World Mycotoxin Journal, August 2008; 1(3): 315-323

Wageningen Academic Publishers

Fate of fusarium mycotoxins in the cereal industry: recent UK studies

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Received: 26 June 2007 / Accepted: 12 December 2007

Abstract

The cereal food chain covers events from the sowing of the seed until the point of ingestion of a food by the consumer. Mycotoxins may develop prior to harvest or through inadequate storage. Most mycotoxins are inherently stable natural chemicals but cleaning, milling and different methods of processing can change their concentrations. Legislation is necessary to protect the consumer so it is important to consider, among other things, the relationship between concentrations of mycotoxins in the raw grains and those in the product purchased by the consumer, especially where different limits are specified at successive stages in manufacture. Recent studies of the fate of fusarium mycotoxins in the cereal food chain carried out alongside industry in the UK have examined changes in the concentrations of deoxynivalenol, nivalenol, T-2 toxin, HT-2 toxin and zearalenone in wheat, maize and oats and the fumonisin mycotoxins in maize at key stages in the cereal chain. For example, fumonisin concentrations in maize grits after milling were reduced by about 75% compared with the raw maize, but remained similar to the maize in the flour and were increased (x3 to x5) in the bran and meal. Maize flour and grits were then processed into a range of food products such as breakfast cereals, cornflakes, extruded snack products and tortillas and the changes in concentrations were established. Simple extrusion of flour or grits reduced fumonisins by a further 30-70% depending on the process. Deoxynivalenol and zearalenone were found to be more stable than fumonisins during most processes.

Keywords: deoxynivalenol, nivalenol, HT-2 toxin, T-2 toxin, zearalenone, fumonisins, milling, processing

1. Introduction

Cereals are invaded by a range of fungi both in the field before harvest and during storage. Some species of these moulds, in particular the Fusaria, can produce mycotoxins that persist through harvesting, drying, milling and processing and can thus be present in detectable quantities in products purchased by the consumer. The risk to human health posed by mycotoxins has been assessed by international organisations including WHO/FAO and the EC and as a result maximum permissible limits for certain mycotoxins have been introduced or are currently under consideration (EC, 2006a, 2007). Limits have been set within the EU for deoxynivalenol (DON) and zearalenone (ZEA) in cereals including wheat, maize, oats and for fumonisins in maize. A lack of data has to date delayed specific proposals for HT-2 toxin (HT-2) and T-2 toxin (T-2).

For those commodities such as cereals that undergo significant processing, the concentration of a mycotoxin in a food item that reaches the consumer may be considerably lower than in the raw harvested crop, although this is not always so. If these relationships can be established, it may be acceptable to set limits for the raw product at a higher level than for the processed food, without compromising human safety. The main operations where changes in mycotoxin concentrations are likely to occur are the initial cleaning of the grain, the milling of the whole cereal and the processing of the different cereal milling streams to manufacture the consumer product. Co-products or by-products of milling operations often produce the cereal fractions in which mycotoxins tend to be concentrated and are normally used for animal feed.

Legislation needs to be based on sound risk assessment taking into account known toxicological information, occurrence data and the dietary intake of different groups within the target geographical region, e.g. the EU. Limits are often set at different points in the food chain such as in the raw material, the derived milling streams, the finished food product and infant food. The fate of mycotoxins, including that of the fusarium mycotoxins, is an area for which data have not been available, particularly in the commercial situation. This does not reflect either the legislative approach or the commercial practice. Failure to take this into account raises the possibility that buyers accepting consignments meeting statutory requirements at intake will be challenged later in the food chain when the expected 'reduction' in concentration is not achieved.

The validity of such relationships usually remains unchallenged when maximum permissible levels are set at concentrations that are rarely encountered in normal practice and thus the consequences of 'unsound' limits do not arise. However, when concentrations near to, or in excess of, statutory limits at intake occur it is essential that the reduction expected in subsequent processing is consistently achieved. Climatic conditions in Europe in 2006 led to undesirably high concentrations of fumonisins occurring in maize. In the absence of legislative limits a risk assessment needs to be undertaken to assess any use of contaminated crops for human food. Such action should be taken only when there is sufficient toxicological evidence of a significant risk to human health and after the economic consequences have been considered. In developing countries the need to feed a starving population may be a more immediate priority.

