Mycotoxin Contamination of Australian Maize: a Strategic Risk Management Plan

Purpose of the Plan

This plan was devised to assist the Australian maize industry to manage the problem of mycotoxin contamination via supply chain protocols and documented quality assurance systems, augmented by strategies for improved cross-industry communication and further research.

The Plan is based on current knowledge of the occurrence of mycotoxins in Australian maize, factors contributing to this, and the associated risks to end-users. It incorporates the perspectives of a project team of Australian specialists in mycotoxins and plant disease, and a steering group representing key sectors of the maize industry (maize growers, seed producers, millers, grain handlers and feed manufacturers) chaired by the Grains Research & Development Corporation (GRDC).

The Plan explains the overall set of strategies that was pursued during the project, and its rationale, objectives, success criteria and achievements in relation to those strategies. It then recommends a number of actions that need to be taken by industry. While it is anticipated that the Maize Association of Australia (MAA) and GRDC will take a lead role, it should become clear that all industry participants are required to play an important role if the issue is to be managed.

The Plan also provides a Risk Assessment and Review of Mycotoxin Occurrence in Australian Maize (APPENDIX A), a set of Supply Chain and Export Protocols to assist industry participants to assure quality of maize (APPENDIX B), and a Guide to incorporating good agricultural practices in quality programs within a HACCP framework (APPENDIX C). The plan has the full support of the MAA, and is addressed to all persons and organisations that have a stake in the future success of the Australian maize industry.

Background

The ability to demonstrate that maize meets acceptable standards for contaminants derived from moulds (mycotoxins) is critical for effective marketing, both domestically and internationally. Mycotoxins adversely affect health, and must be controlled in human food and in feed for pets and livestock. The most important group of mycotoxins in Australian maize is undoubtedly aflatoxins, followed by fumonisins. A few others are either rare (ochratoxins) or restricted to certain cool wetter districts (zearalenone, nivalenol and deoxynivalenol). Supporting information is presented in APPENDIX A.

It is desirable that a consistent and coordinated approach is taken to detect contaminated maize and ensure that it is diverted away from human food and sensitive markets, including export markets. However, this has proved difficult in the past with production and marketing spread among so many different groups and regions. Some sections of the industry regularly test incoming maize for mycotoxins, but other sections are unaware of the potential problem, which leaves the industry as a whole vulnerable to incidents of contamination.

From mid-2003 until the end of 2006, the maize industry and GRDC supported a project proposed by officers of the Queensland Department of Primary Industries & Fisheries (DPI&F) to develop improved methods of managing this issue. This project dissected the mycotoxin problem and devised a set of strategies to pursue. This Plan explains those strategies, how they were addressed, what was achieved during the project, and makes a number of recommendations to the maize industry about further actions and future research.

While there were many gaps in our technical knowledge which need to be addressed through research programs, the primary need appeared to be improved coordination and quality programs across the industry, and making information available to all industry stakeholders. This was seen as the essential first step that would allow resources to be targeted towards the most critical areas requiring investigation.

The purpose of this plan is to provide a blueprint for future activities aimed at continuous improvement of maize quality management systems. It is hoped it will be accepted as a resource by organisations guiding the maize industry, such as the MAA and GRDC, and periodically updated as new information and better techniques become available.

Policy principles and framework of the plan

- Mycotoxin contamination of maize is a National issue: maize is an important component of human food and animal feed. Gross production during the years 2000/01 to 2004/05 ranged from 300 - 450,000 t, with a gross value ranging from $70 -$80 million. including about $10 million in maize exports. Over 97% is grown in Qld and NSW, with smaller amounts in Victoria and WA.

- The Australian community expects that systems be in place to ensure that food containing maize is as safe and wholesome as practicable, and our international trading partners have similar expectations – quality standards must be justifiable, transparent, and perceived to be met.

