FUSARIUM TOXINS IN ANIMAL NUTRITION

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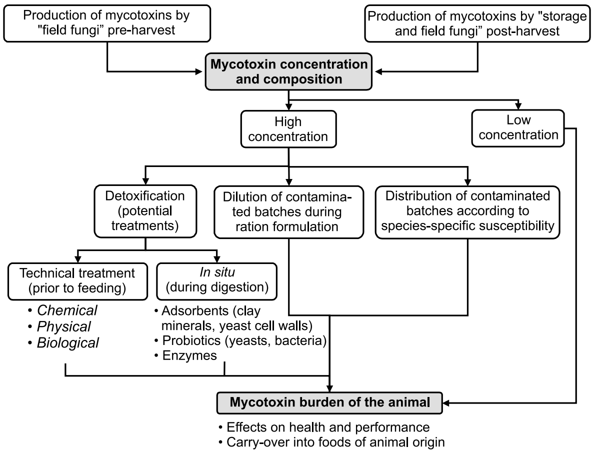
Introduction

Mycotoxins, secondary metabolites of phytopathogenic micromycetes, play a significant role in animal nutrition, especially those generated in the field (Fig. 1).

Figure 1: Management of mycotoxins in animal nutrition



The most important representatives of these field fungi, which are well adapted to constantly changing climatic conditions in the field and therefore hard to control by agrotechnical methods, include several species of the genus *Fusarium* (Table 1). The effect of a heavy infestation of cereal plants with *Fusarium* species is twofold: it can lead to massive revenue losses and the potential mycotoxins produced by these fungi can enter the human food chain via the use of contaminated cereal batches as animal fodder or food. Of the mycotoxins produced by *Fusarium* the most significant under production conditions in the Federal Republic of Germany are deoxynivalenol (DON) and zearalenone (ZON). This is due to the fact that DON and ZON can occur in toxicologically relevant concentrations in harvested cereal.

Table 1: Mycotoxin-producing fungi and their mycotoxins (selection)

Mycotoxin producers	Mycotoxins
Fusarium species *(F. graminearum, F. culmorum, F. avenaceum, F. poae, F. sporotrichioides, F. moniliforme)*	**Zearalenone (ZON)** Trichothecenes - Type A: T-2 toxin, HT-2 toxin, diacetoxyscirpenol; - Type B: **Deoxynivalenol (DON)**, 3-acetyl-DON, 15-acetyl-DON, nivalenol, fusarenone X Moniliformin Fumonisine B_1, B_2, B_3
Alternaria alternata	Tenuazonic acid
Claviceps purpurea	Ergot alkaloids
Aspergillus flavus, A. parasiticus	Aflatoxins, especially aflatoxin B_1
A. alutaceus, Penicillium verrucosum	Ochratoxins, especially ochratoxin A
P. citrinum, verrucosum	P. citrinin

An assessment of the risk potential throughout the food chain has to consider not only the susceptibility of different livestock species to these mycotoxins but also the potential for carry-over of toxins or their metabolites into foodstuffs of animal origin. The objective of animal nutrition must be to minimise the mycotoxin burden of livestock in the interests of animal health and productivity and to protect the consumer. This can be done by using the methods described in Figure 1 if efforts to reduce mycotoxin production in the field to a level where feed batches with high concentrations do not occur in the first place have been unsuccessful.

Some aspects of mycotoxin management are described in greater detail below.

Incidence and detection

Surveys on the incidence of Fusarium toxins in Germany were published by OLDENBURG et al. (2000) and MÜLLER et al. (2001). A survey for Europe was conducted by GAREIS et al. (1989). It became apparent that, compared with other Fusarium toxins, DON and ZON can occur in concentrations which can impair animal health and productivity in certain livestock species. The effect of the "mycotoxin cocktail" which is always present in naturally contaminated cereal is often attributed solely to the most prevalent lead toxins DON and ZON, although an isolated analysis of identical modes of action or interactions between different mycotoxins can in individual cases lead to an under- or overestimate of the influence of the lead toxins.

Table 2 gives an overview of the incidence of DON and ZON in German wheat. The data show that every so often there are years, referred to as "Fusarium years", when the maximum and mean concentrations of both mycotoxins are higher than usual. When analysing the data it is important to bear in mind that different analytical methods applying different detection limits will influence the mean value of the positive samples and the incidence.

Table 2: Deoxynivalenol and zearalenone concentrations in wheat from Germany (years with a high incidence (= "Fusarium years" are shown in bold))

Year, region	Deoxyivalenol			Zearalenone		
	N (of which positive, %)	Range [µg/kg]	Mean[1)] [µg/kg]	N (of which positive, %)	Range [µg/kg]	Mean[1)] [µg/kg]
1987, Baden-Württemberg	**84 (96)**	**4-20540**	**1690**	**84 (80)**	**1-8040**	**180**
1989, Baden-Württemberg	78 (69)	3-1190	150	78 (14)	1-10	3
1992, Baden-Württemberg	78 (95)	20-5410	340	78 (19)	1-20	4
1998, Thuringia	**150 (71)**	**110-11080**	**1410**	**135 (7)**	**20-250**	**70**
1998, Germany, total	**52 (85)**	**100-34600**	**6820**	**52 (72)**	**10-2200**	**520**

[1)] Means of positive samples
Sources: MÜLLER et al., 1997; DÖLL et al., 2000; ELLNER, 1999

The analysis of ZON in feedingstuffs is usually performed by HPLC with fluorescence detection. The stated detection limits of the relevant HPLC methods are usually about 0.001 - 0.02 mg/kg. There is an official VDLUFA method (HPLC, quantitation limit 0.01 mg/kg). In addition, ELISA quick tests working with a detection limit of about 0.001 - 0.05 mg/kg are gaining acceptance. However, samples testing positive in the ELISA should be confirmed with another method.

