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Mycotoxins: food safety management implications

Anton J. Alldrick[1], Hans P. van Egmond[2], Michele Solfrizzo[3]

1 Campden BRI, Chipping Campden, UK
2 National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands
3 Consiglio Nazionale delle Ricerche, Institute of Sciences of Food Production, (CNR-ISPA), Via Amendola, Bari, Italy

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Correspondence
Anton J. Alldrick, Campden BRI, Chipping Campden, GL55 6LD, UK
Email: a.alldrick@campden.co.uk

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Abstract

Food chemical contaminants are chemicals that are not normally found in a particular food, their ingredients or the original raw material. Their presence is only acceptable when the levels that they occur at do not compromise public safety and are unavoidable after exercise of best practice. Mycotoxins, the toxic metabolites of certain filamentous fungi, are one group of contaminants and specific legislation, regulating permitted levels of contamination exists for a number of mycotoxin/food combinations. In many cases there is now considerable knowledge not only of the conditions conducive to their formation but also of the mechanisms that need to be in place to prevent or limit their occurrence. In a number of cases this knowledge has been converted into guidelines or other strategies, which both farmers and the food industry have adopted. Assessing levels of compliance and efficacy of these measures is achieved through appropriate audit/inspection and chemical-analytical regimes.

Introduction

The purpose of this paper is to discuss the significance of mycotoxins to the agri-food industry and how the hazards presented by them can be managed. In order to achieve this, it is necessary to consider the general challenges faced in managing chemical contaminants in food before discussing the unique ones presented by mycotoxins themselves. Any discussion of the impact of a particular aspect of food safety must include reference to legislation governing the safety of food; because, fundamentally, legislation provides the minimum standard against which any food business must operate. Within the context of this paper therefore, reference will be made to legislation currently operating in the European Union (EU).

Chemical contaminants – overview

Within the EU, the key requirements, which any process set to manage the hazards presented by chemical contamination of food must comply with are detailed within Council Regulation (EEC) 315/93 (European Parliament and Council, 1993). This regulation not only defines what a contaminant is; but also the circumstances under which contaminants are permitted to be present in food. In summary a chemical contaminant is any chemical not normally found in a particular raw material, ingredient or food that is present as a consequence of any operation during its production (agricultural or manufacturing). Chemical food contaminants can be categorized on the basis of how they arise (Table 1). Irrespective of the source of the contaminant, the agri-food industry has, more often than not, developed strategies to manage the probability of contamination occurring and to keep levels of contamination low. For example, in the case of process contaminants, food manufacturers have identified routes to ameliorate the formation of acrylamide in certain carbohydrate-rich products (Confederation of the Food & Drink Industries of the EU, 2007). The inevitability that food may sometimes be contaminated is also recognized within the regulation. Thus it permitted to sell chemically contaminated food providing that the levels of contamination neither immediately compromise public health nor give cause for toxicological concern. This is subject to the provision that

Table 1 Classification of chemical food contaminants

Classification	Example
Natural	Mycotoxins
	Heavy metals
	Nitrate and nitrite
Process	Chloropropanols
	Acrylamide
	Polyaromatic hydrocarbons
Consequential/ environmental	Pesticides
	Antibiotics
	Polychlorinated biphenyls
Adulterant	Unauthorised dyes (e.g., Sudan)
	Melamine
Adventitious	Consequences of poor agricultural/ manufacturing practice (e.g., machine lubricants)

the contaminant's presence is unavoidable even when best (agricultural and/or manufacturing) practice is applied.

In the case of a number of contaminants (irrespective of classification, Table 1), maximum permitted levels for their occurrence in particular foodstuffs have been set. The two key pieces of EU legislation detailing these limits are those concerned with plant protection agents (European Parliament and Council, 2005) and a range of commonly occurring miscellaneous contaminants, including certain mycotoxins (Commission of the European Communities, 2006a, 2007).

In terms of mycotoxins these regulations have considerable commercial impact both for those for which regulatory limits exist and also for those where no limit had been set in law. One example concerning the second scenario concerns fumonisins. Before harmonization of the laws in the EU concerning limits for a number of *Fusarium* spp. toxins (Commission of the European Communities, 2006a, 2007), limits for fumonisins were left to the discretion of Member States. In the case of a number of countries (including the United Kingdom) no such levels had been legislated for. Nevertheless in 2003 a voluntary product recall of certain polenta products was made in the United Kingdom, after the national regulatory and enforcement agency (Food Standards Agency) identified batches of polenta contaminated with high levels of fumonisins (Food Standards Agency, 2003). The recall followed a risk assessment, which demonstrated that levels of contamination were sufficiently high to place certain groups of consumers eating the polenta at risk of exceeding the provisional tolerable weekly intake set for it (Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment, 2003).

