MODELLING MYCOTOXIN CONTAMINATION IN MAIZE

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Abstract

A number of toxigenic fungi including Aspergillus flavus, A. parasiticus, Fusarium graminearum, F. verticillioides and F. proliferatum can infect and potentially contaminate maize (Zea mays L.) grains with harmful mycotoxins. Aflatoxins are most common and highly carcinogenic compounds produced by Aspergillus flavus and A. Parasiticus in a wide range of crops including maize. The ability of these fungi to produce aflatoxins depends upon the coincidence of host susceptibility and specific environmental (mainly moisture and temperature) conditions, and insect vector activity during the season can accentuate the risk. Modelling of the interactions between host plant and environment during the season can enable prediction of pre-harvest aflatoxin risk and its potential management. Initially we developed a simulation model to predict aflatoxin contamination in maize, using a module which was previously developed for peanuts using the APSIM peanut model. The model was further applied in combination with long term weather records to examine the effects of cultural factors such as sowing date, plant population, nitrogen supply, and cultivar duration on pre-harvest aflatoxin risk in a probabilistic framework. Once the module has been fully validated for maize it will be possible to provide growers and industry personnel with both pre-season and in-season probabilities for aflatoxin risk.

Maize samples and associated climate and cultural data from geographically diverse locations within Australia are being sought to further validate the maize aflatoxin model. The principles learnt from this exercise should then allow us to develop similar models to predict occurrences of the other important mycotoxins in maize.

Introduction

Maize (Zea mays L.) is the third most important cereal crop after wheat and rice and is planted to about 120 million hectares worldwide. While the crop is a major source of human food and animal feed, it is also a well known host for a number of toxigenic fungi including Aspergillus flavus, A. parasiticus, Fusarium graminearum, F. verticillioides and F. proliferatum which can potentially contaminate its grains with mycotoxins during both pre-harvest, and post harvest storage and processing. These mycotoxins are harmful to both human and animal populations if ingested (Munkvold 2003). Therefore as for other crops, mycotoxin management in maize has become a worldwide concern to prevent contaminated products entering the food chain and causing serious health impacts.

In Australia, as in other developed countries, a major challenge for mycotoxin management in maize is to limit contamination during the pre-harvest stage as storage and processing technologies are sufficiently advanced to control post-harvest contamination (Webley and Jackson 1998). Although the Australian maize industry is relatively small, it is a significant contributor to the economy of some regional areas in Queensland and NSW (www.abs.gov.au/Ausstats). Until recently, there has been very limited work to understand the nature and extent of pre-harvest contamination of maize in Australia except for very limited field surveys (Blaney et al. 1984). Some significant episodes of high pre-harvest mycotoxin contaminations in a few maize growing regions of Australia have however highlighted a need to investigate the problem (Blaney et al. 2006).

The earlier work has shown that pre-harvest infection by toxigenic fungi and toxin production in maize depend upon geography and weather (Miller 2001, Munkvold 2003). Generally, plant stress factors such as high temperature and drought favour colonization and toxin production by Aspergillus species (Pyne et al. 1986, Sisson 1987). Under rainfed cultivation, several cultural practices, such as high plant population, reduced tillage, and excessive nitrogen fertilization leading to increased severity of drought can also increase aflatoxin contamination. Likewise, cultural practices which mitigate the effects of drought can also reduce the risk of aflatoxin contamination. The development of predictive models can allow assessment of in-season aflatoxin risk based on current seasonal conditions and thus potentially assist in the management of aflatoxin (Wright et al. 2005).
This paper describes development of an aflatoxin prediction model to predict the risk of aflatoxin in the maize crop and its application to examine the potential aflatoxin risks in different environments and under different cultural practices.