Limits are developed to take into account the variability in processing techniques and grain properties that occurs from consignment to consignment and from process to process even in carefully controlled commercial situations. This variability is additional to that resulting from sampling and analysis of mycotoxins that is now well recognised.

Published data on milling and processing sometimes appear conflicting but this may be in part due to failure to understand the complexities of milling technology and/or to the omission of key processing information. For example, with bread it is not always made clear whether values quoted are 'as is' or after correction for moisture content which is commonly around 40%. In addition, other ingredients may be constituents of commercial recipes but may be unknown to, or overlooked by the researcher. To illustrate this, Boyacioglu *et al.* (1993) examined the effect of additives such as potassium bromate, L-ascorbic acid, sodium bisulphite, L-cysteine, ammonium phosphate at varying levels on DON during baking. The reduction found was about 7% in flour without additives. However, potassium bromate and L-ascorbic acid had no effect, but sodium bisulphite, L-cysteine and ammonium phosphate resulted in about 40% reduction of DON.

The UK grows about 15 million tonnes of wheat each year for internal use and export and has a significant oat industry for human food and animal feed. In addition, maize is imported from Europe and South America for use in human foods and snacks and for animal feeding stuffs. The UK Food Standards Agency and DEFRA (Department for Environment, Food and Rural Affairs) together with the Cereal Industry are funding on-going studies which are being carried out at the full industrial scale. These studies aim to determine the fate of fusarium mycotoxins from their occurrence in the raw cereal at mill intake to the products purchased by the consumer and to study the factors that contribute to these changes. Data produced will assist with setting future regulations for mycotoxins and/or to indicate any revision of current limits that may be required. Selected results from these studies are discussed here in relation to the regulations and other published information. Detailed results will be published elsewhere.

2. Current studies within the UK cereal industry

Project consortium

A consortium has been assembled from UK industry, academic institutions, analytical laboratories and consultants with advice from government and cereal organisations to ensure that all major parties are involved in this study. The Industrial partners are drawn from large cereal companies operating in the UK who sample and supply the cereal consignments and processed samples and provide information regarding origin, ingredients and the commercial processes used. In total, three maize, one wheat and one oat millers, two breakfast cereal manufacturers, a snack and a biscuit producer are involved. Extrusion has also been studied using naturally contaminated cereals in a pilot-scale installation at the Chorleywood and Campden FRA, Chipping Campden, UK. Analysis is being carried out at RHM Technology, High Wycombe and at the Central Science Laboratory, York, while operation of rapid test kits for DON is being examined with the assistance of R-Biopharm Rhône, Glasgow. Studies to understand the mechanisms affecting changes in mycotoxin concentrations, and the nature of breakdown or bound species are in progress at the University of Bristol and at Harper Adams University College. An advisory board comprises representatives from the UK FSA (Food Standards Agency), HGCA (Home-Grown Cereals Authority), NABIM (National Association of British and Irish Millers) and SNACMA (The Snack, Nut and Crisp Manufacturers' Association) and a consultant, Professor R Walker (toxicology). The work is coordinated by the current author.

Industrial premises

Samples from milling and processing are collected from commercial premises operating at full production scale. Details of milling operations, milling products and processes are supplied by each Company while commercially sensitive information is supplied on 'a need to know' basis within the Consortium. Cereals processed are the normal trade supply purchased according to current trade standards.

Sampling

The EC lays down sampling protocols for enforcement purposes (EC, 2006b) but states that alternative procedures may be suitable for samples taken for other purposes. This study follows these principles. Each situation was considered and a sampling protocol was agreed by the Consortium as being sound. Sampling from lorries is mostly carried using automatic probes that collect individual samples from 30-60 points within the grain load, from top to bottom. Maize transferred directly from ship to mill is sampled on stream from conveyor belts by taking equal portions at regular intervals. Another situation requires grab samples to be taken from 20 consecutive lorries that represent a 500 tonne consignment. Sampling during processing of ingredients usually involves drawing 10 consecutive samples of 1 kg at regular intervals from intake and exit of processing vessels that are then bulked and mixed. The consignment size for these samples is usually between 1 and 10 tonnes. It is considered that as a cereal consignment progresses from raw state to finished product it becomes progressively mixed and thus more homogenous.

