INTRODUCING HACCP- BASED RISK MANAGEMENT FOR MYCOTOXIN CONTAMINATION IN AUSTRALIAN MAIZE

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Abstract

Recent incidents of mycotoxin contamination have highlighted the need for an industry wide management system to ensure Australian maize meets the standards of all domestic users and export markets. One potential framework is the HACCP (Hazard Analysis Critical Control Point) system, developed to ensure “absolute food safety” and used internationally for quality control in the food industry.

HACCP is a logical process which analyses each step in production and identifies controls critical in minimising contamination. Applying these controls ensures that risk is managed throughout the entire production chain, not just in the end product. Documented monitoring of critical control points contributes to quality assurance and allows purchasers to select product from agents who have followed appropriate management procedures.

The international body Codex Alimentarius has formulated a code of practice for minimising mycotoxins in cereals. We have prepared a step-by-step guide to developing a management plan that applies the principles in the Codex document combined with Good Agricultural Practice (GAP) to the Australian maize production chain within a HACCP framework. The guide uses simple, clear examples to guide growers, bulk handlers, millers and other industry sectors in identifying critical control points in their individual situations.

Introduction

In the last three years the Australian maize crop has experienced a number of cases of mycotoxin contamination including rejection of maize by millers in the MIA in 2003 because of fumonisin and aflatoxin contamination; aflatoxins in bulk maize in Central Queensland in 2004; rejection of a maize shipment to Japan in early 2005 because of aflatoxin contamination; and the effects of severe drought on aflatoxin contamination of maize in southern Queensland in 2005 (Blaney et al. 2006). Despite only affecting a small percentage of Australian maize, these recent incidents have highlighted the need for an industry wide management system to ensure Australian maize meets the standards of all domestic users and export markets.

Mycotoxins are ubiquitous, environmental pollutants which cannot be easily eliminated once contamination has occurred (Blaney 2004). They are formed as metabolic byproducts by a wide variety of fungi and found in most regions of the world in a wide variety of substrates. Mycotoxins that have been found in maize include aflatoxins, citrinin, cyclopiazonic acid (CPA), fumonisins, ochratoxin A, penicillic acid, trichotheccenes (including nivalenol and deoxinivalenol) and zearalenone (Council for Agricultural Science and Technology 2003). Of these, aflatoxins, trichotheccenes, fumonisins, zearalenone and ochratoxin A are of concern, because of the risk they pose to human health as food contaminants (Council for Agricultural Science and Technology 2003, Pitt and Tomaska 2001, 2002, Whitlow Jnr and Hagler Jnr 2003). While no Australian regulatory standards are currently in place, Codex Alimentarius supports the ALARA (as low as reasonably achievable) principle. The National Agricultural Commodities Marketing Association (NACMA) has formulated trading standards for aflatoxins and fumonisins and it is to be expected that these industry standards will be used in most cases.

There are two methods by which mycotoxin contamination of foodstuffs or feedstuffs can be minimised. The reactive approach is for loads to be chemically analysed for the presence of specific mycotoxins and accepted or rejected accordingly; the proactive approach is to implement a quality control system applied to production, transport and storage to produce grain that is more likely to meet standards.
Reliance on testing of the final product creates waste both in terms of potentially wasted money and wasted grain should a load be rejected for all potential purposes. Contaminated maize may be diluted with uncontaminated grain, but the sale price for contaminated grain would be substantially reduced. Mycotoxins occur heterogeneously throughout a load and so accurate sampling for mycotoxin analysis is extensive, time consuming and requires substantial quantities of grain. Chemical analysis is complex, requiring trained analysts, costly consumables and significant time to complete each assay. Additionally, a significant number of chemically diverse mycotoxins occur in maize, with a specific chemical assay required for each one. These factors result in considerable expense for the operator.

Conversely, a proactive quality control system incorporates many of the specific measures already in place in most well-run maize production, transport, storage and marketing operations, particularly with respect to moisture control and storage. The major benefit to a quality control system is that specific points and factors conducive to mycotoxin production are controlled and monitored against specified critical limits. Moisture, for example, is significantly easier to control, monitor and rectify- and significantly less costly- than monitoring for mycotoxins in the end product.

Problems have been identified by various sectors because, although they can assure purchasers that grain has been stored correctly whilst in their possession, there are no guarantees on what has happened further up the chain. A formal quality control system includes appropriate documentation and eliminates this uncertainty and guarantees that maize has been subject to appropriate storage throughout its history. Consequently, buyers can be assured that the risk of mycotoxin contamination of the product is low.

Overseas markets are becoming increasingly important in today’s primary industries. The move toward quality control is occurring rapidly and in order to compete successfully in international markets, Australian producers are finding it necessary to embrace quality control locally. Quality control has been successfully practised in other sectors of Australian primary production and the experience is that product marketed as being generated in compliance with an accredited quality control system demands significantly higher prices than that without the “tick of approval”.

