doi:10.2533/chimia.2008.364 CHIMIA **2008**, *62*, No. 5

Chimia 62 (2008) 364–367

ISSN 0009–4293

Environmental Exposure to Estrogenic and other Myco- and Phytotoxins

Niccolo Hartmann[a], Marianne Erbs[ab], Felix E. Wettstein[a], Corinne C. Hörger[a], Susanne Vogelgsang[a], Hans-Rudolf Forrer[a], René P. Schwarzenbach[c], and Thomas D. Bucheli*[a]

Abstract: Zearalenone (ZON) is known as a very potent, naturally occurring estrogenic mycotoxin. It is one of the most prevalent mycotoxin produced as a secondary metabolite by *Fusarium* species growing on cereals such as wheat and corn. It has been studied extensively in food and feed products for decades but only rarely and somewhat by chance in the environment. We therefore elucidated its agro-environmental fate and behavior by conducting a series of field studies and monitoring campaigns. Specifically, ZON was investigated in plants, soils and drainage waters from wheat and corn fields artificially infected with *Fusarium graminearum*. In addition, manure, sewage sludge and surface waters were analyzed for ZON. Three main input pathways of ZON onto soil could be identified: i) wash-off from *Fusarium*-infected plants (in the order of 100 mg/ha), ii) plant debris remaining on the soil after harvest (up to few g/ha), and iii) manure application (in the order of 100 mg/ha). Our results show that these input sources altogether caused the presence of several g/ha of ZON in topsoil. Compared to this, ZON emission by drainage water from *Fusarium*-infected fields was generally low, with maximum concentrations of 35 ng/l and total amounts of a few mg/ha. Due to dilution, ZON concentrations dropped below environmental relevance in larger surface water bodies. However in small catchments dominated by runoff from agricultural land, ZON might substantially contribute to the estrogenicity of such waters. Apart from ZON, other natural toxins monitored in this study, such as the mycotoxin deoxynivalenol or the estrogenic phytoestrogen formononetin, emitted to and occurred in surface waters at considerably higher amounts. To date their ecotoxicological effects are largely unknown.

Keywords: Endocrine disruptors · Isoflavones · Micropollutants · Runoff · Trichothecenes

Introduction

Mycotoxins are naturally occurring secondary metabolites of fungi growing on a variety of cereals. Among the most important mycotoxin producing fungi are *Fusarium* spp. They pose a severe economical threat, which in the US crop production of the 1990s led to losses of three billion US$.[1] No exact calculations are available for Europe, but in Switzerland both losses of crops and quality have increased in recent years.[2] The extent of *Fusarium* infection and subsequent contamination by mycotoxins is determined by several factors:

i) climatic conditions,
ii) crop rotation,
iii) soil cultivation and
iv) susceptibility of crop varieties.[3]

Out of the many classes of mycotoxins produced by *Fusarium* fungi, resorcyclic acid lactones (RALs) are of particular concern with respect to endocrine disruption. The most prominent representative of the RALs is zearalenone (ZON). The estrogenic activity of ZON is comparable with those of natural estrogens[4] and is orders of magnitudes higher than those of many notorious synthetic endocrine disruptors such as bisphenol A, DDT or atrazine.[5,6] The estrogenically most potent of all RALs, α-zearalanol (α-ZAL), is still used as growth promoter for ruminants in the US and Canada, but has been banned in the EU since 1985. In the past it has been shown that RALs can cause severe reproductive and infertility problems in husbandry animals[7,8] due to their high estrogenic potencies.

Although the occurrence of ZON has been studied extensively in food and feedstuff,[9,10] only little is known about its environmental distribution and impact. Several publications reported the occurrence of ZON in surface waters[11,12] as well as input and effluents of wastewater treatment plants (WWTP).[11,13,14] Concentrations ranged from not detected up to 60 ng/l for individual samples. In some cases also other RALs such as α-zearalenol (α-ZOL), α-ZAL and β-zearalanol (β-ZAL) were detected at similar levels as ZON. For comparison, numbers in the same order of magnitude are observed for natural steroids.[15,16] From the limited data summarized in Bucheli *et al.*,[17] RALs seem to appear in surface waters occasionally throughout the year. Unfortunately, none of the mentioned studies further investigated their potential emission sources. Only Lagana *et al.*[11] postulated the presence of RALs in surface waters to be primarily caused by cattle excretion of growth-promoting residues. RALs data from other environmental compartments are presently not available, although Mortensen *et al.*[18] developed an analytical method to quantify ZON in soils.