Analysis

Methods used for analysis of the trichothecenes, fumonisins and ZEA by the two laboratories are similar, hence they meet the same performance criteria. Details are given in Scudamore *et al.* (2007) and Scudamore and Patel (2000). The laboratories regularly take part in FAPAS and other quality assessment schemes and have a long record of consistently achieving performance scores well within the latitude allowed.

3. Occurrence data

Considerable data exist in the literature reporting the occurrence of fusarium mycotoxins in cereals, e.g. Müller *et al*. (1997, 1998 wheat and oats in Germany), however these will not be discussed in detail here and there is no intention to discuss this aspect here in any detail except to emphasise that the occurrence and concentration of a particular mycotoxin depends on many factors such as climate, cereal variety, etc. The principle fusarium mycotoxins found in this study were DON in wheat, HT-2, T-2, NIV and DON in oats and fumonisins, ZEA and DON in maize. Gareis *et al.* (2003) assembled a collection of occurrence data for fusarium toxins in food as part of the assessment of dietary intake by the population of EU Member States. In the UK the occurrence of fusarium mycotoxins in wheat, barley and oats has been monitored for several years (Edwards and Ray, 2005). Fumonisins, ZEA together with aflatoxins and ochratoxin A in maize have previously been surveyed at mill intake within the UK (Scudamore and Patel, 2000).

4. Milling and processing

The actions that are most important in determining the ultimate fate of mycotoxins are cleaning, milling and processing. In some circumstances processing proceeds without milling such as in the manufacture of whole-wheat breakfast cereals.

Cleaning

Cereals usually undergo a cleaning stage before being milled (Hazel and Patel, 2004). This action has been reported to reduce the mycotoxin content considerably but the outcome depends on the physical condition of the grain when studied and whether operations such as separation of broken grains and dust have been carried out earlier. Abbas *et al*. (1985) reported only between 6 and 19% reduction in DON in cleaning wheat in a commercial mill, while Scudamore and Patel (2000) found a mean reduction of 40% in fumonisin levels in a large industrial mill. In the current UK study cleaning is usually carried out as the first step. However, the precise history of grain consignments purchased by the millers is often uncertain and these may already have been cleaned prior to delivery. It is thus not surprising that the effect of cleaning is extremely variable.

Milling

Mycotoxin concentrations in milling streams should reflect where the mycotoxins are situated in the whole grains and how the original fungi colonised the developing grain seeds. Patey and Gilbert (1989) reviewed the distribution of DON, NIV and ZEA in wheat and maize after dry milling, and Chelkowski and Perkowski (1992) and Trigostockli *et al*. (1996) studied the distribution of DON and ZEA in wheat using a Buhler mill. Levels of all mycotoxins were highest in bran and lowest in flour. In general the mycotoxins were present in all fractions obtained from the wheat but were usually concentrated in the bran, shorts and germ.

In studies with maize, high levels of mycotoxins were found in the germ and bran fractions with lower levels in the grits and flour. Broggi *et al*. (2002) collected corn samples and different dry-milled fractions from an industrial mill in Argentina and analysed these for fumonisins. The concentrations of fumonisins were again highest in the

germ and bran fractions and lowest in the grits and flour. These data show a similar distribution to that found by Scudamore (unpublished data) in samples volunteered by large commercial mills in the UK. They are also consistent with the findings of Saunders *et al*. (2001) and others who showed that fumonisin levels were undetectable or relatively low in dry flaking grits and corn flour while higher in corn germ and highest in corn bran. The principle that mycotoxins concentrate in the bran and cereal seed coats while being lower in the endosperm generally, but not always, holds true.

In the current studies, 30 consignments each of wheat and oats and 90 of maize (30 from each of 3 mills) are being examined over a 3-year period. All the main milling streams are analysed in about 30% of the consignments while only the raw cereal and the main milling stream(s) mostly used for human food products are examined for the remaining 70%. These are white flour from wheat, flakes from oats and flour and grits from maize. Figure 1 shows the mean distribution of DON from 8 consignments in the white flour, wheat germ and bran fractions as a percentage of the concentration found in cleaned wheat. These results are similar to the distribution reported above by others, although the concentrations of DON found during the period were quite low (100-400 µg/kg).