One potential quality control framework is the HACCP (Hazard Analysis Critical Control Point) system, developed to ensure “absolute food safety” for US astronauts (NASA 1998). There is a significant amount of research currently supporting the use of HACCP planning in primary production and specifically in the grain industry (Brandt et al.; EUROPA 2000; FAO 2001; Wyss 2005) and it has been endorsed by the WHO for this purpose (Codex Alimentarius Commission 2003).

The HACCP framework

HACCP is a logical process which analyses each step in production and identifies controls critical in minimising contamination. Applying these controls ensures that risk is managed throughout the entire production chain, not just in the end product. Documented monitoring of critical control points contributes to quality assurance and allows purchasers to select product from agents who have followed appropriate management procedures. Each of these critical control points is assigned an acceptable limit and a method for testing against that limit. Test results are recorded for quality assurance purposes and the HACCP plan is documented and, ideally, certified by an appropriate body.

HACCP has seven basic principles (EMAN 2003), outlined in Table 1.
### Table 1: Principles of HACCP planning

<table>
<thead>
<tr>
<th>HACCP Principle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduct a hazard analysis.</td>
<td>A detailed step by step diagram of the process is prepared, identifying where significant hazards occur.</td>
</tr>
<tr>
<td>Determine critical control points</td>
<td>Critical Control Points (CCPs), points at which the hazards can be controlled, are identified throughout the process.</td>
</tr>
<tr>
<td>Establish critical limits.</td>
<td>These are limits that must be adhered to if risk is to be minimised</td>
</tr>
<tr>
<td>Devise a monitoring programme.</td>
<td>Monitoring is critical in any HACCP programme to ensure control points remain under control</td>
</tr>
<tr>
<td>Define corrective actions.</td>
<td>If a control point is shown to be out of range, corrective measures must be implemented</td>
</tr>
<tr>
<td>Establish verification procedures.</td>
<td>Verification that the HACCP plan is successfully controlling mycotoxin contamination is necessary. At this point, some chemical analysis of the product is required. If contamination is found to exceed limits, immediate action is necessary to identify the step or steps at which failure has occurred. This may mean new CCPs are identified, critical limits are adjusted or the monitoring programme is altered.</td>
</tr>
<tr>
<td>Develop documentation and record keeping.</td>
<td>A successful HACCP programme relies on comprehensive documentation of procedures and records. This will usually involve a flow diagram of the process; the hazard and risk assessment; and a list of CCPs, critical limits and monitoring programmes. Ongoing records of monitoring and corrective action must be kept for consultation as well as the results of verification. Operation requirements for staff and records of staff training should also clearly documented and available. An audit of a HACCP system will include an examination of all this documentation and must be satisfactory should accreditation be desired.</td>
</tr>
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</table>

### Mycotoxin-related hazards in the Australian maize industry

Factors conducive to mycotoxin contamination occur throughout the maize production and marketing process but fall into a number of common categories. These include exposure to infection, plant stress, kernel damage and excess moisture, all of which promote fungal growth. Mycotoxin contamination is cumulative, with no simple step to eliminate contamination after the fact, making continuous quality management the only method for minimising contamination in the end product.

#### Planting

**Exposure to infection**

Preventing exposure to infection begins with reducing the available inoculum. Fungal spores remain dormant in soil from crop to crop and from year to year, increased by yearly layers of infected trash material. Soil contamination can be controlled by removing old seed heads, stalks, and other debris that may serve as substrates for the growth of mycotoxin-producing fungi. In recent years, increasing adherence to no-till cultivation, aimed at preserving topsoil, has led to the potential for an increase in soil contamination with fungal spores, requiring a trade off between mycotoxin control and soil conservation.

Research overseas has shown that rotating crops that share susceptibility to specific fungi increases the availability of inoculum in shared fields. Wheat and maize share a susceptibility to some *Fusarium* sp., particularly *F. graminearum* (Codex Alimentarius Commission 2003). Rotating these two crops in areas of Australia subject to infection with this fungus, such as the Liverpool Plains of NSW, potentially increases the availability of inoculum to these crops and should be avoided where possible.

In most cases, while good practice can reduce the availability of inoculum, it is impossible to eliminate it altogether. Over many years, there has been much research aimed at breeding maize hybrids resistant to fungal infection. Ian Martin of the Queensland Department of Primary Industries and Fisheries (QDPIF) in North Queensland has particularly worked on developing hybrids resistant to *Fusarium* sp. infection. In the future, selection of infection resistant hybrids may become an effective way to eliminate mycotoxin contamination in the field.
Plant stress

Plants suffering from stress caused by poor nutrition or water deficit have greater susceptibility to fungal infection, because this reduces the plant’s natural defences. This can be addressed at planting by ensuring soil pH and nutrients are at recommended levels. Plant spacing is also important to ensure optimum use of available water and nutrients.

