



Mycotoxin occurrence in commodities, feeds and feed ingredients sourced in the Middle East and Africa

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Between February and October 2009, 324 grain, feed and feed commodity samples were sourced directly at animal farms or feed production sites in Middle East and Africa and tested for the presence of A- and B-trichothecenes, zearalenone, fumonisins, aflatoxins and ochratoxin A, or for selected groups of mycotoxins only. Samples were analyzed after clean-up by immunoaffinity or solid-phase extraction followed by HPLC with derivatization where appropriate and fluorescence, UV or mass spectrometric detection. The percentage of positive samples of B-trichothecenes ranged from 0 to 87% of tested samples. The prevalence of fumonisins in the different countries was >50% in most cases. Zearalenone was present in tested commodities from all countries except three. The presence of aflatoxin in analyzed samples varied from 0 to 94%. Ochratoxin A was present in 67% of samples in Sudan and in 100% of Nigerian samples. No A-trichothecenes were found in this survey.

Keywords: animal feed; animal feedingstuffs; mycotoxins; fumonisins; trichothecenes; aflatoxins; fusarium toxins; ochratoxin A; zearalenone

Introduction

The first review on the occurrence of mycotoxins dates back to 1977, when it was presented at the first FAO/WHO/UNEP conference on mycotoxins. At that time, the natural occurrence of aflatoxins, zearalenone, ochratoxin A, citrinin, trichothecenes, patulin, penicillic acid and the ergot alkaloids was indicated to be significant in foods and feeds. The report also acknowledged the co-contamination of grains by *Fusarium* toxins, especially deoxynivalenol and nivalenol, with zearalenone to a lesser extent (Jelinek et al. 1989). Despite improvements in terms of analytical procedures over the years, there is a lack of reports on the occurrence of mycotoxins in feedstuffs and feed. In 2007, Binder et al. (2007) reported the occurrence of mycotoxins in 30% of samples from Asian-Pacific countries and 50% in European and Mediterranean samples, and concluded that the incidence of mycotoxins relevant for animal production is quite high in animal feed.

Other reports have focussed on a single commodity, usually commodities for human consumption, on a single mycotoxin or country, or even on fungal contamination rather than mycotoxins, which does not facilitate a global approach to the subject of mycotoxins in animal feeds. Tangendjaja et al. (2008)

reported aflatoxin levels in Indonesian local corn samples seven times higher than those imported from the USA and Argentina. Upon analyzes of 169 dairy feedstuffs samples from the Netherlands, deoxynivalenol and zearalenone were reported to be the most common mycotoxins in silage, compound feed and feed commodities (Driehuis 2008).

Even if mycotoxin occurrence reports are scarce, the increased understanding and awareness on mycotoxins and their effects on animal and human health has motivated the establishment of limits and regulations for mycotoxins in feed. In the case of the EU, a Directive has set up a maximum content of aflatoxin B1 in feed materials and complete feeding stuffs (Commission Directive 2002). For other mycotoxins, Commission Recommendation of 17 August 2006 sets up recommendation levels for the presence of deoxynivalenol, zearalenone, ochratoxin A, T-2 and HT-2 and fumonisins in products intended for animal feeding (Commission Recommendation 2006). In the case of other countries, regulations are known to focus on the presence of aflatoxin B1 (FAO/WHO 2004).

In regards to the carry-over of these compounds into animal products intended for human consumption, concerns exist in terms of aflatoxins, as it is known that aflatoxin B1 is carried over into the milk as

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aflatoxin M1 at a rate between 1 and 6% (Veldman et al. 1992). To limit human consumption of aflatoxin through milk, specific levels for aflatoxin B1 in feed for dairy animals have been established (FAO/WHO 2004). In terms of ochratoxin A, reports are available on the presence of this mycotoxin in animal-derived products (Gareis and Scheuer 2000). However, exposure assessment indicates that food of animal origin makes only a minor contribution to human dietary exposure to this toxin (EFSA, 2004). Although residual levels of fumonisins, deoxynivalenol and zearalenone may exist in products of animal origin, the European Food Safety Authority (EFSA) has reported that the carry-over of these mycotoxins into animal products does not appear to pose a major threat in terms of public health (EFSA, 2004a,b,c; 2005). Nonetheless, the impacts of these toxic secondary metabolites on animal health have been extensively studied. Aflatoxins are classified as carcinogenic by the International Agency for Research on Cancer (IARC 1993) and within that group, aflatoxin B1 is the strongest naturally occurring carcinogen known (Pestka 2007). Besides having significant negative impacts in terms of performance in poultry, swine and ruminants (Guthrie and Bedell 1979; Diekman and Green 1992; Leeson et al. 1995), important immunosuppressive effects, such as decreased resistance to environmental and microbial stressors and increased susceptibility to diseases, have been described for this group of mycotoxins (Sharma 1991; Diekman and Green 1992; Gareis 1994).

Trichothecenes are known to bind to ribosomes, interrupting protein and DNA synthesis (CAST 2003; Pestka 2007), and cause immunosuppressive effects and decreased performance in farm animals. Gastrointestinal problems such as vomiting and diarrhea have been described, especially with deoxynivalenol in feeds (Pestka 2007). Zearalenone's structural resemblance to oestradiol provides it with strong estrogenic activity (Savard 2007). As in the case of deoxynivalenol, swine seems to be the most sensitive species to zearalenone (CAST 2003); however, reproductive problems have also been recorded in poultry (CAST 2003) and ruminants (Whitlow and Hagler 2005). Ochratoxin has been associated with kidney lesions and damage, anorexia, weight loss and immunosuppression by the inhibition of B and T lymphocytes (Yiannikouris and Jouany 2002). Fumonisin B1, the most recently found mycotoxin, has been associated with several diseases, in particular leukoencephalomalacia in horses and pulmonary oedema in swine. Its structural resemblance to the sphingoid bases explains the blockage of the biosynthesis of shingolipid complexes, leading to cell dysfunction followed by cell death (Yiannikouris and Jouany 2002). Discussion on predisposing factors for mycotoxin accumulation in commodities and strategies for prevention, decontamination and minimization of

mycotoxin toxicity in feeds have been reviewed in several scientific reports (Wicklow 1994; Miller 2001; Schatzmayr et al. 2006; Jouany 2007) and therefore will not be discussed in this paper. This paper aims to contribute to our general knowledge regarding mycotoxin occurrence in various commodities, feeds, feed ingredients from different countries in the Middle East and Africa.