Maize milling results in a number of milling streams produced mainly from the endosperm that decrease in particle size in sequence from flaking grits, coarse grits, fine grits, polenta grade flour to flour. Other fractions obtained are germ, meal and bran although the exact composition of these is likely to vary from mill to mill. The mean percentage distribution of DON, ZEA, and fumonisins B_1, B_2 and B_3 into various milling streams relative to raw whole maize are shown for one of the UK mills participating in this study in Figure 2.

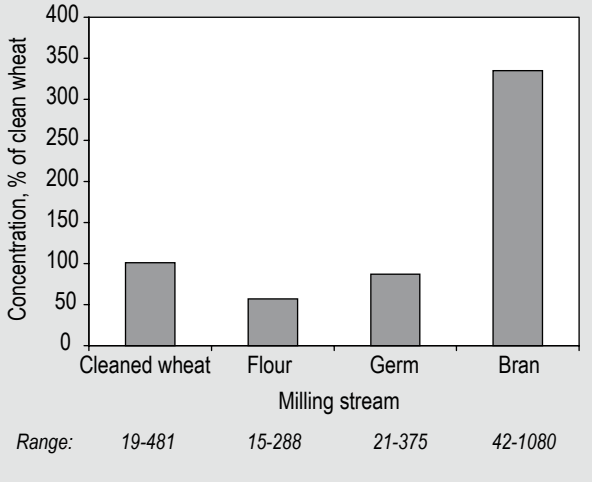

Figure 1. Distribution of DON in milling streams from wheat (mean %, n = 8).

To date a total of 20 consignments of maize and the resulting flour stream have been examined while all the milling streams have been analysed for 7 of these consignments. Actual mycotoxin concentrations in the raw maize have been up to approximately 1500 µg/kg total fumonisins, 500 µg/kg DON and 100 µg/kg ZEA. The results show a progressive increase in mycotoxin content from coarse grits to flour as the particle size of the endosperm fraction decreases. The highest levels were in the germ and in the meal where the mycotoxins were concentrated. This miller

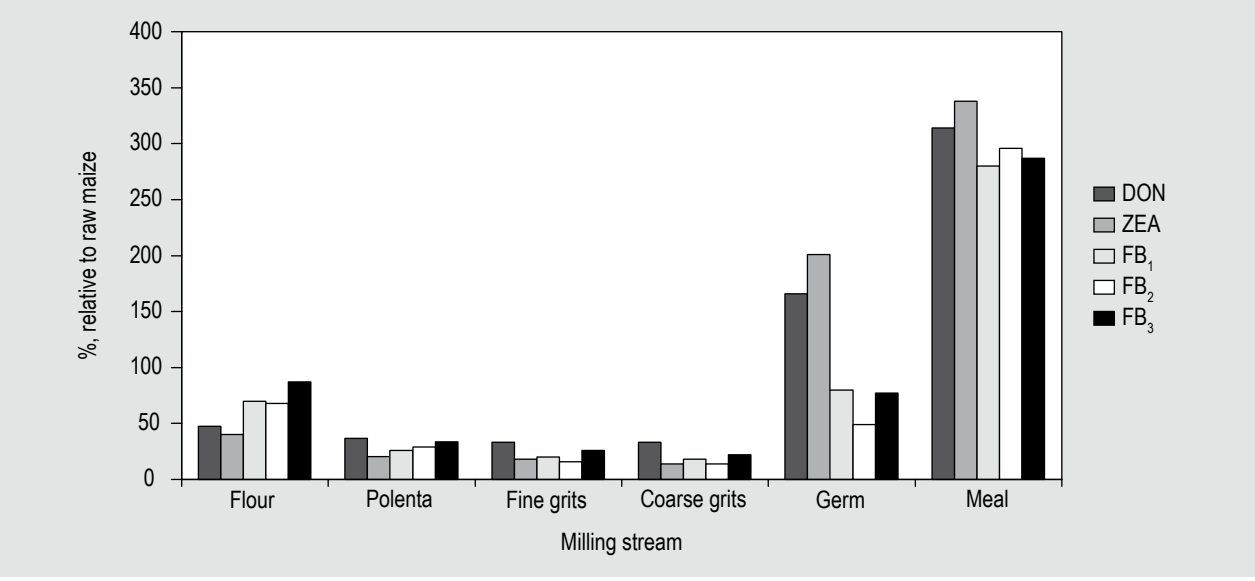

Figure 2. Distribution of fusarium mycotoxins in milling streams (n=20 for maize and maize flour, n=7 for other milled streams). Note: Particle size decreases from coarse grits to flour.

