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Information sources for the detection of emerging mycotoxin risks

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Rapport in het kort

Informatiebronnen voor de waarneming van opkomende mycotoxine risico's

Het RIVM werkt aan een nieuw systeem om de kans op besmetting van voedsel met zogeheten mycotoxines te verkleinen. Mycotoxines zijn giftige chemische stoffen die door schimmels worden geproduceerd. Deze stoffen kunnen op diverse manieren in voedingsbronnen terechtkomen en tot allerlei aandoeningen leiden. Een voorbeeld is aflatoxine b1, dat soms in noten wordt aangetroffen. Deze stof kan bij langdurige blootstelling kanker veroorzaken of voor een leververgiftiging zorgen. Om consumenten daartegen te kunnen beschermen is het noodzakelijk om een mogelijke besmetting met schimmels zo vroeg mogelijk te ontdekken, bij voorkeur voordat de toxines in de voedselketen terechtkomen.

Er bestaan al langer richtlijnen om *binnen* de voedselvoorzieningsketen de kans op besmetting met mycotoxines te verkleinen. Het instituut heeft zich echter specifiek gericht op factoren *buiten* de voedselvoorzieningsketen. Voorbeelden van deze 'omgevingsfactoren' zijn klimaatveranderingen, consumententrends en het gebruik van nieuwe technologieën. Zo kunnen een hogere temperatuur en een vochtig klimaat het risico op het ontstaan van bepaalde mycotoxines verhogen. Deze factoren zijn vaak niet direct te beïnvloeden. Wel kunnen risico's mogelijk worden voorspeld door veranderingen in deze factoren in de gaten te houden, bijvoorbeeld tijdens de groei en opslag van producten.

Om veranderingen in omgevingsfactoren te kunnen waarnemen, zijn voor elke omgevingsfactor indicatoren gedefinieerd. Dit zijn meetbare gegevens, zoals regenval en temperatuur bij de omgevingsfactor 'klimaat'. Deze indicatoren maken het wellicht mogelijk om tijdig een waarschuwingsignaal af te geven en zonodig voorzorgsmaatregelen te nemen.

Vervolgens zijn diverse informatiebronnen verzameld die de gewenste indicatoren kunnen leveren. Deze informatiebronnen variëren van online-databases tot nieuwsbrieven over markttrends. In een vervolgstudie zal het voorspellende vermogen van de verzamelde indicatoren en informatiebronnen verder worden onderzocht.

Trefwoorden: mycotoxines, voeding, opkomende risico's, indicatoren, informatiebronnen.

Abstract

Information sources for the detection of emerging mycotoxin risks

RIVM is working on the development of a new system to decrease the chance of contamination of food with so-called mycotoxins, poisonous chemicals produced by fungi. These chemicals causing various disorders can end up in human food sources via different pathways. An example of a mycotoxin is aflatoxin b1, sometimes found in nuts. On long-term exposure, this mycotoxin can cause cancer or liver poisoning. To protect consumers, therefore, it is essential to discover a potential contamination with mycotoxins as soon as possible, preferably before the toxins enter the food source.

Guidelines have already been developed to prevent contamination of the food source with mycotoxins within the food supply chain. However, the institute has specifically addressed factors outside the food supply chain. Examples of these ‘host environment factors’ are climate changes, consumer trends and the use of new technologies. For instance, a higher than normal temperature and a damp climate can increase the risk of particular mycotoxins emerging. Although it is often not possible to influence these factors, risks may be predicted by monitoring changes in these, for example, changes occurring during the growth and storage of products.

To monitor changes in host environment factors, indicators – such as rainfall and temperature for the host environment factor ‘climate’ – have been identified for every host environment factor. These indicators may be used to issue a timely warning signal and take measures if necessary.

Various information sources (from online databases to newsletters on market trends) that could provide the identified indicators were then collected. The predictive potential of these indicators and their information sources will be investigated further in a subsequent study.

Key words: mycotoxins, food, emerging risks, indicators, information sources

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Samenvatting

Dit rapport geeft een overzicht van informatiebronnen die nuttig kunnen zijn voor het monitoren van indicatoren van opkomende mycotoxinerisico's. De studie is uitgevoerd in het kader van een project voor het ontwikkelen van een nieuwe risicomanagement aanpak, dat als doel heeft voedingsgerelateerde ziektes in een eerder stadium te identificeren. De aanpak omvat het monitoren van niet alleen de voedselvoorzieningsketen, maar ook omgevingsfactoren die mogelijk risico's voor voedingsgerelateerde ziektes beïnvloeden.
Aan de hand van informatie van mycotoxinepreventietools uit de voedselvoorzieningsketen, bestaande waarschuwingssystemen, mycotoxicosis casestudies en persoonlijke communicatie met experts zijn de meest kritische omgevingsfactoren geïdentificeerd. Omgevingsfactoren die een belangrijke rol kunnen spelen in opkomende mycotoxinerisico's zijn: klimaat, markt- en consumententrends, economie, internationale handel, transport, nieuwe technologieën, plagen en ontwikkelingen op het gebied van wetgeving.
De volgende stap in de studie was het identificeren van indicatoren voor deze factoren die gecontroleerd kunnen worden om veranderingen waar te nemen die een opkomend risico aanduiden. Diverse informatiebronnen voor zulke indicatoren zijn verzameld, variërend van online databases tot nieuwsbrieven. De informatiebronnen verschillen in regionale specificiteit, mogelijkheid om trends en plotselinge veranderingen waar te nemen, mogelijkheid tot kwantificering, algemeenheid en kosten. Of de geïdentificeerde indicatoren en hun informatiebronnen daadwerkelijk opkomende mycotoxinerisico's kunnen voorspellen zal getest moeten worden in vervolgstudies.

Summary

This report gives an overview of information sources that may be useful to monitor indicators of emerging mycotoxin risks. The study was conducted as part of a project to develop a new risk management approach which aims to enable the identification of food-borne diseases at an earlier stage. The approach includes monitoring not just the food supply chain, but also host environment factors that may influence risks for food-borne diseases. Based on information from supply chain based mycotoxin prevention tools, existing early warning systems, mycotoxicosis case studies and personal communication with experts of different fields, the most critical host environment factors have been identified. Host environment factors that may be of importance for emerging mycotoxin risks are: climate, market and consumer trends, economy, global trade, transport, new technologies, pests, and legislative developments.

The next step in the study was to identify indicators for these factors which can be monitored to detect changes that may point to an emerging risk. Diverse information sources for such indicators have been gathered, ranging from online databases to newsletters. The information sources vary in their regional specificity, their ability to detect trends or sudden changes, quantification ability, generality and cost. Whether the identified indicators and their information sources can truly predict an emerging mycotoxin risk will need to be tested in subsequent studies.

1. Introduction

In 2004, in the framework of ERA-NET of the 6th framework program of the EU, the Dutch Food and Consumer Product Safety Authority (VWA) coordinated the PERIAPT project to identify food-related emerging risks. This project is one of many efforts to improve the risk management of food-borne diseases by using a proactive, anticipating and forward-looking approach. It was recognized that, traditionally, the identification of food related risks was solely achieved by analysing the relevant food supply chain. However, to control emerging risks proactively, it was considered necessary to explore a broader area of disciplines which are more or less related to the food production chain. Within PERIAPT, a holistic approach was developed in which factors from the supply chain as well as the host environment that are possibly involved in food safety risks were identified (Figure 1). The underlying purpose for identifying these factors is to adopt indicators as signals with the power to predict food safety risks.

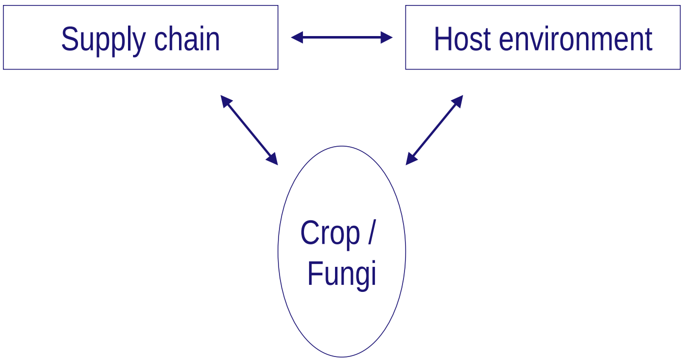


Figure 1 Representation of the integrated holistic approach for mycotoxins

As part of the PERIAPT project team, RIVM (National Institute for Public Health and the Environment) tested this approach with regard to mycotoxins. A preliminary inventory was made of indicators in the food supply chain for fungal growth and mycotoxin production in various crops (coffee, peanut, grape, fig, wheat). It was learned that fungal growth is expected to occur to an important extent at early stages of the food supply chain. General indicators (applicable to most fungi) are related to temperature, humidity of air, soil and/or product and stress factors in plants and fungi.

