In Search of a Magic Bullet!
Strategies for Dealing with *Fusarium*-Contaminated Grains in the Swine Industry

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**Introduction**

*Fusarium* head blight (FHB) is a fungal disease that affects cereal crops worldwide, leading to substantial economic losses through reduced grain yields and grain quality. In just the last ten years, this disease has established a stronghold in fields in Manitoba and the eastern prairie region of Canada, and the incidence is spreading westward. While the severity of an FHB outbreak will depend on the particular conditions of the growing season (ie: precipitation at time of flowering, temperature, cropping history, etc...), there is no question that the disease is here and here to stay. Recent crop surveys have provided strong evidence that the major fungal species leading to FHB in Manitoba is *Fusarium graminearum* (1). This *Fusarium* species, like others, produces metabolites during the course of its normal metabolism. Some of these metabolites can have toxicological effects when consumed by livestock, and are therefore referred to as mycotoxins. On the basis of recent surveys, the primary mycotoxin found on cereal grains in Manitoba is deoxynivalenol, also known as DON or vomitoxin (2). This particular mycotoxin poses a serious threat to the sustainability of the swine sector in Manitoba and the eastern prairie region of Canada.

**Impact of DON on the Swine Sector**

The mycotoxin DON was identified by Vesonder et al. (3) to be the compound responsible for causing feed refusal and vomiting in swine. In fact, the observation that DON consumption caused swine to vomit led to the use of the term vomitoxin to describe this compound. However, vomiting is seldom reported in studies examining the impact of DON on swine performance and this term no longer routinely used. What is generally observed when swine are offered diets containing DON is some degree of feed refusal and concomitant reductions in performance. Figure 1 depicts data derived from a number of studies (4-10) that were conducted to examine the impact of dietary DON on feed intake, measured during the first few weeks of exposure. Each point represents a treatment mean value and the line of best fit has been plotted. On the basis of simple regression analysis, an estimated 7.5% reduction in feed intake is expected for every 1 ppm DON found in the diet.

In 1990, the Canadian Food Inspection Agency recommended that swine diets should not contain DON at levels higher than 1 ppm, and further stated that diets for pregnant and lactating swine should be “DON-free” (11). While this should be the goal for feed formulators, the feasibility of this approach will depend on a number of factors, chief amongst which is the availability of competitively priced, DON-free grains. Heavy *Fusarium* pressure over the last few years has made sourcing local DON-free grains difficult. For example, the DON content of barley grown at the University of Manitoba Glenlea Research Station was greater than 5 ppm for the 1999-2001 growing seasons. This severely restricts the utilization of this grain for on-farm mixing of swine diets, if CFIA guidelines are maintained. As a result, clean feed grains have been imported into Manitoba from Western Canada and the US. This fact has led to upward pressures on feed costs and an erosion of the competitive advantage that Manitoba has possessed relative to costs of production for pork.
In light of the high levels of *Fusarium* loads in Manitoba, strategies are needed for the effective management and utilization of DON-contaminated grains by the swine sector, in order to promote the sustainability of this industry. In particular, knowledge is required in the following areas:

1. What is the maximum amount of DON-contaminated grains that can be fed to various classes of swine?
2. Are there any effective decontamination strategies that could be used?
3. Are there any feed additives that could be used?

The balance of this paper will address past and present research, including that being conducted at the University of Manitoba, aimed at addressing these issues, and the future research required to address gaps in our knowledge.

**Assessing the Impact of Don on Swine Performance**

As depicted in Figure 1., the primary effect of the presence of DON in swine feeds is feed refusal. This figure represents a composite of numerous research trials with the following general designs:

1. Conducted primarily in Eastern Canada
2. Use of traditional genotypes, primarily Yorkshires

The fact that a substantial proportion of the data available comes from research conducted in Eastern Canada raises the questions as to whether regional differences in mycotoxin profiles and grain utilization (corn vs. wheat and barley) could influence the responses observed. As discussed above, the most common mycotoxin found in Manitoba cereal grains is DON, resulting from the metabolic activity of *Fusarium graminearum*. However, fungal infections are
known to produce many different metabolites, each with varying degrees of toxicity towards livestock. With respect to the utilization of traditional genotypes, the question remains as to whether advanced genetic lines reflective of the current industry maintain the same sensitivity to DON. To date, studies comparing the response of different genotypes to diets containing similar DON levels have not been conducted. To address these issues, we conducted a series of studies aimed at generating data with current genotypes, using grains produced in the eastern prairie region of Canada.