produces a product identified as 'meal' that comprises the bran, together with additional material recovered from unseparated germ and endosperm. Because of a considerable variation in the nomenclature used for different milled maize products it has been proposed that products are referred to by particle size as either <500 µ or >500 µ and animal feed components with appropriate limits set for these designations. It is important to note that each mill, at least in the UK, is likely to have its own unique set up for milling giving rise to a virtually infinite variety of possible products.

To date the mean concentration of fumonisin B_1 in flour from 38 consignments collected from all three maize mills has averaged 89% of that in the raw maize. This indicates the relative values for fumonisins in raw maize and maize flour within UK maize mills during the study period and should be reflected in EU legislation.

Information on the fate of fusarium mycotoxins during the commercial processing of oats is limited. Current results from this study carried out in a large UK oat mill show that the main mycotoxins that occur in UK and Scandinavian oats are HT-2, T-2, NIV and DON (Scudamore *et al.*, 2007). Combined levels of HT-2 and T-2 exceeded 3000 µg/kg in some samples. Mycotoxins were concentrated in the outer hull layer and were thus removed in a large part by dehulling. Only about 5-10% remained in the groat, which forms the basis of all human oat-based food products. In contrast, high concentrations of HT-2, T-2, NIV and DON remained in the removed oat 'pellet' used for animal feed. Related trichothecenes such as neosolaniol and T-2 triol were also sometimes detected in this co-product as a result of the concentration of mycotoxins in the removed hull fraction. Figure 3 shows the distribution of HT-2 toxin found in the milling of oats shown on a logarithmic scale. At least 90% of the mycotoxins are removed in the dehulling stage so that amounts present are very small in the oat flakes that are used for human food products. Similar results have been obtained in the studies for T-2, DON and NIV (results not shown) although HT-2 is the mycotoxin usually present in the highest concentration in UK-grown oats (Food Standards Agency, 2004).

Processing

The food processing industry uses a range of techniques such as boiling, fermentation, baking, frying and extrusion for manufacturing cereal-based foods. Scudamore (2004) reviewed secondary processing of mycotoxins and the factors that affect the stability of mycotoxins.

DON, NIV, ZEA, HT-2 and T-2 have generally been shown to be quite stable in commercial processing. However, in bread production, Samar *et al.* (2001) found that fermentation reduced naturally occurring DON in Argentinean bread processing technology using a pilot scale plant. French bread and Vienna bread were prepared from wheat flour naturally contaminated with DON at 150 µg/kg in which dough was fermented at 30-50 °C according to standard procedures used in Argentina. The maximum reduction obtained in dough at 50 °C was 46% for the Vienna bread and 41% for French bread. This is in agreement with results obtained by Neira *et al.* (1997) in which 8 types of product were prepared in a low technology bakery that showed a significant reduction of DON during the bread making process. Gilbert *et al.* (1984) showed that 80% of DON survived in both spiked and naturally