In addition, during a workshop involving experts from different disciplines, a number of critical factors for the 'host environment analysis' that may influence food safety risks in general were identified (Table 1).

Table 1 List of sectors and factors, generally applicable to a host environment analysis. Source: Willemen and Bos (2004)

Influential sector	Critical factors
Science, technology and industry	- New scientific knowledge
	- New technologies
	- Processing and distribution
Nature and environment	- Climate
	- Pollution
	- Natural catastrophes
Government and politics	- New legislation
	- Supervision / enforcement
	- Trade barriers
	- Food terrorism
Information	- Media
	- Communication interest
	- Expert roles
Culture and demography	- Lifestyle
	- Mobility
	- Education
	- Ageing
Agriculture	- Plant and animal health
	- Production systems
	- Biodiversity
Consumer behaviour	- Consumer perception
	- Diet
	- Attitude
Economy	- Trade
	- Supply and demand
	- Wealth and income levels
	- Globalisation
Public health and welfare	– Infrastructure
	– Lifestyle
	– Diseases

The approach was tested by means of a case study on aflatoxicosis in Kenya, provided by the Food and Agricultural Organization of the United Nations (FAO, 2004). It was concluded that the main factors contributing to this particular aflatoxicosis incident were:

- Food availability in the population
- Lack of application of Good Practices
- Changing weather patterns
- Immunocompromised status of the population

In the current project, RIVM intends to further develop a holistic approach for identifying emerging mycotoxin risks. A starting point in this project is to select the most critical factors and associated suitable indicators from both the food supply chain and the host environment. These factors and indicators can be identified by analysing tools developed to prevent mycotoxins, case studies on the occurrence of mycotoxins and mycotoxicosis, and other sources. For the most important indicators identified, the project aims to locate appropriate information sources that can be used to monitor changes in the indicators, with the purpose to develop an early warning system for emerging mycotoxin risks.

2. Identification of most important critical factors

Within the PERIAPT project, it was found that numerous critical factors can be considered important for emerging risk identification on mycotoxins. Some examples were given:

- New technologies (in cultivation and storage)
- Pollution (as a stress factor for fungi and polluted crops may be more liable to fungi)
- New legislation (a ban on specific pesticides, production measures)
- Trade barriers (establishing a trade barrier can e.g. influence storage duration)
- Biodiversity (a monoculture in crops may cause a monoculture in fungi)
- Lifestyle (a change in diet affects intake of mycotoxins)

One aim of the current project is to identify the most important critical factors for mycotoxin risks. Factors involved in mycotoxin risks are identified by analysing information from supply chain based mycotoxin prevention tools, existing early warning systems, mycotoxicosis case studies and other sources. In addition, advice is sought from experts in different fields of the host environment.

By using information from these different sources, it is anticipated that most important factors can be identified. At this point, a literature review was kept to a minimum due to time constraints. It is however assumed that the most important critical factors influencing mycotoxin risk have been included in the supply chain based mycotoxin prevention tools and are based on scientific research.

2.1 Critical factors from supply chain based tools

Within the food supply chain, several tools are or have been developed to prevent the presence of mycotoxins in foodstuffs, some of which are specific for mycotoxins of particular concern. These tools mainly aim at controlling fungal growth in crops during production, by providing Good Agricultural, Storage and Manufacturing Practices guidelines and Hazard Analysis and Critical Control Point (HACCP) programs. The tools focus on critical steps in the production processes which may increase mycotoxin contamination. For the purpose of the current project, the tools may be useful to identify critical factors influencing the growth of fungi and/or the production of mycotoxins.

2.1.1 Mycotoxins in the cereal chain

The EU initiated a concerted action (Project PL98-4094) with the objective to prevent mycotoxin contamination due to *Fusarium* fungi in cereal based food and feed production. A working relationship at the European level between all the partners of the production chain of cereal based food and feed products was established (EU, 2002). Recommendations to

improve good agricultural practice during the whole cereal production chain were presented, based on factors that were found to influence mycotoxin contamination.
Factors reported to influence mycotoxin contamination at the pre-harvest stage are:

- Weather conditions
- Crop rotation
- Soil preparation

Factors reported to influence mycotoxin contamination at the (post-)harvest stage are:

- Water activity[1]
- Moisture content
- Rapidity of drying
- Temperature
- Time of storage
- Composition of the substrate
- Mechanical damages to the seed
- Oxygen and carbon dioxide availability
- Fungal abundance
- Prevalence of toxigenic strains
- Spore load
- Microbial interactions
- Invertebrates

A protocol for use throughout the chain was not developed, since organizations such as the Codex Alimentarius, had already studies underway for establishing such protocols.

2.1.2 Code of practice for the prevention and reduction of mycotoxin contamination in cereals

The Codex Alimentarius developed a General Code of Practice containing general principles for the reduction of various mycotoxins in cereals that should be sanctioned by national authorities. The principles are based on Good Agricultural Practices (GAP) and Good Manufacturing Practices (GMP).
Factors reported to influence mycotoxin contamination are:

- Crop variation: a crop rotation schedule using crops invulnerable to mycotoxins reduces the inoculum in the field
- Presence of substrates for fungi growth
- Plant stress

[1] Water activity reflects the active part of moisture content or the part which, under normal circumstances, can be exchanged between the product and its environment. Water activity is usually defined under static conditions of equilibrium. Under such conditions, the partial pressure of water vapor (p) at the surface of the product is equal to the partial pressure of water vapor in the immediate environment of the product. Any exchange of moisture between the product and its environment is driven by a difference between these two partial pressures.

- High temperature and draught
- Overcrowding
- Pests
- Mechanical damage
- Humidity
- Equipment quality
- Hygiene
- Ventilation

2.1.3 Mycotoxin-Prevention Cluster

An EU project on the prevention of mycotoxins entering the animal and human food chain (Mycotoxin-Prevention Cluster) consists of a number of subprojects which include the identification of critical control points in the production system where mycotoxins may enter human food products, mainly cereals (EU, 2003a).

The objective of one subproject is to reduce ochratoxin A in cereals produced in Europe, by identifying the key elements in an effective HACCP programme and providing tools for preventive and corrective actions. The first results indicated that humidity is a key element in the growth of *Penicillium verrucosum*, the main producer of ochratoxin. This strain is very competitive compared to other fungi between water activities 0.90 and 0.95. This water activity range should therefore be avoided. It is also recommended not to buffer store grain at lower moisture content than 18% before final drying. Proper aeration and ventilation during storage are also recommended. An effective tool to restrict the growth of *P. verrucosum* and the formation of ochratoxin A is to maintain a low process temperature, although this may not be practical.

A second subproject was aimed to prevent *Fusarium* mycotoxins entering the human and animal food chain, specifically in wheat, barley, oats and maize. The objective was to use an HACCP framework to examine and identify key points in the food production chain where prevention strategies can be effectively implemented. As part of this subproject, two-dimensional environmental profiles for deoxynivalenol and nivalenol by *Fusarium culmorum* were developed. The key factors in these profiles were water activity and temperature (Hope and Magan, 2003). In subsequent research, comparable profiles were developed for deoxynivalenol production by *F. graminearum.* Although the key factors influencing growth and mycotoxin production were water activity and temperature, comparing the profiles for the two strains indicated that the requirements for growth and mycotoxin production between the strains differ considerably (Hope et al., 2005).

An ongoing related EU project involves the risk assessment and integrated ochratoxin A (OTA) management in grape and wine (EU, 2003b). The objective of this project is to identify key elements for OTA in grape and wine and providing tools for preventive and corrective actions according to an integrated approach.

In summary, the main factors reported to influence mycotoxin contamination are thus:

- Water activity
- Temperature

2.1.4 Code of practice for the enhancement of coffee quality through prevention of mould formation

The European Coffee Cooperation has established a code of practice for the enhancement of coffee quality through prevention of mould formation (European Coffee Cooperation, 2002). Factors reported to influence mycotoxin contamination are:

- Contamination with mould from other sources (soil, husks, etcetera)
- Long storage times
- Poor ventilation
- High humidity
- Poor hygiene

2.1.5 HACCP system for the prevention and control of mycotoxins

In collaboration with the International Atomic Energy Agency (IAEA), the FAO has developed a HACCP system for prevention and control of mycotoxins in general, with specific focus on mycotoxins in grains (FAO, 2001). In this system, factors reported to affect the presence of mycotoxins were organized per commodity or per spoilage. Factors in a commodity system that may affect the presence of mycotoxins are:

- Agronomy (soil management, pest and disease control)
- Harvesting
- Processing
- Drying
- Storage
- Transportation
- Marketing
- Financing
- Consumption

It was noted that these factors are interrelated. Also, systems for different commodities may affect each other. For example, an increase in importance of one commodity will frequently lead to the allocation of fewer resources towards the care of other commodities.
Factors in a Spoilage system that may affect the presence of mycotoxins are:

- Moisture
- Temperature
- Pests
- Broken kernels
- Proportions of oxygen, nitrogen and carbon dioxide

Similar to the factors in the commodity system, these factors are often interrelated.
The HACCP manual contains information on the optimal fungal growth and mycotoxin production conditions for some mycotoxins of worldwide importance, in particular with regard to (optimum) water activity and temperature. This information has been summarised in Table 2.