*Correspondence: Dr. T. D. Bucheli[a]
Tel.: + 41 44 377 73 42
Fax: + 41 44 377 72 01
E-mail: thomas.bucheli@art.admin.ch
[a]Agroscope Reckenholz-Tänikon Research Station ART
Reckenholzstrasse 191
CH-8046 Zürich
[b]MDS Pharma Service Switzerland AG
Allmendstrasse 32
CH-8320 Fehraltorf
[c]Institute of Biogeochemistry and Pollutant Dynamics (IBP)
ETH Zürich
CH-8092 Zürich

The goal of this work was to elucidate the environmental distribution of ZON. Thereby, our main focus was on the input from small grain cereal and corn production as this is where mycotoxins are initially produced and known to occur. To our knowledge, this is the first time the occurrence of ZON and its metabolites were investigated in such detail, and with a view to relate their presence in the environment to possible sources.

Furthermore we reveal that ZON stands as an example for a wider range of naturally occurring toxins. Given the diversity of agricultural production systems, many other compounds, *e.g.* other mycotoxins like deoxynivalenol (DON), or phytoestrogens such as the isoflavones exhibit the potential to enter the environment. In particular, we argue that natural toxins of this kind should be considered as aquatic micropollutants.[19,20]

Experimental

To elucidate the pathways of RALs into the environment, we developed analytical methods for aqueous (drainage water, river water, WWTP effluent)[21] and solid phases (soil, manure, sewage sludge, plant materials).[22] Using adequate extraction and concentrations steps, ZON, α-ZOL, β-zearalenol, α-ZAL, β-ZAL and zearalanone could be detected by LC-MS/MS in the low ng/l and ng/g range for aqueous and solid matrices, respectively.

Several complementary approaches were chosen to study the environmental distribution of ZON. First, we investigated the presence of ZON in plants and soil of wheat- and cornfields infected with a mixture of RALs producing *Fusarium graminearum* isolates, as well as its emission *via* drainage water. This field site is briefly described in Hartmann *et al.*,[21] Erbs *et al.*[23] and Bucheli *et al.*[20] A more detailed description will be published elsewhere.[24] Secondly, we assessed the ZON input manure application by analyzing a range of manure samples from the Swiss soil monitoring network (NABO). Additional information about manure application practice allowed calculations of potential annual ZON loads[22] entering agricultural land. Third, ZON was monitored in digested sewage sludge, which integrated hydrophobic micropollutants from the respective WWTP catchments. Digested sludge samples were gathered from the existing monitoring network named Observation of the Metabolism of the Anthroposphere (SEA)[25] and further selected WWTPs. In addition, certain wastewater samples were also analyzed. Detailed information about catchment area characteristics (rural, urban, separated or mixed sewer systems, *etc.*) of each WWTP facilitated the apportionment of ZON input sources.[22] Fourth, surface water samples were gathered from two existing monitoring networks a) Office for Waste, Water, Energy, and Air of the Canton of Zürich (AWEL) and b) National Long-Term Surveillance of Swiss Rivers of the Swiss government (NADUF).[20,24] Sampling stations were chosen based on their orographically cumulated ratio of winter wheat area within their catchment to water discharge.[17,20] Finally, air was sampled by a high volume air sampler before and during harvest time at the field site to monitor possible ZON emissions *via* airborne soil- and plant particles.