In our first study, 144 Cotswold pigs (72 barrows, 72 gilts), with a starting weight of 22 kg, were allocated to one of three dietary treatments: 0, 1, or 2 ppm DON, with twelve pigs per pen (6 barrows:6 gilts). The diets were formulated using barley as the primary cereal grain. DON concentrations in the final diets were realized by diluting DON-free barley (<0.2 ppm) with an appropriate amount of DON-contaminated barley. The barley contaminated with DON was grown at the Glenlea Research Station in 1999 and had a DON concentration of 4.9 ppm. The diets were formulated to meet the protein and digestible energy needs of pigs over the entire grower-finisher period. Figure 2 summarizes data obtained from a grower-finisher trial conducted during the period of October 2001-January 2002 at the Glenlea Swine Research Facility.

The presence of DON in the diet at 2 ppm resulted in a 7.6% reduction in feed intake relative to the 0 ppm DON diet, with pigs consuming the 1 ppm diet having intermediate levels of feed refusal. Despite the reduction in feed intake, average daily gain was not affected (approx. 820 g/d). Because the animals were not split sex fed, it was not possible to determine the impact of

**Figure 2.** The effect of increasing DON concentrations in grower-finisher diets on the time required for barrows and gilts to reach market weight (110 kg; Ref.# 12)
DON on feed intake for the sexes, but as illustrated in Figure 2., gilts were more sensitive to the presence of DON than were barrows, as judged by the time required to reach market weight. The presence of DON in the diet at 1 and 2 ppm increased the median time required to reach market weight by 5.2 and 14.1 days, respectively, relative to the 0 ppm treatment (P<0.05). This delay in attaining market weight reduces opportunities for marketing large batches of gilts, and reduces the number of pigs that can be finished within a year. On the other hand, barrows were not affected by the presence of up to 2 ppm DON in the diet. This observation may signify an opportunity to use greater amounts of DON-contaminated barley in diets for barrows for those employing split-sex feeding programs. An examination of the carcass data revealed that when pigs were marketed at the same weight, carcass weight, index, and backfat measurements were not affected by the presence of DON in the diet for either barrows or gilts. The only effects of DON that were observed were slightly higher loin premiums, due to greater loin depths, for both barrows ($2.34 vs. $1.77) and gilts ($2.63 vs. $1.90) consuming the 2 ppm DON diets versus the control diet. These results were unexpected and, to date, we have no explanation for these findings. To summarize our first trial, DON at levels of 2 ppm were well tolerated by barrows, however gilts showed a higher sensitivity to the presence of this mycotoxin in the diet.

In a subsequent study designed to determine the impact of higher levels of DON, the same study design as indicated above was used, however the diets contained 0, 2 or 4 ppm DON. For this study, the DON-contaminated barley was procured from the same experimental farm, but from the 2001 growing season, and contained 9.8 ppm DON. The study was conducted over the period of May-August, 2002. In this study, the presence of DON up to 4 ppm had no effect on feed intake, gain, feed efficiency, days required to reach 110 kg, or carcass measures for either barrows or gilts. The pigs took the same amount of time to reach market weight as observed in the first study, with barrows and gilts attaining 110 kg in a median time of 158.8 and 170.8 days, respectively. To summarize the second trial, the presence of up to 4 ppm DON in the diet had no adverse effects on swine over the entire grower-finisher period. Therefore, unlike the previous study, gilts did not seem to be sensitive to the presence of DON in the diet.

The reason for the different results between the two trials is not readily apparent, but may be related

Different sources of DON-contaminated grain: The contaminated barley was procured from the same experimental farm, but during different growing seasons. Therefore, the possibility exists that, even though the DON content of the experimental diets were set (and confirmed), other mycotoxins might be present that could influence the results. We screened both contaminated barleys for the presence of T-2, HT-2, 3-acetyl-DON, and 15-acetyl-DON and no toxins were found. However, other toxins might be present that are currently not considered relevant in Manitoba. Other toxins, such as fusaric acid, have been previously shown to augment the effects of DON (10), however the presence of this mycotoxin in Manitoba grains has not been established.

