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Mycotoxin production in major crops as influenced by growing, harvesting, storage and processing, with emphasis on the achievement of Food Safety Objectives

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ABSTRACT

The concept of Food Safety Objective (FSO) has mostly been applied to understanding the effects of handling and processing on levels of bacterial pathogens in foods, but it is also applicable to the formation and removal of mycotoxins. This paper provides a general overview of how the concept of FSO can be used to understand increases and decreases in mycotoxin levels in foods, on the basis that international regulatory limits are equivalent to an FSO. Detailed information is provided on the ecology of the formation of aflatoxins, fumonisins, ochratoxin A and deoxynivalenol in major commodities. Methods in use to reduce levels of these mycotoxins, to meet an FSO, are then detailed. Each of the major mycotoxin – food combinations is visualised using a novel graphical method.

1. Introduction

Regulatory efforts internationally have focused on the use of risk assessment tools to drive food safety policy and standards away from prescriptive to outcomes based on concepts such as the Food Safety Objective (FSO) and Performance Objectives (CAC, 2007; ICMSF, 2002a). These approaches provides a scientific basis that promotes flexibility and innovation by allowing industry to select and implement control measures specific to particular operations. Many current food safety issues are complex in nature, requiring approaches through the production chain and relying on more than one control measure to manage risk effectively. It is envisaged by regulators around the world that the new risk management guidelines will offer a framework that will facilitate communication between stakeholders on the most effective food safety management options as well as providing a scientific basis for equivalency.

The risk management framework approach has seen wide application in the development of Codex Alimentarius codes for the control of *Listeria* in ready to eat products and within the hygienic code of practice for powdered infant formula. More recently, this framework has been used as the basis for the validation of control measures in a food chain and in the consideration of alternative measures to ensure the safety of commercially sterile foods (Anderson et al., 2011).

The FSO concept has generally been applied to issues regarding safety from pathogenic and toxigenic bacteria, but has wider application, for example in regard to the formation and control of mycotoxins. Theoretical aspects of this topic have recently been reviewed by García-Cela, Ramos, Sanchis, and Marin (2012). In the current paper, the ICMSF/CODEX risk management framework is used as a tool to assist in explaining the ecology of mycotoxin formation in major food commodities and to highlight the control measures available to manage mycotoxin levels in foods, to meet Food Safety Objectives.

The toxicity of important mycotoxins has been evaluated by international specialists, most notably by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), the European Food Safety Authority (EFSA) and the US National Toxicology Program (NTP). In particular, JECFA provides estimates of toxicity to Codex, which determines levels of mycotoxins permissible in foods and food commodities in international trade. Although explicitly stated only rarely, i.e. in ICMSF (2002b) and García-Cela et al. (2012), such maximum permitted levels possess essentially the same status as FSOs determined for bacteria in foods.

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In the case of bacteria, the general formula

$$H_o - \sum R + \sum I = FSO$$

is relevant, as reductions in numbers of bacteria result from some form of processing such as heating, and increases in numbers may occur subsequently (ICMSF, 2002a). In the case of mycotoxins, the formula is more logically used in the reverse order

$$H_o + \sum I - \sum R = FSO$$

as increases in mycotoxin levels may occur before or after harvest, during drying, or during storage ($\sum I$). Reduction in mycotoxin levels, $\sum R$, takes place during processing (ICMSF, 2002b).

1.1. *Assumptions and caveats*

The time when "H_o", the initial level of contamination, occurs during mycotoxin formation is debatable. Some logic exists in placing H_o at the time when edible portions of crops begin to develop, or begin to mature. However, those points are at best uncertain, i.e. mycotoxin levels are not usually analysed then, and levels are almost always uncontrolled. Drying and storage may take place on farm, and some merit exists in placing H_o at the time of harvest. However, these steps rarely result in any decrease in mycotoxin levels (except for cleaning, a process neglected here). For the sake of simplicity, for the purposes of this work, H_o is designated as the time of sale from the farm to distributors or processors, following which mycotoxin reduction usually takes place. For present purposes, drying and storage on farm is not differentiated from later drying and storage, as the effects of poor drying and storage on farm or in warehouse or factory, or in transport, are similar.