Deoxynivalenol is usually determined by GC/ECD or HPLC/UV. If other trichothecenes are to be detected as well, GC/MS methods are often used. The detection limits of the GC methods are 0.1 mg/kg, but the HPLC methods are less sensitive (about 0.1 - 0.3 mg/kg). ELISA quick tests employ a detection limit of about 0.0015 - 0.11 mg/kg. They are mainly suitable for screening purposes; a quantitative assay is too inaccurate due to cross-reactions (e.g. with acetylated deoxynivalenol compounds). An official VDLUFA method is in preparation.

Mechanisms of action in the animal body

Although ZON is not derived from the basic steran skeleton (Fig. 2), its spatial conformation resembles that of endogenous estrogens (Fig. 3). It is therefore capable of competing with endogenous estrogens for binding to estrogen receptors, thus mimicking estrogenic actions, which then manifest themselves in hyperestrogenism.

Figure 2: Structural formulae of deoxynivalenol (DON) and zearalenone (ZON)

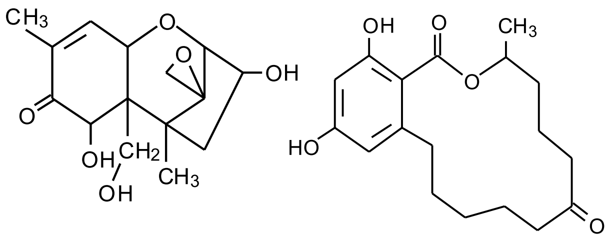
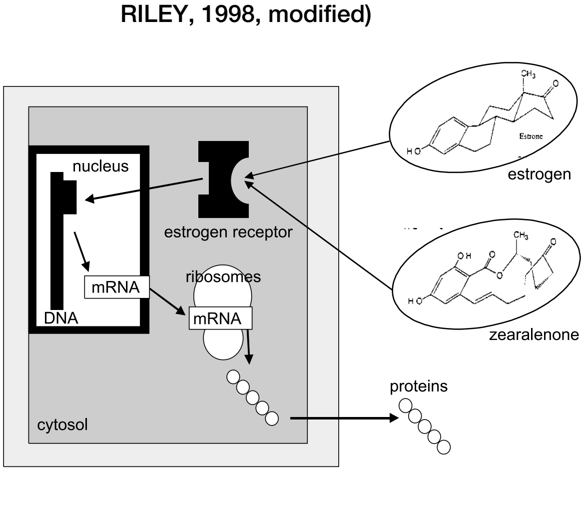


Figure 3: Mechanism of action of zearalenone (after RILEY, 1998, modified)



FITZPATRICK et al. (1989) showed in competitive binding studies that α-zearalenol, which can be produced from ZON in the intestinal mucosa and the liver and in ruminants additionally in the rumen, has a greater affinity for the estrogen receptor than the parent substance. It was also noted that affinity for the receptors is apparently greater in the pig than in the chicken (Table 3), which goes some way towards explaining the higher susceptibility of pigs to ZON.

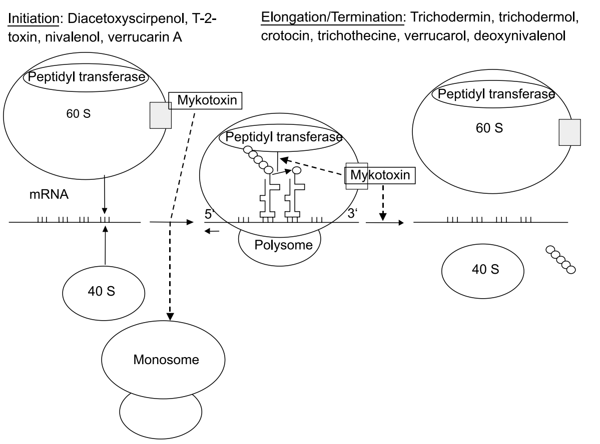
Table 3: Comparison of the relative binding affinity of zearalenone and its metabolites (in % of the standard) in the uterus of pigs and rats and in the oviduct of chickens (FITZPATRICK et al., 1989)

	Pig	Rat	Chicken
Standard[1]	100	100	100
α-Zearalenone	138	94.3	55.7
Zearalenone	7.4	8.0	7.2
β-Zearalenone	0.5	0.6	0.2

1 Diethylstilbestrol

The cellular mechanisms of action of the trichothecenes were described in a review paper by FEINBERG and McLAUGHLIN (1989). The common feature of the trichothecene mycotoxins, which include DON (Fig. 2), is the presence of an epoxide group in the molecule, which is the prerequisite for binding to the large subunit of the ribosomes. This bond prevents the creation of functional ribosomes, thereby blocking the translation at the initiation stage. But the mycotoxin can also bind to the functional ribosome, in which case the translation is blocked by inhibition of peptidyl transferase due to conformational modifications of the large subunit (Fig. 4). Differences in the toxicity of individual trichothecenes are due to differences in the side chains.