Seasonal effects: The first trial was conducted in the late fall-early winter and the second trial was conducted in the summer. The possibility exists that temperature, ventilation rates, disease pressure, or other factors may have influenced the data obtained. To date, the interplay of environment and mycotoxins has received little attention.

The studies mentioned above provide evidence that grower-finisher pigs, in particular barrows, have the ability to tolerate levels of DON higher than that recommended by CFIA (11). In order to address the issue of whether younger pigs may be sensitive to DON, a study was
conducted with 96 Cotswold pigs (48 barrows; 48 gilts), weaned at 17 days of age and with a weaning weight of 6.2 kg. Pigs were separated by sex and allocated to receive starter diets containing either 0, 1 or 2 ppm DON, from the DON-contaminated barley procured from Glenlea in 2001. Diets were formulated to meet the nutrient requirements of early weaned pigs, and contained barley (20.6% from either DON-free or contaminated barley), rolled oats (33.55%), soybean meal (18%), dried whey (17%), spray-dried porcine plasma (6%), vegetable oil (1.3%), and a vitamin and mineral pre-mix. These diets were fed for 14 days. After two weeks, diets were reformulated to remove the spray-dried porcine plasma, however DON-content was kept the same. The DON content of the diets were confirmed. The trial lasted for 35 days, during which time data for feed intake, average daily gain, and feed efficiency were measured weekly. As depicted in Figure 3., the presence of DON up to 2 ppm in the diet did not affect feed intake in either barrows or gilts, nor did it influence average daily gain or feed efficiency. It must be noted that the source of contaminated barley used in this study was the same as that used in the second grower-finisher trial. In addition, the trial was conducted during the summer months as well. Therefore, it is not known whether a different season or source of contaminated barley would have produced differing data. But on the basis of our results, starter pigs of both sexes are able to tolerate DON levels up to 2 ppm, when the source of the DON is contaminated barley.
grown in Manitoba.

On the basis of the above findings, both starter and grower-finisher pigs, of modern genotype, are able to tolerate DON in the diet when present at levels above 1 ppm. Barrows, appear able to tolerate levels of DON up to 4 ppm in the grower-finisher stage. Producers using split-sex feeding programs may be able to channel DON-contaminated grains to the feeding of male pigs. However, on the basis of the results from the first grower-finisher trial, care must be taken when formulating diets for gilts, and CFIA guidelines (maximum 1 ppm DON) should be adhered to. While data on the impact of DON on the reproductive herd is minimal (13,14), the observed sensitivity of gilts to DON provides some justification for ensuring that the DON content of gestation and lactation diets is as low as possible. Further research with the reproductive herd is critical before this recommendation can change.

DON creates variability, both within and between herds, and makes simple solutions for handling this mycotoxin difficult to obtain. Ideally, on the basis of the DON content of the grain, one could predict the decline in intake that is likely and make adjustments to the diet to compensate (ie: increase lysine, increase digestible energy content). However, until we have a better understanding of the interplay between DON and factors such as environment, swine genetics, other mycotoxins, nutrition, and disease, our ability to predict how pigs will respond to a given level of DON in the diet will be limited. As such, alternative strategies are needed to help us remove some of the variability resulting from the feeding of DON-contaminated grains to swine. One such approach is the use of specific decontamination processes for the removal of DON from grains prior to their usage as feed ingredients in swine diets.

**Strategies for the Removal of DON from Feed Grains**

A number of approaches have been tried with the objective of reducing or removing DON from feed ingredients. In general, these approaches can be divided into three categories: 1) physical methods, 2) chemical methods, and 3) biological methods. Physical methods that have been investigated for their potential to reduce DON concentration in grains include heat treatment, including the heating associated with pelleting and extrusion. In general, DON is stable during the short exposure times that are realized for these processes, and therefore heat treatment alone is not sufficient for DON decontamination (15). One physical method that shows great promise in the removal of DON from cereal grains is pearling. Pearling involves the contact of grains with a rotating abrasive disk, such that the outer, contaminated portions of the grain are polished away. In laboratory-scale studies, pearling was shown to be highly effective in removing DON from hulled barley (Figure 4). Removal of 15% of the weight of the barley kernel, an amount equivalent to the hull fraction, resulted in a reduction in the DON content by 65%, irrespective of the amount of DON present in the original sample. Further reduction in the DON content is possible with further pearling. An additional benefit to the pearling procedure is the fact that the calculated digestible energy value of the barley is increased by 10-15%, due to the removal of the fibrous hull. This research has entered into the second phase - an examination of the practicality of using commercially available pearling equipment for the decontamination of DON-containing cereal grains and an assessment of the impact of that this pearling procedure has on the feeding value of the grains for swine. Additionally, this second phase of the study will include an assessment of the cost effectiveness of this procedure for enhancing the utilization of locally-produced cereal grains.

