Mycotoxins and Toxicological Impact in Swine

James D. House

Departments of Human Nutritional Sciences & Animal Science, 408 Human Ecology Building, University of Manitoba, Winnipeg, MB  R3T 2N2; Email: j_house@umanitoba.ca

Introduction

The North American pork production industry is heavily dependent on relatively few feed ingredients, including the cereal grains (corn, wheat, and barley), oilseed meals (soybean meal) and industry co-products (DDGS). As such, factors that impact the quality of these feed ingredients can pose serious challenges relative to the formulation of pig diets. One such factor that impacts the quality of feed ingredients is fungal infections. Fungal infections of crops typically occur either in the field or during storage, but infections can also occur if complete feeds are stored improperly (example: high temperature and moisture conditions). The susceptibility of major feed crops to fungal spoilage increases the risk for the presence of mycotoxins in the Canadian feed supply. The term “mycotoxin” is a generic reference to a heterogeneous class of toxic secondary metabolites produced by fungi. These metabolites can have a variety of toxicological effects, including reductions in feed intake, growth depression, liver and kidney damage, and impairments in reproductive health.

Mycotoxins in the Canadian Feed Supply

Table 1 provides a summary of the major mycotoxins, their associated toxicological effects and action levels for Canadian swine diets. Infections in the field by different species of Fusarium (F) fungi can lead to the presence of so-called fusariotoxins. The trichothecene family of fusariotoxins includes deoxynivalenol (DON, vomitoxin), zearalenone, T2, and HT2, as well as various acetylated forms, including 3- and 15-acetylDON (D'Mello et al., 1999). Another class of fusariotoxins includes the fumonisins. From a Canadian perspective, the major species of Fusarium (F) species that affects
feed crops is *F. graminearum*, however other species including *F. culmorum* and *F. avenaceum*, are present as well. In Western Canada, the infection of wheat and barley crops by *Fusarium* typically leads to the presence of DON (and its acetylated forms) in the cereal grains. A similar situation prevails in Eastern Canada, however zearalenone can be found at a higher incidence rate, particularly in *Fusarium*-infected corn. The presence of other fusariotoxins tends to be more sporadic in feed ingredients produced in Canada. By far, DON is the mycotoxin that is screened for most in Canadian feeds, particularly in years when fusarium infection rates are high. The presence of quick tests for DON is a primary driver of these surveys.

**Table 1. Overview of the major mycotoxin risks for Canadian swine diets**

<table>
<thead>
<tr>
<th>Mycotoxin</th>
<th>Primary Toxicological Effects in Swine</th>
<th>Major Risk of Exposure in Canadian Swine Diets</th>
<th>Guideline Limits for Complete Swine Feeds(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DON</td>
<td>Anorexia, Immunosuppression</td>
<td><em>Fusarium</em>-contaminated small grains (wheat, barley); <em>Fusarium</em>-contaminated corn</td>
<td>&lt; 1 mg/kg (ppm)</td>
</tr>
<tr>
<td>Zearalenone</td>
<td>Reproductive failure in gilts</td>
<td><em>Fusarium</em>-contaminated corn</td>
<td>&lt; 3 mg/kg</td>
</tr>
<tr>
<td>T-2</td>
<td>Oral lesions/dermatitis of snout; Lesions on Pars Esophagea region of stomach (ulceration)</td>
<td><em>Fusarium</em>-contaminated small grains (wheat, barley); <em>Fusarium</em>-contaminated corn</td>
<td>&lt; 1 mg/kg</td>
</tr>
<tr>
<td>Fumonisins</td>
<td>Lung damage, Gastric ulcers</td>
<td><em>Fusarium</em>-contaminated small grains (wheat, barley); <em>Fusarium</em>-contaminated corn</td>
<td>&lt; 10 mg/kg</td>
</tr>
<tr>
<td>Ochratoxin</td>
<td>Kidney damage</td>
<td>Grains stored under less than ideal conditions (high moisture; insect damage)</td>
<td>&lt; 2 mg/kg</td>
</tr>
<tr>
<td>Aflatoxin (B1)</td>
<td>Liver damage</td>
<td>Corn and by-products from southern US</td>
<td>&lt; 20 µg/kg (ppb)</td>
</tr>
</tbody>
</table>

Fungal infections also occur post-harvest, and these typically prevail when grain are stored at higher moisture contents or when other factors are present to encourage fungal growth (ie: insect or mechanical damage to the grain). Two storage mycotoxins that can be found in Canadian feed ingredients include ochratoxin-A (OA) and citrinin. These mycotoxins are produced from fungi, including *Aspergillus ochraceous* and certain *Penicillium* species. Levels of OA can reach extremely high limits (110 ppm) in grain samples in Western Canada, and surveys have documented significant levels of OA in human serum, particularly in residents of Western Canada (Scott et al., 1998), presumably through the consumption of grains or meat products contaminated with OA. Research on citrinin levels in Canadian grains is more limited. The survey of these mycotoxins has become increasingly more intense due to the fact that European standards are dictating much tighter tolerance levels for these compounds in grains destined for import into the European Union.

