Mycotoxin Reduction in Grain Chains

John F. Leslie & Antonio F. Logrieco

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Preface

Mycotoxins are fungal secondary metabolites that may be found in human foods and animal feeds. These compounds belong to families of organic molecules that share no significant properties other than the ability to confer death, disease, and misery on humans and other animals that consume them. Mycotoxins, and the fungi that synthesize them, frequently are detected by discoloration or other symptoms of fungal growth, but insidious contamination where the infected foodstuff appears normal to the eye is a significant problem. In developed countries, food safety regulatory systems are effective and efficient at identifying contaminated materials and removing them from primary food and feed channels. Rare incidents where animals are killed following consumption of mycotoxin-contaminated pet foods make national headlines, and most consumers know neither the names of the toxins nor the consequences of their consumption.

In less developed countries, especially in rural areas, the food commonly consumed often is a miasmatic mixture of inferior grain consistently contaminated with one or more mycotoxins, yet outright toxic outbreaks with multiple deaths are not common. Continuous sub-acute exposure to mycotoxins, however, suppresses immune system activity and retards the normal mental and physical development of children, and is likely responsible for far more human debilitation than are the much more sensational outbreaks where deaths occur. The physical separation of contaminated and uncontaminated food is a prelude to discarding the contaminated material in the developed world, but merely increases the exposure of those in less developed countries who are too poor to be able to afford anything else. As long as food security remains a significant issue, the threat of starving tomorrow will always be more significant than the threat of cancer in some 10–20 years. Trade regulations that lead to rejection of food lots containing any mycotoxins, effectively reduce food safety in developing countries as only the best quality food makes it to international trade and all of the rest remains for local consumption in the country of origin. Climate change and the pressure to expand production into marginal areas to be able to feed 9 billion people will only increase mycotoxin contamination problems, which are most common in stressed plants growing in less-than-optimal environments.

Most mycotoxin exposure is a result of consuming one or more of the world's five most commonly grown grains—wheat, maize, rice, barley, and sorghum—although some people also may be exposed to high levels of toxins following the consumption of peanuts. In this volume mycotoxin contamination is evaluated for these five grains, with emphases on wheat (and barley) and maize. For wheat and maize the entire grain chain from breeding to storage to food processing is considered, while for rice and sorghum, where mycotoxin problems are much less important, a literature review is provided. In many cases the authors look at current status as well as to future needs and desirable innovations. Developing rapid, simple techniques for detecting mycotoxins remains a major challenge as does breeding host plants that are resistant to the fungal diseases and depress accumulation

of the toxins the fungi can produce. Proper post-harvest storage can retain grain quality and prevent the synthesis of new toxins even if toxin-producing fungi are present. While HAACP-type protocols are not yet available to prevent mycotoxin contamination many of the critical parameters are known, and an important goal is to increase the efficacy of processes and protocols already identified as significant.

This book is unusual in that it looks at all five of the world's major grains and evaluates the entire grain chain from planted seed to processed food. We hope that it provides answers to many questions about the problems posed by and the controls available for mycotoxins, and that some readers will find all they need to know (and perhaps more than they want to know) within these pages. At the same time we know that there are many who will likely find this book as a first comprehensive introduction to these compounds and to the broadly interdisciplinary research that is needed to understand their implications, impacts, and costs in today's world. For them we hope this book, supported by a European Union FP 7 project—MycoRed, provides a good guide for where to go next. It is clear that mycotoxins are a significant problem that is becoming more widely recognized as such, and that the broadly integrated efforts of a variety of life, physical and social scientists is needed to effectively address it.

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1 An Introduction to the MycoRed Project

Antonio F. Logrieco and Angelo Visconti

Abstract

To comply with the needs of the European Union and to address global strategies for mycotoxin reduction, a 4-year large collaborative project, termed MycoRed (www.mycored.eu), was approved within the European FP7—"Food, Agriculture and Biotechnologies" Work Program. MycoRed's goal is to develop strategic solutions to reduce contamination by mycotoxins of major concern in economically important food and feed chains. Novel methodologies, efficient food handling procedures, and information dissemination and educational strategies are considered in a context of multidisciplinary integration of know-how and technology to reduce global exposure to mycotoxins. In this context, this volume brings together for the first time eminent scientists (many of them involved in the MycoRed project) on subjects relevant to mycotoxin production and accumulation in the cereal and maize food chains and ways that these toxins can be reduced or eliminated in the global food supply.