**Materials and methods**

*The maize aflatoxin model*

The model was developed as a sub-component of the APSIM (Agricultural Production Systems Simulator) maize module (Keating et al. 2003) which uses ambient temperature, radiation, rainfall, soil water and soil nitrogen to simulate maize growth and yield on an area basis in a daily time step. The maize aflatoxin model is based on the principles that have been used to predict aflatoxin risk in peanuts (Wright et al. 2005; [www.apsim.info/apsim/afloman](http://www.apsim.info/apsim/afloman)). It enables the integration of soil water and ambient air temperature higher than 22ºC during the grain filling stage to simulate aflatoxin risk.

*Prediction of aflatoxin incidence using the maize aflatoxin model*

To validate the model, results of mycotoxin assays of 184 samples obtained from rainfed and irrigated maize growing areas throughout Queensland and NSW during the 2005 season were used (Blaney et al. 2006). The aflatoxin contents of samples obtained from different farms within a location were averaged. The weather data for each of the locations in which positive aflatoxin contamination occurred was accessed from the ‘Silo’ weather site ([www.nrm.qld.gov.au/silo](http://www.nrm.qld.gov.au/silo)). Rainfall and irrigation details provided by growers were patched onto the weather data obtained from Silo. Aflatoxin risk reports for these locations were generated using a web-interface of the maize aflatoxin model available at [www.apsim.info/apsim/afloman](http://www.apsim.info/apsim/afloman). The predicted aflatoxin risk index was then regressed against observed aflatoxin B1 content in the contaminated samples.

*Long term probability analysis of aflatoxin risk in Queensland’s dryland production regions*

The APSIM maize model incorporating aflatoxin module was run using 106 years of weather data for Burnett (Kingaroy and Coalstoun Lakes), Central Queensland (Emerald) and North Queensland (Atherton Tableland) regions to gain an appreciation of the long term risk of aflatoxin contamination. The plant available water holding capacity of the soil used in these simulations was set at 120 mm.

*Effect of cultural practices to minimize aflatoxin risk in maize*

The effect of cultivar, sowing time, plant population and nitrogen on rainfed maize was simulated using 106 years of weather data of the above mentioned locations.

**Results and discussion**

Of the 184 samples analysed for aflatoxin in 2005, while about 22% were positive for aflatoxin, only 4% exceeded the 20 µg/kg limit set for maize and maize products in the United States (Lubulwa and Davis 1994). The majority of these > 20 µg/kg samples came from three sites, two from the Burnett region in Queensland (Wooroolin, Coalstoun Lakes) and the other from the Narropoint region of New South Wales (NSW) (Table 1). The samples from Coalstoun Lakes in the north Burnett were particularly high compared to those from the nearby south Burnett locations in Kumbia, Kingaroy and Wooroolin. Most of the rainfed maize crops throughout the Burnett district suffered from significant drought during the season, however there were substantial differences in aflatoxin risk between regions. The only two samples that were positive in the NSW were from locations in which crops were only partially irrigated.
Table 1. Range of observed aflatoxin content in 39 samples in key positive sites out of a total of 184 sites monitored in 2005 in Queensland (QLD) and New South Wales (NSW).

<table>
<thead>
<tr>
<th>Location</th>
<th>State</th>
<th>Irrigated</th>
<th>Positive (%) aflatoxin range</th>
<th>Aflatoxin (µg/kg) mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darlington Point</td>
<td>NSW</td>
<td>Yes</td>
<td>33</td>
<td>0 - 5.3</td>
</tr>
<tr>
<td>Narropoint</td>
<td>NSW</td>
<td>Yes</td>
<td>80</td>
<td>0 - 80.0</td>
</tr>
<tr>
<td>Kumbia</td>
<td>QLD</td>
<td>No</td>
<td>55</td>
<td>0 - 2.7</td>
</tr>
<tr>
<td>Kingaroy</td>
<td>QLD</td>
<td>No</td>
<td>19</td>
<td>0 - 6.7</td>
</tr>
<tr>
<td>Wooroolin</td>
<td>QLD</td>
<td>No</td>
<td>55</td>
<td>0 - 20.0</td>
</tr>
<tr>
<td>Coalstoun Lakes</td>
<td>QLD</td>
<td>No</td>
<td>90</td>
<td>0 - 53.4</td>
</tr>
</tbody>
</table>