- There is a significant public benefit to managing this problem; otherwise there could be serious socio-economic consequences for some sections of the rural community, so it is appropriate for government to assist industry in this matter.

- The Queensland State Government is a suitable agency to lead this initiative, because 40- 60% of the crop is produced in that State and its staff have past experience in mycotoxin management. However, it must maintain close collaboration with other States, the Commonwealth, other research agencies, and industry organisations.

- Industry standards and market forces should provide the main driver for improved mycotoxin management, with regulation as the last resort.

The processes and interventions recommended in this Plan needed to be consistent with the values embodied in:

- Ensuring that all stakeholders remain informed about the issue and can contribute to the solution;

- Accurately defining the nature and extent of the problem, so that rational choices relating to production and use of maize can be made by growers, handlers, processors and end users;

- Maximising production of best quality maize through breeding resistant hybrids, management strategies to limit contamination of crops, by not discouraging people from growing and using maize; and

- Developing a system for sustaining the knowledge and processes recommended in the Plan into the future.

Situation analysis

1. Much is known about the factors that can contribute to increased mycotoxin contamination of maize, although these factors have not all been fully investigated in Australia. However, available information has not been readily accessible by industry, and confusion often has arisen over the impact of mycotoxins and the associated risks to health and marketing. Dissemination of information has been hindered by commercial competition and perceived vulnerabilities.

2. Inability to predict occasional instances of increased contamination in the past has greatly disrupted the production and supply chains. Lack of knowledge of the fungi involved, and factors determining their range and prevalence, hindered intervention techniques.

3. Analytical methods were available to detect mycotoxins, but often used inappropriately. Commonly used sampling procedures were not effective for detecting mycotoxins. Assays were expensive and too slow for real-time monitoring at maize intake points at harvest.

4. The tolerances of different animal species to mycotoxins was not well known, and lack of knowledge of the risks involved often led either to additional expense for unnecessary mycotoxin assays, or to excessive price downgrading of contaminated maize.

5. The resistance of local maize hybrids to mycotoxin contamination was not known, nor was reducing risk of mycotoxin contamination fully incorporated into breeding goals.

The situation was addressed by 5 meta-strategies:

1. Improving cross-industry communication and coordination
2. Prediction, prevention and management of disease outbreaks
3. Detection and rapid assessment of contamination
4. Effective use of contaminated maize in livestock feeds
5. Improving resistance of plants to specific fungi and mycotoxins

[Note: The basis and justification for these meta-strategies was presented by the project leader at 'Water to Gold', the 6th Triennial Conference of the Maize Association of Australia in Griffith, NSW (February 2006), and the information will be published later in 2007 in the Australian Journal of Experimental Agriculture (APPENDIX D).]

1. Communication & Coordination

Objective

To ensure all stakeholders remain informed about the current state of knowledge on the issue and can contribute to the solution.

Strategies

- √ Established a project team that included several of the top mycotoxin and plant disease specialists in Australia, and placed them under the influence of a steering group chaired by GRDC and representing key sectors of the maize industry (maize growers, seed producers, grain handlers, feed manufacturers, R&D corporations and research scientists).
- √ At regular meetings and workshops of this team, directed activities to those deemed to be of highest priority by the steering group.
- √ Devised a composite communication plan to ensure distribution of knowledge to key industry and regulatory authorities. This was based on a stakeholder analysis (who needed to know what and when). Developed mail and e-mail distribution lists.
- √ Accessed relevant scientific literature and distributed this among project team members.
- √ Undertook a formal risk analysis of the food safety hazards from mycotoxin contamination of maize, based on known and projected hypothetical levels of contamination (part of a PhD study program).
- √ Adapted the Guidelines for Good Agricultural Practice for Managing Mycotoxins in Grain published by the *Codex Alimentarius Commission* (CODEX) to the specifics of mycotoxins in Australian maize.
- × Develop an information management process that includes an industry mycotoxin coordinator, and an information store for mycotoxin data.
- × Develop a portfolio of multimedia packages to distribute information on managing mycotoxins in maize (possibly brochures, fact sheets and Web pages).