Table 2 Growth and mycotoxin production conditions for moulds of world-wide importance

Mould species	**Mycotoxins produced**	**Fungal growth at water activity (optimum)**	**Fungal growth at temperature (optimum)**	**Mycotoxin production: water activity temperature (optimum)**
Aspergillus parasiticus	Aflatoxins B_1, B_2, G_1, G_2	0.83 - >0.99 (0.99)	unknown (30˚C)	≥0.87 unknown (28˚C)
Aspergillus flavus	Aflatoxins B_1, B_2	0.82 – >0.99 (0.99)	10 - 43˚C (30˚C)	High water activity 15 - 37˚C (20 - 30˚C)
Fusarium sporotrichioides	T-2 toxin	0.88 - >0.99 (unknown)	2 - 35˚C (22.5 - 27.5˚C)	unknown
Fusarium graminearum	Deoxynivalenol Zearalenone	0.90 - >0.99 (unknown)	unknown (24 - 26˚C)	unknown
Fusarium moniliforme (verticillioides)	Fumonisin B_1	0.87 - >0.99 (unknown)	2.5 - 37˚C (22.5 - 27.5˚C)	unknown
Penicillium verrucosum	Ochratoxin A	≥0.80 (unknown)	0 - 31˚C (unknown)	≥0.86 0 - 31˚C (unknown)
Aspergillus ochraceus	Ochratoxin A	≥0.79 (unknown)	8 - 37˚C (25 - 31˚C)	unknown 15 - 37˚C (25 - 28˚C)

To prevent the growth of most moulds, the water activity needs to be ≤ 0.70, which translates into different moisture contents of commodities at different temperatures. Climate therefore obviously plays a key role in the contamination with mycotoxins. However, the stage of production at which the climate is important differs per mould species. For example, fumonisin B_1 contamination occurs invariably during pre-harvest stages, whereas under some climatic conditions the highest risk for aflatoxin contamination occurs during storage, post-harvest.

In general, the pre-harvest impact of climate involves draught stress, resulting in crop damage which leaves the crop more prone to mould growth. The (post-)harvest impact of the climate involves poor drying conditions, for example due to prolonged rains, favouring mould growth.

Other critical factors that can lead to damage of crops are pests and crop handling. For example, the contamination of apples with patulin from the fungus *Penicillium expansum* is more likely in apples that have been damaged due to poor handling. Pests are more likely to invest pistachio nuts from a damaged hull, caused by early splitting. In general, contamination with mycotoxins takes place early in the production stage, either pre-harvest or during storage and transport. First time contamination during further processing appears less likely for most crops.
In summary, factors reported to influence mycotoxin contamination are:

- Climate
- Pests
- Crop damage
- Crop handling
- Storage conditions
- Water activity
- Temperature

2.2 Critical factors from existing systems reported by FAO

The FAO reported that a number of systems, so-called rapid alert or early warning systems, have already been developed to provide early detection information on specific mycotoxins of concern.

A Deoxynivalenol (DON- produced by *Fusarium* spp.) early warning system has been developed by FAO/ESNS and other partner agencies in Latin America. This system considers the particular weather conditions, crop hybrids used, soil data and other factors to advise its users of possible high risk of mycotoxin contamination and measures to take to avoid crises. The control measures prescribed include time of harvesting; levels of product drying; use, type, timing and dosage of fungicides, etcetera.

Ministries of Agriculture in several countries in the world issue advice to farmers to control mycotoxin production, based on climatic conditions of the country.

Within the EU Mycotoxin prevention cluster (MYCOTOX-CLUSTER) project, the Università Cattolica Sacro Cuore, Piacenza, Italy, has developed an early warning system for risk assessment and integrated Ochratoxin A (OTA) management in grapes and wine, called a decision support system (DSS) for integrated management of grape.

The European Coffee Co-operation Task Force on OTA [2] is conducting on-going monitoring of OTA levels in coffee imports to the EU, and providing an informal early warning system to industry.

2.3 Critical factors from analysing case studies

Information on factors influencing fungus growth and mycotoxin production can be obtained from case studies.

Anecdotes of pandemic diseases dating as far back as the 14^{th} century have been related to poor food quality, often suggesting the involvement of mycotoxins (Prandini et al., 2005). For example, in England in the 17^{th} century, a series of serious nervous disorders and low fertility occurred, which were related to an increase in price of wheat leading to an increase in the consumption of rye of possibly poor quality. Even the particular ferocity encountered during the French Revolution in the 18^{th} century has been attributed to the consumption of rye of poor quality, caused by adverse climatic conditions of that period.
A more recent account of mycotoxin contamination involves that of the unusual high levels of aflatoxin M1 in milk reported in Italy in 2003 (Prandini et al., 2005). The high levels appeared to be due to ingestion by cows of corn with elevated levels of aflatoxin B1, which was likely caused by the high temperatures and drought for over four months during the summer of 2003.
Factors important in causing mycotoxin contamination in these case studies were:

- Change of crop price
- Change in diet
- Adverse climatic conditions

A case study analyzed risk factors considered important in the contamination of milk and dairy products with aflatoxin M_1 (Prandini et al., 2005):

- Choice of seeding times and hybrids that need to be harvested in very warm periods
- Drought
- Temperature
- Seeding density
- Minimum tillage or sod seeding
- Absent or inefficient weed killing
- Lack of fertilisation (K_2O and N)
- Excessive fertilisation (N)
- High organic fertilisation (manure)
- No or insufficient use of insecticides (especially against pyralis; *Ostrinia nubilalis*)
- Phytophagous damages (insects, birds, rodents)

[2] This OTA Task Force represents the entire European coffee sector and several scientific bodies.

- Absent or insufficient irrigation
- Prolonged drying in field
- Mechanical damage due to harvesting operations
- Moisture content of corn
- Cleaning (of corn kernels)
- Cutting (of corn silage)
- Storage conditions (layering, drying process, moisture content, temperature, pests)
- Transport conditions (temperature, moisture content)
- Feeding practices of cows
- Removal of contaminated corn from feed

In another case study, the occurrence of ochratoxin A and deoxynivalenol (DON) in organic and conventional bread was analyzed (Prandini et al., 2005). Risk factors for the occurrence of ochratoxin A were not given, probably since the mycotoxin can be produced by different species of fungi, which have very different ecological niches in terms of their target crops, geographical regions and growth conditions. However, risk factors for the occurrence of DON in bread via wheat were reported:

- (Pre-)harvest weather conditions (temperature, moisture, rainfall)
- Crop precession by corn or sorghum
- No crop residue removal
- Sod seeding or minimal tillage
- Excessive N fertilisation
- Choice of variety with high sensitivity to DON
- Insufficient pest control
- Prolonged storage in field
- Storage and transport conditions (moisture levels, temperature, aeration, hygiene)
- Insufficient removal of damaged kernels
- Production of wholemeal bread containing bran instead of flour

As discussed before, the FAO provided a case study on aflatoxicosis in Kenya in an earlier phase of the project. Factors that were considered most important in causing the aflatoxin poisoning included:

- Food availability
- Unusual climatic conditions
- Lack of application of Good Practices
- Immuno-compromised status of the population

Many case studies involving food borne human acute mycotoxin poisoning have been reported in the literature, mostly in developing countries. However, these case studies did not include an analysis of the cause for the presence of mycotoxins in the food source.

2.4 Critical factors from other sources

Contamination of human food sources with mycotoxins has received increasing attention from food safety authorities and legislators. This has lead to many studies investigating the occurrence of mycotoxins in different foodstuffs.

