycotoxins.

Plant pathologist D. Fravel observes the growth of *fusarium oxysporum*, the pathogen that causes fusarium wilt. Photo: USDA ARS (Keith Weller)

Most serious mycotoxin contamination episodes involve grains and are triggered or made worse by inclement weather. A first line of defense in preventing serious mycotoxin problems is assuring that on-farm grain harvest, drying, and storage equipment and facilities are adequate, properly maintained, and used with skill. The organic grain milling and livestock industries should work together to fund themselves, or encourage the USDA to carry out:

A survey of grain harvest, drying, and storage facilitates and practices on organic grain farms, with special attention to their capacity to reduce moisture levels quickly and evenly.

Scientists have just begun to explore how organic farming practices and systems impact the risk of fungal infections and mycotoxin formation. This promising area of research will advance the reliability of disease management practices on organic and conventional farms. Public agencies and private organizations should:

Build assessment of the impacts of organic and conventional farming practices on the production of mycotoxins into research focused on plant disease management.

Disparity between U.S. mycotoxin standards and policies and those in the European Union will likely grow and may become a factor impacting access to the European market for U.S.-produced organic and conventional foods. Organizations working with and on behalf of organic farmers and food companies should:

Monitor changing laws and public policies impacting allowable levels of mycotoxins in food around the world, with special attention to how new standards might impact the flow of organic commodities in international commerce.

New science is likely to push U.S. mycotoxin limits lower, especially for foods marketed to infants and young children. Recent findings on the developmental effects of low levels of mycotoxin exposure are worrisome. To assist the U.S. organic community and public health specialists in staying abreast of the science driving the regulation of mycotoxins, the government should:

Provide an up-to-date overview of tolerable daily intakes (TDIs) for mycotoxins in different countries and segments of the population and for farm animals, as well as the science supporting TDIs and the establishment of mycotoxin limits in specific foods.

Consumers should be assured that both organic and conventional farmers in the United States are currently doing a good job in preventing serious mycotoxin contamination in the nation's food supply.

Still, mysteries remain in the world of mycotoxins: why fungi produce them, what controls their production, how farmers and the food industry can detect and avoid them, and their health effects. The minimization of mycotoxin risks is a daily challenge and a long-term mission. Deeper understanding of how organic farmers prevent damaging fungal infections will serve as a road map toward farming methods that can enhance margins of food safety, while also promoting efficient and environmentally sound farming systems.

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