- √ Fostered the development of educational and awareness programs for industry participants (extension activities, field days, grain update workshops).
- √ Responded to media queries in a balanced manner, and worked to correct any media distortion of facts.

Success criteria

- ➢ Project team and steering group work effectively, national strategy is endorsed by key stakeholders, information on managing mycotoxins in maize is distributed and adopted across industry.

Achievements

- √ Members of the project team and steering group worked amicably and effectively together. Results on mycotoxin occurrence derived from government and industry mycotoxin monitoring programs were shared. Regular workshops of the project team gathered the most recent information relevant to mycotoxin management in maize, and this was incorporated into regular articles published in The Cob magazine, several presentations at the Australian Maize Conference at Griffith in February 2006, and explained at several shed meetings at the post-conference tour.

- √ The Codex guidelines for good agricultural practice and quality management have been incorporated into Supply Chain & Export Protocols for Australian Maize (APPENDIX B), a Guide to developing a HACCP-based quality plan (APPENDIX C) and other information products. The intention is to publish these on various Websites, such as those of the MAA, GRDC and DPI&F.

- √ A formal risk analysis of the food safety hazards from mycotoxin contamination of maize is being conducted by PhD candidate Ms Lisa Bricknell, based on mycotoxin survey results obtained over the 2003 to 2006 seasons, and data from previous surveys and industry programs.

- √ The recommendations of this Plan and other protocols were discussed and distributed for comment at a cross-industry forum, hosted by the MAA in Brisbane in October 2006. It is expected that comment and subsequent feed-back from these industries will assist in refining and finalising the Plan for wider industry adoption.

Recommendations for further action

- ➢ That the Maize Association of Australia be supported by all industry participants as the key agency for communications across the industry. The MAA has recognised that mycotoxins are a very serious issue, and is prepared to strongly promote adoption of the protocols and quality plans contained in this document.

- ➢ That the MAA seek to have the Supply Chain & Export Protocols for Australian Maize (APPENDIX B) adopted as an industry standard. This will probably involve further consultation with the National Agricultural Commodities Marketing Association (NACMA) and other lead agencies and private companies involved in marketing and use of maize in regard to obtaining formal support for the protocols. The protocols should then be published as a pamphlet and/or on appropriate Websites.

- ➢ Protocols for managing mycotoxins in maize should be incorporated into existing industry QA plans, and end-users of maize should only purchase maize from growers, agents and bulk traders who have established such Plans. QA plans should be documented and based on HACCP principles as described in APPENDIX C.

- ➢ The Maize Association's Website should be more regularly maintained, and used for publication of standards and protocols developed for managing maize. Cross links with other key sites like GRDC must also be maintained. An information extension officer needs to be employed by the association to maintain the coordination required.

- ➢ The Grains Research & Development Corporation should continue to support the MAA, particularly in regard to publication of The Cob magazine. Mycotoxin management should be featured on a regular basis in The Cob and in GRDC publications like Ground Cover, and GRDC Research Updates. Organisers of the Maize Conference (or Summer Crops Expo) should seek to include updates on current research on mycotoxin management in the program, perhaps with invited overseas speakers.

2. Prediction, prevention and management of mycotoxin contamination

Objective

To predict high risks associated with pre-harvest mycotoxin contamination, to advise farmers how to reduce this risk and deal with outbreaks. To provide guidelines for preventing mycotoxin contamination during storage and transport.

Strategies

√ Disseminated information on the factors contributing to production of aflatoxin and other mycotoxins during storage and transport.

√ Investigated all outbreaks of pre-harvest contamination, such as occurred at Coleambally in the MIA in 2003, to determine key factors contributing.

√ Clarified the identity of the fungi involved in diseases giving rise to mycotoxin contamination.