Mycotoxins – legal and commercial perspectives

Mycotoxins are the toxic metabolites of certain filamentous fungi. It has been estimated that approximately 25% of the world's crop production is to one degree or another contaminated with them (Charmley *et al*., 1995). As such, they present a significant hazard to both man and his livestock. They are a diverse group of compounds both in terms of their chemical structures and also their toxic effects. In addition to these characteristics, mycotoxins have others that present significant challenges to the agri-food industry. These revolve around the biology of mycotoxin production and the fact that the process of mycotoxin contamination usually takes place within the commodity or raw material before it is processed into a finished food for consumption.

A key factor that has to be taken into consideration is that where legislation exists for maximum residue limits these tend to progressively decrease as the raw material is progressively processed into a food intended for human consumption. Within the EU one such example concerns wheat and the mycotoxin deoxynivalenol (DON) (Figure 1). Of note in this case is the fact that while the maximum permissible limit for DON in wheat intended for food processing is 1250 $\mu g\,kg^{-1}$ (Commission of the European Communities, 2007), the limits for the ingredients and products ultimately derived from the grain progressively reduce.

From Figure 1, it can be clearly seen that there are considerable reductions in the limits set for wheat *ex farm* and the flour that might be produced from it (1250–750 $\mu g\,kg^{-1}$) or from breakfast cereals produced from whole wheat kernels (1250–500 $\mu g\,kg^{-1}$). This can provide a challenge to grain purchasers in setting mycotoxin limits as part of a commercial specification. In terms of cereals, physical sorting methods such as the use of specific-gravity tables can lead to the removal of certain types of contaminated grains and hence, reduce mycotoxin loading (Tkachuk *et al*., 1991).

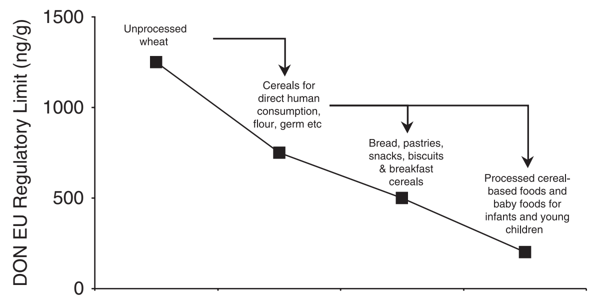

Figure 1 Schema showing European Union (EU) permitted levels of the mycotoxin deoxynivalenol (DON) in wheat and the various foods made from it.

The efficacy of such systems presupposes that DON contamination is only associated with damaged or substandard kernels. This does not necessarily appear to be the case (Edwards *et al*., 2001). In terms of the milling process itself, as in the case of ochratoxin A (Alldrick, 1996), removal of the bran layers (e.g., by pearling or dehulling) in the milling of wheat or barley to produce white flours can also lead to reductions in the DON loading of the finished product (Abbas *et al*., 1985; Lepschy & Suess, 1996; House *et al*., 2003). A 67% reduction of DON during durum wheat processing for spaghetti production has also been reported (Visconti *et al*., 2004).

Such reductions would not be expected in the production of 100% extraction flours where the bran is retained. Therefore, particularly in the case of high extraction rate white flours, the substantive reductions (1250–750 $\mu g\,kg^{-1}$) in mycotoxin content required might not be achieved through the milling process.

Theoretically, a second approach to replace or augment physical removal of mycotoxins is through chemical decontamination. While physical sorting of contaminated material or removal of contaminated fractions of raw materials intended for human consumption is permitted under EU law, chemical decontamination is not (Commission of the European Communities, 2006a). Furthermore such treatments more often than not impair or destroy the raw material's technological properties (e.g., Alldrick, 1996). Relying on food-manufacturing processes as a means of inactivating mycotoxins is also inadvisable. With the possible exception of breakfast cereals produced from fumonisin-contaminated maize (De Girolamo *et al*., 2001), generally speaking the thermal processes normally associated with food processing do not bring about substantive reductions in mycotoxin content (e.g., Scott *et al*., 1983; Abbas *et al*., 1985)

Given these constraints, it is unsurprising that those responsible for processing commodities and raw materials will often set lower limits for mycotoxin contamination in their specifications and contracts with their suppliers (discussed by Alldrick *et al*., 2009a). It is therefore incumbent on those supplying raw materials into the food industry to adopt strategies that assure a consistent supply of material meeting not only limits on contamination set out in regulation but also the (probably more) stringent requirements of their customers.