Figure 4: Mechanisms of protein synthesis inhibition through Fusarium toxins (schematic)



Toxicological relevance

Acute toxicity

Acute toxicity studies were often conducted in rodents or chicks and any conclusions concerning species-related differences must therefore be treated with caution. It was found that in chicks DON has the lowest acute toxicity of the trichothecenes (Table 4), whereas T-2 toxin has far greater acute toxicity. Metabolisation of T-2 toxin via HT-2 toxin to T-2 tetraol is associated with a reduction of acute toxicity. ZON was found to have no acute toxicity in chicks. In pigs increased chewing, teeth-grinding, salivation and vomiting were observed from 7 to 22 minutes after an intravenous DON injection of 0.25 mg/kg bodyweight (PRELUSKY et al., 1992). The emetic effect of DON is the reason why it has been given the trivial names “emetic factor” or “vomitoxin”. When administered with the feed, DON leads to a dose-dependent reduction in the feed intake after a few hours or days; this reduction is apparently greater when the same DON concentrations are administered via naturally contaminated feedingstuffs (Fig. 5).

These differences are often attributed to other mycotoxins occurring in association with DON (lead toxin) in naturally contaminated feedingstuffs. It must not be overlooked that a naturally contaminated feedingstuff is often also spoilt in its sensory characteristics, which can contribute to a further reduction in feed consumption. Moreover, in some cases the analytical result may be considerably distorted due to sampling errors, especially within the range of commercially relevant DON concentrations (~ 1 to 2 mg/kg), which is confirmed by the high coefficients of variation (Fig. 6).

Table 4: Acute toxicity (LD50, mg/kg bodyweight) of Fusarium toxins in farm animals

Toxin	Species or category	Route of administration	LD50	Source
T-2 Toxin	Broiler (day-old chick)	oral	4.97	CHI et al. (1978)
	Pig	i.v.	1.21	WEAVER et al. (1978)
	Trout	oral	6.1	UENO (1985)
HT-2 Toxin	Broiler (day-old chick)	oral	7.22	CHI et al. (1978)
HT-2 Toxin (de-acetylated)	Broiler (day-old chick)	oral	30.18	CHI et al. (1978)
T-2 tetraol	Broiler (day-old chick)	oral	33.79	CHI et al. (1978)
DON	Broiler (day-old chick)	oral	140	HUFF et al. (1981)
	Duck (day-old chick)	s.c.	27	UENO (1985)
ZON	Layer chick (2 weeks)	oral	>15000	CHI et al. (1980)

Chronic toxicity

Chronically latent mycotoxicoses, which are often associated with an unspecific productivity loss or infertility, are probably of greater significance than acute toxicoses at the mycotoxin concentrations likely to be encountered in practical feeding situations. The term mycotoxicosis refers to clinical symptoms that are caused by mycotoxins and are characterised as follows (SCHIEFER, 1990):

1. They probably occur frequently, but are often not recognised as such (unspecific reduction in productivity).
2. The adverse health effects associated with toxicoses are not transmissible to other animals, i.e. mycotoxicoses are not infectious.

Figure 5: Effect of the dietary DON concentration on the voluntary feed intake of pigs in a short-term experiment (3 d) (FORSYTH et al., 1977)

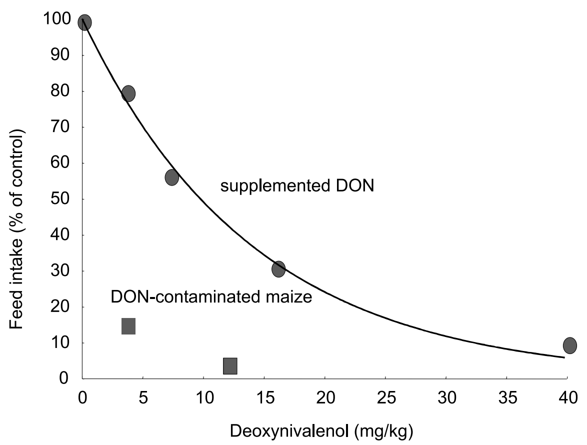
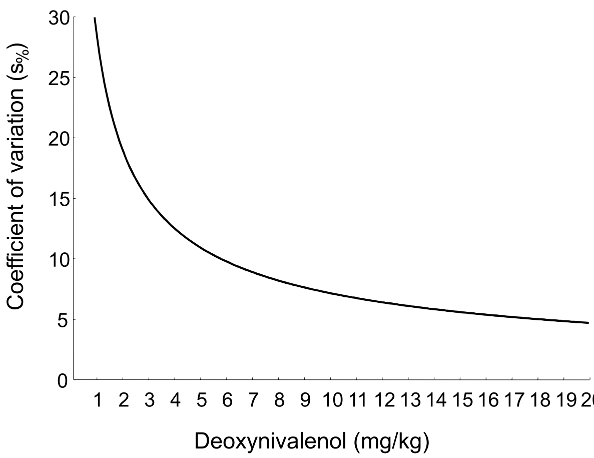


Figure 6: Effect of the deoxynivalenol concentration in wheat on the variation of the analytical result (WHITAKER et al., 2000)



3. Treatment with antibiotics or other drugs is usually unsuccessful.
4. Outbreaks are mostly seasonal and weather conditions that encourage mycotoxin production can also be associated with an increase in the incidence of mycotoxicoses.
5. Epidemiological surveys often confirm a causal link with a specific (contaminated) feed batch.
6. Heavy fungal infestation of feedingstuffs is not necessarily associated with a high mycotoxin burden or vice versa.