In peanut, the aflatoxin model was able to predict aflatoxin risk with accuracy of up to 75% (Rachaputi et al., unpublished data). In the present study with the limited observations of one season, a comparable accuracy was obtained (Fig. 1). However, to have a greater confidence in the maize aflatoxin model, more validation over several seasons would need to be performed, as has been done for peanuts. The model predicted appreciable aflatoxin risk in maize at Coalstoun Lakes, moderate risk at Wooroolin and the Narropoint location in NSW, but only slight risk in the Kingaroy and Kumbia regions of the Burnett (Fig. 1). At all the Queensland sites, maize was grown under rainfed conditions on a soil with only about 120 mm plant available water holding capacity, while at the NSW locations the crops were grown with limited irrigation. Running the model with the actual amount of water used by the grower for the NSW location with an aflatoxin positive sample, indicated that the amount of water applied was inadequate for a fully irrigated crop. This highlights the need to provide adequate irrigation throughout crop growth to completely eliminate the possibility of aflatoxin risk under irrigated conditions. In-season monitoring of the crop using this model can assist growers to monitor whether applied irrigation is adequate for preventing aflatoxin risk. The model could also be used to schedule irrigation to maximize yield and minimize aflatoxin risk.

Probability of aflatoxin incidence in Queensland’s dryland production regions

Being a relatively photoperiod insensitive crop, maize is sown at a wide range of sowing dates in Queensland depending upon the rainfall availability. While drought can occur any time during the growing season, the reproductive phase of maize in early sowings may experience consistently higher ambient temperatures. This together with the incidence of unpredictable terminal droughts can create favourable conditions for the Aspergillus fungus to accumulate aflatoxin. Irrespective of the location, the simulated risk of aflatoxin was greater in sowings commencing in the early summer season compared to those late in the season (Fig. 2 and Fig 3). Amongst the four different locations simulated, the probability of aflatoxin risk was greater at Emerald and Coalstoun Lakes and lesser at the Kingaroy and Kairi regions for each of the sowing dates between 15-October and 15-January (Fig. 2). Figure 2 indicates that most sowings in Kairi and Kingaroy will have lower risk of aflatoxin than at Coalstoun Lakes and Emerald. While the degree of drought in the Coalstoun Lakes region may not be more than Kingaroy, it is generally warmer throughout the reproductive period (Fig. 3). At Kairi (representing Atherton Tableland), the lower aflatoxin risk was mainly due to the higher and more reliable rainfall experienced during the grain filling period, while at Kingaroy cooler weather was more closely associated with lower aflatoxin risk (Fig. 3). The riskiness of Coalstoun Lake was confirmed by the high positive aflatoxin samples obtained in 2005. In 16 samples collected from the Atherton Tableland region in 2005, none were found to have aflatoxin. Similarly, in a survey conducted in the Atherton Tableland region in 1982, Blaney et al. (1984) found aflatoxin was only a minor problem in maize. A similar observation of regional differences in aflatoxin risk in the Burnett and Atherton Tableland has been made in peanuts (Wright and Hansen 1997). Assuming environmental limits for toxin production in maize are similar for peanuts, it is likely that areas that are risky for peanuts would also be risky for maize. With peanut having a subterranean growth habit however, it is likely to respond more to soil temperature compared to maize which would respond more closely to ambient temperatures. Appropriate modifications in the calculation of temperature factors for the maize crop were therefore introduced into the model. Another major difference in the two crops is that of substrate specificity, which is not accounted for in the model.
Figure 1. Relationship between measured aflatoxin B1 and simulated aflatoxin risk index (%) using data of locations with the aflatoxin positive samples.

\[
y = 1.7208x - 1.0687 \\
R^2 = 0.9776
\]