Timing planting to avoid high temperatures and drought stress during the period of seed development and maturation is also an important precaution (Codex Alimentarius Commission 2003), particularly in Australian conditions. As part of the GRDC project, Yash Chahuan and colleagues at the QDPIF research station in Kingaroy have been developing a computer based model for prediction of aflatoxin levels based on climatic conditions, time of planting and date of harvest (Chahuan et al. 2006).

Preharvest

Plant stress

Stress during the growth period is often caused by competition for water and nutrients with pest species. To combat this, control weeds in the crop by use of mechanical methods or by use of registered herbicides or other safe and suitable weed eradication practices.

Another common cause of plant stress is insufficient available water. Plants affected by drought stress are not only more susceptible to fungal attack but the low moisture also favours Aspergillus flavus and A. parasiticus, the fungi responsible for aflatoxin, over other, more common fungi that normally out compete these toxin producers. It is essential to ensure sufficient available moisture throughout the growth period (Codex Alimentarius Commission 2003). Monitoring soil moisture is particularly important in areas of Southern Queensland, where crops are predominantly rain fed. When irrigation is used, ensure even irrigation and time irrigation according to the predominant mycotoxin threat; for example, in areas subject to aflatoxin contamination, soil moisture is critical during kernel development while humidity should be low at harvesting.

Kernel damage

Damage to kernels caused by insect attack, mechanical cultivation equipment or drought stress allows the fungi to penetrate the husk and infect the kernel. To address the issue of insect attack, minimize insect damage and fungal infection by using appropriate pesticides and fungicides and other appropriate practices within an integrated pest management program as well as attempting to minimize mechanical damage to plants during cultivation. Ensuring sufficient water is available through the growing process as recommended above will prevent kernels from cracking under drought stress.

Harvest

Exposure to infection

While mycotoxin contamination occurs frequently in the field, fungal growth causing serious contamination most commonly occurs in storage. Fungi in soil and infected plant material contaminating grain during harvest can introduce inoculum to the stored maize and, if conditions are conducive to colony growth, significant contamination can result. To avoid infection, avoid contact with soil during the harvesting operation; minimize the spread of infected seed heads, chaff, stalks, and debris; and freshly harvested cereals should be cleaned to remove damaged kernels and other foreign matter.

Kernel damage

Mechanical harvesters can cause significant damage to the kernel, leaving it open to in-storage infection. To prevent this, harvest grain at low moisture levels (when grain is hard and dry).
Excess moisture

Moisture in storage is the most significant cause of in-storage fungal growth and mycotoxin contamination. To prevent this, grain should be harvested when cobs are at full maturity and after kernels have dried to a moisture content of less than 14%. In situations where the mature cob is expected to be exposed to high rainfall conditions prior to harvest, there may need to be a trade off between an early, less mature harvest and good quality, low moisture maize.

Storage

Prevent infection

Infection occurring during storage, as opposed to prior to storage is most likely to occur through cross contamination from insect and rodent pests or from contaminated storage vessels and areas. Controls include protecting maize from contamination by pests using vermin proof construction and an appropriate pest control program as well as ensuring storage silos and other containers are clean and disinfected before grain is unloaded.

Excess moisture

Excess moisture in storage is the primary cause of fungal growth; keeping grain cool and dry is imperative in controlling mycotoxin contamination in storage. The most important strategy is ensuring moisture content of maize destined for storage is below 14%. Maize that does not meet this criteria may need further drying before storage.

An important method for moisture and temperature control is the aeration of grain by circulation of air through the storage area. Vertical silos can be problematic, even when mechanical aeration is used, with “dead” zones occurring in the central areas of the silo. Appropriate monitoring of airflow is essential.

Other strategies include cooling grain as quickly as possible after harvest; maintaining proper and uniform temperature levels throughout the storage area.

Transport from storage

Exposure to infection

As discussed previously, infection during transport may occur through cross contamination from insect and rodent pests or from contaminated storage vessels and areas. To prevent this, transport vehicles must be kept clean and free from infection. Avoid insect, bird and rodent infestation during transport by the use of insect-and rodent proof containers or insect and rodent repellent chemical treatments if they are approved for the intended end use of the grain.

Excess moisture

Excess moisture in transported maize caused a serious trade incident in 2005 when maize exported to Japan for milling purposes was contaminated with aflatoxin (Blaney et al. 2006). While there are some questions over whether the initial moisture content of the grain was below 14%, the primary reason for fungal growth and related mycotoxin production during transport was moisture migration and accumulation within shipping containers held at tropical summer temperatures for several weeks. The risks of these can be minimised by ensuring shipping containers are placed on lower decks during transport to avoid temperature fluctuations, measures to remove causes of condensation, and including moisture absorbing materials in containers during transport.