Managing mycotoxin contamination in commodities

Given the above, there is a general consensus that the fundamental route to ensuring that levels of mycotoxin contamination remain within acceptable levels is the adoption of a 'prevention is better than cure' approach (Battaglia *et al*., 1996). In other words prevent or minimize mycotoxin contamination in the first instance. Managing mycotoxin contamination of any commodity requires an appreciation of the mechanisms underlying their formation and developing strategies that minimise the probability of it occurring. In terms of the strategies needed to control them, mycotoxins can be broadly classified as being either of 'field' or 'storage' (Miller, 1995). Essentially such terminology refers to that stage in the life cycle of a commodity when the mycotoxin is formed. In other words either before (field) or after (storage) harvest. Inevitably such a classification has an arbitrary element, however, it is generally accepted that of those mycotoxins subject to direct (or planned) regulatory limits, DON together with T-2 and HT-2 are considered to be 'field' mycotoxins while ochratoxin A is a 'storage' mycotoxin – with the exception of grape-wine, which becomes contaminated in the vineyard (Visconti *et al*., 2008). There is, however, a 'grey area.' Although fumonisins and zearalenone are produced by *Fusarium* spp., plant pathogens that infect the plant during active growth of the crop; their formation appears to take place shortly before and to continue after harvest (depending on the crop's water activity). A similar case can hold for aflatoxins. Historically they have been regarded as storage mycotoxins, however, there is evidence to show that under certain circumstances they can be produced in the developing peanut crop (Hill *et al*., 1983).

Irrespective of whether mycotoxins are 'field' or 'storage' in nature the process by which commodities become contaminated with them is the same. Essentially this comprises three stages (Figure 2). The commodity must first become infected with the toxigenic fungus, which must then grow on the plant. Fungal growth is eventually accompanied by mycotoxin production. However, as shown in Figure 2 the probability of each stage occurring can be dependent on a range of factors. Strategies for minimizing mycotoxin contamination are, therefore, based on an understanding of how current agri-food industrial practices impact on the biology of mycotoxin formation. An early example of outputs from such thinking was advice provided to Swedish farmers concerning the post-harvest handling of grain in respect of potential ochratoxin A contamination. This was with particular regard to the correct operation of grain dryers (Jonsson, 1996). Since then the knowledge base has been expanded both in terms of the breadth of best practice advice available (e.g., Home Grown Cereals Authority, 2008) and the management systems in, which they should be

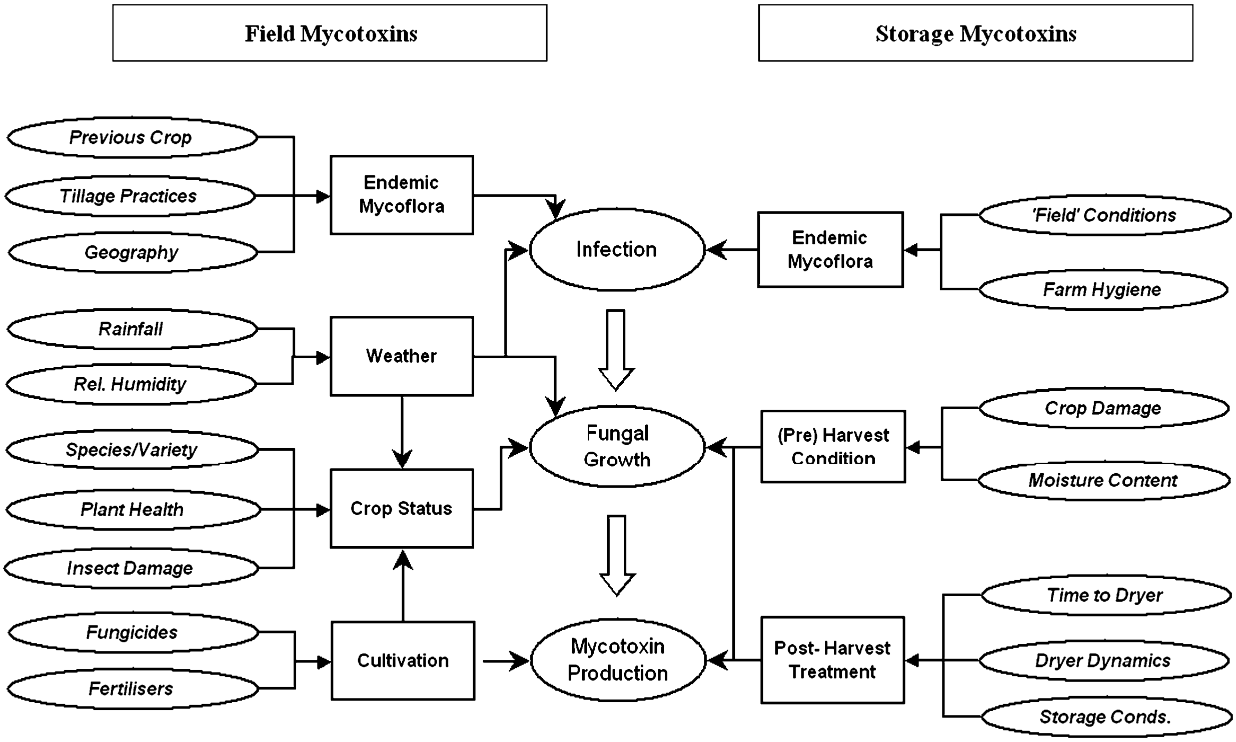

Figure 2 Schema showing a basic model for the formation of both 'field' or 'storage' mycotoxins in commodities and the interaction of a selection of external modifying factors on their formation.