The unspecific loss of productivity that can occur when low mycotoxin concentrations are fed for prolonged periods and which is often not clearly identifiable as mycotoxicosis is the most significant symptom in practical feeding situations. Under controlled feeding conditions in an exact trial, where production-related stressors are often minimised, signs of toxicosis are often only observed at concentrations higher than those which are sufficient to induce typical symptoms in field surveys and case reports.

SCHUH (1981, 1983) reported clinical symptoms of fusariotoxicosis in livestock on various Austrian farms where Fusarium toxin-containing feed was used. In his surveys piglets fed mixtures with a DON concentration of as little as 0.2 mg/kg showed growth depressions. DON concentrations of 1.04 mg/kg caused vomiting and haemorrhaging of the digestive tract.

In experiments with pigs it is not possible at concentrations below 1 mg DON/kg feed to establish a clear correlation between the dietary DON concentration and changes in feed intake or weight gains relative to the control group (Fig. 7 and 8). Although this form of graphic evaluation incorporates multiple experimental conditions to an equal extent (DON source, method of DON analysis, feeding period, age of animals, breed, feeding technique), it can be seen that feed consumption declines by about 4 % relative to the control group when the dietary DON concentration is raised by 1 mg. This can only indicate a rough trend, especially at commercially relevant DON concentrations.

Figure 7: Effect of the deoxynivalenol concentration in pig fattening feed on the feed intake (control = 100 %) after evaluation of 94 trials (DÄNICKE et al., 2001a)

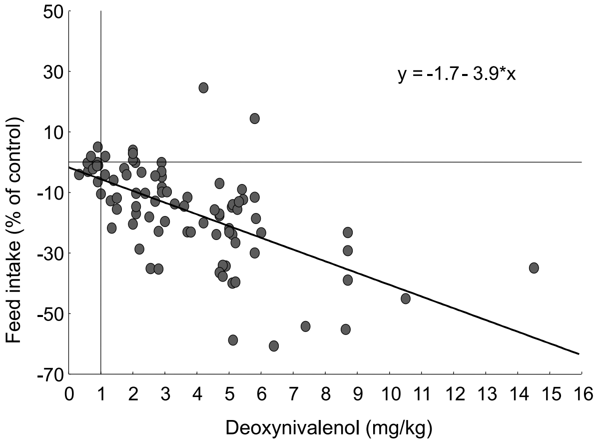
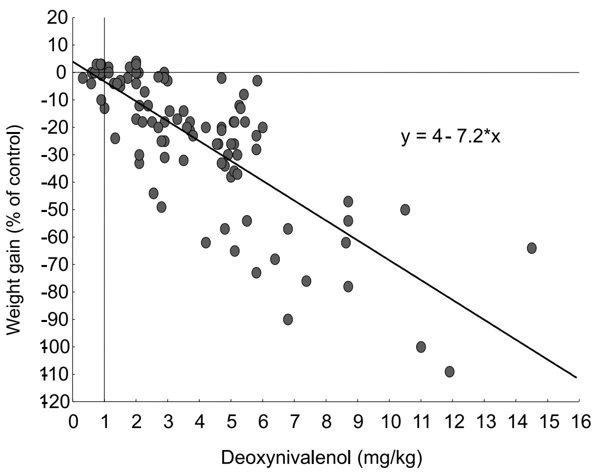


Figure 8: Effect of the deoxynivalenol concentration in pig fattening feed on weight gains (control = 100 %) after evaluation of 94 trials (DÄNICKE et al., 2001a)



Similar discrepancies between experiment and practice occur in the case of zearalenone, which makes it difficult to establish critical concentrations in feed. According to a literature study by BAUER (2000), many experiments with prepubertal gilts only tested ZON concentrations of 1 mg/kg or higher, with observed results ranging from hyperestrogenism to no observable adverse effect on reproductive performance. Practical ZON concentrations of 0.25 mg/kg or 0.05 mg/kg caused hyperestrogenism and increased formation of tertiary follicles in this age group (BAUER et al., 1987). In cyclic sows, too, adverse effects often occurred only at commercially non-relevant concentrations of more than 1 mg/kg and manifested themselves as anestrous, reduction of uterine, placental and fetal weight with a consequent increase in the number of stillbirths and fewer piglets born alive and weaned.

In ruminants the data are uncertain; few exact trials have been conducted, mostly over short periods and with few animals, so that our knowledge of the effect of DON and ZON is largely based on case studies.

Prolonged feeding of dairy concentrate with DON concentrations of 6 or 12 mg/kg to lactating Holstein cows over a 10-week period had no adverse effect on forage or concentrate intakes (CHARMLEY et al., 1993). Milk yield was not affected either. The reduction in the milk fat concentration and milk output at a DON concentration of 6 mg/kg was not attributable to the action of DON because this effect was absent at the higher DON concentration of 12 mg/kg. INGALLS (1966) observed no negative effect on feed intake or milk yield of cows at a DON concentration in the concentrate of 14.6 mg per kg (equivalent to 31 mg/100 kg liveweight) during a 3-week trial. Case reports and experiments concerning the effect of ZON in female cattle are summarised in Table 5. When evaluating these data it should be borne in mind that in some case reports no dietary ZON concentration was stated. Moreover, the aforementioned discrepancy between an exact experiment and a case study is apparent, as reflected in far lower trigger concentrations of ZON in the case study than can be reproduced in a scientific trial.