Keywords: global trade; international research collaboration; mycotoxin contamination reduction; food safety; industry competitiveness; training

Introduction

The main objective of the European Commission in the food sector is to create a knowledge-based bio-economy (KBBE). New models, tools, and methods—developed by science, industry, and other stakeholders—are required to assure the sustainable production of high-quality food and feed. To reach a KBBE, the vision for 2020 of the European Technology Platform (ETP), Food4Life, is the "effective integration of strategically focused, transnational, concerted research in the nutritional, food and consumer sciences and food chain management so as to deliver innovative, novel and improved food products for, and to, national, regional and global markets in line with consumer needs and expectations."

Protection of human health and the environment are important aspects of a KBBE. Reducing mycotoxin contamination in the worldwide food and feed chains is a major challenge to improve human and animal health. Mycotoxins are responsible for a variety of noxious problems in humans, including the induction of cancer, and digestive, blood, kidney, and nerve problems. One quarter of the world's food crops, including many basic foods, are potentially contaminated by mycotoxin-producing fungi. The mycotoxin problem is particularly important for human health in tropical

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areas, e.g., Sub-Saharan Africa, where crops are particularly susceptible to contamination with the carcinogenic aflatoxins and fumonisins. Globalization of trade has complicated the way we deal with mycotoxins in that regulatory standards often become bargaining chips in world trade negotiations (FAO, 2004; van Egmond *et al.*, 2007). While developed countries have numerous mycotoxin regulations and a well-developed infrastructure for enforcing food quality standards, people in developing countries are not protected by food quality monitoring or by the enforcement of safe standards within their countries. Food commodities that enter international commerce are expected to comply with *CODEX Alimentarius* standards. This requirement may indirectly increase the risk of mycotoxin exposure in developing countries because the best quality foods leave the country, while the lower quality food is consumed, often by humans, and not discarded. The consequences of this requirement to comply with the needs of the European Union and its consequences for global strategies for mycotoxin reduction need further consideration.

Due to numerous stringent mycotoxin regulations, particularly in Europe, the export/import agro-food industries must improve handling procedures during storage and processing, and utilize low-cost, user-friendly, multi-analysis detection kits (Leslie *et al.*, 2008; Piñeiro, 2008). One objective of the MycoRed (www.mycored.eu) project is to develop new practical technological solutions that may impact mycotoxin detection and management, e.g., micro-systems for ambient intelligence, new biomarkers, and multi-mycotoxin analyses.

Multidisciplinary integration of know-how and technology is required to address the broad requirements for reducing mycotoxins in agro-food chains. The project is based on the integration of specific technologies in the whole food/feed chain with respect to wheat, maize, grapes, nuts, and dried fruits. The main consumer demands posed in the agro-food sector drive research and technological developments in MycoRed. The need to improve prevention to minimize mycotoxins in products at different critical steps of the food chain, i.e., raw materials, storage, feed supply, food processing, and final products, is addressed by MycoRed through vertical (across food and feed chains) and horizontal (among methodologies and procedures) integration of experiences to develop a set of systems with clear breakthrough solutions to specific mycotoxicological problems. Additionally, dissemination of information and best practice education strategies to enhance the involvement of operators at all levels along the food and feed chains, facilitating participation and cooperation at the European and global levels, commensurate with the interest of the European Union community, is also a MycoRed priority.