Implementing HACCP

One of the greatest criticisms of HACCP to date has been the complexity and time consuming nature of the paperwork. However, for smaller operations HACCP need not be overly complicated nor include large amounts of paperwork that then require document control.
The most important part of any HACCP plan is the Critical Control Point (CCP). In a simple operation, to avoid unnecessary paperwork and labour, there should be no more than half a dozen CCPs. Not all hazards will be CCPs. CCPs will only rarely involve mycotoxin levels. In most cases a CCP will be a physical variable such as temperature, moisture or damage control.

CCPs must be selected carefully, and must meet the following criteria.

- Do preventative / control measures exist for the identified hazard?
- Is the step specifically designed to eliminate or reduce the likely occurrence of a hazard to an acceptable level?
- Could contamination occur or increase to unacceptable level(s)?

Will a subsequent step or action eliminate or reduce the hazard to an acceptable level?

Other primary components revolve around the Critical Control Points and include a documented monitoring procedure with records of monitoring results and documented corrective action with associated records.

The guidebook

The guide acknowledges the fact that the grower/operator has the best understanding of their own process or production line. As such, the module will not provide a plan ready prepared, but will assist operators to develop their own plan using examples and recommendations specific to Australian conditions and the maize industry. These incorporate the Codex Alimentarius code of practice for minimising mycotoxins in cereals (Codex Alimentarius Commission 2003).

The book is designed to guide growers/ operators in identifying critical control points at various stages of their production process, defining critical limits, devising a monitoring programme and documenting their plan. Each concept will be introduced in a separate chapter with background information, step by step instructions, a generic example and a blank worksheet. By completing the tasks in each chapter, a grower or operator will successfully complete a simple HACCP plan for their operation. A sample plan is illustrated in Figure 1.

For the future, a computer program has been proposed that will guide the grower/operator through the chapters and tasks electronically and automatically compile the plan. This program could link to the computer based prediction model previously referred to in this paper. (Refer Figure 1 on next page).

Conclusions

With the worldwide move toward total quality control and risk management it is in the maize industry’s benefit to manage mycotoxin contamination during production, rather than rely on regulatory standards that apply to the end product. While it is accepted that it is not possible to eliminate mycotoxin contamination (Blaney 2004), it is possible, through good agronomic practice, to minimise contamination and limit the negative effects to industry by using effective risk management strategies.
Figure 1. Sample HACCP plan

## HACCP Plan - Bulk handler example

<table>
<thead>
<tr>
<th>Process step</th>
<th>Hazard Analysis</th>
<th>Monitoring</th>
<th>Corrective action</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hazard</td>
<td>Control</td>
<td>Critical limit</td>
</tr>
<tr>
<td>Purchase</td>
<td>Grain carrying</td>
<td>Purchase</td>
<td>Certificate</td>
</tr>
<tr>
<td></td>
<td>spores of</td>
<td>from grower with accredited quality assurance program</td>
<td>of mycotoxin producing fungi- will contribute to contamination of soil</td>
</tr>
<tr>
<td>Delivery</td>
<td>vehicle</td>
<td>Certificate</td>
<td>Record check</td>
</tr>
<tr>
<td></td>
<td>contaminated</td>
<td>of quality assurance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>with fungal spores</td>
<td>from grower</td>
<td></td>
</tr>
<tr>
<td>Pre-storage</td>
<td>Moisture content</td>
<td>Accept/</td>
<td>Max kernel moisture</td>
</tr>
<tr>
<td>check</td>
<td>of kernels</td>
<td>refuse load</td>
<td>14%</td>
</tr>
<tr>
<td>Storage</td>
<td>Excessive</td>
<td>Aerate grain in</td>
<td>Measure and record airflow</td>
</tr>
<tr>
<td></td>
<td>environmental</td>
<td>storage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>moisture in</td>
<td>Airflow.../l/sec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pest control</td>
<td>Inoculum</td>
<td>Treatment</td>
<td>Certificate from pest control operator</td>
</tr>
<tr>
<td></td>
<td>introduced by</td>
<td>by licensed pest control operator</td>
<td></td>
</tr>
<tr>
<td></td>
<td>rodents and/ or</td>
<td>operator</td>
<td></td>
</tr>
<tr>
<td></td>
<td>insects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>Transport vehicle</td>
<td>Wash with 20% solution of BanMould on walls, floors, ceilings of truck</td>
<td>Record of treatment-amount used, date, person responsible for treatment</td>
</tr>
<tr>
<td>decontamination</td>
<td>contaminated with inoculum</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### References