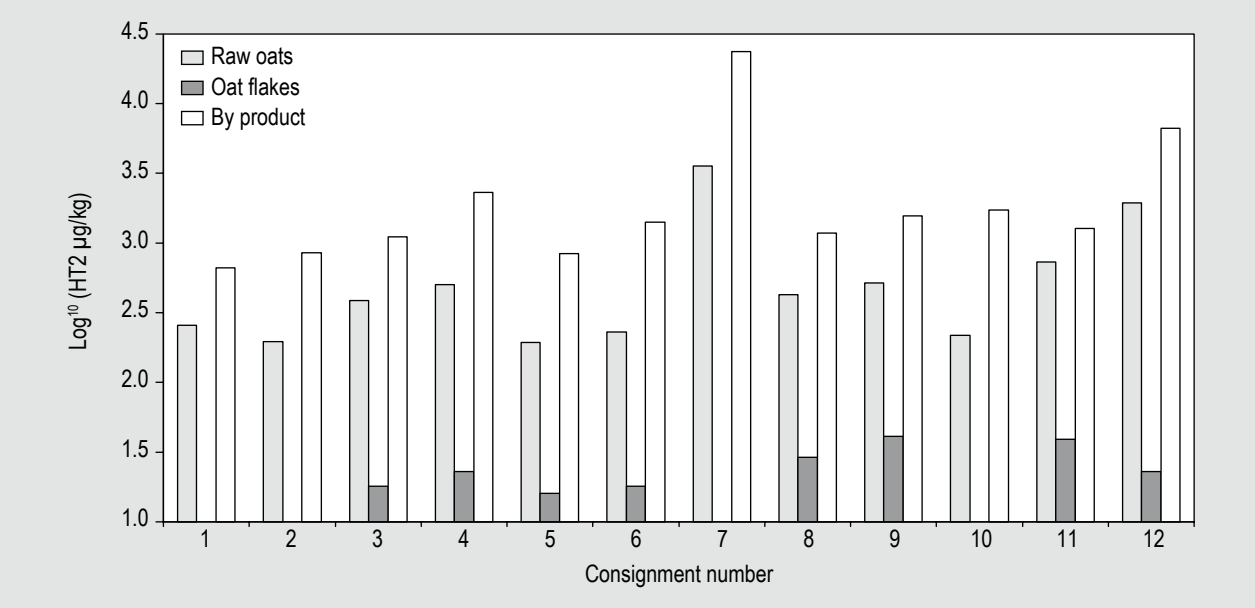

Figure 3. Concentration of HT-2 during the processing of 12 consignments of oats.

contaminated wheat although Abbas *et al.* (1985) obtained variable losses of from 19 to 69%. Baking at 170 °C did not degrade NIV and ZEA (Tanaka *et al.*, 1986).

In the current studies in which bread was produced by the Chorleywood process (Axford *et al.,* 1963) only about 10% DON was lost from both white and wholemeal flour, although the analytical value in the bread was about 50% of that in the flour due to the dilution effect of increased moisture content (Table 1). It is clear that the percentage reduction from wheat to bread (60%) for DON in wheat at the limit (1250 µg/kg) required by legislation, would be met for white bread but not for wholemeal bread.

In results described for other processes, trichothecene levels in Japanese noodles fell by about 30% for T-2 toxin and diacetoxyscirpenol, 40% for DON and NIV, and 60% for fusarenon-X and neosolaniol when boiled at 98 °C for ten minutes (Kamimura *et al.*, 1980). The authors speculated that loss might be due to extraction into the cooking liquid. Variable results were obtained after boiling in water when uncooked foods were spiked with DON (Isohata *et al.*, 1986). The loss for boiled rice was 23% and up to 97% for noodles while losses were 20-30% for noodles in a similar study for nivalenol, although up to 98% on one occasion. In the current study, 2 household names of whole-wheat breakfast cereals prepared by digestion of naturally contaminated wheat in boiling aqueous systems show the loss of DON to be about 40% under one set of conditions but almost 100% in the second after the product was dried and toasted. The higher loss occurred when excess cooking liquor was drained off suggesting a possible reason for this. The DON contamination in the wheat remained low (<100 µg/kg) throughout this study. This suggests that loss of DON and related trichothecenes is very dependant on the processing conditions.

Reports also vary on the stability of trichothecene mycotoxins during extrusion. Wolf-Hall *et al.* (1999) showed DON to be quite stable in heat-treated foods when the effects of high temperature and high pressure processing of foods spiked with the mycotoxin were examined. There was no significant reduction in extruded corn grits, extruded dry dog food and autoclaved moist dog food after processing. Autoclaved cream style corn showed a reduction in DON of only 12%. However, Accerbi *et al.* (1999) showed that soaking wheat highly naturally contaminated with DON in sodium bisulphite solution reduced levels from 7.3 to 0.8 mg/kg and then after further extrusion to 0.3 mg/kg. Ryu *et al.* (1999) studied the reduction in ZEA during extrusion to make a corn product. Between 65 and 83% reduction of spiked ZEA occurred although this varied slightly with screw configuration and was not affected by the moisture content of the grits. Losses were higher at 120 °C than at 160 °C.