MycoRed Objectives

A set of mycotoxin reduction targets of vital importance have been identified by some international food organizations, e.g., FAO, CIMMYT, EFSA, IITA, and SAFE consortium, European Union reports, and relevant food industry representatives (Barug *et al.*, 2006; CAST, 2003; Logrieco, 2001; Logrieco and Visconti, 2004; Visconti and Logrieco, 2005). In this respect, the knowledge and reduction of aflatoxins, trichothecenes (deoxynivalenol, nivalenol, T-2 and HT-2 toxins, etc.), zearalenone, fumonisins, and ochratoxin A are the most important issues addressed in the project. Aflatoxin B_1 is a proven carcinogen for humans. It is immunotoxic and causes stunted growth in children and growth retardation in animals. *Fusarium* toxins, especially fumonisins, are neurotoxic and possible carcinogens; trichothecenes are immunotoxic; and zearalenone is estrogenic. Ochratoxin A is a nephrotoxin, possibly carcinogenic to humans, and associated with Balkan endemic nephropathy. Mixtures of mycotoxins probably have at least an additive, if not synergistic, egregious effects. These toxins are primary sources of both yield losses and increased management

Table 1.1 Food/feed chains and relative mycotoxins and fungi studied under the MycoRed program

Plant	Chain	Toxin	Fungal genus
Maize	Food/feed	Fumonisins	*Fusarium*
		Aflatoxins	*Aspergillus*
Wheat	Food/feed	Trichothecenes	*Fusarium*
		Zearalenone	*Fusarium*
		Ochratoxin A	*Penicillium*
Grapes—including raisins and sultanas	Food and wine	Ochratoxin A	*Aspergillus*
Nuts and dried fruits—peanuts, figs, pistachios, and almonds	Food	Aflatoxins	*Aspergillus*

costs worldwide. MycoRed has an integrated vision of a reduction system as a horizontal task ensuring dissemination of different technological solutions developed by the research activities in the project.

MycoRed targeted strategic solutions for reducing contamination by the mycotoxins of major concern in economically important selected food and feed chains. The following toxins and commodities have been focused on in the project: trichothecenes, fumonisins, and aflatoxins in wheat/maize-based food and feed chains; ochratoxin A in the grape, wine and wheat chains; and aflatoxins in the nut and dried fruit chain (Table 1.1). Novel methodologies, efficient handling procedures, and information dissemination and educational strategies were considered in a context of a multidisciplinary integration of know-how and technology to reduce mycotoxins worldwide from the field to the market.

Wheat and maize, in particular, have major mycotoxin safety concerns worldwide and are being studied up and down their food and feed chains. Research on mycotoxins in wheat has been much more intensive than it has been recently in maize, even though maize is at least as significant toxicologically as wheat. In Europe there generally are no data on the economic costs of mycotoxins. One exception is Hungary, where the direct and indirect losses attributable to a 1998 wheat epidemic were estimated at €100 million. In the United States alone, the mean economic annual costs at the farm gate of cereal crop losses due to aflatoxins, fumonisins, and trichothecenes combined are estimated to be $932 million (CAST, 2003), which dwarfs the USDA budget for research on this problem by some 600×.

The overall objectives of MycoRed are:

- to develop novel, solution-driven methodologies and handling procedures to reduce both pre- and postharvest mycotoxin contamination in selected feed and food chains; and
- to generate and disseminate information and education strategies to reduce mycotoxin risks at a global level. High-risk areas receive major attention through cooperation with international agriculture and food organizations and through applications of the results of all of the technical work packages in the project.

The multidisciplinary approach and the numerous existing collaborations/networks involving MycoRed partners that are already in place have ensured that European, American, African, and Australian scientists are actively engaged with one another and have resulted in synergistic advances in the development of practical solutions with applications in both developed and developing countries. The integration of multidisciplinary expertise in chemistry, microbiology/plant pathology, genetics, plant breeding, agronomy, toxicology, plant and animal physiology, molecular biology,

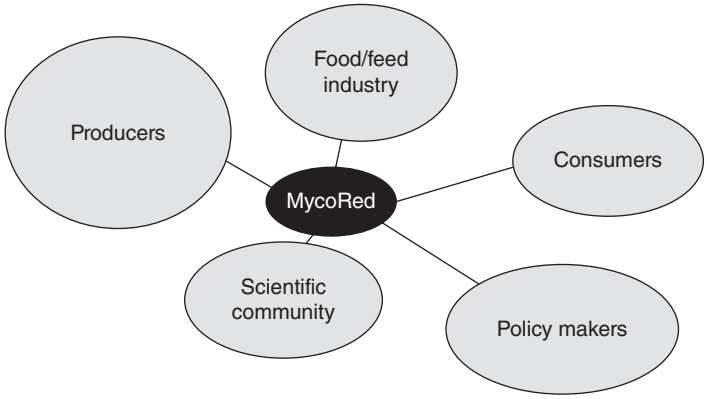

Figure 1.1 MycoRed stakeholders. The size of the circle indicates the relative importance of the user group. The relative distance of the circle to the user group indicates the relative strength of the communication with that group, with shorter lines indicating stronger communications than longer ones.