Figure 2. Long term probability of aflatoxin risk at different sowings at Kairi, Emerald, Coalstoun Lakes and Kingaroy.
Scenario analysis of the relative aflatoxin risk in quick and slow maturing cultivars

Growers often have to make decisions about what length of maturity will be suitable for their region. Often this decision is based on the yield or price that is realized. For high aflatoxin risk environments, the incidence of aflatoxin may also impact on profitability. Fig. 4 indicates the comparative simulated performances of two maize cultivars which differed in maturity by about 20 to 30 days in an early and late sowing, respectively. While the slow maturing cultivar had invariably higher yield in both the sowings (data not shown), it was simulated to have much higher aflatoxin risk for the early sowing, whereas the opposite was true for late sowings. The quick maturing cultivar although yielding less, may escape from terminal drought in the early sowings and thus have lower aflatoxin risk. In late sowings, it may however be exposed to much higher temperatures during maturation compared to a slow maturing cultivar.
Figure 4. Probability of aflatoxin risk in early (October) and late (January) sowings of quick and slow maturing maize hybrids grown in the Coalstoun Lakes region.

Scenario analysis of the effect of agronomic practices on aflatoxin risk

Plant population is one of the crucial factors in managing aflatoxin, as plant density in dryland cropping systems will impact on the degree of stress development, especially in environments such as Coalstoun Lakes, where the probabilities of end-of-season drought are high. The simulated aflatoxin risk at 5 plants/m² was much higher for all locations indicating that under rainfed conditions water availability may not adequately support the higher plant population. In higher rainfall environments, such as Kairi, variations in plant density had only small effects on overall aflatoxin risk. Similarly, the amount of applied fertilizer should be determined judiciously, as simulations indicated that higher rates could result in more highly stressed plants with correspondingly higher aflatoxin risk (Fig. 6). The no N fertilizer treatment may however, be a practical option to manage aflatoxin risk as it often results in very low yields. Clearly, in environments with high risk of aflatoxin such as Coalstoun Lakes and Emerald, use of the optimal agronomic package, including the choice of cultivar and sowing date may have implications on maize quality as well as final yield.

Options for minimizing aflatoxin risk in maize with the help of aflatoxin model

As aflatoxin risk is associated with severe drought and elevated temperatures, the management of crops in such environments will be important for the minimisation of aflatoxin risk. When long term scenario analysis suggests an increased risk of aflatoxin, in-season monitoring will be helpful in deciding when aflatoxin accumulation has commenced. If limited irrigation is available growers/consultants could use it to alleviate drought during the silking and grain filling phases. However, there is little that can be done to reduce the risk of late season infection by *A. flavus* by way of agronomic management, except that once aflatoxin risk is detected by the model, the crop should harvested immediately, to reduce the chance of contamination. In peanuts, early harvesting is a key strategy for minimizing aflatoxin (Rachaputi et al. 2002)
Figure 5: Box plots showing the effect of plant population on simulated aflatoxin risk in rainfed maize sown on 15- November at four locations in Queensland.

Figure 6: Box plots showing the effect of different rates of nitrogen application on simulated aflatoxin risk index (%) in rainfed maize sown on 15-November in four environments in Queensland.
Summary and conclusions

The initial validation simulations have suggested that the maize aflatoxin model is able to successfully predict aflatoxin risk with a reasonable level of accuracy. The model was able to identify regional differences in aflatoxin risk. Further fine tuning and validation of the model is needed by further monitoring of maize crops. Scenarios analyses of a range of agronomic factors that could impact on aflatoxin risk in maize have been presented. These factors also need to be validated before they can be widely adopted by the industry. Maize cultivation in areas with low risk should be encouraged to take full advantage of the season, whereas in environments where the risk is high, either supplementary irrigation or appropriate management practices to minimize risk of drought should be considered. The available literature suggests that the accumulation of other mycotoxins, such as fumonisin and deoxynivalenol, also depends upon weather conditions hence it should be possible to modify the maize aflatoxin risk model to predict risks of these other major mycotoxins.

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References