Materials and methods

Analytical samples

A total of 324 grain, feed and other feed commodity samples were sourced directly at animal farms or animal feed production sites in the Middle East and Africa between February and October 2009. Samples were sourced from Algeria, Egypt, Ghana, Israel, Jordan, Kenya, Lebanon, Nigeria, South Africa, Sudan, Syria, United Arab Emirates (UAE) and Yemen. Sample providers were advised to follow principles of good sampling (Richard, 2000); however, analytical personnel and/or laboratory staff were not involved and, therefore, did not influence any part of this procedure. Samples of approximately 1 kg were received by the laboratory technicians for analysis. Generally, a representative sample should involve the collection of several small randomly selected samples from the whole lot to form what is known as a "lot sample". After grinding the lot sample, a subsample is taken for the actual analytical process. A choice is then made regarding the mycotoxins to be analysed for either (1) a "full toxin screen", which covered A-trichothecenes (diacetoxyscirpenol, DAS), HT-2 toxin (HT-2) and T-2 toxin (T-2) and B-trichothecenes (nivalenol, Niv), deoxynivalenol, DON) and acetyl-deoxynivalenol (Ac-DON)), zearalenone (ZON), fumonisins (sum of fumonisin B1 and fumonisin B2), aflatoxins (sum of aflatoxin B1, B2, G1 and G2), and ochratoxin A (OTA), or (2) analyses of selected mycotoxins. This is why, in the results below the number of analysed mycotoxins sometimes differs depending on the specific mycotoxin. The origin (name and location of submitter) of the samples was kept strictly confidentially; analytical certificates were submitted only to the originators of samples.

This paper summarizes the occurrence of mycotoxins with regard to provenance and commodity type. Surveyed samples were grouped in categories, namely maize, wheat/wheat bran, finished feed, soybean/soybean meal and other feedstuffs. The latter refers to different commodities for which the number of samples was insufficient to display in a separate group, specifically grass and alfalfa silage, cotton seed, sunflower meal, gluten, sorghum, barley, fish meal and ground nut.

Results are given as the sum of the major toxins of the relevant mycotoxin groups (Tables 8 and 9), or as analytical findings of single toxins (Tables 10 and 11).

Reagents

Organic solvents, HPLC-grade water, and salts and other chemicals were purchased from Merck AG (Darmstadt, Germany). Mycotoxin standards were purchased from Biopure® Referenzsubstanzen GmbH (Tulln, Austria).

Sample preparation and clean-up procedures

Samples were ground and subsampled using a Romer® Series II mill (Romer Labs. Inc., Union, MO, USA). A 25-g aliquot of each sample was extracted with 100 ml of acetonitrile/water (84:16, v/v) for the trichothecenes and zearalenone (acetonitrile/water (60:40, v/v) for aflatoxin and ochratoxins) determination using an Osterizer blender (USA) in 250-ml blender jars (3 min). For analysis of fumonisins, extraction was done with acetonitrile/methanol/water (25:25:50, v/v) on a rotary shaker for 90 min.

Extracts were filtered through a folded filter (#595 1/2, Schleicher & Schüll, Dassel, Germany). Clean-up for analysis of trichothecenes and ochratoxin was performed according to Binder et al. (2007), using Mycosep® columns for trichothecenes and immunoaffinity columns for ochratoxin (Romer). For the purification of fumonisins, zearalenone and aflatoxins extracts, immunoaffinity columns FumoniStar, ZearaStar and AflaStar (Romer) were used, respectively, according to the manufacturer's specifications. In brief, extracts were diluted with PBS buffer (pH 7.0) and passed through the respective immunoaffinity column at a flow rate of approximately 1 ml min⁻¹. After washing with PBS or water, mycotoxins were eluted with methanol, evaporated to dryness and re-dissolved in the HPLC mobile phase.

High performance liquid chromatography (HPLC)

HPLC analyses were performed according to Binder et al. (2007) using an HPLC series 1100 from Agilent® Technologies (Waldbronn, Germany), comprising a micro-vacuum degasser, a binary capillary pump, micro-autosampler, column oven and an API-ES interface in the case of T-2 toxin and fumonisin analysis, a variable wavelength detector for DON, and a fluorescence detector for zearalenone, derivatized fumonisins, aflatoxins and ochratoxin A determination.

The limits of quantification (LOQ) and detection (LOD) of the applied methods are given in Table 1. Determination of type B-trichothecenes (DON, NIV

Table 1. Limits of quantification (LOQ) and detection (LOD) of the applied methods.

Mycotoxins	Limit of quantification (µg kg ⁻¹)	Limit of detection (µg kg ⁻¹)
B-trichothecenes (Niv, DON, Ac-DON)	150 (50)	
T-2 toxin	80 (25)	
HT-2 toxin	140 (50)	
DAS	125 (40)	
Fumonisin B1, B2, B3	80 (25)	
Ochratoxin A	0.5 (0.2)	
Aflatoxin B1	0.8 (0.3)	
Aflatoxin B2, G1, G2	0.7 (0.1)	
Zearalenone	25 (10)	

Table 2. Determination of type B-trichothecenes (DON, NIV and AcDON) by HPLC-UV after MycoSep clean-up (Recoveries are included in the results. LOD: 50 µg kg⁻¹).

Recovery	Maize	Wheat flour	Chicken feed	Pig feed	Silage
Deoxynivalenol	72%	88%	95%	79%	98%
Ac-Deoxynivalenol	73%	87%	88%	95%	85%
Nivalenol	54%	60%	43%	43%	53%

Table 3. Determination of zearalenone (ZON) by HPLC-FLD after immunoaffinity clean-up (Recoveries are included in the results. LOD: 10 µg kg⁻¹).

Recovery	Maize	Wheat	Feedstuff
Zearalenone	61%	62%	72%

and AcDON), zearalenone (ZON), aflatoxins (B1, B2, G1, G2), ochratoxin A, type A-trichothecenes (T-2 toxin, HT-2 toxin and diacetoxyscirpenol) and the fumonisins (B1,B2) is given in Table 2–7, respectively.