While the above mentioned mycotoxins can be found in grains of Canadian origin, additional concerns arise due to the importation of grains and industry co-products from the US and elsewhere. The presence of aflatoxins, or toxins produced from *Aspergillus flavus*, in corn produced in the Southern United States raises the potential for this toxin to be present in imported corn and corn by-products, including co-products from the ethanol industry (Zhang et al., 2009). The conditions necessary for the growth of *A. flavus* are consistent with those present in southern climates (mild winters, warm temperatures, high humidity, presence of substantial inoculum, etc…). While aflatoxins do not appear to be a threat to Canadian grains, this may shift over time with changes in climatic conditions and the potential for importation of inoculum into a given region. The establishment of *Fusarium graminearum*, the species responsible for the production of DON in small grains, within the Red River Valley region of Manitoba is thought to be traced to the importation of contaminated seed corn in the early 1990’s.

- **Toxicological Impacts of Major Mycotoxins**

A review of the major toxicological symptoms observed in animals consuming diets contaminated with mycotoxins is presented in Table 1. For the purposes of this review, discussion will be limited to the major identified mycotoxins of concern in Canadian swine diets, namely DON, zearalenone, and Ochratoxin-A. Given the substantial importation of American corn into the Canadian feed system, a review of the toxicological impacts of aflatoxins will also be presented.

The major toxicological impact of the presence of DON in swine feeds is the associated feed refusal. Regression analysis of the impact of DON on feed refusal provided evidence of a reduction in feed intake of 7.5% (relative to
controls) for every 1 ppm of DON in the feed (House, 2003). Current feeding guidelines for swine indicate the final DON content in swine diets should be less than 1 ppm. While these guidelines remain prudent, we have previously documented that DON levels up to 4 ppm had only minor impacts on feed intake in grower-finisher pigs (House, 2003). In studies with mice, the inclusion of DON in semi-purified diets has elicited impairments in immunocompetence, including reductions in secondary antibody response (Pestka & Smolinski, 2005). However, data from swine studies remains variable and inconclusive. In fact, much of the research with DON in swine is characterized by variability, due possibly to the confounding effects of other mycotoxins present in naturally-contaminated grains.

The presence of zearalenone in pig diets is generally associated with disturbances in reproduction, due principally to the estrogenic potential of the mycotoxin. Zearalenone has been shown to have relatively low acute toxicity potential, but has a high affinity for the estrogen receptors α and β. Classic exposure symptoms include reddening and swelling of the vulva in gilts and sows, disruption in the maturation of ovarian follicles, and decreased luteinizing hormone and progesterone secretion (Zinedine et al., 2007). The latter effects are associated with reduced litter sizes and reductions in conception rates. Boars exposed to zearalenone exhibit depressed libido, presumably due to a reduction in testosterone secretion. Evidence of an effect of zearalenone on immune suppression is limited to in vitro studies and experiments in rodents using high exposure levels via injection.

Within the Balkans, a disease called Endemic Nephropathy, a chronic interstitial renal disease, has been linked to the consumption of grains that contain Ochratoxin-A (OA). The link between OA contaminated grain and nephropathy arose from the knowledge that outbreaks of nephropathy in Scandinavian pigs could be attributed to the consumption of grains containing OA. This was confirmed in subsequent controlled feeding trials. Levels of OA can reach extremely high levels (110 ppm) in grain samples in Western Canada, and surveys have documented significant levels of OA in human serum, particularly in residents of Western Canada (Scott et al., 1998), presumably through the consumption of grains or meat products contaminated with OA. Studies in our lab have documented that OA leads to significant reductions in feed intake, with concomitant reductions in weight gain of young pigs (Aukema et al., 2004). Renal biopsy samples taken from pigs exposed to OA showed marked fibrosis following 4 weeks of consuming diets containing OA at levels of 4 and 6 ppm. The same pigs also showed marked elevations in serum creatinine, indicative of a decline in renal function.