Other natural toxins suspected to act as aquatic micropollutants were included in the above described studies at certain times. Specifically, DON, the estrogenic isoflavones formononetin (FOR), biochanin A, daidzein, genistein, equol, as well as coumestrol were quantified in drainage and surface waters over the period of their main production in spring and summer of 2007, using the analytical method described in Bucheli *et al.*[20] and Erbs *et al.*[23]

Results and Discussion

The Fig. illustrates in a simplified manner the probable environmental and urban distribution of RALs as suggested by the results of our studies. Pathways and compartments of food and feed production have already been thoroughly investigated[26] and are basically understood. Therefore, they were not a part of this study. All samples gathered were analyzed for all RALs, but only ZON was detected regularly, Hence, the following discussion will be limited to ZON.

Input of ZON into the Terrestrial Environment

We investigated two potentially main input pathways of ZON into agricultural soils, *i.e.* wash-off from the plant before harvest or from plant debris remaining on the soil after harvest, and manure application (Fig.). During heavy rain events water puddles containing ZON in concentrations of several hundred ng/l[24] were formed on the wheat field. Since these puddles occurred before harvest at a time where the plants were severely infected by *Fusarium graminearum* it is reasonable to assume that the quantified ZON was washed off the wheat plant directly by rainwater. Assuming a rain event of 30 mm and a ZON concentration of 250 ng/l in the puddle water, around 75 mg/ha ZON would have reached the soil surface. Based on two to four such rain events during the period where wheat plants were heavily infested by *Fusarium graminearum,* this translates to 150 and 300 mg ZON per ha. Direct wash off from *Fusarium*-infested corn plants also takes place, but was not specifically investigated. The very high ZON concentrations ranging from 0.1 to 17 µg/g dry weight (dw) quantified here in several wheat and corn plant organs[24] suggest that *Fusarium*-infested plant debris remaining on the field after harvest constitutes the more significant input source. During 1999 to 2005 Swiss feedstuff contained ZON levels of 50–100 ng/g dw in 0–30% and 10–35% of the wheat and corn samples, respectively.[27] Highest levels exceeded 400 ng/g dw which is within the observed levels in our field study. For other countries, levels up to 10 µg/g dw were reported in cereal grains and animal feed.[28] Although concentrations varied

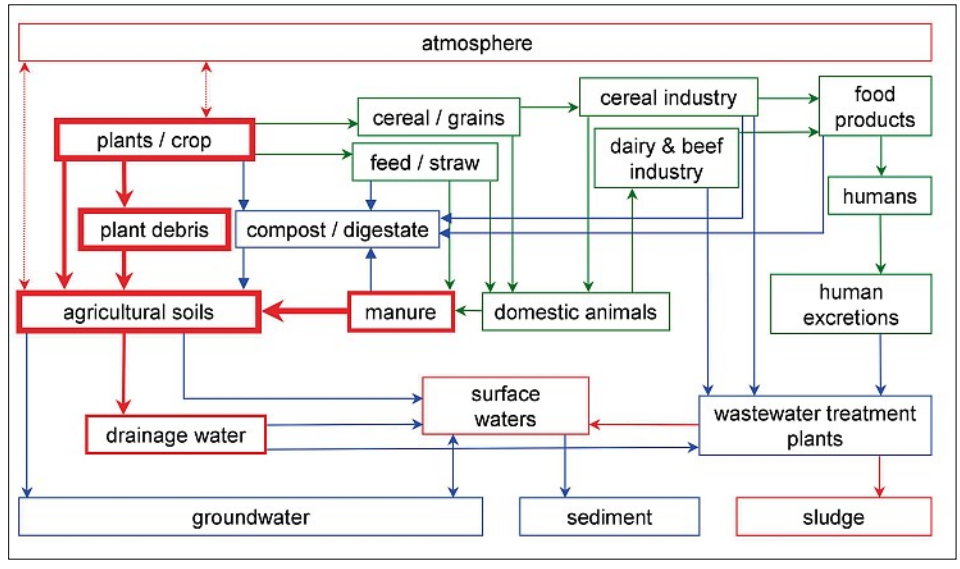

Fig. Suggested environmental distribution of RALs: Red colored pathways and compartments: investigated (thickness of red lines reflects the relative importance); Red dotted lines: investigated, ZON transfer does not occur; Green: not investigated because well investigated and understood; Blue: not investigated in this study.

strongly between plant organs, up to 15 g of ZON per hectare may be accommodated by straw on the soil surface after harvest.[24] Please note that the actual amount of ZON deposited on soil in this way depends very much on the agricultural practice.