applied to ensure the operation and effectiveness. In the latter case, application of Hazard Analysis Critical Control Point (Codex Alimentarius Commission, 2003a) principles has led to both generic (e.g., Codex Alimentarius Commission, 2003b) and also commodity specific (e.g., fusarial mycotoxins in grain, Commission of the European Communities, 2006b; patulin in apple juice, Commission of the European Communities, 2003) and; ochratoxin A in coffee, Lopez-Garcia *et al.*, 2008 as well as wine, (Codex Alimentarius Commission, 2007) guidelines to minimize mycotoxin contamination. These general principles of management have been supported by the development of specific tools to assist in ameliorating mycotoxin contamination. An example of a specific tool is DONcast^{TM} (Weather Innovations Incorporated, 2008), a weather prediction-based tool to assist Canadian wheat farmers in deciding whether or not to apply appropriate fungicide treatments at anthesis to reduce the risk of eventual DON contamination. Of a more general nature is the development of a conceptual model aimed at predicting the occurrence of emerging toxins (Van der Fels-Klerx *et al.*, 2008). This model takes a supply chain approach (wheat) and can handle various types of indicators (weather conditions, agronomical practices, trade and legislation, as well as a variety of information sources, e.g., from farm records and statistical organizations).

Mycotoxins – assuring consumer safety

Food businesses have both a moral and legal duty to ensure that, 'Food shall not be placed on the market if it is unsafe' (European Parliament and Council, 2002). Given the general resistance of mycotoxins to degradation under normal food processing conditions, the key defence for a food business to avoid producing excessively contaminated food is through the use of commodities/raw materials with sufficiently low mycotoxin contents (discussed above) to avoid giving cause for concern. This can only be achieved through sourcing raw materials from suppliers of demonstrable competence. Food businesses accomplish this objective through a process of 'Supplier Quality Assurance,' which is a core requirement of most recognized international quality standards for food manufacture (e.g., British Retail Consortium, 2008).

To ensure any food-safety management process continues to operate optimally, it is important that its efficacy be verified on a regular basis. In the case of mycotoxins this may take a number of routes but in particular by audit of the supply chain and analysis of raw materials in accordance with a predetermined schedule. Verification by audit can take place at one of three levels, internal audits/inspections (first party), inspections by purchaser (second party) or inspections by a third party in order to confirm compliance with a particular good agricultural or manufacturing standard. In terms of managing mycotoxins, such standards will often require those businesses certified to them to adopt best practice for example in terms of general agronomy, crop drying and storage (e.g., Assured Combinable Crops Producing Trust, 2008). It is important to note that, both generally and specifically in the case of mycotoxins, audit and inspection verify that, at the time the inspection was undertaken and also on a historical basis, procedures put in place as part of the mycotoxin-control management system were complied with. Such activities do not, however, verify the efficacy of those management systems. This can only be achieved through analysis of the material concerned for the relevant mycotoxins.

Within the EU, food businesses have a legal obligation to undertake relevant analyses at an appropriate frequency (European Parliament and Council, 2004). Given the resource implications, the frequency and extent of mycotoxin analyses undertaken by a food business will be dependent on some form of risk analysis (discussed by Poms *et al*., 2009). It should also be realized that the fundamental reason why most analyses are undertaken is to verify the efficacy of the food-safety management systems in assuring that levels of mycotoxin contamination do not exceed those limits set out within those systems. This is not the same as establishing compliance with a particular specification or regulation *per se*. Consequently the evidential standard required both in generating the sample necessary for performing the analysis, together with the analytical method used are generally lower than for those used in establishing regulatory compliance or in commercial arbitration.

Conclusion

Mycotoxins are chemical contaminants. Under EU law their presence in food is only permitted if the levels of contamination not only do not immediately compromise public health or give cause for toxicological concern but also if their presence is unavoidable after exercise of best practice. Given the almost ubiquity of mycotoxin contamination in certain foods, regulatory limits for particular mycotoxins in foods and the raw materials they are made from have been set. Consumer safety in respect of mycotoxin contamination is assured by all parts of the food chain demonstrating that practices aimed at avoiding or minimizing contamination are actively and effectively used. The efficacy of such practices is verified through the use of appropriate audit/inspection and sample analysis programmes.

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