√ Investigated potential for mycotoxin production by different sub-groups of fungi, esp. *Fusarium* species, affecting maize.

√ Developed a model to predict mycotoxin contamination of maize from climatic variables, starting with a similar approach used for aflatoxin in peanuts.

× Develop similar models for fumonisin production by *F. verticillioides* and zearalenone and trichothecene production by *F. graminearum*.

Success criteria

- ➢ Epidemiology and aetiology of the plant pathogens producing mycotoxins well understood, and control measures available.

- ➢ Maize growers and other industry participants able to predict seasons with a high risk of pre-harvest contamination, and take measures to minimise the impact of this on their operation.

Achievements

- ➢ Guidelines to prevent aflatoxin contamination during the storage and transport of maize were incorporated into Supply Chain & Export Protocols and other publications (APPENDICES B and C)

- ➢ Factors leading to increased fumonisin contamination at Coleambally were investigated. Water stress and insect damage were implicated, and although the cause was not completely clear, sufficient was known to make recommendations to reduce risk of recurrence. Growth of *F. verticillioides* in irrigated crops seemed to be promoted by uneven moisture at the fringes of fields. This can cause contraction and expansion of kernels, causing fine cracks to appear in a star-burst pattern (white streaks radiating from the point of silk attachment at the cap of the kernel or from the base).

- ➢ Available information on the fungi producing mycotoxins in maize was collated by collaborating plant pathologists and *Fusarium* specialists. *F. verticillioides*, *F. proliferatum*, *F. thapsinum* and *F. nygamai* are all on record as producing fumonisins and were all shown to occur in Australian maize. *F.*

verticillioides appeared to be the main source of contamination, but this might not be the case in all situations and the relative toxigenic potential of different *Fusarium* isolates should be explored.

- Research was conducted with *F.graminearum* isolates from northern Queensland and New South Wales, which showed them to be genetically different groups, in accordance with their production of either nivalenol or deoxynivalenol (both groups also produce zearalenone). *F. graminearum* is only common in localities with high summer rainfall including the northern rivers of NSW, parts of the coastal strip of south-east Qld and the Atherton tableland of far-north Qld.

- The cause of increased aflatoxin contamination detected in many rainfed crops across the central Burnett in 2005 and 2006 was shown to be clearly related to drought and heat stress. The producing fungi *Aspergillus flavus* and *A. parasiticus* are well known to be favoured by such conditions, and cause serious problems in rainfed peanuts in this region. The occasional instances of significant aflatoxin contamination in other regions also appeared to be related to moisture deficits and heat stress on developing ears, but local farming practices (planting time, adequacy of irrigation, etc) probably exacerbated the problem. Insect damage plays an important part in contamination in other countries, but the importance of this in Australian maize is unknown.

- A model that simulates aflatoxin risk in maize was developed using a similar approach as is currently used to predict aflatoxin risk in peanuts. Coincidence of diurnal ambient air temperatures between 22-35^{o}C, when fractional available soil moisture was <20% during grain filling, were used as the criteria of risk. The model performed reasonably well in regard to predicting aflatoxin risk across a number of locations during 2005 and 2006. Scenario analysis suggested that risk could be reduced by selecting a hybrid maturation rate and a sowing date, so as to avoid high temperatures during grain filling (~January), and by optimising plant population to reduce water stress.

Recommendations for action

- That mycotoxin contamination both pre- and post-harvest be minimised by adoption of Good Agricultural Practices and documented HACCP-based quality assurance systems throughout the supply chain (APPENDIX C).

- That further research on the aflatoxin-prediction model and its validation across a wide range of production environments should be supported. The model needs to be further refined with insect-damage incorporated and validated in controlled circumstances. It could then be feasible to establish a Web-based system to allow growers to input their own specific cultural and climate information to allow them to ascertain within-season aflatoxin risk (a similar system is in place for peanut growers, called ‘AFLOMAN’).