In addition, much scientific research is ongoing to elucidate the key factors affecting growth of fungi and production of mycotoxins. A recent review reported a number of key factors that need to be considered to reduce trichothecene accumulation in cereal grain (Aldred and Magan, 2004). These factors included:

- Weather conditions during flowering
- Type and amount of fungicides
- Ecology of the key species
- Moisture content at harvest

In a report on emerging mycotoxin risks in foods with focus on high and low input agriculture, several factors were reported to affect mycotoxin contamination (Prandini et al., 2005):

- Susceptibility of the crop
- Compatible toxigenic fungus
- Temperature
- Moisture
- Substrate aeration
- Inoculum concentrations
- Microbial interactions
- Mechanical injury
- Insect/bird damage
- Crop maturity at harvest
- Distribution to human food chain (transportation system and global trading)

2.5 Personal communication with experts

A number of experts of different fields have been consulted with regard to their opinion on factors that may influence mycotoxin risk.

Dr. De Waard of the Laboratory of Pathology of Wageningen University is an expert in the area of (prevention of) fungal diseases in plants. He described a number of factors that may reduce the effectiveness of mycotoxin prevention methods.

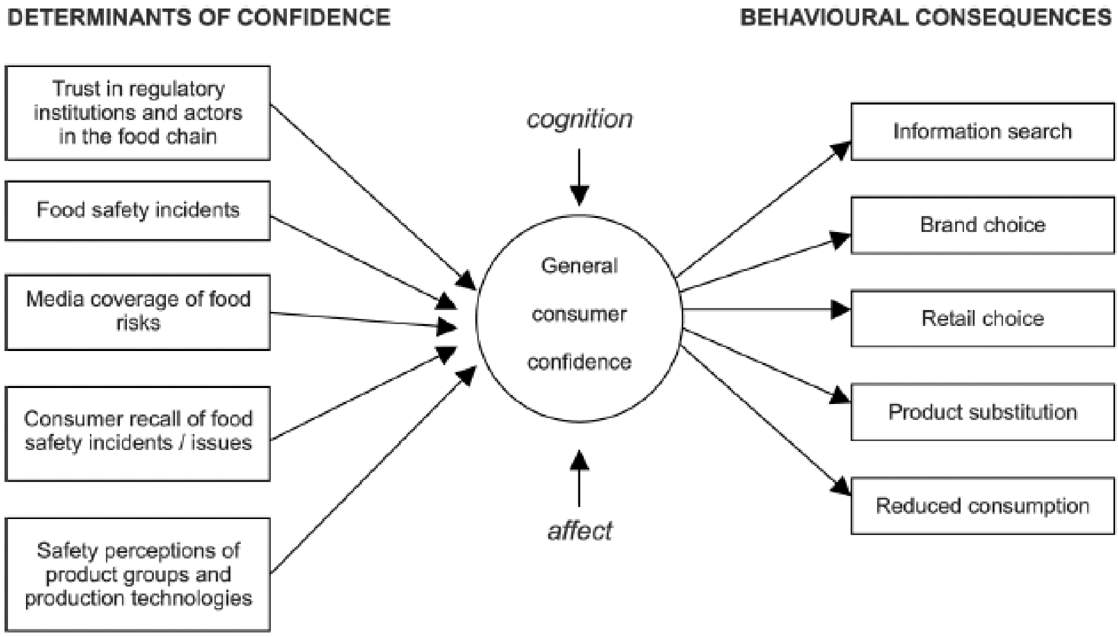
- Climate: wet weather may increase the growth of many kinds of fungi and decrease the effectiveness of fungicides, due to application difficulties.

- Fertilisation level of the crop: inappropriate fertilising of the crops (too much or too little) may reduce the health of the crop.
- Crop strain: preference of fungi-sensitive cultivars with a high yield over resistant cultivars.
- Development of resistance of the fungi to the fungicide. In this case, the fungicide will fail completely and the crop producer will cease using it. However, in some situations, the resistance to the fungicide may be hard to detect, for example, when the resistance is weak or when the resistant fungicide is part of a mix of fungicides.

Dr. Mangen works at RIVM's Centre for Prevention and Health Services Research. Recently she has been working on a cost-utility analysis regarding the control of *Campylobacter* in the chicken meat chain with the aim to advise the Dutch government on the effectiveness and efficiency of a number of intervention methods to prevent *Campylobacter* infections (Mangen et al., 2005).
One of the conclusions of this research was that expensive prevention methods may lead to a weakened competitive position of farmers, especially in the absence of legislation to use these methods for other farmers and imported products. If consumers cannot be convinced of the benefits of the more expensive products from farmers which have used effective prevention and reduction methods, the consumption of cheaper but potentially less safe products may actually increase.
The situation described may also apply to mycotoxin prevention methods for agricultural crops. Factors that therefore may influence mycotoxin risks are:

- (International) legislation
- Competitive position of farmers
- Consumer demand
- Global trade

Ms. de Jonge is a PhD student at the Marketing and Consumer Behaviour Group of Wageningen University. She is currently working on the development of a monitor to assess consumer confidence in food safety (De Jonge et al., 2004) (Figure 2). Factors that may be included in the monitor and which are thought to potentially influence consumer confidence are past food safety incidents, increased media attention to food safety issues and trust in regulatory bodies and actors in the food chain. In turn, the trust of a consumer in product safety is thought to greatly influence consumer purchase behaviour with regard to information search, brand choice, retail choice, product substitution and amount of consumption.



Notes: The central part of the monitor is general consumer confidence in food safety, which is likely to have both a cognitive and an affective dimension. The boxes at the left are the potential factors that affect consumer confidence in food safety and the boxes at the right represent the possible behavioural consequences of changes in general consumer confidence in food safety

Figure 2 Proposed monitor for consumer confidence in food safety. Source: De Jonge et al. (2004).

A possible link to mycotoxin risks consists of the effect of factors influencing consumer purchase behaviour, because these factors may affect the amount of consumption of products with high or low mycotoxin risks. In addition, the factors influencing confidence in food safety may also affect consumers' perception of a healthy diet, which may have similar purchase behavioural consequences.
In summary, possible factors influencing consumer purchase behaviour and therefore mycotoxin risks are:

- Trust in regulatory bodies and actors in the food chain
- Food safety incidents
- Media coverage of food risks (and healthy diets)
- Consumer recall of food safety incidents/issues
- Safety (health) perceptions of product groups and production technologies

2.6 Summary: Important critical factors

Many important critical factors in mycotoxin contamination can be derived from sources such as Code of Practices and literature. Predictably, the most frequently reported factors are directly related to the food supply chain, such as harvest and storage conditions. Most

HACCP systems assume that the highest risk for mycotoxin contamination takes place at the start of the production chain; during crop growth and harvest, and during storage and transport. Although many of these factors are specific for certain crops or mycotoxins, a number of factors can be named that appear to be important in mycotoxin contamination in general:

Preharvest:
- Soil preparation
- Crop strain and rotation
- Fertilisation
- Pest and disease control
- Crop damage

Harvest, storage and transport
- Timing of harvest
- Moisture content
- Temperature
- Time of storage
- Ventilation
- Hygiene

Little information is available to derive critical factors from the host environment, the exception being local weather conditions. Other factors reported were:
- Market and consumer trends
- Economy
- (International) legislation
- Food availability
- Immune-compromised status of the population
- Global trading

Food availability and an immune-compromised status of the population are factors that appear to be less relevant for the situation in Europe. As the focus of the project is to detect emerging risks in food safety in Europe, these factors will not be considered further.

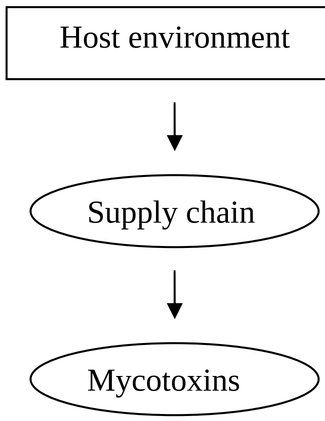
The European Mycotoxin Awareness Network (EMAN) produces several fact/information sheets reporting on the following mycotoxin related areas (EMAN, 2006):
- Test kits
- Analytical methods
- HACCP/Prevention
- Evaluation and Risk
- Quality Assurance

- Sampling/Legislation
- Surveillance

The information is gathered at both the national and international level and within food companies, published both in scientific journals or other public notices. This network may be a good starting point to gather information on the different factors influencing mycotoxin risks.

3. Discussion of host environment factors

The cause-effect relationships between the more indirect host environment factors and mycotoxin risks are hard to pinpoint. It can be argued that Good Agricultural Practices, Good Storage Practices and Good Manufacturing Practices should prevent mycotoxin contamination, rendering the identification of important host environment factors redundant. However, a number of abnormal conditions may lead to difficulties in following Good Practices. In fact, according to some experts the attempt to apply HACCP to the pre-harvest situation is fundamentally flawed due to the lack of control in the field situation (Aldred and Magan, 2004). It would therefore be useful to monitor host environment factors which may predict a risk for mycotoxin contamination. In this chapter, an attempt has been made to investigate the cause-effect relationship between the reported host environment factors and mycotoxin risks by considering their effect on critical factors from the food supply chain:



In addition, other host environment factors that have not directly been linked to mycotoxin contamination but are related to the food supply chain will be discussed.