In the current study, DON, NIV and ZEA in wholemeal wheat flour were mostly stable during extrusion over the range 140 °C to 180 °C and moistures of 15% to 21% although with an apparent increase of NIV under some conditions (Scudamore *et al.*, 2007). DON was also stable in a further similar study with maize grits. In summary DON and ZEA appear relatively unaffected by extrusion but some added components can partially degrade these compounds.

Many studies have been carried out on the stability of the fumonisins during processing since their identification and the recognition that they can occur in very high levels. The grits and flour fractions from maize are used for production of a wide variety of products. Saunders *et al.* (2001) showed that extrusion of dry milled products reduced fumonisin concentrations by 30-90% for mixing type extruders and 20-50% for non-mixing extruders. The effects of extrusion cooking, gelatinisation and corn flaking on the stability of fumonisins in artificially contaminated maize grits spiked with fumonisins B_1 and fumonisins B_2 at levels of 2 and 0.6 mg/kg, respectively, was investigated by Meuster (2001). All the samples showed significant decreases in the fumonisin levels. Cooking, extrusion and gelatinisation reduced fumonisin levels to approximately 30-55%, cooking the grits for flaking to approximately 20-65%, and roasting the flakes to approximately 6-35% (depending on the technological parameters selected).

Reduction of fumonisin concentrations in maize grits in this study are shown in Table 2 and ranged from 11 to 37%. Loss of fumonisin appeared relatively unaffected

Table 1. Reduction of DON from flour to bread (mean values n = 10 white, n = 5 wholemeal).

DON, µg/kg		White bread		Wholemeal bread	
		Flour	Bread	Flour	Bread
Mean	'as is'	115	71	83	52
	moisture corrected	130	113	94	84
Range	'as is'	61-284	31-186	51-110	28-71
	moisture corrected	72-322	63-285	58-125	48-118

Table 2. Loss of fumonisin B_1 during pilot scale extrusion of maize grits. Starting concentration of FB1 in maize grits used was 274 µg/kg.

Temperature, °C	Moisture, %	Fumonisin B_1, % loss
140	17	26.1
160	17	37.4
180	17	36.5
140	21	11.2
160	21	14.4
180	21	15.1

by temperature while loss increased at lower moisture content. This suggests that in maize grits or flour containing fumonisins at the statutory levels proposed the concentrations in products made by direct extrusion are unlikely to result in the reduction expected by the EC guidelines/proposals current at 20 May 2007.

Jackson *et al.* (1997) examined the effects of baking and frying on fumonisins in corn-based foods. Those studies suggested that fumonisins are quite heat stable under the conditions used. Losses in baking corn muffins were between 16 and 28% depending on temperature. However, frying corn chips for 15 minutes at 190 °C caused a loss of 67% of the fumonisin. Castelo *et al.* (1998) showed that bread baking resulted in a 48% decrease in fumonisins in artificially or naturally contaminated corn although corn muffin mix showed no decrease in fumonisin levels. However, muffins containing added glucose had lower fumonisin concentrations than the samples containing sucrose, fructose or no sugar although the reason for this is unclear (Castelo *et al.,* 2001).

Cooking and canning generally had little effect on fumonisin content (Saunders *et al.*, 2001). Shephard *et al.* (2002) showed that about 23% of fumonisin content was lost during production of typical South African corn porridge. In the masa process, measurable fumonisin was reduced following the cooking, soaking and washing steps, with little conversion of fumonisin to the hydrolysed form, while Castelo *et al.* (1998) studied the effect of canning on artificially and naturally fumonisin contaminated corn-based foods and showed that canning of whole cereal resulted in a decrease of 11-15% in fumonisins. However, when alkaline steeping of corn contaminated with fumonisins was used in producing tortillas (nixtamalisation) their concentration was reduced by about 90%, although some hydrolysed fumonisin B_1 was produced (Dombrink-Kurtzman *et al.*, 2000). Up to 80% loss was also obtained by Voss *et al.* (2001). Partially hydrolysed and fully hydrolysed fumonisin B_1 were both produced. The partially hydrolysed product was predominately in the steeping liquid and solid waste. De La Campa *et al.* (2004) showed that the loss of fumonisins in traditional masa production methods was greatly influenced by the particular method used.