- That hybrid selection, planting time, effective irrigation, good nutrition and insect control practices be recognised as key factors preventing mycotoxin contamination, and that this information be incorporated into all industry extension literature on maize production.

- That research and extension programs on control of *Fusarium* diseases be supported in terms of their impact of mycotoxin contamination. In particular, more research is needed on fumonisin production by *F. verticillioides* versus other fumonisin-producing species.

- That research being conducted in other countries on the effects of fungal competition on mycotoxin production in maize should be carefully monitored, since this might eventually lead to biological control measures.

- That the potential role of insects in increasing mycotoxin contamination of Australian maize should be investigated, and that IPM programs take this potential into account when defining the criteria for intervention.

3. Detection & Rapid assessment

Objective

- To rapidly assess the quality of maize so as to determine its value for different end-uses.

Strategies

√ Develop a sampling protocol appropriate to Australian maize (on farm, and after harvest).

√ Compile and promulgate information on physical indicators of contamination (BGYF tests, % purple kernels, bulk density, etc).

√ Investigate NIR technology for rapid assessment of contamination.

√ Establish and validate chromatographic assay methods for all mycotoxins on interest.

× Assess ELISA methods in comparison to chromatographic methods.

√ Maintain a list of Australian laboratories capable of mycotoxin assay. (NATA web site)

√ Assay maize from all major production regions in each season over the life of the project (three to four seasons)

× Investigate impact of moulds on nutritional quality of maize and develop rapid assessment methods for this.

Success criteria

- A suite of sensitive, specific or rapid assay methods, and sampling methods, available to industry for testing maize.
- Detailed information on mycotoxin contamination of the Australian maize crop over four seasons.
- Indices for predicting value of grain based on physical parameters.

Achievements

- Sampling plans were investigated and the system applied by The Grains Inspection, Packers and Stockyards Administration (GIPSA) of the USDA is most appropriate. A critical aspect is the need for taking and grinding large samples of grain (4-5 kg) to obtain an acceptable measure of aflatoxin. Special mills are required for this. Assay methods must be thoroughly validated and conducted in a laboratory certified as capable of conducting mycotoxin assays (preferably by the National Association of Testing Authorities, NATA). Sampling and assay methods are reviewed in the Supply Chain & Export Protocols in APPENDIX B.
- About 600 samples of maize were assayed for mycotoxins from the 2004, 2005 and 2006 seasons. Aflatoxins were detected in 25% of samples (>0.001 mg/kg), and fumonisins were detected in 66% of samples (>0.1 mg/kg). However, 85% complied with the ‘Milling’ standard of <0.005 mg aflatoxins/kg, and <2 mg fumonisins/kg. A further 12% met the ‘Prime’ standard of <0.015 mg aflatoxins/kg and <5 mg fumonisins/kg. Only a couple of samples identified as screenings did not meet the ‘Feed No 2’ grade of <0.08 mg aflatoxin/kg and <40 mg fumonisins/kg. The highest proportion of aflatoxin-positive samples was in rainfed crops grown in parts in the central Burnett, which also has the highest risk for aflatoxin in peanuts.

Note: A summary of these results was presented at 'Water to Gold', the 6th Triennial Conference of the Maize Association of Australia in Griffith (February 2006), and the information will be published later in 2007 in the Australian Journal of Experimental Agriculture (APPENDIX E).

- Ochratoxin was not detected in any sample (<0.001 mg/kg), a result consistent with previous surveys. With only a few exceptions, zearalenone was almost totally confined to the known higher risk areas of the Atherton Tableland of far-north Queensland.