Analytical quality assurance

Analyses were performed at Romer® Labs Diagnostic GmbH (Tulln, Austria), which is accredited according to ISO 17025. Performance criteria of analytical methods were defined as required by Commission Regulation (EC) No 401/2006 of 23 February 2006, with the “fitness-for-purpose” approach applied for calculation of measurement uncertainty. Quality control of routine analytical processes was performed using Biopure matrix reference materials obtained

Table 4. Determination of aflatoxins (B1, B2, G1, G2) by HPLC–FLD detection after Immunoaffinity clean-up (Recoveries are included in the results. LODs for aflatoxin B1: 0.3 $\mu\text{g kg}^{-1}$; aflatoxin B2, G1, G2: 0.1 $\mu\text{g kg}^{-1}$).

Recovery	Maize	Wheat	Chicken feed	Pig feed	Silage	DDGS
Aflatoxin B1	93,0%	82%	102,0%	100%	99%	98%
Aflatoxin B2	97,0%	87%	100,0%	98%	94%	93%
Aflatoxin G1	96,0%	106%	102,0%	99%	99%	97%
Aflatoxin G2	99,0%	106%	100,0%	99%	99%	97%

Table 5. Determination of ochratoxin A by HPLC–FLD after immunoaffinity clean-up (Recoveries are included in the results. LOD: 0.2 $\mu\text{g kg}^{-1}$).

Recovery	Maize	Wheat	Barley	Feed	Silage
Ochratoxin A	76%	75%	92%	83%	69%

Table 6. Determination of type A-trichothecenes (T-2 toxin, HT-2 toxin and diacetoxyscirpenol) by LC–MS after MycoSep clean-up (Recoveries are included in the results. LODs for T2-Toxin: 25 $\mu\text{g kg}^{-1}$; HT2-toxin: 50 $\mu\text{g kg}^{-1}$; DAS: 40 $\mu\text{g kg}^{-1}$).

Recovery	Maize	Wheat	Barley	Feed	Silage
Diacetoxyscirpenol	89,7%	98,8%	94,4%	91%	82%
HT-2	116,4%	114,6%	111,9%	102%	102%
T-2 Toxin	94,8%	94,9%	95,3%	98%	96%

Table 7. Determination of fumonisins (B1,B2) by LC–MS after immunoaffinity clean-up (Recoveries are included in the results. LOD: 25 $\mu\text{g kg}^{-1}$).

Recovery	Maize	Wheat	Mixed feed
Fumonisin B1	50,9%	41,2%	50,3%
Fumonisin B2	50,9%	48,0%	55,1%

from Romer Austria. Homogenised grain was analysed on five different days, four times each day, resulting in a control chart ($n=20$), which was plotted using a CCPro Plus computer program (ChemSW, Fairfield, CA, USA). Control samples were analysed with each series of routine samples, results plotted in the software and tested for alignment. General laboratory performance was verified by annual participation in the FAPAS[®] proficiency testing program as provided for each mycotoxin (group) by the FAPAS[®] assessment scheme.

Results

Mycotoxin occurrence in Middle East and African countries with regard to provenance

Table 8 presents mycotoxin contamination levels detected in samples sourced in the Middle East and Africa. Data is separated and analyzed by country and by mycotoxin group.

Samples from Algeria accounted for 4.3% of the samples in this survey. FUM were the only group of mycotoxins found, with 64% of the samples testing positive for this mycotoxin at a mean level of 977 ng g^{-1} ; the highest mean level found within the surveyed countries.

A total of 4.9% of the samples were sourced in Egypt. The most prevalent mycotoxins were FUM and B-trichothecenes, with 81 and 38% of the samples testing positive for these mycotoxins at mean values of 266 and 643 ng g^{-1} , respectively. The mean level of B-trichothecenes from this area was the third highest in Middle East and Africa. Samples sourced in Ghana account for 5.6% of survey samples, and 89% were positive for FUM, 72% for Afla and 50% for B-trichothecenes. Only 11% of the samples showed ZON contamination; however, the mean contamination was the highest within all surveyed regions (178 ng g^{-1}). Mean B-trichothecenes levels were the second highest for the whole survey (955 ng g^{-1}).

A high number of samples came from Israel, accounting for 13.3% of the survey. The most prevalent mycotoxin was FUM, with 63% positive samples at a mean value of 414 ng g^{-1} . A total of 28% of the samples tested positive for B-trichothecenes, with a mean value of 131 ng g^{-1} . ZON was found at mean levels of 25 ng g^{-1} in 19% of the samples.

The most prevalent mycotoxins in samples sourced in Jordan were FUM, B-trichothecenes and Afla, with 85, 50 and 45% of samples testing positive for these mycotoxins. A total of 6.2% of all survey samples came from this country.

Unlike other Middle East and African countries, Afla was the major contaminant in Kenyan samples, with 78% testing positive for this group of mycotoxins. FUM were present in 76% of tested samples and ZON in 56%. Mean levels for FUM (956 ng g^{-1}) were the second highest in the survey. Likewise, mean values for Afla (52 ng g^{-1}) were the second highest within the all surveyed samples.

Samples from Lebanon were the least representative of the survey, accounting for 2.2% of total surveyed samples; therefore, conclusions are difficult to draw. Nevertheless, 86% of them were positive for FUM contamination, even though at a low mean value (183 ng g^{-1}).

Nigerian samples represented 15.4% of the whole survey. Afla is a major contaminant in the country, with 94% of the samples testing positive for this group

Table 8. Mycotoxin contamination levels detected in samples from the surveyed Middle East and African countries (results by country and toxin group).