While the above-mentioned mycotoxins can be found in feed ingredients of Canadian origin, the importation of corn and corn by-products from the US and elsewhere creates risks for the exposure of pigs to aflatoxins. First identified as the primary compound responsible for the death of turkeys in
England during the 1960’s (Turkey X disease), aflatoxins have since been extensively studied.

The primary pathology associated with aflatoxin ingestion is liver damage. Additional symptoms, including reduced feed intake, reproductive dysfunction, and immune dysfunction may be secondary to hepatic affects.

The etiology of mycotoxicosis is not straightforward. Research in various animal models has studied the impact of singular exposure to purified mycotoxins with a resultant assessment of the toxicological outcomes. In reality, swine are likely exposed to multiple dietary toxicants, complicating the clinical presentation of mycotoxin-related pathologies and leading to variability in responses. From a practical standpoint, avoiding the risk of mycotoxins is the best practice; however this is not a simple task.

- **Mycotoxin Mitigation Strategies**

A number of strategies have been developed and promoted for mitigating the risks associated with mycotoxins in swine diets.

**Strategy 1: Avoidance.**

This sounds simple, but in reality it is difficult to achieve. Establishing clear maximum permissible levels of mycotoxins in swine ingredients is currently industry practice for DON and aflatoxins. The enforcement of these specifications is aided by the availability of relatively quick and inexpensive tests for the presence of DON and aflatoxins that can be performed in a quality control lab at an elevator or feed company. At present, quick tests are not readily available for other mycotoxins, including OA, however they are in the development stages.

**Strategy 2: Binders and Detoxifiers.**

Significant research effort has been placed into the development of agents to bind mycotoxins, thus making them unavailable for absorption. For example, clays, bentonites, and organic polymers, including yeast cell wall extracts, have been examined for their potential to reduce the severity of DON-induced feed refusal (Mahan, 2010). Beyond subtle changes in biochemical profiles, the evidence to support their current usage for DON-contaminated feeds is underwhelming. Evidence for the potential effectiveness of a “cocktail” product (antioxidants, amino acids, preservatives, etc..) towards increasing feed intake in young pigs consuming diets with high levels of DON has recently been reported (Mahan, 2010). Adsorbents have been shown to be effective for certain mycotoxins, including aflatoxins. Other approaches to mitigating the risk associated with confirmed mycotoxin presence in swine
feeds includes the use of biological agents, including enzymes and microorganisms to degrade the mycotoxin. For example, the incubation of DON-contaminated grains with the intestinal contents from chickens led to a reduction in the DON content. When fed to pigs, improvements in feed intake and weight gain were noted (He et al., 1993). Further research is warranted in order to yield an effective and commercially available product.

**Strategy 3: Chemical Detoxification.**

The treatment of DON- or aflatoxin-contaminated grains with heat and wet alkaline conditions has been shown to effectively reduce the level of the corresponding mycotoxin. For example, the incubation barley, that had an initial DON content of 19 ppm, with 1 M sodium carbonate at 80 degrees Celsius resulted in the complete removal of DON from the grain (Abramson et al., 2005). While effective, the practicality of treating feed grains with moist alkaline conditions is questionable. Where opportunity for this approach may be feasible is as an additional step during the processing of corn or wheat into ethanol, where water and heat are already part of the process. An examination of the mycotoxin levels in corn DDGS (Zhang et al., 2009) provides evidence that, while overall contamination levels are low, the risk for this product to serve as an additional source of DON is real. In Canada, the use of wheat-based DDGS may present additional challenges. An adjunct strategy, such as a chemical detoxification process, may prove advantageous in years of heavy contamination.

**Strategy 4: Physical Detoxification.**

In general, mycotoxin levels are concentrated on the outermost portion of the grain kernel. As such, the removal of the outer hull of cereal grains has proven to be an effective means of reducing the level of mycotoxins in the final product. By pearling DON-contaminated barley, for example, the removal of 15% of the weight of the barley kernel, roughly equivalent to the hull fraction, 85% of the DON can be removed (House et al., 2003). Effective co-product management strategies (contaminated hulls) and an overall economic assessment of the processes are warranted to determine the overall feasibility of this, and other, mitigation approaches.

- **Summary**

The complex etiology of mycotoxicosis necessitates increased vigilance with respect to the screening and mitigation of risk associated with mycotoxin-contaminated grains. New feed ingredients and increased complexity with respect to feed ration development creates a more complicated backdrop for identifying the toxicological impacts of mycotoxins in swine diets. As such, the
development of practical and affordable mitigation strategies will remain critical for the advancement of the Canadian swine sector.

References