A study of tortilla chip production in this current project showed that fumonisins were reduced by between 20 and 80 % through the whole production process although DON and ZEA survived without loss.

It is not well known that cornflakes are produced by two distinct processes. Maize flour is extruded, dried and toasted to make one product while large flaking grits are cooked, dried and toasted to form the second product. We have shown in Table 3 that fumonisins already naturally low in flaking grits are further greatly reduced during cooking and toasting. The reduction occurs almost entirely during the cooking step. In contrast, DON appears almost unaffected by this method of production although the starting concentrations in the grits were very low. Fumonisin concentrations in cornflakes produced by the alternative extrusion method are likely to be higher as fumonisin levels in flour are usually much higher than in grits and will be reduced less during extrusion. Thus De Girolamo *et al.* (2001) investigated the stability of fumonisins B_1 and fumonisins B_2 during the production of corn flakes from raw corn flour by extrusion and roasting and found loss through the whole process was about 60-70% but with less than 30% loss during the extrusion step. Further studies on hydrolysed fumonisins were reported (Kim *et al.,* 2003) that showed their presence in corn flakes and recommended that this should be taken into account by food safety authorities in estimates of human exposure to protein bound fumonisin.

In other processes extrusion processing of grits containing either sucrose or glucose destroyed more fumonisins than in the control, but glucose was again the most effective so that when the conditions were optimised, 92% loss of fumonisin B_1 occurred (Castelo *et al.,* 2001). The inclusion

Table 3. The fate of DON and fumonisin B_1 in cornflakes prepared from maize flaking grits using the traditional cooking process.

		Mycotoxin, µg/kg	
		Grits	Cornflakes
DON	Mean	13	18
	Median	<10	14
	Above analytical limit	7	12
	Range	<10-43	<10-44
FB_1	Mean	105	<10
	Median	102	<10
	Above analytical limit	14	1
	Range	49-181	<10-13

of glucose as part of further studies on extrusion with maize flour in the current work greatly increases the loss of fumonisins (studies in progress).

Katta *et al*. (1998) examined the stability of fumonisin B_1 during the extrusion of corn grits using different temperatures and extruder screw speeds. The barrel temperature and the screw speed both affected the loss of fumonisin in the product which ranged from 34-95% and 46-76% in those that gave acceptable expansion and colour. Cortez-Rocha *et al*. (2002) also showed that extrusion parameters such as die configuration could affect losses of fumonisins during processing.

5. Conclusions

Cereal milling produces a redistribution of mycotoxins in the milling streams related to the site of the toxin in the intact grains. This has the effect of reducing concentrations in some ingredients while increasing them in others. The subsequent degree of reduction achieved through processing depends both on the process and the properties of the mycotoxin. The availability of such data is vital when setting legislative limits. These should incorporate sufficient flexibility required by the range of changes in mycotoxins concentrations expected under different milling and processing conditions so that buyers avoid setting unnecessarily demanding mycotoxin standards from their suppliers. Processing alone cannot always be relied upon to reduce levels of fusarium mycotoxins.

Cereal-based foods are manufactured by a wide range of processes. These include cooking in water under raised temperature and pressure, fermentation, baking, frying, drying, toasting and extrusion. It is thus important when setting limits to consider the effects of processing on mycotoxin levels in the consumer product. Collaboration with industry is important to find out what happens in the commercial situation with naturally contaminated cereals.

The individual mill manager may also change the working settings of the machinery to provide ingredients with specific properties (e.g. particle size or oil content) or because of the properties of a specific consignment both at the milling stage and during processing. This in itself may affect the ultimate concentrations of mycotoxins. Thus, literature reports do not always agree, in part because full details of the conditions, recipes and machinery setting are not always stated. Milled ingredients or food products may also not be clearly defined. In summary, DON, NIV, ZEA HT-2, T-2 and the related trichothecenes are generally quite stable and survive many processes although the fumonisins may be partially degraded particularly by hydrolysis. The nature and possible toxicology of potential breakdown products such as hydrolysed fumonisins also needs to be considered.

Acknowledgements

This paper includes reports of the work of a Consortium from UK industry and research organisations carrying out studies funded by the UK Food Standards Agency, the UK DEFRA, Food Quality and Safety LINK Programme and the Cereal Industry.

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