- Viewing under ultraviolet light for Bright Greenish-Yellow Fluorescent Particles has been previously validated in Queensland as a useful screening procedure for detecting samples with higher risk of aflatoxin. It has been used in the past by some milling companies and is still used in some. Until other systems like NIR are validated, it is the only procedure that can be used at intake point for rapid assessment of higher risk loads. However, it has been observed by members of the project team as being used inappropriately with too small a sample, so standardisation and further training is warranted, where the system is still used. A minimum of 2 kg of maize must be cracked with a maize cracker, so that each kernel splits on average into 3 or 4 pieces, and examined on a shallow tray with stirring to illuminate all particles. Each examination takes around 5 minutes.

- Research reports on reduction of mycotoxin concentrations in maize during some forms of processing were noted. For example, higher concentrations are associated with the outer layers of the kernel, so grits can have less aflatoxin and fumonisin than indicated by the source grain. Some forms of roasting or baking can produce some reduction in mycotoxins, and moist heat and alkalie treatment affects fumonisin concentration. While none of these processes eliminate aflatoxin and fumonisin, it might well be the case that bulk maize of 0.015 mg aflatoxins/kg ('Prime' grade) produces a product of <0.005 mg/kg after processing. The low frequency of contaminated samples in an incoming stream, if compared to a high frequency of samples with <0.001 mg/kg, might also be allowed for in the risk management process.

- All samples collected and assayed during 2004-2006 were scanned by Near Infra Red (NIR) Spectrometry, in order to investigate a correlation for predicting samples with higher concentrations of aflatoxins and fumonisins. The results are still preliminary, but very promising as a potential technique for intake screening. Using whole maize samples with a scanning NIR analytical instrument, the detection limit for aflatoxins was about 2 ug/kg, with an error of ± 0.4 ug/kg. However, this was achieved by restricting the data range, and the overall correlation is not yet satisfactory, correctly picking only 70% of samples falling either > or < 5 ug/kg. If the data range is less restricted, it might detect 95% of samples falling either > or < 20 ug/kg, with some loss in sensitivity and detection limit. For fumonisin, the results were similar, with a detection limit of about 1 mg/kg with an error of ± 0.3 mg/kg, but the correlation needs improvement. At some point, the correlation will need to be tried with fixed wavelength receival instruments. Our approach was aimed at rapid assay of samples at grain intake, or potentially in the field during harvest. However, it is noted that another approach being taken in the USA is to develop systems that use NIR to detect and remove individual kernels contaminated with aflatoxins and fumonisins, and this work also needs to be monitored. Peanuts contaminated with aflatoxin are removed with a similar approach in Queensland.

Recommendations for action

- That aflatoxins be recognised as the major mycotoxins of concern in Australian maize, and that most monitoring efforts be directed there.

- That users of maize for human food give due consideration to the effects of processing on aflatoxin concentrations, for example whether use of the NACMA 'Prime' grade with 0.015 mg aflatoxins/kg would result in their final product meeting the standard of <0.005 mg/kg. The relative frequency of contaminated crops going into bulk storage should also be considered in the risk management process.

- That fumonisins also be tested regularly, but only for milling maize and certain sensitive markets like pet food and horse feed. High fumonisin contents will most commonly be associated with visible damage (star-burst pattern) to kernels on the ear, and the lightweight fraction of bulk grain.

- That regular monitoring for ochratoxin is not warranted and represents an unnecessary cost to industry, except when there is evidence of mould growth during storage.

- That regular monitoring for *Fusarium graminearum* mycotoxins (zearalenone, nivalenol and deoxynivalenol) is not warranted, except in cool wetter locations of the Atherton Tableland and the coastal districts of northern NSW and southern Queensland. Samples with significant levels of these mycotoxins can generally be identified as visually damaged and by the presence of >1% of kernels of a deep-reddish purple or even black appearance.

- That all organisations sourcing mycotoxin assays ensure that they engage laboratories that are using suitably validated assay methods, and that these are certified by the National Association of Testing Authorities (NATA). Inter-laboratory proficiency trials for mycotoxin assays should be supported.