Chickens respond to increasing dietary DON concentrations with a reduction in productivity only at very high levels in the region of 5 to 10 mg/kg. There is no evidence of a clear dose-response relationship in broilers (Fig. 9). The situation is similar in laying hens.

Based on scientific data concerning the effect of DON and ZON in pigs, cattle and chickens, values for critical concentrations in feed were elaborated, discussed by various scientific bodies (Gesellschaft für Mykotoxinforschung e.V., “Carry-over” group of the BMVEL, DLG working group on mycotoxins) and finally published as reference values by the Federal Ministry for Consumer Protection, Food and Agriculture (Table 6).

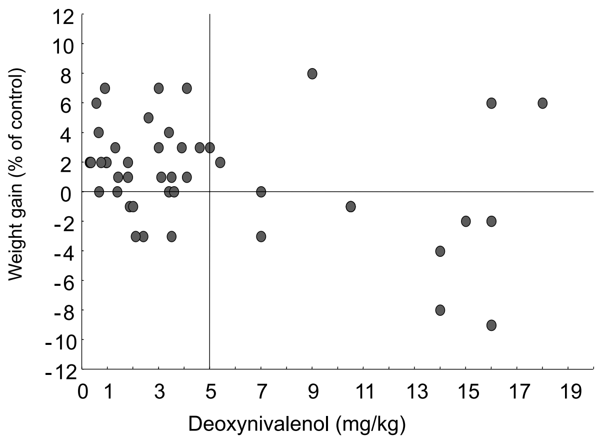
Studies on the carry-over of these toxins into milk, meat, eggs and edible tissues demonstrate that no significant residue formation occurs under practical feeding conditions. The carry-over of DON and ZON was therefore not taken into consideration when setting the reference values.

These reference values for maximum concentrations in the total ration assuming a basic dry matter content of 88 %, are intended to support the application of the minimising principle for mycotoxin concentrations in feedingstuffs and are designed to ensure that under normal production conditions neither animal performance nor animal health

Table 5: Effect of zearalenone (ZON) on the fertility of female cattle

ZON source	ZON dosage	Type of study	Effects	Source
Hay	14 mg/kg feed	Case study	Insemination index rose from 1.2 to 4 after feeding the contaminated hay and returned to normal after withdrawal of the hay	MIROCHA et al. (1968)
Concentrate	*F. graminearum* and *F. culmorum* isolated from the concentrate synthesised ZON *in vitro*	Case study	Hyperestrogenism, mucoid vaginal discharge	ROINE et al. (1971)
Maize meal	5 - 75 mg/kg feed	Case study	Swelling of the vulva, reduced milk yield, loss of appetite	VANYI (1974)
Maize meal	ZON-positive	Case study	Two of 20 heifers (8 and 12 months old) developed hyperestrogenism: swollen udder, skim milk-like secretion. Withdrawal of the contaminated feed alleviated the symptoms; no effect on subsequent fertility	BLOOMQUIST et al. (1982)
Wheat	1.25 mg/kg feed	Field surveys	Cystic degeneration of the ovaries, changes in uterine consistency	SCHUH et al. (1981, 1983)
Pure ZON	250 mg/head and day (about 50 mg/kg feed)	Experiment	The conception rate of the treated group was 62 % compared with 87 % in the control group (3 estrous cycles)	WEAVER et al. (1986a)
Pure ZON	500 mg/head and day)	Experiment	No changes in the genital tract, no change in the progesterone concentration of the blood	WEAVER et al. (1986b)
Feed	about 0.1 mg/kg feed	Case studies	Increased estrous mucus, behavioural changes	DROCHNER (1990)

Figure 9: Effect of the deoxynivalenol concentration in broiler diets on weight gain (control = 100 %) after evaluation of 49 trials (DÄNICKE et al., 2001a)



are adversely affected. When applying the reference values it is important to bear in mind that the critical concentrations can shift downwards in the presence of general health problems in the herd and/or poor management and feeding conditions. New scientific data on critical dietary concentrations can be drawn upon to further adapt or improve the accuracy of the reference values. Recent experiments indicating lower critical concentrations of ZON in sow feed (LÜCKHOF et al., 2001) for instance should be taken into account in future discussions on reference values.

Table 6: Reference values for critical concentrations of deoxynivalenol and zearalenone in diets of pigs, chickens and cattle (mg/kg, 88 % dry matter) (BMVEL, 2000)

Species or category:	Deoxynivalenol	Zearalenone
Pig		
Prepubertal female breeding pigs	1	0.05
Fattening pigs and breeding sows	1	0.25
Cattle		
Preruminant	2	0.25
Growing heifer/dairy cow	5	0.50
Beef cattle	5	-[1]
Chicken		
(Laying hens, broilers)	5	-[1]

[1] No reference values necessary according to the current state of knowledge as the usual dietary concentrations are well below the effective dose

Detoxification

Detoxification procedures for contaminated feed batches should always be used when other measures of mycotoxin management such as diet formulation or feeding to less sensitive livestock species are not feasible (cf. Fig. 1). Technical detoxification measures which can be applied prior to feeding during feed processing have been described in several review papers (e.g. MÜLLER, 1982, 1983; SCOTT, 1984; BAUER, 1994; CHARMLEY and PRELUSKY, 1994; KAN, 1994; SCOTT, 1998; DÄNICKE et al., 2000).