	B-Trichothecenes	A-Trichothecenes	Fumonisin	Zearalenone	Aflatoxins	Ochratoxin A
Algeria						
Total samples ^a	14	14	14	14	14	n.a.
Number of positive	0	0	9	0	0	–
% of positive	0	0	64	0	0	–
Mean (ng g ⁻¹) ^b	–	–	977	–	–	–
Median of positive (ng g ⁻¹) ^c	–	–	1376	–	–	–
Maximum level (ng g ⁻¹) ^d	–	–	2948	–	–	–
Egypt						
Total samples ^a	16	16	16	16	16	n.a.
Number of positive	6	0	13	3	3	–
% of positive	38	0	81	19	19	–
Mean (ng g ⁻¹) ^b	643	–	266	9	1	–
Median of positive (ng g ⁻¹) ^c	512	–	404	40	2	–
Maximum level (ng g ⁻¹) ^d	1493	–	1338	76	6	–
Ghana						
Total samples ^a	18	18	18	18	18	n.a.
Number of positive	9	0	16	2	13	–
% of positive	50	0	89	11	72	–
Mean (ng g ⁻¹) ^b	955	–	500	178	26	–
Median of positive (ng g ⁻¹) ^c	989	–	414	178	8	–
Maximum level (ng g ⁻¹) ^d	1550	–	929	310	199	–
Israel						
Total samples ^a	43	43	43	43	43	n.a.
Number of positive	12	0	27	8	3	–
% of positive	28	0	63	19	7	–
Mean (ng g ⁻¹) ^b	131	–	414	25	1	–
Median of positive (ng g ⁻¹) ^c	249	–	404	77	3	–
Maximum level (ng g ⁻¹) ^d	1232	–	3226	392	18	–
Jordan						
Total samples ^a	20	20	20	20	20	n.a.
Number of positive	10	0	17	1	9	–
% of positive	50	0	85	5	45	–
Mean (ng g ⁻¹) ^b	257	–	450	57	4	–
Median of positive (ng g ⁻¹) ^c	229	–	532	57	1	–
Maximum level (ng g ⁻¹) ^d	374	–	1627	57	17	–
Kenya						
Total samples ^a	25	25	25	25	27	2
Number of positive	12	0	19	14	21	1
% of positive	48	0	76	56	78	50
Mean (ng g ⁻¹) ^b	422	–	956	67	52	2
Median of positive (ng g ⁻¹) ^c	420	–	670	61	24	2
Maximum level (ng g ⁻¹) ^d	3859	–	10485	167	556	2
Lebanon						
Total samples ^a	7	7	7	7	7	n.a.
Number of positive	1	0	6	2	0	–
% of positive	14	0	86	29	0	–
Mean (ng g ⁻¹) ^b	165	–	183	19	–	–
Median of positive (ng g ⁻¹) ^c	165	–	179	68	–	–
Maximum level (ng g ⁻¹) ^d	165	–	281	107	–	–
Nigeria						
Total samples ^a	45	45	45	45	50	5
Number of positive	26	0	35	23	47	5
% of positive	58	0	78	51	94	100
Mean (ng g ⁻¹) ^b	316	–	919	46	115	12
Median of positive (ng g ⁻¹) ^c	330,5	–	1918	41	80,3	12
Maximum level (ng g ⁻¹) ^d	463	–	2860	80	435,9	12
South Africa						
Total samples ^a	77	77	77	77	77	n.a.

(continued)

Table 8. Continued.

	B-Trichothecenes	A-Trichothecenes	Fumonisin	Zearalenone	Aflatoxins	Ochratoxin A
Number of positive	67	0	44	22	5	–
% of positive	87	0	57	29	6	–
Mean (ng g ⁻¹) ^b	1469	–	454	86	0,2	–
Median of positive (ng g ⁻¹) ^c	600	–	600	88	2	–
Maximum level (ng g ⁻¹) ^d	11022	–	4398	195	7	–
Sudan						
Total samples ^a	9	9	9	9	13	6
Number of positive	3	0	1	0	7	4
% of positive	33	0	11	0	54	67
Mean (ng g ⁻¹) ^b	100	–	23	–	90	15
Median of positive (ng g ⁻¹) ^c	294	–	208	–	75	19
Maximum level (ng g ⁻¹) ^d	353	–	208	–	388	31
Syria						
Total samples ^a	11	11	11	11	11	n.a.
Number of positive	8	0	5	3	2	–
% of positive	73	0	45	27	18	–
Mean (ng g ⁻¹) ^b	167	0	545	11	1	–
Median of positive (ng g ⁻¹) ^c	243	0	1052	32	5	–
Maximum level (ng g ⁻¹) ^d	293	0	2035	68	8	–
UAE						
Total samples ^a	19	19	19	19	19	n.a.
Number of positive	9	0	2	3	3	–
% of positive	47	0	11	16	16	–
Mean (ng g ⁻¹) ^b	450	–	209	68	4	–
Median of positive (ng g ⁻¹) ^c	465	–	203	51	5	–
Maximum level (ng g ⁻¹) ^d	1000	–	324	108	6	–
Yemen						
Total samples ^a	9	9	9	7	9	n.a.
Number of positive	7	0	2	0	1	–
% of positive	78	0	22	0	11	–
Mean (ng g ⁻¹) ^b	246	–	233	–	2	–
Median of positive (ng g ⁻¹) ^c	267	–	199	–	2	–
Maximum level (ng g ⁻¹) ^d	323	–	340	–	2	–

Notes: n.a. – not analysed.

^aTotal number of analysed samples (ng g⁻¹).

^bArithmetic mean of all analysed samples (ng g⁻¹).

^cMedian of all positive samples (ng g⁻¹).

^dMaximum contamination level found (ng g⁻¹).

of mycotoxins at a mean value of 115 ng g⁻¹, the highest for the whole region. FUM were found in 78% of the surveyed samples, with mean levels of 919 ng g⁻¹, the third highest for the whole survey.

The highest proportion of samples (23.8%) was sourced in South Africa. B-Trichothecenes were the main contaminant, with 87% of samples testing positive at a mean contamination level of 1469 ng g⁻¹, the highest in the whole survey for this group of mycotoxins. FUM and ZON were detected in 57 and 29% of the tested samples, with mean values of 454 and 86 ng g⁻¹, respectively; the latter being the second highest mean ZON value found within the whole survey.

Although accounting only for 4% of the surveyed samples, Sudanese samples showed a high prevalence of Afla, with 54% testing positive for this group of mycotoxins. Mean values for this mycotoxin (90 ng g⁻¹) were the second greatest in the whole

survey. OTA was the main contaminant of samples from this country, present in 67%, with mean values of 15 ng g⁻¹. Nonetheless, OTA and Afla were not the only mycotoxins found in Sudan as 33% of the samples tested positive for B-trichothecenes.