3.1 Climate

As discussed in many HACCP systems and Codes of Practices for the prevention of mycotoxins, local weather conditions during crop growth and harvest are well-known to play a key role in the contamination of crops with mycotoxins. A demonstration of this is that agrometereological information preceding and during ripening can be used for predicting risk of DON contamination of wheat by *F. graminearum* and *F. culmorum*, respectively (Aldred and Magan, 2004). In general:

- Extreme draught may lead to damage in the crops, leaving them more susceptible for fungus infestation.

- A prolonged rain season may pose difficulties for the drying process of the crops. In addition, excessive rain fall may decrease the efficiency of fungicides.

Monitoring the local weather conditions in areas of crop growth may therefore be extremely useful for emerging mycotoxin risks.

3.2 Market and consumer trends

Market developments determine crop demands for both downstream users (for example cereal or animal feed producers) and direct consumers. In turn, changes in crop demand may indirectly affect the presence of mycotoxin risks. On one hand, an abnormal increase in crop demand may lead to shorter drying periods to meet the demand from domestic and export markets. In addition, a farmer may choose a different crop with a higher yield, but which may be less resistant to certain fungi. An increased popularity of organic food, the production of which generally does not include the use of fungicides, may also lead to a higher intake of mycotoxins if the organic crops are not sufficiently resistant to mycotoxin producing fungi.
On the other hand, an abnormal decrease in crop demand may lead to prolonged storage and the use of fewer resources towards this crop. Market development, and more specifically crop demand, therefore appears to be an important factor affecting mycotoxin risks. Market development can be influenced by companies directly affecting consumer behaviour by advertisement. In addition, a certain crop may be more popular in specific seasons, for example if it is associated with specific holidays. Public health institutes or media may advocate or discourage the use of certain crops as well.

The trends and sudden changes in the market for certain crops is therefore another factor that should be monitored in the identification of emerging risks. A difficult aspect is the question for which crops the market should be monitored. Naturally, crops that are known to be vulnerable to mycotoxin risks, such as grains and nuts, should be included. However, it is possible that mycotoxins are present in crops that have not previously been investigated for such a risk. A sudden increase in the consumption of such crops may also present a risk for mycotoxins.

3.3 Economy

Economic pressure may have more influence on field management, cropping systems and chemical input and other farming practices than best practice for disease elimination such as mycotoxin prevention (Aldred and Magan, 2004). The application of Good Agricultural Practices is currently voluntary and generally increases production costs. If benefits of these Practices are not immediately seen by the downstream producer or the consumer, it may actually weaken the competitiveness of the crop farmer, as the downstream producer or

consumer will choose a cheaper product instead. However, due to the regulations on the maximum permitted levels of mycotoxins in foods, the benefits for Good Agricultural Practices to prevent mycotoxins are likely well recognized, especially if strict enforcement of these regulations takes place.
Nevertheless, an overall poor financial situation of the crop farmer may lead to fewer resources towards the crops, such as poor storage and transport facilities and fewer employees. In addition, a long term poor national economy may result in poor infrastructure and education facilities.

Although economical situations of individual crop producers will be hard to monitor, the national economy may be a factor to consider in detecting mycotoxin risks.

3.4 Global trade

The increased globalisation of the food industry may sometimes result in a longer food chain in terms of transportation times for the crops, which in turn may complicate maintaining proper storage conditions. Trade barriers for a specific crop may increase storage times for the crops or even affect crop demand for the specific crop and its competing crops.

Monitoring global trading developments for a specific crop may therefore provide useful information for the identification of emerging mycotoxin risks.

3.5 Transport

Developments in the transportation chain of a crop causing transport to be unavailable may result in the crops being stored at inappropriate conditions, favouring the presence of mycotoxins. The proper functioning of the transportation chain should therefore be monitored.
Inappropriate transport conditions may also occur during transport by ship owners sailing under a flag of convenience, where there may be less inspection of the storage conditions.

3.6 New technologies

As discussed before, the implementation of Good Agricultural Practices and Good Manufacturing Practices should prevent mycotoxin presence in food stuffs. These Good Practices should in theory evolve with the development of new crops and new production or transport technologies. However, the use of new technologies may have unforeseen consequences that affect food quality. For example, recent pathogenic outbreaks have been suggested to be due in part to the change in agricultural food production, with more intensive farming practices (Byrne et al., in preparation). Similarly, new technologies may affect fungal growth and mycotoxin production in a negative way. For example, a change in crop strain or the use of monocultures to increase crop yield may lead to an unexpected increase in fungal growth and mycotoxin production if the new crop strain is less resistant to fungi.

Unforeseen consequences of new technologies may have a significant impact on mycotoxin risks. It would therefore be useful to monitor the development of new technologies in the food supply chain of crops in general, including transport facilities and technologies available to down-stream users of the crops.

3.7 Pests

In theory, appropriate pest control measures should prevent damage to the crops by birds and insects and as such prevent fungus growth and mycotoxin production. In addition, the use of fungicides and herbicides should decrease the presence of fungus on the crop directly by killing the fungus or indirectly by reducing the plant stress, respectively. However, excessive invasion of pests or new pests may occasionally surpass pest control measures. The excessive invasion may be caused by two important factors:

- Poor resistance of the crop to the pest. Some cultivars may be preferred over other, more resistant cultivars, because they produce a higher yield. The crop may also be less resistant to pests if inappropriate fertilisation has been used.
- The development of resistance of the pest to its control measures. It has been hypothesized that the use of antimicrobial drugs may be a significant driving force in accelerating the emergence of drug resistance in food borne pathogens (Byrne et al., in preparation). Similar to the effects of antimicrobial drugs on pathogens, the use of fungicides may lead to resistance of fungi and as such lead to an increase in mycotoxin production instead of the intended decrease (for example Reimann and Deising, 2005). A mathematical analysis by Hall et al. (2004) has shown that the two key determinants of the ability of a resistant pest to invade are any inherent fitness costs to the resistant subpopulation, and the effect of treatment on the sensitive and resistant subpopulations. For tricothecenes, there is some evidence that under certain conditions the use of fungicides may reduce fungus abundance but actually stimulate toxin production (Aldred and Magan, 2004).

It would therefore be useful to monitor the scientific literature on problems encountered with pest control management. Also, a surveillance system monitoring the presence of important pests in crop growing areas may prove useful.

3.8 Legislative developments

New legislation, both within and outside the EU, concerning the whole crop production chain may influence mycotoxin risks in a number of ways.
A difference in legislation between countries may affect crop prices, influence the competitive position of crop farmers or downstream producers of certain countries and cause a shift in crop demand.
For example the ban on the use of a certain pesticide in one country may lead to alternative expensive production methods or methods that are not (yet) sufficiently controlled by Good Practices. It also may lead downstream producers to choose a different source for their crops, causing a shift in crop demands.
Emerging mycotoxin risks should therefore be monitored by keeping track of legislation concerning different areas of agricultural crops, including crop growth, transport and production.

3.9 Summary

A number of host environment factors that potentially influence mycotoxin risk have been discussed: climate, market and consumer trends, economy, global trade, transport, new technologies, pests and legislative developments. It is clear that many of these factors are interrelated, with many factors influencing one another. The factors probably differ in their influence on mycotoxin risks, some factors having greater and more direct influence than others. However, at this point in the study, it is impossible to conclude the amount of influence of each factor. The approach of studying the effect of host environment factors on mycotoxin risks is new and very little information is available. In addition, the list of host environment factors that have been discussed in this report is by no means exhaustive. The factors have been gathered mainly on the basis of brainstorming sessions and other factors unknown at this point may be of great importance.

4. Identification of important indicators

In the previous chapter, a number of important critical factors influencing mycotoxin contamination have been identified. A change in these factors may reflect an increased or decreased risk for mycotoxin contamination. It is therefore key to identify indicators for these factors which can be monitored on a regular basis. Possible indicators associated with important critical factors are listed below.