At the same time, we detected ZON concentrations in the topsoil (0–10 cm) up to 4 ng/g dw, corresponding to almost 6 g/ha. Unfortunately very little is known about the fate of ZON in soils. A recent study estimated a half-life time for ZON in Danish soils of 6–11 days, but did not differentiate between degradation and sequestration processes.[29] Results from our own soil sorption experiments revealed considerable overall sorption coefficients (K_d) of 132–223 l/kg, with organic carbon as the dominating solid phase fraction (K_{oc} = 3318 l/kg$_{oc}$). Since the ZON concentrations reported in this study reflect a worst case situation in terms of *Fusarium* infection they may be inappropriate for up-scaling. However, they still represent realistic local scenarios where ZON amounts in this order of magnitude may occur.

Frequent presence of ZON in feedstuff (see above) lead to the excretion of substantial fractions of ZON in manure by husbandry animals,[30] and becomes therefore another possibly relevant input source of ZON. Concentrations in manure samples were between 7–330 µg/kg dw corresponding to 50–150 mg/ha ZON reaching agricultural soils *via* manure application annually.[22] In comparison, 17β-estradiol concentrations in swine and cattle manure varied between 100 and 1215 µg/kg dw[31] and 0.8 and 30 µg/kg wet weight.[32] These ZON loads are in the same range as those washed off from *Fusarium* infested cereals by rain (see above).

Although not investigated within the current project, the application of compost and digestate used as soil improver and fertilizer should be kept in mind as another potential input source of ZON (and other mycotoxins) to soil, because contaminated straw and residues from cereal processing may be used as input material. Estimates based on average to high concentrations of ZON in these products, the assumption of the chemical stability of ZON during processing, and a standard fertilization of 70 kg P_2O_5 per hectare in the form of compost or digestate application, lead to a ZON load that could be comparable to those described above for other soil input pathways.[33]

We did not detect ZON in any air samples sampled at our field site, not even those covering the critical time of harvest during which a lot of dust was generated. Hence, outdoor occupational exposure with mycotoxins is probably less a problem compared with indoor workplaces on farms or other grain production sites.[34,35]

Estrogenic and Other Mycotoxins and Phytoestrogens as Aquatic Micropollutants

We investigated the emission of ZON *via* drainage water from *Fusarium*-infested wheat and corn fields to assess its relative importance in comparison with other endocrine disrupting chemicals in surface waters.[36] A detailed presentation and discussion of this emission study will be published elsewhere.[24] Here, we focus on a limited period of time from our three-year study. From July to August 2007, the ZON concentrations in drainage water were on average 3 ng/l with a maximum of 35 ng/l (Table) and the total ZON load emitted from the field site was 3 mg[21,24] during that period of time. Compared to the 15 g initially present on the field (see above), the fraction emitted *via* drainage water constituted only 0.02%.

Micropollutants such as 17β-estradiol[39] and sulfonamide antibiotics[40] were reported to emit from manure treated fields during rain events. It is reasonable to assume that this process takes place for ZON as well, since the aqueous solubilities of ZON and 17β-estradiol are comparable.[17]

In contrast to recent reports,[11,13,14] ZON was not detected in any of the WWTP effluent samples analyzed here.[23] However, we detected ZON below the quantification limit in about 25% of 87 individual sewage sludge samples and quantified it at several ng/g dw in two samples.[22] Although these results show that ZON occasionally occur in wastewater, its input *via* WWTP effluents into surface waters is probably negligible, especially in comparison with steroid hormones.

Out of several hundred surface water samples regularly taken between 2005 and 2007, ZON was detected below quantification limit in only four samples from summer 2007[20] (Table).