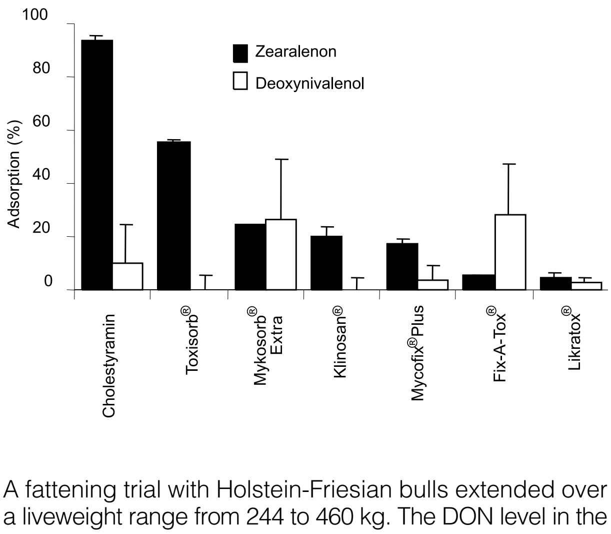
Of greater practical interest are detoxification measures that are relatively simple and can be implemented at low cost, in particular feed additives. Many of these commercially available products contain components (clay minerals, yeast cell wall constituents) which, owing to their physical and chemical properties, are claimed to adsorptively bind mycotoxins under the conditions prevailing in the digestive tract (notably moisture and pH). As a result, their absorption and hence their biological activity is prevented to a large extent. Some products contain other ingredients (yeasts with enzymes), which are designed to induce enzymatic degradation.

In-vitro studies have shown, however, that the adsorption capacity of several commercial detoxification agents for ZON was in the moderate to low range, while DON adsorption was generally very low and variable, which suggests very loose binding to the detoxification agent (Fig. 10). As a general comment on the results of in-vitro binding studies it should be noted that these only indicate a potential adsorption capacity; efficacy in vivo must be demonstrated in each case by a reduction of the biological effects of DON and ZON.

To this end the German Institute for Animal Nutrition of the Federal Research Institute for Agriculture conducted a number of experiments with a commercial detoxification product (according to the manufacturer a mixture of an adsorbent and an enzymatic component) in fattening pigs, broilers, laying hens and beef bulls. A two-factor experimental design was applied by testing both the non-contaminated control diet and the Fusarium toxin-contaminated experimental diet in the absence and in the presence of the detoxification agent.

In fattening pigs (about 30 to 110 kg liveweight) feeding the DON-contaminated diets (3.2 to 3.6 mg DON/kg feed) - irrespective of the presence or absence of the detoxifying agent - significantly impaired performance as a result of lower feed intakes of ad libitum fed pigs in a growth trial, but improved nutrient digestibility in pigs on a restrictive feeding regime in a balance experiment.

Figure 10: In vitro adsorption of deoxynivalenol and zearalenone to different detoxifying agents and to cholestyramine (DÖLL et al., 2001)



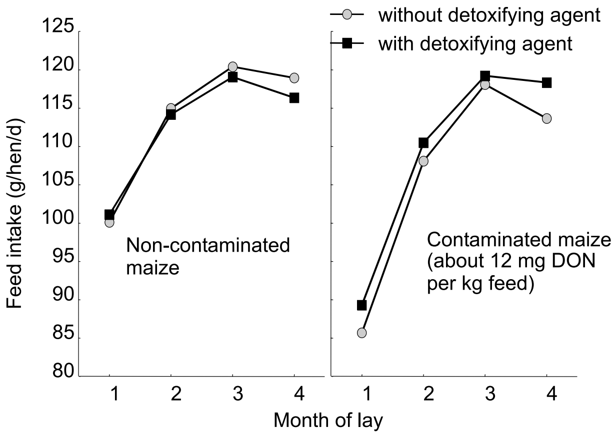
A fattening trial with Holstein-Friesian bulls extended over a liveweight range from 244 to 460 kg. The DON level in the concentrate of about 10 mg/kg had no effect on weight gain or feed consumption. Adding the detoxifying agent to the concentrate caused a marginal reduction in weight gains both in the control and the contaminated group from 1370 g/head and day to 1300 g/head and day. A metabolism trial in rams resulted in a significant, detoxifying agent-induced reduction in crude fibre digestibility and a significant increase in crude protein digestibility of both the control wheat and the mycotoxin-contaminated wheat.

In a trial with laying hens feeding diets containing about 12 mg DON per kg feed from contaminated maize caused a depression in the feed intake when compared with non-contaminated maize, which could not be offsett by the addition of the detoxifying agent (Fig. 11).

As the trial progressed, the hens fed mycotoxins managed to adjust their feed intake to the level of the control groups. The individual egg mass was increased by the addition of the detoxifying agent, both after feeding the control diet and the mycotoxin-contaminated diet (Fig. 12); the interactions between maize (non-contaminated, contaminated) and detoxifying agent (absent, present) were not significant, which suggests a mycotoxin-independent effect of the detoxifying agent.