Table 3 Important critical host environment factors and associated possible indicators

Critical Factor	**Indicators**
Climate	– Draught – Temperature changes – Rainfall
Market and consumer trends	– Crop demand: price, production – Trends: market research report data, newsletter coverage
Economy	– Gross Domestic Product – Inflation rate – Other economy indicators
Global trade	– Import and export data – Trade barriers
Transportation	– Strikes – Transport company registration
New technologies	– Scientific journal coverage – Newsletter coverage
Pests	– Prevalence of pests – Scientific journal coverage
Legislative developments	– Newsletter coverage – Pesticide registration

The next step is to determine how these indicators can be monitored in terms of their sudden changes or trends.

5. Sources of information for important indicators

A number of indicators have been identified which may assist in detecting emerging risks for mycotoxins. The next step is to identify the information sources available for these indicators. Below are examples of information sources and their potential use for identifying emerging risks for mycotoxins.

5.1 Climate

Free weather forecast services are widely available for practically every location in the world, such as for example MeteoConsult in the Netherlands (MeteoConsult, 2006). However, these services usually provide forecasts of no more than one week ahead and are as such not appropriate as an indicator for the purpose of identifying mycotoxin risks.

5.1.1 Draught, temperature changes and rainfall

The World Climate Service is a joint enterprise of Weather Ventures Ltd. and ZedX, inc., in collaboration with MeteoConsult in the Netherlands and its affiliates throughout Europe (World Climate Service, 2007). Against payment, it provides analysis of seasonal trends and outlooks for the entire world. Products include periodic newsletters and a website providing probabilistic seasonal forecasts of temperature and precipitation for selected geographical regions or the entire world. The World Climate Service Website provides monthly updates of forecasts for each of the next six months in probabilistic formats for six continents or geographical areas:

- North America and Central America
- South America
- Europe and the Middle East
- Africa
- Asia
- Australia and Oceania

Premium services include:

- user-decision aids specifying probabilities of occurrence of user-defined events
- climatological analyses tailored to user requirements.

The World Climate Service will also provide its services in forms designed and branded by users under conditions to be negotiated individually.

This worldwide information source could potentially detect areas where extreme draught, prolonged rainfall and major temperature changes are expected. Crops grown in that region may then potentially be at risk for mycotoxin contamination and should be monitored more closely. The system could then monitor both trends and sudden changes in climate for these crops. More specifically, for individual crop sources, periods of extreme draught during growth or the length of the rain season during or after harvest can be monitored or even predicted.

5.2 Market and consumer trends

The market development for a certain crop for both down-stream producers and direct consumers is influenced by many factors such as media attention, public health developments and fashion. As such, it can be monitored by means of several indicators, some of which are more readily quantifiable than others. Below are two examples of indicators that may be useful: crop demand and trends.

5.2.1 Crop demand: price and production

A straightforward indicator reflecting the market for a certain crop is its demand. However, the demand for a crop is hard to survey, as it is a function of its price. Demand is inversely correlated with supply, which can be monitored by means of production. Import and export data are also useful indicators for crop demand, but will be discussed in section 5.4 covering global trade. Data on price and production of crops are available from two free of charge information sources: EUROSTAT and FAOSTAT.

5.2.1.1 EUROSTAT

EUROSTAT is the Statistical Office of the European Communities situated in Luxembourg (EUROSTAT, 2007a). Its task is to provide the European Union with statistics at European level that enable comparisons between countries and regions. A number of databases within EUROSTAT may prove useful in monitoring several indicators for crop demand.

The EUROSTAT agricultural prices and price indices database covers annual or monthly prices and price indices of crops produced in the EU and can be searched by product, time period, and country. This database is useful if price information is needed on a known crop, but due to its limits in search volume is less appropriate to identify which crops undergo sudden changes in price (index). However, this information may be relatively easy to obtain by extracting the data from different search queries into a data processing programme, such that more data can be analysed simultaneously and sudden price changes may become apparent.

The agricultural crops products database covers statistics on the production of crop products in the EU and can be searched by product, time period and country. This database covers annual production only, but considering the time it takes to grow a crop, collecting more frequent data is not relevant. Crop production may therefore be useful as a trend indicator, but is less sensitive to monitor sudden changes in crop demand.

5.2.1.2 FAOSTAT

Statistical databases similar to EUROSTAT are available from the Food and Agricultural Organization (FAO) of the United Nations: FAOSTAT. Price and production of crops per country both inside and outside the EU can be extracted (FAOSTAT, 2006). However, information in these databases dates from 2004 or older and it is unknown when more recent data will be uploaded.

EUROSTAT and FAOSTAT can be used to monitor quantitative worldwide data on crop demand related indicators. However, up to date information is only available for crops produced in the EU.

5.2.2 Trends: market research report data and newsletter coverage

The driving forces of a market for a certain crop are the interests of consumers and downstream producers. With regard to downstream producers, it is important to not only focus on producers of consumer end products but also on producers of animal feed. It has been reported that dairy cows consuming grain contaminated with aflatoxin B_1 excrete aflatoxin M_1 in their milk (Prandini et al., 2005). Similar processes may occur for other mycotoxins.

The trends of consumers and downstream producers with regard to their interest in a certain crop may be quantified by monitoring market research report data. Limited quantification of trends is also possible by monitoring the number of citations in time in a selected number of newsletters from market researchers and public health institutes.

5.2.2.1 Market research sources

Several specialist journals and websites closely watch trends in the international food market:

- The Erasmus Food Management Instituut (EFMI) is a business school for the Dutch foods sector (EFMI, 2007). The EFMI conducts 5-6 research projects per year, which are made available for member companies of EFMI in the form of practical management reports. One of the themes of the research focuses on trends in the foods sector.

- The Market Intelligence Unit of Leatherhead Food International continually monitors market and industry developments as well as having in-house access to the largest industry-specific database (Leatherhead Food International, 2007). Reports can be purchased online and the company also offers monthly industry updates in market developments in the global food and drink industry. In addition, a Global Food Markets Database is available in hard copy, electronic or Internet format. This database provides up to date data, in terms of market size and trends, segmentation and market shares, in the form charts for the 25 most important sectors in the processed food industry, across 25 countries, incorporating local knowledge of developing markets. Economic, demographic

and retailing data are also available for each country. The information is updated on a regular basis and is constantly being expanded in terms of geographic coverage.
- Decision News Media is Europe’s leading market research aggregator of global business intelligence for Food, Beverage & Nutrition (Decision News Media, 2007). They sell a range of reports in this area from leading market research companies in Europe, the USA and beyond (for example market reports for breakfast goods, fruits and vegetables and pasta, bread and rice). News on food marketing and retailing is freely accessible. It is also possible to sign up for newsletters in the food, beverage and nutrition area.
- Just-food.com is a food trade site offering news, research reports and other relevant information for the worldwide food industry (Just-food.com, 2007). Full (paying) members have access to exclusive management briefings, an example of which is the June’s briefing titled ‘Adults’ modern eating trends in major consuming countries’. An automated article and news delivery agent is available for members, allowing for regular updates on selected topics of interest.

These websites may be useful for monitoring consumer trends from the industry’s point of view. Press releases on new legislations, production techniques and other relevant news may also be reported here.

5.2.2.2 Public health sources

The European Food Safety Authority (EFSA) is the keystone of European Union (EU) risk assessment regarding food and feed safety (EFSA, 2006). In close collaboration with all national food authorities in Europe and in open consultation with its stakeholders, EFSA provides independent scientific advice and clear communication on existing and emerging risks. The goal of the press room of the EFSA is effective, consistent, accurate and timely information for all stakeholders and the public at large, based on the risk assessments and scientific expertise of the Authority’s Scientific Committee and Panels.

This information source covers both the scientific and the public view on food health. Monitoring this website may help identify trends that may lead to greater mycotoxin risks, for example, an encouragement to eat more cereals.

5.3 Economy

National economy probably mostly influences mycotoxin risks with regard to long term weakening of the economy at the source of the crop, leading to economic pressure of the crop farmer and a deterioration of education and infrastructure.

5.3.1 Economy indicators: GDP, inflation rate and others

The World Economic Outlook presents the International Monetary Fund (IMF) staff’s analysis and projections of economic developments at the global level, in major country groups (classified by region, stage of development, etcetera), and in many individual countries (International Monetary Fund, 2005). It focuses on major economic policy issues as well as on the analysis of economic developments and prospects. It is usually prepared twice a year, as documentation for meetings of the International Monetary and Financial Committee, and forms the main instrument of the IMF’s global surveillance activities. The information is available in a database that is updated twice per year.

The database allows monitoring of relevant indicators (Gross Domestic Product, Inflation Rate) of national economies worldwide to detect trends that may lead to a poor financial situation of the crop producer, or more generally, a deterioration of education and infrastructure on a national level. A deterioration of education and infrastructure at the crop source caused by economic changes is more likely to occur gradually rather than as a sudden change and the database update twice a year may be sufficient to detect such trends.