A total of 3.4% of all samples were sourced in Syria. B-Trichothecenes were the main contaminant, followed by FUM and ZON, with 73, 45 and 27% positive, respectively.

In UAE samples (5.9% of total samples), a prevalence of B-trichothecenes was observed, with 47% of samples testing positive at mean values of 450 ng g⁻¹. ZON and Afla contaminated 11 and 16% of the samples, respectively. Mean values of ZON (68 ng g⁻¹) were the third highest within the whole survey.

Finally, samples from Yemen accounted for only 2.8% of the survey. A high prevalence of B-trichothecenes (78%) was found.

Table 9. Mycotoxin levels in samples from the surveyed Middle East and African countries (results by commodity and toxin group).

	B-Trichothecenes	A-Trichothecenes	Fumonisin	Zearalenone	Aflatoxins	Ochratoxin A
Maize						
Total samples ^a	63	63	63	63	63	1
Number of positive	24	0	53	10	22	0
% of positive	38	0	84	16	35	0
Mean (ng g ⁻¹) ^b	239	0	987	17	28	–
Median of positive (ng g ⁻¹) ^c	277	0	1116	82	32	–
Maximum level (ng g ⁻¹) ^d	3035	0	4398	310	343	–
Wheat/wheat bran						
Total samples ^a	32	32	32	32	32	1
Number of positive	17	0	3	8	6	0
% of positive	53	0	9	25	19	0
Mean (ng g ⁻¹) ^b	563	0	29	31	1	–
Median of positive (ng g ⁻¹) ^c	380	0	318	48	2	–
Maximum level (ng g ⁻¹) ^d	11022	0	404	392	7	–
Finished feed						
Total samples ^a	119	119	119	119	119	n.a.
Number of positive	74	0	99	33	50	–
% of positive	62	0	83	28	42	–
Mean (ng g ⁻¹) ^b	304	0	713	14	24	–
Median of positive (ng g ⁻¹) ^c	413	0	1009	40	47	–
Maximum level (ng g ⁻¹) ^d	2786	0	2588	135	213	–
Soybean/soybean meal						
Total samples ^a	33	43	33	33	33	n.a.
Number of positive	11	0	4	0	8	–
% of positive	33	0	12	0	24	–
Mean (ng g ⁻¹) ^b	93	0	71	0	4	–
Median of positive (ng g ⁻¹) ^c	210	0	103	0	9	–
Maximum level (ng g ⁻¹) ^d	547	0	2035	0	42	–
Other feedstuffs						
Total samples ^a	65	65	65	65	76	11
Number of positive	43	0	32	29	59	10
% of positive	66	0	49	45	38	91
Mean (ng g ⁻¹) ^b	1441	0	528	32	57	14
Median of positive (ng g ⁻¹) ^c	934	0	973	62	128	12
Maximum level (ng g ⁻¹) ^d	8795	0	10485	195	556	31

Notes: n.a. – not analysed.

^aTotal number of analysed samples (ng g⁻¹).

^bArithmetic mean of all analysed samples (ng g⁻¹).

^cMedian of all positive samples (ng g⁻¹).

^dMaximum contamination level found (ng g⁻¹).

As general remarks, FUM seem to be a ubiquitous contaminant as it was found in all surveyed countries. In countries where there was a high prevalence of Afla, such as Nigeria, Sudan and Kenya, OTA also seemed to be present, a fact that is not surprising since both mycotoxins are produced by *Aspergillus* spp. fungi.

Mycotoxin occurrence in Middle East and African countries according to commodity types

Table 9 gives an overview of the contamination of the commodities tested, showing the number of samples, the number and percentage of positives, the mean and median of positives and the maximum concentrations per commodity. A total of 63 maize samples were

analyzed for all mycotoxins, except for OTA, for which only one sample was analyzed. Maize samples accounted for 19% of all analyzed samples in the survey. The most prevalent mycotoxin was FUM, present in 84% of tested samples, with mean and median of positives values of 987 and 1116 ng g⁻¹, respectively. The maximum contamination level found for this mycotoxin was present in a sample sourced in South Africa (4398 ng g⁻¹). In a similar way, the highest level found for B-trichothecenes was present in a maize sample from the same country (3035 ng g⁻¹). A maize sample from Ghana presented the highest ZON contamination (310 ng g⁻¹). For Afla contamination in this commodity, the highest level was found in a sample sourced in Nigeria (343 ng g⁻¹).

Table 10. Mycotoxin levels in samples from the surveyed Middle East and African countries (results by country and individual mycotoxin).