and food technology will have a synergistic effect on the development of practical solutions to minimize mycotoxins in the food and feed chains. Some of the proposed solutions are generic and will have direct application to other food/feed chains. The numerous dissemination events have ensured the widespread distribution of the information and technologies generated and encouraged scientific cross-fertilization between different disciplines.

Thus, MycoRed's goals are to increase mycotoxin awareness in five user communities (Figure 1.1) with interests in mycotoxins:

- *For consumers*—Increased food safety for humans and feed safety for animals, i.e., minimize health risks from mycotoxin-contaminated food and feed, especially in high-risk areas.
- *For agro-food producers* (farmers and animal and plant breeders)—Provide tools and demonstrate advantages of pre- and postharvest solutions to reduce and control mycotoxin contamination in plant products and in the consequent food/feed chains. To obtain agro-industrial products with major added value that results in increased economic development in rural areas.
- *For food/feed industries*—Generate opportunities for new applied research and development. Use current research results for developing novel preventive and curative (bio)control measures against toxigenic fungi. Reduction of mycotoxin contamination by improved handling procedures during storage and processing. Availability of new mycotoxin and mycotoxigenic fungi detection kits.
- *For policy makers and legislators*—Provide improved information and know-how for evaluating real and potential mycotoxin risks, including possible outcomes of climate change and increased international trade. Provide indicators for assessing the risk of contaminated commodities.
- *For the scientific community*—Increase advanced knowledge, e.g., fungal and plant genomics, metabolomics, and proteomics, of the mycotoxin-producing fungi and their hosts. Improve global communications, international networking, and dissemination of innovative research results with the support of learned societies, e.g., the International Society for Mycotoxicology, and dedicated scientific journals, e.g., *Food Additives and Contaminants* and the *World Mycotoxin Journal*, that help knit the interdisciplinary mycotoxin research community together.

MycoRed Structure

The MycoRed approach uses global, multidisciplinary, and integrated strategies, that are effectively applied along the food and feed chains and linked to decision-making bodies and consumers through effective mycotoxin risk assessment and information and education programs. Five work packages develop novel solution-driven strategies and handling procedures to reduce both pre- and postharvest contamination in feed and food chains; two work packages have horizontal disciplinary foci on detection; and a final work package focuses on communication and outreach:

- *Work Package 1*—optimization of plant resistance and fungicide use;
- *Work Package 2*—biological control to reduce toxigenic fungi in cropping systems;
- *Work Package 3*—modeling and developing decision support systems;
- *Work Package 4*—postharvest and storage practices;
- *Work Package 5*—application of new food-processing technologies;
- *Work Package 6*—develop methodologies for advanced diagnostics and quantitative detection of toxigenic fungi;
- *Work Package 7*—rapid and multi-analyte detection and quantification of mycotoxins and relevant biomarkers;
- *Work Package 8*—information, education, dissemination, and demonstration activities to reduce mycotoxin risks worldwide based on the results generated by the other seven work packages and other knowledge of methodologies and handling procedures actually in use for particular crops in various geographical areas.

The project has a solid technical foundation due to the involvement of well-regarded European groups who developed collaborative programs through previous European projects funded in Framework 5 and Framework 6 in the area of mycotoxins and toxigenic fungi. In particular, MycoRed partners have previously been involved in 22 projects funded by the European Commission and have coordinated 8 others that are scientifically linked to MycoRed. This project offers one of the best opportunities for reducing mycotoxin contamination in food and feed chains worldwide.