The EUROSTAT databases, discussed in section 5.2.1.1, also contain the same and many other economic indicators, but for European countries and few other developed countries only.

The information sources are less suitable to monitor sudden changes in the financial situation of the crop producer. However, it is unlikely that such individual financial information is publicly available at all.

5.4 Global trade

The global trade of food commodities possibly leads to new trends in crop consumption and longer time periods between crop growth and consumption due to transportation times. In addition, a change in legislation in one country may affect crop demand and production methods in another country.

5.4.1 Import and export data

The EUROSTAT External trade statistics database covers all goods imported by and exported from the EU Member States with some 250 trading partner countries (extra-EU trade) and between EU Member States (intra-EU trade) (EUROSTAT, 2007b). The following information is available:

- Goods, presented according to several classifications
- Flow (import, export and balance)
- Reference period
- Reporting country (EU)
- Partner country (EU Member States or third countries) or geo-economic area

The following periods are covered:

- Annual statistics from 1976 to 1987
- Monthly, quarterly, half-yearly and annual statistics from 1988

The database only covers information from import and export reported by EU countries. In other words, information on goods imported by and exported from countries outside the EU cannot be extracted from this database.

The FAOSTAT databases provide information on quantities of crops imported by and exported from countries outside the EU. Information on both source and destination of crops can be extracted for cereals only (FAOSTAT, 2006). However, as with other FAOSTAT data, most information in these databases dates from 2004 or older and it is unknown when more recent data will be uploaded.

5.4.2 Trade barriers

The World Trade Organization (WTO) is the only global international organization dealing with the rules of trade between nations. At its heart are the WTO agreements, negotiated and signed by the bulk of the world's trading nations and ratified in their parliaments. The goal is to help producers of goods and services, exporters, and importers conduct their business. The documents online database provides access to the official documentation of the WTO, including the legal texts of the WTO agreements (World Trade Organization, 2007). Documents can be searched for by product type, country, and other keywords. Recently distributed documents can be consulted to keep track of the latest developments in international trade.

Trade barriers for the crop source are hard to quantify in terms of a measurable indicator. However, monitoring the qualitative information on trade barriers in the WTO database is useful to predict potential shifts in crop demands.

5.5 Transport

Transport problems may pose a risk for mycotoxin contamination due to improper storage conditions. It may therefore be useful to be alert when transport problems arise which may affect the transportation of crops within and out of their country of origin.

5.5.1 Strikes

A major cause for transport problems is the occurrence of strikes. Crops may be transported by road, air or water. Strikes in each of these transport sectors should therefore be monitored. It has to be noted that not only truck drivers, airline personnel and ship masters may go on strike. Border patrol, airport and harbour personnel may also put their work down for any given amount of time, potentially leading to long and unforeseen storage of crops.

No single source of information could be found alerting for all strikes in the transport section worldwide. Update information on strikes would have to be gathered from for example international news sites and travel agency sites.

5.5.2 Transport company registration

An increased use of unreliable transport companies which lead to a lack of supervision on proper storage and transport conditions may also increase mycotoxin risks. To this end, it would be useful to centrally register all transport companies used to transport agricultural crops to and within the EU, along with information on their quality assurance policies. To our knowledge, no such registry is currently available.

5.6 New technologies

A farmer may have several reasons to change a crop strain, crop rotation or type of fungicide. For example, the new technologies may increase the food production, or may be more appropriate due to new regulations. Similarly, downstream users may opt for new production methods that are cheaper or better serve the size of the company.

5.6.1 Scientific journal coverage

The Institute of Food Technologists (IFT) is a non-profit scientific society for people working in food science, food technology, and related professions in industry, academia and government (IFT, 2005). IFT publishes various resources for the food industry, including Food Technology and the Journal of Food Science.

5.6.2 Newsletter coverage

Trends in food production technologies may also be followed in newsletter of market research sources, such as those mentioned in section 5.2.2.1.

These sources may be useful for monitoring trends in production technologies from the view of scientific society and the production market. A (limited) quantitative indicator may be the number of citations in these information sources.

5.7 Pests

As discussed, Good Agricultural Practices usually include guidelines on pest control measures to prevent mycotoxins, either directly through fungicides, or indirectly through preventing damage and stress to the crop with insecticides, rodenticides and herbicides and preventing damage by birds.

5.7.1 Prevalence of Pests

A risk with using pesticides is the development of resistance of pests against such measures. A similar and well-known situation occurring in the cattle and poultry breeding industry is the development of antimicrobial resistance of bacteria. To closely monitor this situation, the DG SANCO of the European Commission and the Dutch Ministry of Health, Welfare and Sports funded the development of the European Antimicrobial Resistance Surveillance System (EARSS, 2007). The project is coordinated by RIVM and its aim is to maintain a comprehensive surveillance and information system that links national networks by providing comparable and validated data on the prevalence and spread of major invasive bacteria with clinically and epidemiologically relevant antimicrobial resistance in Europe. Although at present, pest resistance in agriculture seems not to have reached the same scale as antimicrobial resistance, current high input agricultural practices may necessitate the development of a similar system in the future. To our knowledge, no indicators are currently available to monitor the prevalence of pests in agricultural crops.

The North Carolina State University / Animal and Plant Health Inspection Service Plant Pathogen Forecasting System (NAPPFAST) is a novel Internet based research tool used to predict the potential establishment of exotic pathogens and pests (NAPPFAST, 2007). The primary purpose for the design of the system is to support the predictive pest mapping needs of the Cooperative Agricultural Pest Survey (CAPS) program. By doing a simple literature search environmental values can be obtained that correspond to the requirements of the casual organism on a specific host. For instance, apple scab, caused by *Venturia inaequalis (Cke.) Wint.*, requires a known number of wet hours at a specific temperature threshold to fulfil the environmental requirements for infection to occur. Based on similar literature searches models have been constructed for plant pathogens and arthropod pests. NAPPFAST can be used as a tool for historical analysis by allowing users to run models for past seasons or time periods and for specific weather stations.

A system similar to NAPPFAST may prove useful in the prevention of mycotoxin risks in Europe. A signal from the system indicating a risk for the establishment of a pest that may damage the crop would also indicate a risk for fungal growth and mycotoxin production. However, such a system is quite cost and labour intensive, as it requires crop and pest specific information input at the crop source. With this information, the tool has the potential to predict both sudden changes and trends of pest invasion and resulting mycotoxin risks for individual crop sources.

5.7.2 Scientific journal coverage

Pesticide Science is an international journal of research and technology on crop protection and pest control. Since its launch in 1970, the journal has become the premier forum for papers covering all aspects of research and development, application, use and impact on the environment of products designed for pest control and crop protection.

5.8 Legislative developments

Legislative developments may potentially be an important factor in mycotoxin contamination, for example in case of a ban on certain fungicides or other production techniques. Such developments need to be monitored in both the country of crop origin as well as countries of downstream users and consumers.

5.8.1 Newsletter coverage

Information on new legislations will often be published widely, for example in newsletters of market research sources discussed in section 5.2.2.1. A more specific regulatory information source can be found in Leatherhead Food International (LFI). This organization is a global and independent provider of food information, market intelligence and technical and food research services and has a special section on food law. For example, members of LFI have access to a team of regulatory experts to provide tailored responses to individual queries, be they for one country or several or perhaps in relation to EC or Codex law. If more detailed research is required, this can be handled on a consultancy basis. Keeping aware of potential changes in food law is possible by means of a weekly international e-mail alert on regulatory changes, database services in food and beverage legislation and the ‘Food law today’ website (LFI, 2007).

As with other indicators, the developments of new legislation in the international agricultural sector are hard to quantify other than keeping track of the number of citations in food regulation information sources such as newsletters.

5.8.2 Pesticide registration

For pesticides specifically, a change in registered pesticides could be monitored. Most countries operate a pesticide registration scheme, but no international information source could be found covering the registered pesticides in each country.

5.9 General considerations for indicator information sources

Collecting and monitoring a number of useful indicators and their information sources for the early warning for mycotoxin risks is a difficult task. A number of considerations in relation to the usefulness of an indicator need to be taken into account, some of which are outlined below.

- Global versus local information sources. Crops consumed in the EU are imported from all over the world. In order to obtain consistent information on the indicators, a single well-recognized source covering global as well as local changes rather than many different sources covering local changes only would be preferred.