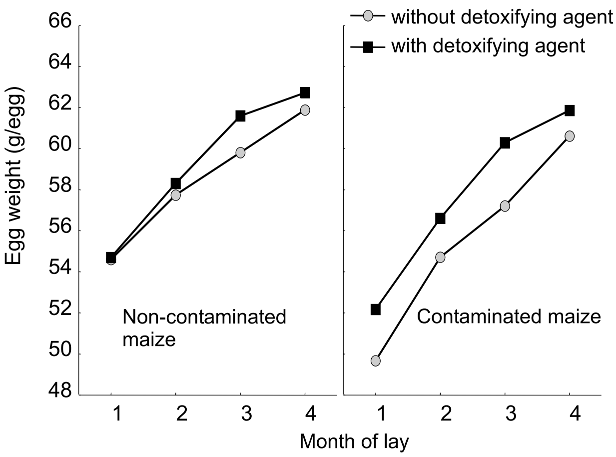
This mycotoxin-independent effect of adding the agent was also demonstrated for crude protein digestibility and the level of metabolisable energy (AME_N) in the diets. As DON inhibits protein synthesis it is assumed that cells and tissues with high protein turnover rates such as small intestinal tissue, liver and the immune system are most severely affected by DON intoxication. Review papers on the immune modulating effect of DON were published by CORRIER (1991), PESTKA et al. (1994) and ROTTER et al. (1996).

Figure 11: Effect of interactions between maize (non-contaminated, contaminated), detoxifying agent (without and with detoxifying agent) and month of lay on the feed intake of laying hens (DÄNICKE et al., 2001b)



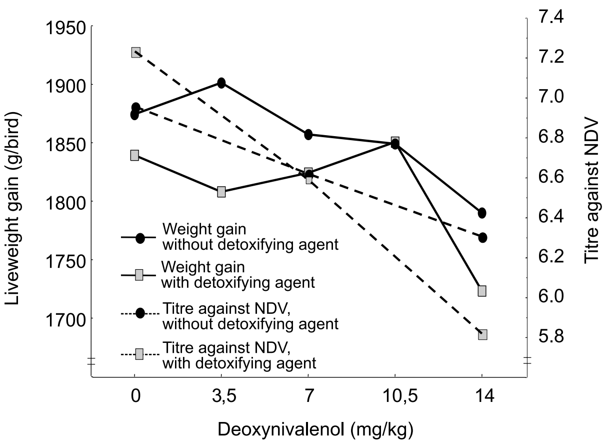
In our studies with laying hens we observed that feeding Fusarium toxin-containing diets reduced antibody titres against Newcastle Disease Virus (NDV) after previous vaccination, whereas titres against the bacterial antigen K88 in the egg yolk were significantly raised. None of these effects were affected by adding the detoxifying agent to the diet. In broilers, too, a linear reduction of titres against NDV was observed with rising dietary DON concentrations (Fig. 13), irrespective of the supplemented detoxifying agent. Weight gains declined significantly when the dietary DON concentration exceeded 10 mg/kg.

Figure 12: Effect of interactions between maize (non-contaminated, contaminated), detoxifying agent (without and with detoxifying agent) and month of lay on egg weight (DÄNICKE et al., 2001b)



The influence of trichothecenes on the immune system is of major importance inasmuch as effects can occur without having a visible influence on performance. In the presence of other adverse factors (management, feeding, general health of the flock) a latent immunosuppression caused by chronic mycotoxicosis can be implicated in the aetiology of multifactorial infections.

Figure 13: Effect of the dietary deoxynivelanol concentration and a detoxifying agent on weight gain and NDV antibody titres in broilers (DÄNICKE et al., 2001c)



In studies on the effect of adding yeast cell wall constituents to broiler diets containing various mycotoxins either alone or in combination, it was found that the supplement compensated only partially for the toxin-induced reduction in liveweight. In none of these cases was it possible to match the level of the control group. Here, too, mycotoxin-unrelated effects of the supplemented yeast cell wall constituents were observed in the control group (Fig. 14).

It has already been mentioned that the prepubertal female pig is particularly sensitive to high dietary ZON concentrations. This was also confirmed in the trial by COENEN and BOYENS (2001) (Table 7), where the addition of 0.18 mg and 0.36 mg ZON to the diet of ovariectomised piglets led to an increase in uterine weight, which was offset only partially by supplementation with zeolithe.