The direct involvement of ICPC countries, i.e., Russia, Egypt, and Argentina, and International Organizations, i.e., CIMMYT and IITA, that focus on developing countries in Africa, South and Central America, and Asia will benefit areas of the world where mycotoxin problems are critically important for human health and trade. These countries and institutions are of particular importance for MycoRed information/dissemination/education activities, and scientific conferences sponsored by MycoRed have been held in all of these regions.

Strategic alliances with major public research institutions in the United States (three USDA centers and four universities), Australia, South Africa, and Malaysia are of particular value and strengthen the project by sharing experience and resources from numerous past and current mycotoxin projects at a global level. Mutual interest in this intercontinental collaboration has resulted in mutual benefits from joint efforts in national, regional, and international research and development programs. For example, the results of ongoing mycotoxin research programs involving three USDA partner locations (with an annual investment of US $3.5 million) is being shared with corresponding European researchers working in the same area.

An External Advisory Board, composed of scientists from concerned disciplines and related initiatives, industrialists from the agro-food sector and food regulatory bodies, and representatives from the ETP Food4Life program, provides an external perspective to the project, advises the

consortium on issues of knowledge transfer and exploitation, and recommends effective actions to reach the project goals.

Social and Economic Impact

A significant reduction of mycotoxins in the food and feed industries is one of the key challenges for increased sanitary quality in the European food market. MycoRed has addressed this challenge by developing and utilizing innovative, multidisciplinary strategic solutions that provide higher value added and are changing the agro-food industry as it adapts to the requirements of the future European consumer society.

The objective-oriented approach of this project addresses a strong potential socioeconomic impact. We expect the MycoRed solutions to significantly reduce mycotoxin contamination in food and feed chains in Europe and, for some targets, worldwide. The reduction of these principal mycotoxins by novel, multidisciplinary, integrated strategies through the maize, wheat, grape, and dried fruit chains will produce the following socioeconomic impacts:

- A significant decrease in the number of acute and chronic pathologies in Europe and in ICPC countries due to the consumption of mycotoxin-contaminated products. This reduction will directly reduce costs in the human and animal health-care systems.
- A decrease in the costs of rejection of contaminated raw crop materials, especially dried fruits and cereals, and processed products. This impact will be very important for farmers, food/feed producers, and retailers. Over the past years, mycotoxin regulations in the European Union have changed rapidly and proliferated, posing significant challenges to more sectors of the food industry than ever before. Failure to comply with the latest standards can have major economic consequences for exporters and importers, ranging from costly retesting and reprocessing to impounded, rejected, or destroyed shipments.
- Improved ability to reduce safety problems due to mycotoxin contamination beginning at any stage in the production chain—pre-, postharvest, and processing.
- Increased safety of feed and food stuffs due to the application of various innovative technical solutions developed through research sponsored by MycoRed. Ultimately there will be full and effective interconnections and communication between sensing systems and decision-making bodies. The earlier in the food chain that corrective actions can be taken, the better, simpler, and easier the storage/shipment and production processes.
- An increase in the competitiveness of European agro-food industries resulting from the application of research results, e.g., safety of food/feed, predictive models, antagonist formulations, and new detection kits, to relevant problems.
- Promotion of new spin-off small and medium-sized enterprises (SMEs) in Europe and ICPC countries that serve the agro-food application markets. Training activities carried out under MycoRed have helped to satisfy the demands for skilled employees in the area of food safety.

Thus, the MycoRed project has a potentially huge economic impact on both the international agro-food community (farmers, animal and plant breeders, etc.) and the European agro-food industries. There are no European economic analyses that have evaluated the scientific improvements and altered strategies that have resulted from research sponsored by MycoRed and targeted at the reduction of global mycotoxin contamination. MycoRed is now sponsoring such a study to identify

additional areas in which new technologies and improved handling solutions could have an economic impact on food safety.

Conclusions

MycoRed plays an important role in European and global mycotoxin food/feed safety through its integrated research projects on mycotoxin reduction. It shares the information gathered through training and dissemination programs and through cooperative efforts with other similar initiatives, e.g., ISM and MoniQa. MycoRed enables the sharing of data and knowledge for harmonizing good agricultural practices, good management practices, and good storage practices in diverse geographic areas and multiple food/feed chains, through publications such as this book.

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