Apart from ZON, several other natural toxins such as other mycotoxins or phytoestrogens could occur in drainage and surface waters as a consequence of the environmental distribution processes elucidated above. To test this hypothesis, we selected two model compounds and monitored these during the time of their main production in spring and summer 2007. DON was selected as a representative of other *Fusarium* mycotoxins[20] whereas FOR represents the estrogenic isoflavones present in legumes such as red clover.[41] The Table compiles emission and surface water data obtained in our studies for ZON, DON and FOR. For comparison, emission data reported in the literature for pesticides – representing classical micropollutants – are included in the Table as well. The amounts of ZON and DON produced on *Fusarium*-infested wheat fields are comparable with application rates of modern pesticides, which are used at amounts of a few dozen grams per hectare. The estimated amount of FOR on grassland was several orders of magnitudes higher than those of ZON and DON, and was even higher than usual application rates of pesticides. The differences in the amounts and fractions of ZON, DON and FOR emitted *via* drainage water can be explained by several factors, such as the availability at the plant surface for washoff, the aqueous solubility, and related to the former, the solid-aqueous phase distribution in soil. Overall, emitted amounts and

Table. Compilation of emission and river water data for ZON, DON, FOR and pesticides

	ZON	DON	FOR	Pesticides[a]
Emission studies (data per ha)				
period of investigation	Jul–Aug 07	Jul–Aug 07	Mar–Sept 07	season
amounts produced/applied	15 g	50 g	several kg	50 g – 1 kg
amounts emitted	3 mg	650 mg[b]	40 mg	3 mg – 56 g[c]
fraction emitted	0.02%	1.3%[b]	n.a.	0.0002 – 1.0%[c]
average conc.	3 ng/l	560 ng/l[b]	189 ng/l	ng/l – µg/l
maximum conc.	35 ng/l	4.9 µg/l [b]	1.7 µg/l	µg/l – mg/l
Concentrations in river waters				
period of investigation	Apr 05–Oct 06, Jul 07	Jul–Aug 07	Mar–Sept 07	1999–2005[d]
no. of analyses/no. of detects	several hundreds/4	52/31[b]	262/259	617/653[d]
average conc. (of detects)	det.	8 ng/l[b]	10 ng/l	–[e]
maximum conc.	det.	22 ng/l[b]	132 ng/l	1.49 µg/l[d]

[a]Atrazine data. [b]ref. [20] [c]ref. [37] [d]ref. [38] [e]327 of 653 analyses <50 ng/l[41]
n.a. not available

fractions were within the range reported for pesticides such as atrazine, metolachlor and dimethenamid.[40] DON and FOR concentrations of up to 132 ng/l detected in river waters in this study are comparable to the atrazine levels found in Swiss rivers,[41] where 50% of all values ranged from not detected to 50 ng/l.

The ecotoxicological consequences of the occasional presence ZON, DON and FOR in the ng/l to µg/l range in aqueous environments remain to be elucidated. We assume that in most surface waters, ZON from agricultural runoff will be diluted to concentrations well below environmental relevance. However, in small water bodies receiving mainly runoff from wheat and corn fields and in case of *Fusarium graminearum* infection, ZON might contribute to the total estrogenicity. As for other mycotoxins and phytoestrogens, including DON and FOR, their ecotoxicological significance is largely unknown, since they are normally considered a risk for food and feed only, and thus do not undergo ecotoxicity testing. It is known however that enniatins and beauvericins[42] as well as certain other trichothecenes,[43] exhibit insecticidal effects. From the limited data currently available for FOR, we estimate its estrogenic activity in surface waters to be somewhat similar to that of ZON.