- That the GIPSA maize sampling protocols for aflatoxins be adopted for Australian maize. Apart from the need to take many primary samples in a representative manner, this will in most cases involve grinding a sample of 4 kg of maize before an analytical sample is drawn.

- That where screening of maize under ultraviolet light for BGY particles is performed, that it be only conducted by the validated procedure of viewing a minimum of 2 kg of maize cracked with a maize cracker and in a shallow tray. The validated procedure should be detailed and standardised.

- That further research should be supported into use of NIR for predicting higher risk of mycotoxins in maize samples during maize intake screening. This would include collection of maize samples in future seasons, assay and screening. Maize milling and processing industries conducting mycotoxin assays on maize should also be approached to retain samples of whole and milled maize for NIR screening, to add to the database. The economics and feasibility of using the systems being developed in the USA for physically removing contaminated kernels should be examined in the Australian context.

4. Effective use of maize in livestock feeds

Objective

- On the basis of mycotoxin contamination and grain quality, to derive the best possible value from different batches of maize in livestock feed.

Strategies

√ Collate all available data on tolerances of livestock to different mycotoxins, and provide these data to industry.

√ Perform risk assessments on the potential for reduced livestock production by different levels of contamination, including the risk of residues in livestock products.

√ Facilitate the establishment of industry and regulatory standards for mycotoxins in maize, based on good science, which balance the ability of growers to produce quality grain with the requirements of end-users.

√ Assess the value of contaminated grain as livestock feed, in view of any affects on productivity and the risk of this occurring.

√ Maintain awareness of any scientific studies that demonstrate the effectiveness of feed additives in binding mycotoxins.

Success criteria

- Rational and transparent standards for acceptable levels of mycotoxins in maize are incorporated into livestock feeding practices.

- Markets accept the standards for effective use of contaminated maize and respond in an economically rational manner.

Achievements

- A review of regulations and standards in Australia and other countries was conducted and supporting research was reviewed. The occurrence of mycotoxins in Australian maize was considered and safety margins set that were consistent with minimising potential losses of grain. Guidelines for maximum aflatoxins and fumonisins concentrations in feeds were proposed (APPENDIX G). These were published in the Spring 2006 issue of The Cob. Guidelines for other mycotoxins are not considered essential, but international limits for zearalenone, nivalenol and deoxynivalenol are about 1 mg/kg, a level that is not commonly reached in Australian maize, even on the Atherton Tableland where the causative fungus is most common.

- The MAA has established trading standards for aflatoxin and fumonisins in NACMA contracts for different grades of maize. These standards are soundly based and rational, and are supported. In that Queensland Stockfood Regulations has aflatoxin B1 standards, and the NACMA standards are in total aflatoxins, it was pointed out to NACMA that the regulations obviously would take precedence in case of any dispute. In consequence, this was harmonised by the addition of the 20 mg aflatoxin B1/kg regulated limit to the Feed #2 specification.

Recommendations for action

- That NACMA standards for aflatoxins and fumonisins in different grades of maize should be accepted by purchasers for all contracts. That mycotoxin assays be properly applied as explained above to test compliance with these standards. Specifications for maximum mycotoxin levels in maize for different end-uses must be based on valid and transparent risk assessments. Processors of maize for human and pet food should give due consideration to the effects of processing on mycotoxin concentrations and dilution in the end product. Relative frequency of contaminated crops going into bulk storage should also be considered in the risk management process.

- That the guidelines for use of the various maize grades as set in APPENDIX G be accepted for use of maize for different animal feeds. Purchasers of feed grade maize should take account of the risks involved for the various livestock classes for which the maize is to be used, and the options for further dilution and blending as an effective means to reduce that risk.

- That market forces determine the discount for maize to be applied to maize of lower standards, but in any case, it should be recognised that additional costs will be involved in producing higher grades. This includes possible sacrifice of grain yield to reduce stress when planting. Costs of additional mycotoxin assays to assure compliance with Milling and Prime grades also should be factored into the respective prices for those grades.