	DON	NIV	AcDON	FB1	FB2
Algeria					
Total samples ^a	14	14	14	14	14
Number of positive	0	0	0	9	9
% of positive	0	0	0	64	64
Mean (ng g ⁻¹) ^b	–	–	–	720	257
Median of positive (ng g ⁻¹) ^c	–	–	–	967	386
Maximum level (ng g ⁻¹) ^d	–	–	–	2413	675
Egypt					
Total samples ^a	16	16	16	16	16
Number of positive	6	1	3	13	10
% of positive	38	6	19	81	63
Mean (ng g ⁻¹) ^b	208	28	890	238	144
Median of positive (ng g ⁻¹) ^c	331	440	1015	221	196
Maximum level (ng g ⁻¹) ^d	1493	440	1293	1338	559
Ghana					
Total samples ^a	18	18	18	18	18
Number of positive	9	0	0	16	15
% of positive	50	0	0	16	15
Mean (ng g ⁻¹) ^b	478	–	–	562	290
Median of positive (ng g ⁻¹) ^c	989	–	–	638	352
Maximum level (ng g ⁻¹) ^d	1534	–	–	929	442
Israel					
Total samples ^a	43	43	43	43	43
Number of positive	11	0	1	23	5
% of positive	26	0	2	53	12
Mean (ng g ⁻¹) ^b	126	–	4	237	46
Median of positive (ng g ⁻¹) ^c	262	–	183	311	287
Maximum level (ng g ⁻¹) ^d	1232	–	183	1639	622
Jordan					
Total samples ^a	20	20	20	20	20
Number of positive	10	1	1	17	14
% of positive	50	5	5	85	70
Mean (ng g ⁻¹) ^b	124	8	22	444	254
Median of positive (ng g ⁻¹) ^c	229	164	442	320	292
Maximum level (ng g ⁻¹) ^d	374	164	442	1627	881
Kenya					
Total samples ^a	25	25	25	25	25
Number of positive	12	1	4	19	14
% of positive	48	4	16	76	56
Mean (ng g ⁻¹) ^b	326	29	67	695	261
Median of positive (ng g ⁻¹) ^c	420	729	371	614	333
Maximum level (ng g ⁻¹) ^d	3490	729	731	7310	3175
Lebanon					
Total samples ^a	7	7	7	7	7
Number of positive	1	0	0	6	0
% of positive	14	0	0	86	0
Mean (ng g ⁻¹) ^b	24	–	–	157	–
Median of positive (ng g ⁻¹) ^c	165	–	–	179	–
Maximum level (ng g ⁻¹) ^d	165	–	–	281	–
Nigeria					
Total samples ^a	45	45	45	45	45
Number of positive	25	1	2	40	40
% of positive	56	2	4	89	89
Mean (ng g ⁻¹) ^b	181	4	9	1092	338
Median of positive (ng g ⁻¹) ^c	329	186	195	1446	453
Maximum level (ng g ⁻¹) ^d	451	186	239	2860	855
South Africa					
Total samples ^a	77	77	77	77	77
Number of positive	63	1	38	44	40
% of positive	82	1	49	57	52

(continued)

Table 10. Continued.

	DON	NIV	AcDON	FB1	FB2
Mean (ng g ⁻¹) ^b	943	20	578	323	143
Median of positive (ng g ⁻¹) ^c	444	1498	613	377	217
Maximum level (ng g ⁻¹) ^d	11022	1498	5435	3449	949
Sudan					
Total samples ^a	9	9	9	9	9
Number of positive	3	0	0	1	0
% of positive	33	0	0	11	0
Mean (ng g ⁻¹) ^b	100	–	–	23	–
Median of positive (ng g ⁻¹) ^c	294	–	–	208	–
Maximum level (ng g ⁻¹) ^d	353	–	–	208	–
Syria					
Total samples ^a	11	11	11	11	11
Number of positive	6	0	0	4	4
% of positive	55	0	0	36	36
Mean (ng g ⁻¹) ^b	122	–	–	242	118
Median of positive (ng g ⁻¹) ^c	243	–	–	672	316
Maximum level (ng g ⁻¹) ^d	267	–	–	815	402
UAE					
Total samples ^a	19	19	19	19	19
Number of positive	8	0	4	2	2
% of positive	42	0	21	11	11
Mean (ng g ⁻¹) ^b	163	–	0127	29	15
Median of positive (ng g ⁻¹) ^c	318	–	613	275	143
Maximum level (ng g ⁻¹) ^d	1000	–	642	324	180
Yemen					
Total samples ^a	9	9	9	9	9
Number of positive	7	0	0	2	1
% of positive	78	0	0	22	11
Mean (ng g ⁻¹) ^b	191	–	–	56	22
Median of positive (ng g ⁻¹) ^c	267	–	–	251	199
Maximum level (ng g ⁻¹) ^d	323	–	–	340	199

Notes: n.a. – not analysed.

^aTotal number of analysed samples (ng g⁻¹).

^bArithmetic mean of all analysed samples (ng g⁻¹).

^cMedian of all positive samples (ng g⁻¹).

^dMaximum contamination level found (ng g⁻¹).

For wheat/wheat bran, the most prevalent mycotoxin in these commodities was B-trichothecenes, found in 53% of the 32 samples analyzed (10% of survey samples). The mean level found in the analyzed samples was 564 ng g⁻¹ and the median of positive 380 ng g⁻¹. A wheat sample from South Africa presented the highest contamination level for both B-trichothecenes (11022 ng g⁻¹) and Afla (7 ng g⁻¹). This level of deoxynivalenol is above the European Commission guidance value of 8000 ng g⁻¹ established for cereals and cereal by-products used as feed materials. Finished feed samples accounted for 37% of analysed samples, making this the most representative group. FUM were the most prevalent mycotoxins, present in 83% of samples at mean values of 713 ng g⁻¹. The highest contamination level found for this mycotoxin was 2588 ng g⁻¹ in a broiler feed sample sourced in Nigeria. B-Trichothecenes were the second most prevalent mycotoxin, present in 62% of tested samples. The highest levels found for B-trichothecenes,

ZON and Afla were 2786, 135 and 213 ng g⁻¹, respectively, in a broiler feed sample from Egypt, a horse feed sample from South Africa and a layer feed sample from Ghana. Soybean and soybean samples represented 10% of all analyzed samples. In relation to other commodities, soybean and soybean meal samples presented lower incidence and lower contamination levels. Nevertheless, 33% of analyzed samples tested positive for B-trichothecenes, with a median of positive of 210 ng g⁻¹. The sample presenting the highest contamination for this group of mycotoxins was sourced in the UAE (547 ng g⁻¹). Other mycotoxins found in this commodity were aflatoxins (24% of tested samples with mean contamination level of 4 ng g⁻¹) and fumonisins (12% of tested samples with mean contamination of 71 ng g⁻¹). A total of 23% of all samples tested in this survey were allocated to a separate group named “Other Feedstuffs”. Due to the different nature of these samples, it is not possible to present a trend for this group but some facts can be

Table 11. Mycotoxin levels in samples from the surveyed Middle East and African countries (results by country and individual mycotoxin).