While chemical processes like ammoniation are effective in reducing the content of aflatoxin, another mycotoxin, on corn, this procedure is generally ineffective for DON. The
chemical processes shown to be most effective include washing in either water or a solution of sodium carbonate, in order to remove the soluble DON from the grain, or sodium carbonate treatment coupled with heat exposure. The washing procedures have been shown to be effective at removing 70-90% of the DON (16), however the major drawback of this technique is the fact that a wet product results, limiting the use of this technique to either those equipped to use wet feeds or willing to incur additional costs associated with drying the product. Mixing contaminated barley with 4:1 with a solution of 1 M sodium carbonate, followed by heating at 80 degrees Celcius is effective in reducing the DON content to less than 25% of original values after 1 day, and less than 10% after 3 days (17). The main drawback to this procedure is the length of time the product must be at elevated temperatures in order to reduce DON concentrations.

The final approach to detoxifying DON in feed ingredients involves the use of biological agents, including microorganisms or the enzymes that they produce (18). Certain bacteria have been shown to able to effectively degrade DON to a non-toxic form. For example, the incubation of DON-contaminated grains with the intestinal contents from chickens led to a reduction in DON content and, when the grains were fed to pigs, the pigs showed improvements in feed intake and weight gain (19). While this remains an exciting and promising area, further research in this area is warranted in order to yield an effective and commercially available product.

The choice of which decontamination method to use, physical, chemical or biological, must balance efficacy with economics. The data derived in our research facility highlights the

**Figure 4.** The effect of pearling time (abrasive dehulling) on the removal of grain mass and DON from hulled barley
promise of pearling for the removal of DON, however this method must be shown to be economical at commercial scale. Continued investigation of additional decontamination strategies may yield new approaches for the effective removal of DON, either by acting alone or in concert with another decontamination procedure.

**Dietary Strategies to Cope with DON**

A final strategy for dealing with DON-contaminated grains involves the manipulation of swine diets, through either fortification or the use of dietary additives to reduce the negative impact that DON can have on such measures as days required to reach market weight. As previously mentioned, the major effect of DON in swine is the reduction of feed intake. If diets are fortified with additional protein/lysine and digestible energy (added fat), it is possible that swine can continue to gain normally, despite a reduction in intake (6). The main limitation to this approach is the fact that one needs to have some idea of the reduction in feed intake that can be expected given the DON content present. However, as discussed above, this prediction is complicated due to the presence of multiple confounding factors. The use of dietary adsorbents, such as clays, bentonites, and organic polymers, including yeast cell wall extracts, have received considerable attention for their potential to reduce the severity of DON-induced feed refusal and subsequent impacts on performance (20). Adsorbents have been shown to be effective for certain mycotoxins, including aflatoxins, however their usefulness against DON is subject to considerable debate. To date, little evidence exists beyond subtle changes in biochemical profiles to show that dietary adsorbents can reverse the feed refusal seen in swine consuming diets contaminated with DON. Other dietary additives that have been tried with little success include flavouring agents and acidifiers. In fairness, however, little research has been done in this area in the last 15 years.

**There is no magic bullet - Yet!**

The presence of DON in feed grains in Manitoba has eroded the competitive advantage the swine industry has held in this province. The investigation of strategies to manage DON-contaminated grains effectively holds the promise of allowing more locally-produced grains to be utilized by the swine industry in Manitoba. However, as of yet, there is no magic bullet for dealing with DON-contaminated grains. In the end, effective strategies are likely to represent a multi-pronged approached derived from an understanding of how swine respond to DON, in conjunction with effective decontamination procedures or dietary strategies. The anticipated development of such an approach will help to ensure the sustainability of the swine sector in the province of Manitoba.

**References**