The approach taken here is entirely qualitative, i.e. no weight is given to slopes of lines in the figures, so all have been drawn at the same angle. In practice, increases or decreases in mycotoxin levels in any commodity are strongly dependent on climate, storage and processing conditions. Any quantitative risk management framework for a particular situation would require the appropriate data to allow estimation of stochastic aspects at each stage. A similar approach to that of Zwietering, Stewart, Whiting, and International Commission on Microbiological Specifications for Foods (2010) would be required. Climatic modelling has been shown to assist in managing aflatoxin in Australian peanuts (Chauhan et al., 2010) and deoxynivalenol in Canadian wheat (Schaafsma & Hooker, 2007). In the same way, no figures are given for FSOs, as the focus of this paper is the conveyance of the concept of risk management to the issue of mycocotin control, not quantifying acceptable levels of protection.

It is recognised that the following discussion relates to what is believed to be normal commercial practice. Under exceptional circumstances, mycotoxins may form at different times, or different reduction strategies may apply. It is impractical to attempt to accommodate all such possibilities in a general paper of this type.

1.2. *Mycotoxins*

According to Miller (1995) five mycotoxin groups are of importance in human health: aflatoxins, ochratoxin A, fumonisins, trichothecenes, specifically deoxynivalenol and closely related compounds, and zearalenone. These will be treated here, with the exception of zearalenone, as it is produced by the same fungi as produce deoxynivalenol, so production and removal follow similar pathways.

2. Aflatoxins

Aflatoxins are produced by a number of species of *Aspergillus*, of which *Aspergillus flavus* and *Aspergillus parasiticus* are the most important in foods. *A. flavus* produces B aflatoxins, while *A. parasiticus* produces both B and G forms. While only 40% of *A. flavus* isolates produce aflatoxins in culture, essentially all *A. parasiticus* strains are producers. The most important commodities affected by these species are peanuts, maize and, in the USA, cottonseed. Although *A. flavus* infects all of these crops, *A. parasiticus* is usually only associated with peanuts. Aflatoxins occur to a lesser extent in many other crops, including tree nuts, spices, rice, etc (Pitt & Hocking, 2009). Aflatoxins are perhaps unique among mycotoxins, as they are produced both before and after harvest under conditions that occur quite commonly.

Aflatoxins are the most important mycotoxins, as aflatoxin B_1 is the most potent liver carcinogen known. It is likely that aflatoxins produce other effects in humans as well (Khlangwiset, Shephard, & Wu, 2011; Williams et al., 2004).

2.1. *Aflatoxins in peanuts*

Peanuts are unique among nut crops, as the nuts develop underground, conditions favourable for attack by both insects and fungi. The time course of aflatoxin development and reduction in peanuts in good commercial practice is shown in Fig. 1.

2.1.1. *Preharvest*

Under conditions of adequate rainfall or irrigation, aflatoxin usually does not occur in peanuts. However, much of the world's peanut crop is produced under less than ideal conditions. Peanut plants have deep tap roots and so have more resistance to drought than many other crops. For this reason, peanuts are often grown under moisture limiting conditions, and in the tropics that often means towards the end of the rainy season, after rice or some other more drought sensitive crop. The major factors influencing *A. flavus* and *A. parasiticus* infection in peanuts are insect damage to the developing nuts and plant stress due to drought and high soil temperatures before harvest (Dorner, Cole, & Blankenship, 1998; Pitt, 2004). Although it is known that developing peanuts can be infected by a variety of means, including through flowers or systemically, most infection takes place directly from the soil surrounding the nut. Insect damage provides direct access through the shell. Drought stress acts in three ways: first, by reducing the plant's natural defences against infection (well developed in a nut that forms underground) as the plant wilts and loses metabolic activity; second, by reducing the water activity in the soil, which reduces growth and activity of bacteria, amoebae and competing fungi; and third, by promoting growth of *A. flavus* and *A. parasiticus*, which are xerophiles (Pitt & Hocking, 2009).

Reductions in drought stress by irrigation, or rain, limiting insect damage by good agricultural practice, or competitive exclusion by introduced nontoxigenic strains of *A. flavus* (biocontrol; Dorner, Cole, & Blankenship, 1992; Pitt, 2004), all assist in reducing the occurrence of aflatoxins before harvest. However, drought stress cannot be prevented under the dry culture condition under which most of the world peanut crop is produced. In much of the world, good agricultural practice cannot prevent aflatoxin production in peanuts before harvest.

2.1.2. *Postharvest*

As with other crops, rapid drying of peanuts will prevent any increase in aflatoxin production. This requires mechanical systems. The usual practice in industrialised economies is to pull bushes from the soil and invert them on the row to permit sun drying.