	AFB1	AFB2	AFG1	AFG2
Egypt				
Total samples ^a	16	16	16	16
Number of positive	3	1	1	0
% of positive	19	6	6	0
Mean (ng g ⁻¹) ^b	0.4	0	0	–
Median of positive (ng g ⁻¹) ^c	1	1	1	–
Maximum level (ng g ⁻¹) ^d	5	1	1	–
Ghana				
Total samples ^a	18	18	18	18
Number of positive	13	15	6	0
% of positive	72	83	33	0
Mean (ng g ⁻¹) ^b	31	2	1	–
Median of positive (ng g ⁻¹) ^c	5	10	3	–
Maximum level (ng g ⁻¹) ^d	199	15	7	–
Israel				
Total samples ^a	43	43	43	43
Number of positive	3	1	1	0
% of positive	7	2	2	0
Mean (ng g ⁻¹) ^b	1	0	0	–
Median of positive (ng g ⁻¹) ^c	3	1	1	–
Maximum level (ng g ⁻¹) ^d	16	1	1	–
Jordan				
Total samples ^a	20	20	20	20
Number of positive	9	1	1	0
% of positive	45	5	5	0
Mean (ng g ⁻¹) ^b	2	0.1	0.4	–
Median of positive (ng g ⁻¹) ^c	1	2	8	–
Maximum level (ng g ⁻¹) ^d	17	2	8	–
Kenya				
Total samples ^a	27	27	27	27
Number of positive	21	18	17	10
% of positive	78	67	63	37
Mean (ng g ⁻¹) ^b	36	2	12	1
Median of positive (ng g ⁻¹) ^c	27	5	4	2
Maximum level (ng g ⁻¹) ^d	161	14	89	10
Nigeria				
Total samples ^a	50	50	50	50
Number of positive	47	39	43	29
% of positive	94	78	86	58
Mean (ng g ⁻¹) ^b	89	5	21	1
Median of positive (ng g ⁻¹) ^c	54	5	17	1
Maximum level (ng g ⁻¹) ^d	417	19	110	4
South Africa				
Total samples ^a	77	77	77	77
Number of positive	3	2	2	1
% of positive	4	3	3	1
Mean (ng g ⁻¹) ^b	0.3	0.1	0	0
Median of positive (ng g ⁻¹) ^c	5	1	1	1
Maximum level (ng g ⁻¹) ^d	6	2	1	1
Sudan				
Total samples ^a	13	13	13	13
Number of positive	7	6	2	0
% of positive	54	46	15	0
Mean (ng g ⁻¹) ^b	80	10	0.3	–
Median of positive (ng g ⁻¹) ^c	68	19	2	–
Maximum level (ng g ⁻¹) ^d	346	40	3	–
Syria				
Total samples ^a	11	11	11	11
Number of positive	2	0	0	0

(continued)

Table 11. Continued.

	AFB1	AFB2	AFG1	AFG2
% of positive	18	0	0	0
Mean (ng g ⁻¹) ^b	1	–	–	–
Median of positive (ng g ⁻¹) ^c	5	–	–	–
Maximum level (ng g ⁻¹) ^d	8	–	–	–
UAE				
Total samples ^a	19	19	19	19
Number of positive	3	3	0	0
% of positive	16	16	0	0
Mean (ng g ⁻¹) ^b	1	0.3	–	–
Median of positive (ng g ⁻¹) ^c	5	1	–	–
Maximum level (ng g ⁻¹) ^d	6	3	–	–
Yemen				
Total samples ^a	9	9	9	9
Number of positive	1	0	0	0
% of positive	11	0	0	0
Mean (ng g ⁻¹) ^b	0.2	–	–	–
Median of positive (ng g ⁻¹) ^c	2	–	–	–
Maximum level (ng g ⁻¹) ^d	2	–	–	–

Notes: n.a. – not analysed.

^aTotal number of analysed samples (ng g⁻¹).^bArithmetic mean of all analysed samples (ng g⁻¹).^cMedian of all positive samples (ng g⁻¹).^dMaximum contamination level found (ng g⁻¹).

highlighted. A gluten sample from Kenya presented the highest level of fumonisins found in the whole survey (10485 ng g⁻¹). Likewise, the highest contamination level found for aflatoxins in the whole survey (556 ng g⁻¹) was recorded in a sunflower meal sample from the same country. Zearalenone was present in 45% of other feedstuff samples and the maximum level found for this mycotoxin was 195 ng g⁻¹ in a gluten sample from South Africa. Interestingly, more samples of this group were analyzed for OTA and 91% of them tested positive for this mycotoxin. The highest level of OTA was found in a ground nut sample from Sudan (31 ng g⁻¹).

Results of analytical findings for single toxins are given in Tables 10 and 11.

Discussion and conclusions

The results of this study indicate that the pattern of mycotoxin occurrence depends on provenance, i.e. the region where the commodity originated. Warmer countries, such as Nigeria, Kenya and Ghana, have a higher occurrence of aflatoxins, whereas more temperate countries, such as South Africa, exhibit a totally different contamination pattern, with a higher prevalence of B-trichothecenes. Despite the fact that more *Aspergillus*-produced mycotoxins or *Fusarium* toxins were found, all commodities are at risk of being contaminated by these secondary metabolites of molds,

which has a major economic impact on the grain trade and animal production. Although difficult to measure, economic losses due to mycotoxins derive from five main sources (Wu 2007; Schmaile and Munkvold 2009): (1) yield losses due to diseases induced by toxigenic fungi; (2) reduced crop value caused by mycotoxin contamination and related trade losses due to grain rejection; (3) losses in animal productivity from mycotoxicoses and mycotoxin-related health problems; (4) human health costs and, last, but not least, (5) costs of prevention, sampling, mitigation, litigation and research.

Simulations (Vardon et al. 2003) have shown that the potential annual cost of mycotoxin contamination of crops, in the US alone, ranges from US\$418 million to US\$1.66 billion, with the mean estimated cost of about US\$932 million. If mitigation costs and livestock losses are considered, another US\$466 million and US\$6 million, respectively, can be added to this mean value. In a more recent case study, fumonisins in animal feed in the US were estimated to cause animal life losses totalizing US\$126,000 and US\$320,000, in “normal” and “outbreak” years of *Fusarium* ear rot, respectively. If market losses are considered, this sum may vary between US\$1 and US\$46 million, depending on the severity of *Fusarium* ear rot on the field (Wu, 2007).

Costs are borne by all participants along the food and feed supply chains: crop producers, animal producers, grain handlers and distributors, processors and, ultimately, by consumers and society as a whole.