Figure 14: Effect of different mycotoxin combinations and glucomannan supplementation ([-] without, [+] with) on liveweight of broilers (RAJU and DEVEGOWDA, 2000)

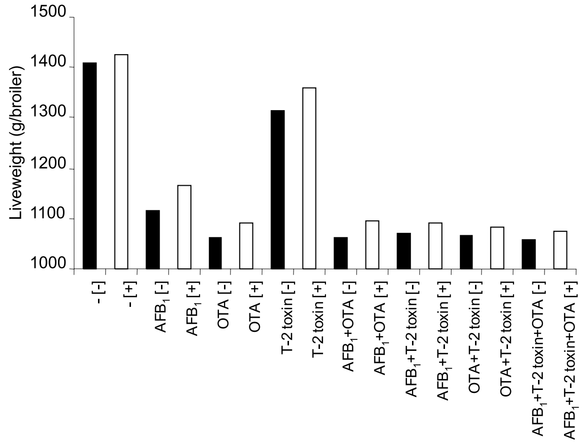


Table 7: Effect of zearalenone and zeolithe on uterine weight of piglets (ovariectomy between 5 and 7 weeks of age, 66-day feeding of the experimental diet, final liveweight about 41 kg) (COENEN and BOYENS, 2001)

Treatment	Zearalenone (µg/kg diet)	Zeolithe (g/kg diet)	Uterine weight (g/kg BW)
Non-castrated	0	0	0.55*
Castrated	0	0	0.16^{a}
Castrated	180	0	0.27^{bc}
Castrated	180	20	0.20^{ade}
Castrated	360	0	0.25^{bceg}
Castrated	360	20	0.28^{bcfg}

[a-g] Means with different superscripts in a column differ significantly (p<0.05)

* Significant relative to all other groups

Reducing the risk of Fusarium toxin production in the field

As mentioned earlier, the management of Fusarium toxins must begin in the field where the real causes of the occurrence of feed batches with elevated DON and ZON concentrations should be controlled.

OLDENBURG et al. (2000) carried out an evaluation of the geographical and agronomic factors affecting the production of Fusarium toxin, which they ranked in the order of their importance based on the current state of scientific research as follows:

Weather ⇒ infection pressure/soil management ⇒ previous maize crop ⇒ crop protection ⇒ variety ⇒ plant nutrition

Wet weather, especially during the flowering period of cereal, combined with a high infection pressure, is considered a major risk factor for a massive Fusarium infection. A particularly high infection pressure is caused by harvest residues of a previous maize crop which were worked into the soil without ploughing. As a result of this increased infection risk the risk of DON production also rises sharply (ELLNER, 2000; OBST et al., 2000). MATTHIES et al. (2000) reported a reduction of the DON concentration by 71 % after tillage with a plough.

The effect of variety is due on the one hand to differences in the duration of flowering and the morphology of the flower and on the other hand to the length of the cereal stalk since a short distance of the ear from the soil as infection source increases the risk of infection. Nutrient deficiency of the plant reduces not only the yield but can also impair the plant's natural protective mechanism against fungal infection. Overfertilisation with nitrogen and excessive plant density can both lead to increased vegetative growth which, as well as reducing resistance to lodging, also promotes plant-to-plant infection.

From the ranking order shown the following recommendations can be derived for farmers with a view to preventing or averting risks leading to increased Fusarium infestation of cultivated plants in the field and a consequent rise in Fusarium toxin levels in crops (OLDENBURG et al., 2000):

- Harvest residues, especially maize, should be ploughed into the soil and ploughless tillage avoided.
- Avoid maize/cereal crop rotations in quick succession.
- Apply suitable fungicides for prevention at the proper times if rapid maize/cereal crop rotations combined with ploughless tillage is practised.
- If available, choose varieties that are appropriate for the location and less susceptible to Fusarium infection.
- Avoid under- and overdosing of nutrients.
- Do not delay the harvest beyond the use-specific maturity date.

Transgenic Bt maize varieties provide an indirect means of reducing mycotoxin contamination of maize grains. Bt maize varieties were developed to reduce revenue losses due to infection with larvae of the European corn borer (*Ostrinia nubilalis*). In addition to the direct effect of the larvae on yields, their feeding activity destroys the integrity of the maize kernel and hence the natural protective mechanism against secondary pests like Fusaria. Bt maize varieties express a protein which kills the larvae, thereby reducing the risk of susceptibility to Fusarium infection caused by feeding damage. Studies have shown that the use of Bt maize varieties can also reduce contamination with deoxynivalenol and zearalenone (Table 8).

Conclusions

The principal measures in the management of Fusarium toxins must be the implementation of soil and crop strategies which minimise the production of these mycotoxins in the field. Reference values for maximum concentrations in the diets of farm animals should not only help to protect livestock from harm but should also support the aforementioned minimising strategies.

Detoxification agents added to the feed with a view to adsorbing Fusarium toxins in the digestive tract show variable adsorption rates for zearalenone in different in-vitro models, while adsorption of DON is minimal. In any event, such studies are not sufficient to draw inferences about their efficacy in animals. This requires experiments measuring the efficiency of these agents in reducing mycotoxin activity in animals. Studies conducted to date are inadequate for this purpose and in some cases show that detoxifying agents can have mycotoxin-unrelated effects.

Table 8: Deoxynivalenol and zearalenone concentrations in Bt and non-Bt maize grains in relation to infestation with larvae of the European corn borer (VALENTA et al., 2001)

Maize	Infestation	N	DON (µg/kg)		ZON (µg/kg)	
			Mean 1)	Median 2)	Mean 1)	Median 2)
non-Bt	infested	15	873	482^{b}	256	80^{c}
non-Bt	not infested	15	77	0^{a}	19	4^{ab}
Bt	infested	10	152	0^{a}	33	12^{bc}
Bt	not infested	15	51	0^{a}	3	1^{a}

1) Mean of all samples; samples below the detection limit were assumed to be zero

2) Samples below the detection limit were assumed to be zero

a-c Means with different superscripts in a column differ significantly ($p<0.05$)

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