Acknowledgements

This work is part of the project 'Environmental Exposure to Estrogenic Mycotoxins' within the National Research Programme NRP50 'Endocrine Disruptors: Relevance to Humans, Animals and Ecosystems' financed by the Swiss National Science Foundation. We gratefully acknowledge A. Keller (NABO) for providing manure samples from different sampling stations throughout Switzerland. Thanks due to T. Kupper (Swiss College of Agriculture) and E. Vermeirssen (EAWAG) and P. Spohn (AWEL) for their support during the sewage sludge monitoring campaign. W. Meier (AWEL) and B. Luder (NADUF) are acknowledged for providing surface water samples from different sampling stations throughout Switzerland. We also thank G. Karlaganis and S. Müller (Swiss Federal Office for the Environment FOEN) for additional financial support. Furthermore, we are thankful to the field staff at ART for their excellent support at the field site.

Received: March 22, 2008

[1] W. E. Nganje, D. A. Bangsund, F. L. Leistritz, W. W. Wilson, N. M. Tiapo, *Rev. Agric. Econ.* **2004**, *26*, 332.
[2] E. Jenny, Agroscope ART, CH-8046 Zürich **2000**, unpublished data.
[3] A. Champeil, J.F. Fourbet, T. Dore, L. Rossignol, *Crop Protection* **2004**, *23*, 531.
[4] R. Le Guevel, F. Pakdel, *Hum. Reprod.* **2001**, *16*, 1030.
[5] J. Matthews, T. Celius, R. Halgren, T. Zacharewski, *J. Steroid. Biochem.* **2000**, *74*, 223.
[6] N. G. Coldham, M. Dave, S. Sivapathasundaram, D. P. Mcdonnell, C. Connor, M. J. Sauer, *Environ. Health Persp.* **1997**, *105*, 734.
[7] T. Kuiper-Goodman, P. M. Scott, H. Watanabe, *Regul. Toxicol. Pharm.* **1987**, *7*, 253.
[8] J. L. Gaumy, J. D. Bailly, G. Bernard, P. Guerre, *Rev. Med. Vet-Toulouse* **2001**, *152*, 123.
[9] P. Rhyn, O. Zoller, *Eur. Food Res. Technol.* **2003**, *216*, 319.
[10] A. Pittet, *Rev. Med. Vet-Toulouse* **1998**, *149*, 479.
[11] A. Lagana, A. Bacaloni, I. De Leva, A. Faberi, G. Fago, A. Marino, *Anal. Chim. Acta* **2004**, *501*, 79.
[12] T. A. Ternes, in 'Pflanzliche hormonell wirksame Stoffe in der aquatischen Umwelt und deren Verhalten bei der Trinkwasseraufbereitung', Ed. T. Eggert, M. Meisenheimer, ESWE-Institut für Wasserforschung und Wassertechnologie GmbH. **2001**, p. 114.
[13] A. Lagana, G. Fago, A. Marino, D. Santarelli, *Rapid Commun. Mass Sp.* **2001**, *15*, 304.
[14] P. Spengler, W. Korner, J. W. Metzger, *Environ. Toxicol. Chem.* **2001**, *20*, 2133.
[15] R. Bätscher, C. Studer, K. Fent, Schriftenreihe Umwelt Nr. 308. Eidg. Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz (EAWAG), Bundesamt für Umwelt, Wald und Landschaft (BUWAL), Bern. **1999**.
[16] G. G. Ying, R. S. Kookana, Y. J. Ru, *Environment International* **2002**, *28*, 545.
[17] T. D. Bucheli, M. Erbs, N. Hartmann, S. Vogelgsang, F. E. Wettstein, H. R. Forrer, *Mitt. Lebensm. Hyg.* **2005**, 386.
[18] G. K. Mortensen, B. W. Strobel, H. C. B. Hansen, *Anal. Bioanal. Chem.* **2003**, *376*, 98.