- Time and frequency of information update. Ideally, information sources should allow the detection of both sudden changes and gradual trends in the indicator in a timely manner. Information sources that are updated frequently, with well-established data collecting procedures which will be available for longer periods of time are therefore most useful.
- Quantitative versus qualitative. In order to use the indicator in an automated computerized system, it is preferable, if not essential, that the indicator is quantifiable. However, a quantifiable indicator is hard to define for some factors, such as legislation and new technologies. Some qualitative, non-computerized monitoring may therefore remain necessary. These are however very labour intensive.
- General versus crop or mycotoxin specific. An indicator is obviously most useful if it can provide a warning signal for any mycotoxin risk originating anywhere in the world. Worldwide climate and economy indicators for example, may provide a signal indicating a possible risk in the area where the change takes place. However, for some indicators such as crop demand, it is virtually impossible with available information sources to track changes in crop demand in all countries for every crop. For such indicators, it may be necessary to develop a priority list of crops of most concern.
- Cost. Freely accessible information sources that meet all criteria listed above are scarce. Some information sources are only accessible against payment; others such as a pest surveillance system would need to be developed or customized in order to meet these criteria.
- Sensitivity. An indicator needs to be sensitive enough to indicate a possible mycotoxin risk, but at the same time should not trigger unnecessary warning signals.

Table 4 gives an overview of all the indicators and their information sources proposed so far, together with their status with regard to the criteria above. The sensitivity criterion has not been included in this overview, as a judgment on the sensitivity of any of these indicators to detect an emerging risk can only be given after testing.

Table 4 Overview of information sources for different potential indicators and their properties related to their usefulness

Factor	**Indicator**	**Information source**	**Global/Local**	**Trends/Sudden changes**	**Qualitative/ Quantitative**	**General/Specific**	**Cost**
Climate	Draught Temperature changes Rainfall	World Climate Service	Global	Both	Both	Both	Paid service[a]
Market and Consumer trends	Crop demand: price	EUROSTAT	Local (EU)	Both	Quantitative	Specific	Free of charge
		FAOSTAT	Global	Trends	Quantitative	Specific	Free of charge
	Crop demand: production	EUROSTAT	Local (EU)	Trends	Quantitative	Specific	Free of charge
		FAOSTAT	Global	Trends	Quantitative	Specific	Free of charge
	Trends: market research report data	EFMI	Local	Trends	Quantitative	Specific	Paid service[a]
		Leatherhead	Global	Both	Quantitative	Specific	Paid service[a]
		Novis	Global	Both	Quantitative	Specific	Paid service[a]
		Just-Food	Global	Both	Quantitative	Specific	Paid service[a]
	Trends: newsletter coverage	Leatherhead	Global	Both	Qualitative[b]	Specific	Free of charge
		Novis	Global	Both	Qualitative[b]	Specific	Free of charge
		Just-Food	Global	Both	Qualitative[b]	Specific	Free of charge
		EFSA	Local (EU)	Both	Qualitative[b]	Specific	Free of charge

Table 4 (continued) Overview of information sources for different potential indicators and their properties related to their usefulness

Factor	**Indicator**	**Information source**	**Global/Local**	**Trends/Sudden changes**	**Qualitative/ Quantitative**	**General/Specific**	**Cost**
Economy	Gross Domestic Product	International Monetary Fund	Global	Trends	Quantitative	General	Free of charge
		EUROSTAT	Local (EU)	Trends	Quantitative	General	Free of charge
	Inflation Rate	International Monetary Fund	Global	Trends	Quantitative	General	Free of charge
		EUROSTAT	Local (EU)	Trends	Quantitative	General	Free of charge
	Other economy indicators	EUROSTAT	Local (EU)	Both	Quantitative	General	Free of charge
Global trade	Import and export data	EUROSTAT	Global	Both	Quantitative	Specific	Free of Charge
		FAOSTAT	Global	Both	Quantitative	Specific	Free of Charge
	Trade barriers	World Trade Organization	Global	Both	Qualitative[b]	Specific	Free of Charge
Transport	Strikes	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
	Transport company registration	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
New technologies	Scientific journal coverage	Pest Management Science	Global	Trends	Qualitative[b]	Specific	Paid service[a]
	Newsletter coverage	Leatherhead	Global	Both	Qualitative[b]	Specific	Free of charge
		Novis	Global	Both	Qualitative[b]	Specific	Free of charge
		Just-Food	Global	Both	Qualitative[b]	Specific	Free of charge
		EFSA	Local (EU)	Both	Qualitative[b]	Specific	Free of charge

Table 4 (continued) Overview of information sources for different potential indicators and their properties related to their usefulness

Factor	**Indicator**	**Information source**	**Global/Local**	**Trends/Sudden changes**	**Qualitative/ Quantitative**	**General/Specific**	**Cost**
Pests	Prevalence of pests	NAPPFAST	Local (US)	Sudden changes	Quantitative	Specific	Paid service[a]
	Scientific Journal coverage	Pest Management Science	Global	Trends	Qualitative[b]	Specific	Paid service[a]
Legislative developments	Newsletter coverage	Leatherhead	Global	Both	Qualitative[b]	Specific	Both
	Pesticide registration	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown

[a] The properties of this information source could not be fully investigated, access to the source required payment

[b] Quantification is limited: tracking number of citations of specified search terms in time

6. Future research and recommendations

Investigations on the involvement of the factors described above during past events of high levels of mycotoxins or mycotoxicosis are sparse, especially for host environment factors. In order to determine which factors and associated indicators are most appropriate and sensitive enough to detect emerging risks with regard to mycotoxins, the indicators could be tested in the following ways:

– Ad hoc: investigate whether changes occurred in these indicators in past mycotoxin contamination events, for example those reported in the Rapid Alert System for Food and Feed (RASFF). Mycotoxin hazards notified to RASFF in the first eight weeks of 2005 involved only aflatoxin and ochratoxin A, mostly in dried fruits, cereals and spices. The countries of origin for the sources were variable, including both EU and non-EU countries (Prandini et al., 2005).
– Surveillance: include the suggested indicators in a targeted surveillance which monitors the levels of the most widespread mycotoxins in the most important crops for a specified period of time, for example aflatoxins in grains.

The results of the evaluation of the indicators should determine whether additional factors or indicators are needed. When all important factors have been identified, a system needs to be developed to simultaneously monitor these factors. It needs to be realized that none of the information sources by itself is capable of generating automatic warning signals. In other words, the warning system will require competent personnel to frequently monitor the indicators and judge whether any change indicates a true risk and requires further action. Two examples in 2004 in which RIVM was involved for advice emphasize the need for a careful supervision on the monitoring of such signals.

The first example relates to the increased levels of dioxins emitted from a waste incineration plant due to a failure of one of the ovens (Baars, 2004a). According to regulations, the dioxin levels were monitored routinely and showed an increasing trend, but no action was taken until dioxin levels exceeded maximum permissible levels.

The second example relates to an event of increased levels of dioxins in milk fat (Baars, 2004b, c). The increased dioxin levels were caused by feeding of dairy cows with potato peels containing high amounts of dioxins due to a production change. Dioxin levels in raw milk are routinely monitored and a trend of increasing dioxin levels in the milk was visible prior to exceeding the maximum permissible levels. However, similar to the previous case, no action was taken until dioxin levels actually exceeded maximum permissible levels.

In both examples, exceeding the maximum permissible levels of dioxins could perhaps have been prevented or limited if appropriate action would have been taken at an earlier stage, when the increased trend became visible. The examples demonstrate the need for defining conditions (benchmarks) for each indicator (and combinations of indicators) regarding what action needs to be taken at which change. Furthermore, there is an obvious need for monitoring trends as well as exceeding certain threshold levels.

As an alternative to monitoring indicators by personnel, an automated system could be developed in which data will be imported and signals will be generated automatically according to predefined conditions regarding both sudden changes and trends in one or a combination of parameters. Obviously, only quantitative indicators can be used in such a system. A system such as the one developed by RIVM for Disease Outbreak Detection may be useful (Widdowson et al., 2003), where data from several information sources are fed into one computerised system. There would still be a need to clearly define what action needs to be taken for each generated warning signal.
Due to the globalisation of the food industry, international cooperation on this level is required. The European Mycotoxin Awareness Network described in section 2.6 may be an appropriate network to introduce an early warning system for risks on mycotoxins.

Even after intense evaluation of the factors and indicators, new risks for mycotoxins may still emerge. The system would therefore require ongoing development and evaluation of critical factors and indicators. A network of experts (for example regulators, market experts, economists, climatologists) will be needed to determine which indicators best suit the purpose for identifying emerging risks for mycotoxins. The cost-effectiveness of this project needs to be seriously considered.

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[1] These reports are not publicly available, but can be viewed at the RIVM via the secretariat of SIR, Postbak 6, P.O. Box 1, 3720 BA, Bilthoven, the Netherlands. Tel: +31 (0)30 2744180