5. Improving plant resistance

Objective

- To promote maize cultivars with sustainable resistance to mycotoxin-producing fungi without loss of desirable grain attributes.

Strategies

√ Collect data that might indicate variable susceptibility of maize cultivars to mycotoxin contamination.

- √ Develop germplasm combining resistance to certain mycotoxigenic fungi, esp. *Fusarium* species, with other desirable characteristics, and make this available for production of commercial cultivars.

- √ Consider the roles of drought stress and insect resistance in mycotoxin contamination, and promote incorporation of such traits in breeding programs.

Success criteria

- Cultivars with appropriate resistance to mycotoxins are planted in higher risk situations.

Achievements

- Maize breeding specialists in the project team are aware that mycotoxin contamination is important, although market forces will obviously determine its relative impact over other traits such as yield.

- Pioneer Hi-Bred and Pacific Seeds provided samples from their on-farm trial plots for mycotoxin survey, and similar samples were collected from the DPI&F breeding program. These data were provided to the breeders. Given the variations in regions and climate, it is not likely that any conclusive association between hybrid and aflatoxin contamination will be demonstrated, but fumonisin data in association with disease ratings of hybrids might provide some leads.

- DPI&F have had a long program of breeding for resistance to diseases on the Atherton Tableland in far-north Queensland. These hybrids have very good resistance to *F. graminearum* ear rots, and feature a very long and tight husk cover. This breeding material could be adapted to hybrids for other areas if *F. graminearum* become a more significant problem there. Comparative resistance to *F. verticillioides* and fumonisins is less clear, but evidence of kernel infection by *F. verticillioides*, once common, is now rarely seen in DPI&F inbreds and hybrids. One private company has recently obtained 7 elite inbreds from this breeding program which probably have good resistance to *F. graminearum* and *F. verticillioides*, so resistant material is finding its way into commercial hybrids.

- Seed companies were active in accessing information from North America. One main lead being followed involved the impact of Bt hybrids on fumonisin, as an indirect result of resistance to European Corn Borer (ECB) and other insects. Bt hybrids might be useful for reducing fumonisin in Australia, through improved resistance to heliothis (*Heliocoverpa* spp), which is a pathway to increased *F. verticillioides* infection.

- Research in North America has not been successful in breeding resistance to aflatoxins. Although insect damage is important, the correlation is not as strong as with fumonisin. Aflatoxin contamination can still be serious without insect damage. Drought resistance (stay-green) is being investigated in some hybrids, but whether this trait would help with aflatoxin is yet to be confirmed. By increasing plant standability in hot, dry conditions, aflatoxins might even increase. The QDPI&F breeding program has developed drought-resistance inbreds which will soon be made available to private seed companies.

- Since hot weather and water stress during grain filling are key factors, efforts to develop a better range of fast or short-maturing hybrids might provide increased options to avoid heat stress during kernel development.

Recommendations for action

- That seed companies include resistance to mycotoxins as another key trait in breeding programs

- That the resistance of Bt hybrids to insects in Australian corn be considered as a possible option for decreasing fumonisin contamination

- Drought-resistant inbreds developed by DPI&F should be made available to private seed companies. Hybrids developed from these should be tested for aflatoxin and fumonisin susceptibility.

- That DPI&F germplasm with resistance to *F. graminearum* be incorporated into cool, wetter regions where this fungus is more likely to develop. That the fumonisin resistance of these hybrids be clarified.

List of appendices

A. Mycotoxins in Australian maize: a risk assessment
B. Supply chain and export protocols for managing mycotoxins in maize
C. A guide to QA-plans based on good agricultural practice and HACCP for mycotoxins in maize
D. Managing mycotoxins in maize: case studies
E. Risk management for mycotoxin contamination of Australian maize
F. Modelling mycotoxins in maize
G. Managing mycotoxins in maize – options when feeding animals

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