[19] R. P. Schwarzenbach, B. I. Escher, K. Fenner, T. B. Hofstetter, C. A. Johnson, U. von Gunten, B. Wehrli, *Science* **2006**, *313*, 1072.
[20] T. D. Bucheli, F. E. Wettstein, N. Hartmann, M. Erbs, S. Vogelgsang, H. R. Forrer, R. P. Schwarzenbach, *J. Agric. Food Chem.* **2008**, *56*, 1029.
[21] N. Hartmann, M. Erbs, F. E. Wettstein, R. P. Schwarzenbach, T. D. Bucheli, *J. Chromatogr. A* **2007**, *1138*, 132.
[22] N. Hartmann, M. Erbs, F. E. Wettstein, C. C. Hoerger, R. P. Schwarzenbach, T. D. Bucheli, *J. Agr. Food Chem.* **2008**, in preparation; ASAP Article, 10.1021/jf8002448.
[23] M. Erbs, C. C. Hoerger, N. Hartmann, T. D. Bucheli, *J. Agr. Food Chem.* **2007**, *55*, 8339.
[24] N. Hartmann, M. Erbs, F. E. Wettstein, S. Vogelgsang, H. R. Forrer, R. P. Schwarzenbach, T. D. Bucheli, *Environ. Sci. Technol.* **2008**, submitted.
[25] T. Kupper, J. D. Berset, R. Etter-Holzer, R. Furrer, J. Tarradellas, *Chemosphere* **2004**, *54*, 1111.
[26] A. Zinedine, J. M. Soriano, J. C. Molto, J. Manes, *Food and Chemical Toxicology* **2007**, *45*, 1.
[27] ALP, Mykotoxin-Erhebungen in CH-Futtergetreide 1999–2005, *http://www.art.admin.ch/themen/00930/00936/index.html?lang=de*, accessed March 10, **2008**.
[28] C. M. Placinta, J. P. F. D'Mello, A. M. C. Macdonald, *Anim. Feed Sci. Tech.* **1999**, *78*, 21.
[29] G. K. Mortensen, B. W. Strobel, H. C. B. Hansen, *Chemosphere* **2006**, *62*, 1673.
[30] K. Seeling, S. Danicke, K. H. Ueberschar, P. Lebzien, G. Flachowsky, *Food Addit. Conatm.* **2005**, *22*, 847.
[31] T. A. Hanselman, D. A. Graetz, A. C. Wilkie, *Environ. Sci. Technol.* **2003**, *37*, 5471.
[32] D. R. Raman, E. L. Williams, A. C. Layton, R. T. Burns, J. P. Easter, A. S. Daugherty, M. D. Mullen, G. S. Sayler, *Environ. Sci. Technol.* **2004**, *38*, 3567.
[33] T. Kupper, Swiss College of Agriculture, CH-3052 Zollikofen, pers. comm. **2008**.
[34] A. S. Halstensen, K. C. Nordby, S. S. Klemsdal, O. Elen, P. E. Clasen, W. Eduard, *J. Occup. Environ. Hyg.* **2006**, *3*, 651.
[35] K. C. Nordby, A. S. Halstensen, O. Elen, P. E. Clasen, W. Langseth, P. Kristensen, W. Eduard, *Ann. Agr. Env. Med.* **2004**, *11*, 75.
[36] J. P. Sumpter, *Acta Hydroch. Hydrob.* **2005**, *33*, 9.
[37] C. Leu, H. Singer, C. Stamm, S. R. Muller, R. P. Schwarzenbach, *Environ. Sci. Technol.* **2004**, *38*, 3835.
[38] C. Balsiger, P. Niederhauser, O. Jäggi, W. Meier, Office for Waste, Water, Energy, and Air of the Canton of Zurich (AWEL), **2004**.
[39] J. Kjaer, P. Olsen, K. Bach, H. C. Barlebo, F. Ingerslev, M. Hansen, B. H. Sorensen, *Environ. Sci. Technol.* **2007**, *41*, 3911.
[40] K. Stoob, H. P. Singer, S. R. Mueller, R. P. Schwarzenbach, C. H. Stamm, *Environ. Sci. Technol.* **2007**, *41*, 7349.
[41] E. Sivesind, P. Seguin, *J. Agr. Food Chem.* **2005**, *53*, 6397.
[42] J. F. Grove, *Mycopathologia* **1980**, *70*, 103.
[43] F. Fornelli, F. Minervini, G. Mule, *In Vitro Cell. Dev-An.* **2004**, *40*, 166.