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References

- Binder EM, Tan LM, Chin LJ, Handl J, Richard J. 2007. Worldwide occurrence of mycotoxins in commodities, feeds and feed ingredients. *Anim Feed Sci Technol.* 137:265–282.
- Commission Directive. 2002. Directive 2002/32/EC of the European Parliament and of the Council on undesirable substances in animal feed. *Off J Eur Union.* L 140:10–22.
- Commission Recommendation. 2006. Commission Recommendation (2006/576/EC) of 17 August 2006 on the presence of deoxynivalenol, zearalenone, ochratoxin A, T-2 and HT-2 and fumonisins in products intended for animal feeding.
- Commission Regulation. 2006. Commission Regulation (EC) No 401/2006 of 23 February 2006 laying down the methods of sampling and analysis for the official control of the levels of mycotoxins in foodstuffs.
- Diekman MA, Green ML. 1992. Mycotoxins and reproduction in domestic livestock. *J Anim Sci.* 70:1615–1627.
- Driehuis F, Spanjer MC, Scholten JM, Giffel te MC. 2008. Occurrence of mycotoxins in feedstuffs of dairy cows and estimation of total dietary intakes. *J Dairy Sci.* 91:4261–4271.
- European Feed Safety Authority (EFSA). 2004a. Opinion of the Scientific Panel on Contaminants in Food Chain on a request from the Commission related to deoxynivalenol (DON) as undesirable substance in animal feed. *EFSA J.* 73:1–41.
- European Feed Safety Authority (EFSA). 2004b. Opinion of the Scientific Panel on Contaminants in Food Chain on a request from the Commission related to zearalenone as undesirable substance in animal feed. *EFSA J.* 89:1–35.
- European Feed Safety Authority (EFSA). 2004c. Opinion of the Scientific Panel on Contaminants in Food Chain on a request from the Commission related to ochratoxin A (OTA) as undesirable substance in animal feed. *EFSA J.* 101:1–36.
- European Feed Safety Authority (EFSA). 2005. Opinion of the Scientific Panel on Contaminants in Food Chain on a request from the Commission related to fumonisins as undesirable substance in animal feed. *EFSA J.* 235:1–32.
- FAO/WHO. 2004. Worldwide regulations for mycotoxins in food and feed in 2003. *FAO Food and Nutrition Papers* 81. Rome: Food and Agriculture Organization.
- Gareis M. 1994. Maskierte Mykotoxine. *Übers Tierernährung.* 22:104–113.
- Gareis M, Scheuer R. 2000. Ochratoxin A in meat and meat products. *Archiv Lebensmittelhyg.* 51:102–104.
- Guthrie LD, Bedell DM. 1979. Effects of aflatoxin in corn on production and reproduction in dairy cattle. *Proc Annu Meet US Anim Health Assoc.* 83:202–204.
- IARC. 1993. International Agency for Research on Cancer monographs on the evaluation of carcinogenic risk to humans. Vol. 56. Lyon: International Agency for Research on Cancer.
- Jelinek CF, Pohland AE, Wood GE. 1989. Worldwide occurrence of mycotoxins in foods and feeds: an update. *J Assoc Off Anal Chem.* 72:223–30.
- Jouany JP. 2007. Methods for preventing, decontaminating and minimizing the toxicity of mycotoxins in feeds. *Anim Feed Sci Technol.* 137:342–362.
- Leeson S, Diaz G, Summers JD. 1995. Poultry metabolic disorders and mycotoxins. Guelph (Ontario, Canada): University Books.
- Miller JD. 2001. Factors that affect the occurrence of fumonisins. *Environ Health Perspect.* 109(Suppl. 2): 321–324.
- Pestka JJ. 2007. Deoxynivalenol: toxicity, mechanisms and health risks. In: DP Morgavi, RT Riley, editors. *Fusarium and their toxins: Mycology, occurrence, toxicity, control and economic impact.* *Anim Feed Sci Technol.* 137:283–298.
- Richard J. 2000. Sampling and sample preparation for mycotoxin analysis. *Romer Labs Guide to Mycotoxins, Vol 2.* Romer Labs. Inc., Union, MO, USA.
- Savard ME. 2007. Mycotoxins – an introduction. *Stewart Postharv Rev.* 4:1–6.
- Schatzmayr G, Zehner F, Schatzmayr D, Klimitsch A, Loibner AP, Binder EM. 2006. Microbiologicals for

- deactivating mycotoxins. *Mol Nutr Food Res.* 50(6):543–551.
- Schmaile III DG, Munkvold GP. 2009. Mycotoxins in crops: a threat to human and domestic animal health. *The Plant Health Instructor*. DOI: 10.1094/PHI-I-2009-0715-01.
- Sharma RP. 1991. Immunotoxic effects of mycotoxins. In: Sharma RP, Salunkhe DK, editors. *Mycotoxins and Phytoalexins*. Boca Raton (FL): CRC Press. p. 81–99.
- Tangendjaja B, Rachmawati S, Wina E. 2008. Mycotoxin contamination on corn used by feed mills in Indonesia. *Indonesian J Agric Sci.* 9:68–76.
- Vardon P, McLaughlin C, Nardinelli C. 2003. Potential economic costs of mycotoxins in the United States. *Mycotoxins: risks in plant, animals, and human systems*. Task Force Report No. 139. Ames (IA): Council for Agricultural Science and Technology (CAST).
- Veldman A, Meijst JAC, Borggreve GJ, Heeres-van der Tol JJ. 1992. Carry-over of aflatoxin from cow's food to milk. *Anim Prod.* 55:163–168.
- Whitlow LW, Hagler Jr WM. 2005. Mycotoxins in dairy cattle: occurrence, toxicity, prevention and treatment. *Proc Southwest Nutr Conf.* 124–138.
- Wicklow DT. 1994. Preharvest origins of toxigenic fungi in stored grain. In: Highley E, Wright EJ, Banks HJ, Champ BR, editors. *Stored Product Protection: Proceedings of the 6th International Working*, Canberra, Australia. Wallingford (UK): CAB International.
- Wu F. 2007. Mycotoxin reduction in Bt corn: potential economic, health, and regulatory impacts. *Transgenic Res.* 15:277–289.
- Yiannikouris A, Jouany JP. 2002. Mycotoxins in feeds and their fate in animals: a review. *Anim Res.* 51:81–99.